ALTERNATIVES FOR PUBLIC TRANSPORT IN RURAL AREAS

W.M. Markus

Alternatives for public transport in rural areas

How can alternative forms of public transport be used more to increase the mobility availability in rural areas in Friesland, The Netherlands

W.M. Markus

Faculty of Civil Engineering and Geosciences, Delft University of Technology
BSc Thesis CTB3000-16
Student: 5405416
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Supervisors: Y. Yuan and S. Nordhoff, TU Delft
External supervisor: N. van Oort, TU Delft

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Preface

In front of you lies the thesis report ”Alternatives for public transport in rural areas”. This report is written as a result of my Bachelor thesis, the final project of the Bachelor Civil Engineering at Delft University of Technology. This was done at the domain Transport and Planning of the faculty Civil Engineering and Geosciences.

During my bachelor I have followed several courses in the Transport and Planning domain, which I found rather interesting. Moreover, ever since I moved to Rotterdam and started to make use of its extensive public transport system, public transport is something I find rather fascinating. This also led me to doing my thesis in the Transport and Planning domain, investigating the public transport system and its alternatives.

I would like to thank my supervisors Dr. Y. Yuan and Dr. S. Nordhoff for their guidance and support in the project, as well as my fellow students that provided me weekly feedback. Furthermore I want to express my gratitude to Dr. Ir. N van Oort for helping me obtain the data used for the research and putting me in contact with some relevant organisations, and also Dr. Ir. M. Salomons for her help in choosing the topic.

W. M. Markus
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Abstract

This research investigates the possible alternatives for regular public transport in rural areas and how these can be used more, with a focus on the Dutch province of Friesland. The availability of public transport in rural regions is low, especially as more and more rural bus lines have disappeared in recent years, because they are not economically feasible. Lack of transportation options pose a problem for local inhabitants, as it limits the services they can access, creating the risk of social exclusion and unemployment, amongst others.

In the first part of this research, a literature research is done. Firstly, to identify and examine the involved stakeholders. Secondly, to investigate the characteristics of different alternative forms of public transport and to find out in what extend these are present in Friesland.

The second part of the research consists of a spatial data analysis on the availability of public transport and alternatives in Friesland.

The study shows that demand responsive transport is a promising alternative for low-demand bus lines, and already widely used in Friesland. However, booking and payment method can impose a threshold for users. Shared mobility can be used to offer last-mile transport, however these are only present in cities. Mobility hubs in rural areas can be implemented more to increase usage. Shared autonomous vehicles can greatly enhance the profitability and accessibility of the transport system in the near future, however several barriers have yet to be overcome to make them omnipresent.

The results of the data analysis show that the availability of transportation options per region can be examined using stop locations. Multiple districts in Friesland do not have any public transport or alternative stop in the area, despite having a relatively high population in some cases.

The study concludes that alternative forms of public transport can help increase the mobility availability in rural areas. They should be implemented more and better, for instance in the regions with a high risk for low mobility that this study identifies in Friesland. The model that is used to quantify mobility options in a region can be improved in further studies to better identify high-risk regions.

Keywords: Public transport, rural areas, alternatives for public transport, mobility availability

Contents

1 Introduction

1.1 Problem definition

In cities in the Netherlands, public transport is widely available. Especially in the Randstad urban area, there are extensive networks of public transport present - such as metro, bus and tram - that can quickly take you from A to B. In rural areas however, the availability of public transport is significantly lower. Even in a relatively small country as the Netherlands, one can argue that you still need a car for transportation in rural areas (Boers, 2023).

The Dutch minister of Infrastructure and Water Management stated in a letter to the parliament that all inhabitants are entitled to accessibility (Ministerie van Infrastructuur en Waterstaat, 2023). However, increasingly more cuts in the - already poorly available - rural bus lines are being made in recent years, as these lines are often economically unfeasible, to the dissatisfaction of the local inhabitants. (Plicht, 2023).

These cuts in bus lines have the result that mobility in rural areas in the Netherlands is under pressure. Bastiaanssen and Breedijk (2022) state in the report 'Toegang voor iedereen?' that people with access to a car have the highest accessibility - by far - to all kinds of services and jobs, even during rush hour. People that are dependent on public transport have a significantly lower mobility accessibility, especially if they live in rural areas. This 'mobility poverty' is increasing, with the consequence that more and more people will have to rely on a car for their transport. This is a problem, especially for people without a driver's license, people without the financial means to afford a car or elderly or disabled people. This group is not insignificant: according to the Centraal Bureau voor de Statistiek (2018) 2.1 million households in the Netherlands (27%) did not possess a motorized vehicle in 2016. Moreover, this is not equally distributed: 45.9% of households with a low income fell into this group. Lack of transportation options can limit access to employment, healthcare, education, friends and family, which can lead to severe consequences such as unemployment, health deterioration, or social isolation (Bastiaanssen and Breedijk, 2022).

Apart from solving this accessibility problem by increasing the regular public transportation availability, there are some alternatives that are not exactly covered by public transport, but are not private transport either, that might offer some part of the solution. Existing examples of these are flexible systems such as shared e-bike services or the so-called 'Belbussen' (dial-a-bus), a system that replaces a regular bus line and will only be active if booked beforehand (Mulley and Nelson, 2016).

1.2 Objective and research questions

In this Bachelor Thesis, the presence and availability of both regular forms as alternative forms of public transport will be analysed.

To narrow the scope of the research down, the Dutch province of Friesland is chosen, excluding the Wadden islands due to their specific nature. An overview of the research area can be seen in Figure 1. The motivation behind this choice is that there are large rural areas present, apart from some urban areas. Furthermore, the borders of the province are non-international and for a significant part the border is the Waddenzee, which makes the transport in the region more isolated and thus easier to analyse. Additionally, there are only a few train lines present, but these do not cover the whole area. A last reason is that there is only one main transport provider in the province (apart from one train connection to the Randstad), namely Arriva (Provincie Fryslân, n.d.).

The main research question of this study is:

> How can alternatives for regular public transport be used more in rural areas to increase the mobility availability, focused on Friesland, The Netherlands?

This will be done by answering the following sub-questions:

1. What are the stakeholders involved in the system of public transport and its alternatives?
2. What are possible alternatives for regular public transport?
3. What is the availability of public transport and its alternatives in Friesland?

The first sub-question will offer an overview of the most relevant parties that are involved in the transportation in rural areas in Friesland, and what their influence and main interests are. The second

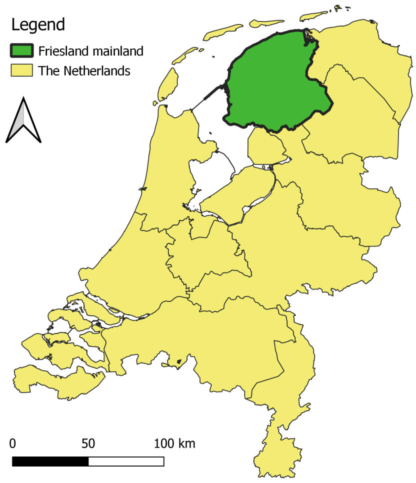


Figure 1: Research area

sub-question will identify the possible alternatives for regular public transport, i.e. non-private but also not normal public transport options, which are already used or will be used most probably in the near future. For each alternative a literature analysis will be done, examining how they influence the mobility accessibility and what their advantages and disadvantages are. Additionally, for every alternative the options currently available in Friesland will be described. This will help to determine what alternatives can be implemented more in to-be-determined areas. Sub-question 3 will address the current availability of the different non-private transport options, where with a spatial data analysis on Friesland these options (regular public transport, alternatives and combined) will be quantified and mapped. With these maps the areas with significantly lower amounts of mobility options can be identified, and recommendations can be made as to where and with which alternatives this mobility can be efficiently increased.

1.3 Societal and scientific relevance

This research addresses the social problem of mobility availability. As described earlier, lack of transportation options has a significant impact on the locations one can access - of employment and healthcare among others - which can lead to severe consequences such as unemployment, health deterioration and/or social isolation (Bastiaanssen and Breedijk, 2022). This research will make several recommendations on how mobility availability can be increased in rural areas in Friesland, and thus try to solve a part of the mobility puzzle.

There have been several studies on alternatives for public transport, such as Butler et al. (2020) and Machado et al. (2018), but these are mainly focused on mobility in urban areas. Some studies have researched specific types of alternative forms of public transport in case studies in rural areas, such as Bronsvoort (2019), Coutinho et al. (2020) and Madani et al. (2022), but these are taking into account only one alternative form. This research tries address this research gap by capturing the most important alternatives for public transport in rural areas, and then couple these to a data analysis case study on the Friesland province.

1.4 Report structure

The structure of this report is as follows. Chapter 2 describes the methodology of this research. In chapter 3 the different stakeholders will be analysed and discussed. Chapter 4 consists of the description of possible alternative forms of public transport. Further on, chapter 5 contains the results of the data analysis on the availability of public transport and its alternatives. Then, the discussion of the results and the limitations of the study is done in chapter 6. Lastly, the conclusions and recommendations for Friesland and for further studies are given in chapter 7.

2 Methodology

In this chapter the methodology of the research is explained. Firstly, the literature analysis that has been done is described in section 2.1. Secondly, the method of the data collection and preparation is described in section 2.2. Lastly, the data analysis that has been done is explained in section 2.3.

2.1 Literature analysis

The first part of the research consists of a literature analysis. The scope of the research was checked more thoroughly, i.e. whether the questions cover some research gaps in the field of study and have not been answered already by earlier studies.

To start with, the stakeholders of the subject were identified, explaining their relation and possible interest. Most information could be found online and additionally in some relevant available reports of (Dutch) government agencies such as the Living Environment Planning Agency (PBL), the Central Agency for Statistics (CBS).

Next, the second sub-question is answered using available literature about the alternatives of public transport, and to what extent these are already used. Databases like Google Scholar and Web of Science are consulted, as well as several relevant sites of mobility innovations that are already running. For this aim, also the knowledge platform for mobility and infrastructure CROW will be used. Only public transport alternatives that are available for the public are considered, e.g. flexible bus systems, ridesharing services and automatic shuttles. Furthermore, their characteristics, advantages and disadvantages are discussed, as well as what the main challenges and impediments are for further implementation. Again, with the main focus on rural areas.

2.2 Data collection and preparation

To obtain more knowledge about the transport operator, its view towards alternative forms of transport, and the organization of public transport, an interview is conducted with a contact person at Arriva. The questions of this interview and a short summary can be found in Appendix A.

The second part of the research consists of a data analysis. The aim was to obtain some relevant public transport data for a certain region, on which an analysis could be done to answer sub-question 3, which provided some quantitative basis to answer the main research question.
The data was obtained from three sources, of which the first two are publicly available:

- OpenStreetMap
- CBS
- CROW

From OpenStreetMap (OSM) basic map locations of stops from train, bus and ferry were obtained using the QuickOSM plugin in QGIS. For this research the data types 'highway_bus_stops' and 'public_transport_station' have been used. The data was recent and could be filtered, but the amount of information available was strongly varying per stop. In some cases, the type of bus was included in the data (e.g. Opstapper), but mostly not. No line numbers and corresponding frequencies could be obtained. This data should be available at the CROW, but this institute could not deliver the data within the time span of this research. To improve the representativeness of the data, a list of Opstapper lines has been imported from Wiki OV in Nederland (2022). This list has been cross-referenced with the names of the stops imported from OSM, which were then identified as Opstapper stops. In total, 254 Opstapper stops were distinguished from regular stops. However, due to the variability in names in the two data sets, not all Opstapper stops could be identified as such, so there are a number of stops wrongly classified in the data. This can be improved using the CROW data, which was not possible for this research.

The CBS has the geographical layout of different types of regions in the Netherlands available. This data was downloaded and put in QGIS. The region type that was chosen for the analysis is the district region ('buurt'), as this is the smallest region type of which the CBS has data available. There are 877 districts in the research area.

For each district the CBS has large amounts of data available about inhabitants, such as population density, number households, average motorized vehicle possession, among many others. In this research only the number of inhabitants was considered. The data about the inhabitants was imported into QGIS, after which it could be coupled to the geographical data using district ID.

2.3 Data analysis

The obtained data could be visualised and compared using the mapping program QGIS. This comparison was done by comparing several variables per region. The variables that have been considered are:

- Number of train stations within 1 km per district
- Number of regular bus stops per district
- Number of Opstapper bus stops per district
- Number of inhabitants per district

The variables that have been considered are rather simple, but this made it easier to compare the districts with each other. The variables that have been used have some limitations in the representation of the transport system, as some aspects will be ignored. Other variables, such as the daily frequency of departures per stop and service hours, have not been implemented into the model, because this data was not available within the time period in which the research was done. Implementing this data into the model would improve the quality of the results.

Mobility cannot be captured in one single variable. In other, more extensive studies, such as that from Bastiaanssen and Breedijk (2022), mobility is modelled in terms of how much services can be reached within a certain time span, calculating mobility as the needed travel time per transport mode. This thesis offers a different approach, in which the transport system is represented more simply, which also makes it possible to include alternative forms of public transport in the data analysis, such as the Opstapper DRT system.

The analysis was done with integrated functions from QGIS, coupling the data of public transport and alternatives with the CBS data about inhabitants from different regions. Then for every variable a map is made to visualise the differences between regions.

For all districts, the number of train stations within the district was computed. Additionally, districts that are located close to a station were identified, as several stations are located near borders of districts. The threshold that was used is a 1000 m radius around the station where the geographical centre must lie within, if so, the district is considered to have a station in its proximity. This same threshold is used in the statement of requirements of the Friesland Province (Provincie Friesland, 2023). In QGIS, this can be done with the 'distance to nearest hub points' tool.

Next, for each district the number of regular bus stops was computed, and the same for the number of Opstapper stops. In these cases the method of proximity attribution - as was done for the train stations - is not applicable. This is due to the more special geographical shapes of the (more rural) districts: in many cases there is an island effect, i.e. a small district on the inside, containing the main village, around which lies a surrounding district containing the more outside areas. An example of this effect can be seen in Figure 2. Due to this island effect, the 'outer' district type would wrongly gain bus stops, as their geographical centre often lies within the 'inner' district in which there are more bus stops. For the train stations this was not the case, as the corresponding districts did not show this island effect.

The results of the data analysis were several maps of Friesland displaying the aforementioned units. To get one map of all variables combined, the first three variables were combined into one mobility score per district that indicates the availability of transport options, and the inhabitants amounts are then used to indicate the districts in which the chance of lacking transportation options is the highest, i.e. more inhabitants result in a higher risk.

The mobility score a district got, is dependent on the number and type of stops or stations that it contains. The scores per transport stop type can be seen in Table 1.

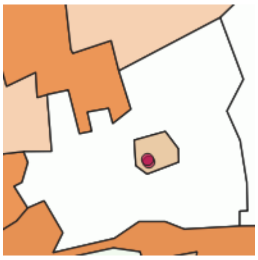


Figure 2: *Example of the 'island' effect in district orientation*

Transport type	**Score**
Train station within 1000m	4
Bus stop	2
Opstapper stop	1

Table 1: *The score per transport mode*

A train station within the district or within 1 km of the districts' centre has the highest score, as one station generally provides a service in two directions. Bus stops on the other hand, are generally one-way only, and have a separate stop across the street for busses in the other direction. This is why the score of a train station is twice the score for a bus stop, no further preference for bus or train is accounted for, as the average frequency for both systems is 1 departure every hour or higher (Arriva, n.d.-a). The Opstapper stop has the lowest score, as the level of service is significantly lower compared to train stations and regular bus stops: it only serves as a feeder for the latter systems. The total mobility score MS for a district is the sum of the amount of transport stop type multiplied by the corresponding type score, see Formula 1.

$$MS = 4 * (\#train\,stations) + 2 * (\#bus\,stops) + 1 * (\#Opstapper\,stops) \quad (1)$$

With these maps indications of the availability gaps in the system could be made, i.e. regions that have a relatively low score given the considered variables. This then provided some concrete areas in which (additional) alternatives to public transport can help to improve the mobility accessibility, thus answering the main research question.

3 Results stakeholder analysis

In this chapter the different stakeholders involved in this topic are listed. For each stakeholder its influence and interests are described. Firstly the governmental stakeholders are discussed in section 3.1, then the transport operating companies in 3.2 and lastly several groups of (potential) travellers are considered in section 3.3. The last part of this chapter, section 3.4, contains the influence and interest graph of all stakeholders.

3.1 Authorities

The governments are a big sponsor of public transport in the Netherlands. According to a report of Rienstra (2022) all the Dutch governments combined spent €12.0 billion (3.5% of its total expenses) on traffic and transport in 2019, of which 36% went to public transport.

Furthermore, the ministry greatly compensated public transport companies for low passenger amounts during COVID-19, this to guarantee the continuous service of public transport. These expenses were over €1 billion in 2020, and €2 billion in 2021 (Ministerie van Fininanciën, n.d.). Due to the large amounts of money invested, the governments have a large influence on (public) transport in the Netherlands.

3.1.1 National government

The Dutch national government is an important stakeholder in the transport system, more specifically in the form of the Ministry of Infrastructure and Water Management (IenW).

In the 'Hoofdlijnennotitie Mobiliteitsvisie 2050' (Mobility vision 2050 Framework Memorandum) the IenW minister states 2 main strategies of mobility in the near future (Ministerie van Infrastructuur en Waterstaat, 2023), namely good quality connections between cities and surrounding population centres and a well-considered choice of location and access strategy for vital socioeconomic services and functions. Furthermore, the minister indicates that everyone is entitled to accessibility, but because of scarcity not all mobility needs can be fulfilled at every moment in every place.

The government's influence on the system is the following: it has a guiding role in the mobility system, through regulations, influencing behaviour and stimulating innovations (Ministerie van Infrastructuur en Waterstaat, 2023). The main interests are to minimise the costs and subsidies on public transport, while maximising social welfare and accessibility for the public (Bronsvoort, 2019). Alternatives of public transport that can help reach these interests are supported.

3.1.2 Province

The provinces (and transport regions) in the Netherlands are responsible for the regional public transport. They are committed to accessible regions and reliable and affordable public transport (Interprovinciaal Overleg, n.d.). In the Regional Mobility Program Fryslân, the province states that all citizens in Friesland must be able to travel, in order to allow them to participate in the society. It aims for affordable mobility accessibility for everyone and reducing mobility poverty (Provincie Fryslân, 2022). In the statement of requirements for the next bus concession, it states that every inhabitant core must be serviced by at least one type of public transport or alternative form (Provincie Friesland, 2023).

3.1.3 Municipalities

The role of municipalities in the Dutch (public) transport system is smaller than that of province and national government but must not be ignored. The municipality plays an important role in improving the quality of public transport locally. The operator needs the municipality for the smooth running of daily rides, and citizens and travellers rely on the municipality for the provision of certain types of information and the accessibility of (bus) stops. On the other hand the municipality itself also has some wishes and demands (e.g. bus connection) that might differ from the regional transport vision, as they have more local interest and a policy to execute in the local transport system (Kesteren, 2007). Municipalities can have a significant influence on making alternatives for public transport more commonly known in its community, as they often have good contact with the inhabitants.

3.2 Transport operators

The main interest of transport operators is to increase the profitability of the provided services. The income of these operators globally consists of revenues from two types of clients: the travellers and the authorities. The first is simply dependent on the fares per trip and the number of trips made by travellers. By improving the quality and quantity of public transport services, more travellers can be attracted. The second is that if the operator meets several requirements imposed by the authorities, a fixed sum or subsidy per traveller or kilometre travelled is provided (Bronsvoort, 2019).

To maximise profits, operators want to make their service as cost-efficient as possible. This has the implication that only (bus)lines that are economically feasible would be exploited, if public transport would not be supported financially by authorities.

In Friesland, the main public transport operator is Arriva, operating all buses and trains except for one train line from Leeuwarden towards the south (Provincie Fryslân, n.d.). For this research, an interview was conducted with T. (Thom) Lageveen, Development Advisor North from Arriva.

Lageveen expressed that as a public transport operator, it is essential to ensure that no one is excluded from accessing public transport across all the areas it serves. Public transport should be available to everyone as a fundamental principle. Arriva aims to provide each core with a form of public transportation. In fact, that is an agreement that has been made with the province of Friesland (Provincie Friesland, 2023). However, it is also crucial to maintain the affordability of the entire public transport system. This means that lines with high demand and corresponding revenue should strike a balance with low-demand lines that may not be profitable on their own.

Operators welcome the possibility of implementing alternatives. Lageveen indicated that in essence, they are all forms of public transportation, but then with significantly lower operational costs compared to a regular bus service. Of course, every alternative form provides a different level of service to the passengers, in terms of service hours, rigid timetable, payment options, etc., and this can sometimes be a disadvantage for passengers. Lageveen claims that the use of alternatives is necessary in order to provide services in all areas.

3.3 Travellers

Travellers play a key role in the public transport system. They want to be able to move efficiently from origin to destination, while minimising the costs and travel time. Alternative forms of public transport can be embraced if they offer new transportation options. Factors that influence travellers' decisions in choosing (alternative) transport type and routes are comfort, reliability, flexibility, and the number of transfers (Bronsvoort, 2019). Additionally, travellers want clear and accessible information about the transport routes, scheduling and ticket fares. Travellers are represented by several travellers' organizations that advise and discuss with the ministry and several transport operators, taking into account the needs of the travellers (Het Locov, n.d.).

There are different types of travellers that each have their own additional needs and interest. An important group to consider is the travellers without (access to) a car. This group is - except for (e-)bike usage - fully dependent on publicly available transport options, such as public transport and shared mobility systems.

Another group of travellers with special demands are the elderly and people with a disability. For this group the accessibility and proximity of transport options is crucial, as they often have more difficulties walking (longer distances). Additionally, this group is in general less familiar with modern technology and experience more difficulties with the use of apps and smartphones. Therefore they often prefer to use fewer digital options (Sörensen et al., 2021). Moreover, this group is not necessarily travelling during rush hour, so availability of transportation outside of these specific time periods is needed.

Schoolchildren and students are a last group to be distinguished. While they need to travel almost daily, they are less likely to posses any motorised vehicles due to their young age, which makes them more dependent on public transport if their education location is relatively far. Another factor that is important for young people is the possibility to book transport without having to call, as especially for younger people calling can impose a threshold (Sebah, n.d.).

3.4 Stakeholder diagram

As a summary of the stakeholder analysis, the stakeholders can be seen in the stakeholder diagram in Figure 3, visualizing their influence versus their interests in the public transport system. Overall, the province and the transport operator are the most important stakeholders, as these organizations have a large influence on the public transport system, and their interests are high as well. However, the influence of the province is still higher, as it determines requirements for the transport operator, and operators have to win a concession in order to provide their services in the area. Travellers have a moderate interest but not much influence, and for the travellers with more special needs such as elderly and disabled the interests are generally higher as they are more dependent on the public transport. Municipalities have a similar role, they have a rather high interests in the local transport system, but do not have much influence on the system as a whole. The national government, however, has a significant influence due to the large amounts of money invested via subsidies, but on a more local scale its interests are not that high.

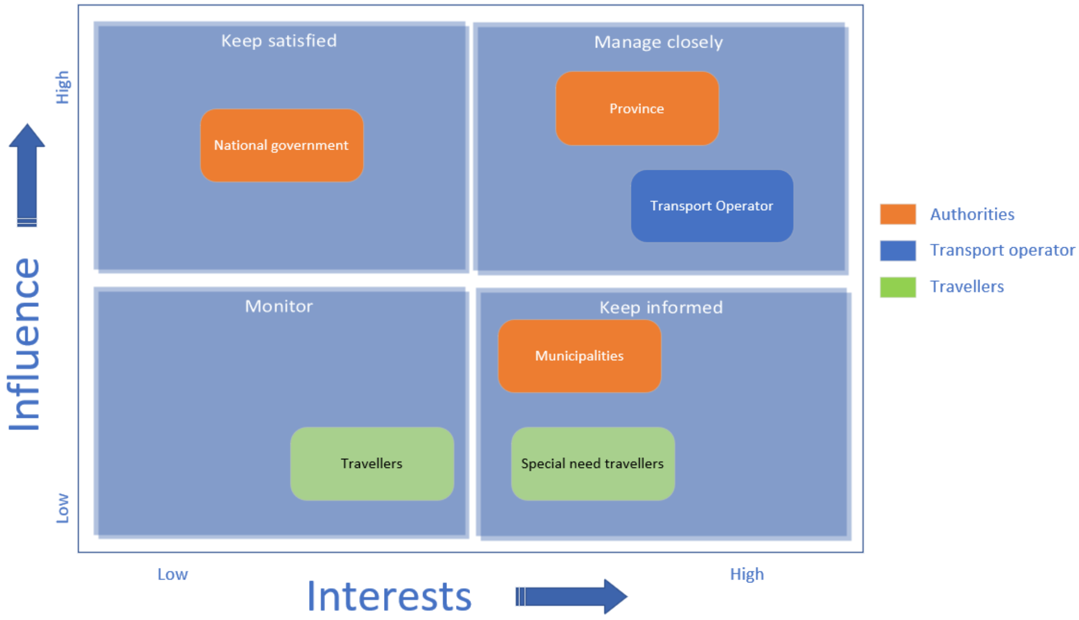


Figure 3: *Interest vs. influence diagram*

4 Results alternative forms of public transport

In this chapter several alternative forms of public transport will be described, their concept will be explained, and some advantages and disadvantages will be discussed. The first section 4.1 will address the concept of demand responsive transport. Secondly, shared mobility services are explained in section 4.2, starting with rental systems such as car, bike and scooter sharing. Then the idea of shared mobility hubs is introduced. Next, personal vehicle sharing systems such as ridesharing and ride-sourcing will be described. In section 4.3 the possibility of automatic systems as an alternative will be discussed. For every alternative, the options that are already currently present in Friesland will be discussed briefly. Lastly, the most important characteristics of each considered alternative are summarised in section 4.4.

4.1 Demand responsive transport

One of the most familiar forms of alternative public transport is the demand responsive transport (DRT). This type of service provides on demand transport, often with a semi-fixed or flexible route, where passengers can request stops or sometimes even be picked up and dropped at home (Butler et al., 2020; Bronsvoort, 2019). DRT is not a recent innovation, as it was promoted for urban transport already in the sixties (Alonso-González et al., 2018), but due to technological advancements in routing automation, ICT, and the presence of smartphones, the potential of DRT is being rediscovered and increasing in popularity amongst transport operators (Butler et al., 2020).

There are many different forms of DRT, in the paper of Alonso-González et al. (2018) the systems characteristics are summarised in five aspects: coverage and routing (varying from door-to-door service to rigid stops), operating hours, vehicle characteristics (most often mini-busses are used), booking system (advanced or real-time, online or by phone) and request acceptance criteria.

The main advantage of DRT systems is that it has the ability to provide coverage over a greater service area with a greater flexibility than normal public transport (Mageean and Nelson, 2003). In a recent study of Knierim and Schlüter (2021), it is stated that DRT systems can significantly enhance mobility for individuals with limited mobility or those reliant on public transportation, thereby helping to prevent social exclusion. Furthermore, a DRT system can act as a replacement for low occupancy public transport that are not economically feasible, such as is the case in low-density and rural areas. A DRT system is often more cost-effective, as it reduces unnecessary trips (Butler et al., 2020).

However, DRT has several disadvantages as well. Almost all systems have a certain pre-travel booking time, which decreases the flexibility offered for the users. According to a study of Mageean and Nelson (2003), this time varies from 15 minutes up to 2 hours ahead of departure time. For Dutch systems reservations can be made at least 1 hour in advance, mostly by phone, and often via an app or a website as well (Bronsvoort, 2019; CROW, 2020). Furthermore DRT vehicles are often smaller than regular busses, which reduces their passenger capacity, more often resulting in fully booked busses in the morning (Sörensen et al., 2021). Another aspect that can be difficult to overcome, is the low patronage attraction, i.e. insufficient awareness or marketing, which can lead to low passenger amounts (Coutinho et al., 2020).

Figure 4: *An Opstapper minibus.* From Jobinder (n.d.)

4.1.1 DRT in Friesland

An example of DRT that is widely present in Friesland is the Opstapper, see Figure 4, which can be booked 1 hour in advance by phone only. However, Lageveen indicated that for the next concession, it might also become possible to reserve via an app. The Opstapper provides a feeder-trunk system service: it has fixed stops in villages, from which it brings people to an interchange stop, where one can change onto a regular bus line or train connection (Arriva, n.d.-b). Departure times are scheduled (rigid) to minimize the waiting time of passengers at the interchange stop, and the system shows up when planning a trip using for instance the 9292 platform. A one-way ticket costs €2,50, and for an additional €4 one can be picked up from or dropped off at a specific address in the service area. Payment is not possible with the regular 'OV-chipkaart' but can only be done by debit card (Arriva, n.d.-b). This is due to the fact that Arriva is outsourcing the service to local taxi providers. In the years 2018-2021 the number of yearly trips was ca. 18,100, with in the years 2020 and 2021 respectively 18,303 and 22,108 passengers (CROW, 2020).

Next to the Opstapper, there is another DRT system present called the 'Arriva Vlinder', but this system only active in the regional capital Leeuwarden. It takes a route with a fixed start and end stop; the rest of the stops must be requested. The concept is different from the Opstapper, as both departure and arrival stop can be requested from a list of stops. Furthermore, the trip can be paid for using both OV-chipkaart and debit card, and the tariffs are comparable to regular public transport (CROW, 2020). Trips can be booked via an app, or 30 minutes ahead of departure by phone (Arriva, n.d.-c).

4.2 Shared mobility

Shared mobility refers to the practice of sharing vehicle - cars, scooters, bicycles, or other transportation modes - allowing users to access them for short periods of time based on their needs. This concept includes various forms of shared transportation, including carsharing, bikesharing, ridesharing, and on-demand ride services (Shaheen et al., 2015).

Machado et al. (2018) state that a large advantage of shared mobility systems is that it acts as a practical substitute to private car ownership, leading to reduced personal, social, and environmental burdens while maximizing travel effectiveness.
Shared mobility systems can be divided into two groups, separated by ownership:

1. Rental sharing from companies
2. Personal vehicle sharing

4.2.1 Rental sharing from companies

This group of shared mobility uses the business-to-consumer principle, where a transportation vehicle from a provider can be temporarily used for a certain cost, mostly within a certain area. According to Shaheen et al. (2015), the users get the benefits of the transportation mode as needed, without the cost and responsibility of ownership. A distinction can be made between car sharing and micromobility sharing, i.e. (e)-bikes, scooters and mopeds. Whereas the first often operates in larger regions in which the car can be used, the micromobility options are often limited to a smaller area or a city.

Shared micromobility can also be used as last-mile transport. This can be encouraged with the implementation of shared mobility hubs. In a study from Blad et al. (2022), the definition used is as follows: "A shared mobility hub is a location where multiple sustainable transport modes come together at one place, providing a seamless connection between modes, offering besides public transport several shared mobility options, but also potentially including other amenities, ranging from retail, workplaces, to parcel pick-up points like lockers.". A visualisation of this concept can be seen in Figure 5. The concept of a mobility hub can increase the accessibility to workplaces and other destinations for the inhabitants a rural region (Frank et al., 2021).

One of the largest difficulties of shared mobility services, according to a research from Schaefer et al. (2022), is the awareness of these services among citizens. Many individuals are unaware or have limited knowledge of shared mobility services due to inadequate information provided to them.

Municipalities can help increase this awareness, by educating the public through both traditional and digital platforms like social media, to generate more demand and attract more users to shared mobility services (Schaefer et al., 2022).

Figure 5: *Illustration of a shared mobility hub.* From Austin (2021)

4.2.2 Personal vehicle sharing

Apart from companies that provide vehicles to customers, vehicles can also be shared by a private owner. The study of Shaheen et al. (2015) combines several types of this principle under the term 'personal vehicle sharing' (PVS). Individuals transform their private vehicles into shared cars, making them available for short-term rentals to other drivers. In general, PVS companies facilitate the transactions between car owners and renters, by offering the essential resources needed for the exchange, including online platforms, customer support, auto insurance, and technology (Machado et al., 2018).

Two main groups of PVS are Peer-to-peer (P2P) carsharing and fractional ownership. The first is similar to rental car sharing, but now the provider company is replaced by an individual car owner that makes his car (temporarily) available for other users to rent. Fractional ownership on the other hand, is a cooperative ownership model where a small group of individuals share the expenses and access to a shared vehicle. Each member has rights and terms that align with their specific needs and the priorities set by the operator. This arrangement allows individuals to enjoy the benefits of vehicles they might not afford individually, such as high-end models or electric vehicles. (Machado et al., 2018).

Other forms of personally shared transport systems are ridesharing and ride-sourcing. Ridesharing is commonly known as carpooling or vanpooling. The largest advantage of ridesharing is the benefit of reducing costs. According to Shaheen et al. (2015), up to two-thirds of the commuting costs of driving a single-occupied car can be saved by flexible carpooling.

A related concept explored in rural areas of eastern Belgium by Madani et al. (2022) is ridesharing benches. Citizens can sit on distinctive blue benches called 'Mitfahrbank' along main access roads to signal their need for a ride, as shown in Figure 6. Drivers traveling in the same direction can voluntarily offer a ride if they have available seats.

Figure 6: *Ridesharing bench in East-Belgium.* From Krickel and BRF (2018)

The researchers found a significant future potential for ridesharing benches. Users expressed interest in combining the benches with scheduled bus services, seeing it as an affordable and practical shared mobility solution, particularly in rural areas with limited public transportation coverage. A disadvantage of the system is the uncertainty in waiting time of users before someone takes them along. Additionally, (social) safety of users is a constraining factor, as well as raising people's knowledge about the concept (Madani et al., 2022).

Ride-sourcing is rather similar to ridesharing, but in ride-sourcing systems, bookings are done through a paid travel-sharing service. There is a service fee that includes fuel costs, driver's fee, the intermediary's compensation for linking the service provider and final consumer, and taxes (Machado et al., 2018).

4.2.3 Shared mobility in Friesland

There are several systems currently already present in Friesland, however most of them only in the regional capital Leeuwarden.

- **Shared (e)-bikes:**
  The OV Fiets from rail operator NS is available at three stations only: Leeuwarden, Heerenveen and Sneek, although the latter has a rather low capacity: only 4 bikes (NS, n.d.). The bikes can be rented for €4,45 per day.
  Arriva Ride&Go has 8 foldable e-bikes available at Leeuwarden station, they can be booked for a daily price of €7,50 (Arriva, 2021).

- **Shared e-mopeds:**
  E-moped provider Check is operating in Leeuwarden, GO Sharing was operating but currently is not. In the rest of the province, there are no shared e-mopeds available (Räker, 2022).

- **Shared cars:**
  There are currently two companies that have several cars available in Friesland: MhyWheels and Greenwheels. However these are only available in the larger cities and have to be returned to the same parking place again (Räker, 2022).

- **Mobility hubs:**
  Apart from some shared options that are available near stations, Friesland does not yet have any real mobility hubs. Two hubs are planned to be opened in 2024, but so far it is unclear where precisely (Robberegt, 2020).

4.3 Automated systems

Autonomous Vehicles (AVs), represent a groundbreaking advancement in transportation technology. These vehicles are capable of navigating and operating without human intervention, relying on a combination of sensors, artificial intelligence, and advanced computing systems (Iclodean et al., 2020).

Although AVs have not been widely adopted due to safety concerns, AVs hold immense potential as the future of transportation (Zhu et al., 2023). A notable advantage of AVs is the ability to reduce traffic congestion and accidents significantly. Moreover, AVs are expected to become cheaper and more sustainable compared to traditional transportation modes. With improved fuel efficiency and the potential for shared mobility, AVs can contribute to reduced emissions and a more environmentally friendly transportation system. Another advantage is the potential increase in comfort for passengers. AVs can provide a smooth ride, eliminating the need for constant acceleration and braking. This enhanced comfort can significantly improve the overall travel experience for individuals, where the opportunity is offered to use travel time more productively as there is no need to drive yourself (Imhof et al., 2020).

The rapid advancements in autonomous technology within the automotive and IT sectors have made it possible to implement AVs in public transport. Autonomous public transport offers significant advantages in terms of efficiency: they can continue driving for 24 hours per day, thus eliminating stop times. AVs in public transport also require lower maintenance due to the elimination of poor or bad driving practices. Additionally, optimized routes contribute to energy efficiency, while independent routes result in improved safety and reduced accidents (Iclodean et al., 2020). Imhof et al. (2020) did a research on simulating Shared Autonomous Vehicles (SAV) in a regional public transport system in Switzerland. They concluded that by replacing the entire public transportation system by SAV, the revenues can actually become larger that the costs, thus making the system no longer dependent on subsidies as is the case now. This is mainly due to the omission of the drivers: the driver's task in busses is responsible for around 50% of the total costs and for trains this is about 15%. The evidence suggests that SAV has the potential to be an excellent public transport solution for rural areas. According to the estimations in the study, it would be possible to provide the service every 10 minutes, which could significantly enhance accessibility in these regions. This is particularly significant considering that buses in rural areas often operate on an hourly or less frequent schedule.

In the future, SAVs can provide several types of mobility services, including, autonomous DRT, carsharing, ridesharing, and mixed services (Butler et al., 2020; Zhu et al., 2023).

However, the implementation of autonomous (shuttle) buses in public passenger transport faces several significant (juridical) barriers. These currently still include the requirement for a human operator to accompany the buses, a limited passenger capacity of up to 15 persons, a maximum speed of 20 km/h, and the high cost of approximately 300,000 Euros per vehicle (Imhof et al., 2020).

Currently, autonomous shuttle buses find successful applications in special areas of public transport. These include night routes with reduced urban traffic and routes through airports, industrial parks, and commercial areas.

Nevertheless, there is a strong and growing interest in autonomous vehicles from both public and private sectors. Researchers predict that autonomous vehicles will become increasingly commonplace in the next 10 to 30 years, with forecasts suggesting that at least 50% of all vehicles will be autonomous by 2050 (Butler et al., 2020).

Figure 7: *The autonomous shuttle from Arriva in Groningen.* From @noth (n.d.)

4.3.1 AVs in Friesland

Currently there are no automated shuttles operating in Friesland. However, the province is collaborating with the other northern provinces of the Netherlands (i.e. Groningen and Drenthe) in the organization @north (Autonomous Transport North Netherlands). In a project that runs since 2018, an autonomous shuttle from Arriva is pending between the Ommelander Ziekenhuis hospital in Groningen and the nearest bus-stop (ca. 1 km), see Figure 7. With it, the potential for deploying self-driving shuttles on a larger scale is investigated. Additionally, the shuttle is undergoing testing in various traffic scenarios, involving different speeds, traffic regulations, and interactions with other vehicles (@noth, n.d.).

4.4 Overview of alternatives

In this chapter several alternative forms of public transport have been addressed. To summarize the mentioned alternatives for public transport, the most important advantages and disadvantages of each alternative is displayed in Table 2. Furthermore, the current presence of each alternative is briefly included.

Alternative	Subtype	Main advantages	Main disadvantages	Present in Friesland
DRT		• Cost-effective for low demand areas • Flexible service • Often greater coverage	• Advanced booking necessary • Awareness • Booking method • Limited capacity	Yes
Shared mobility	Rental shared	• Vehicle access without ownership costs and responsibilities • Offers last mile transport	• Awareness • Booking method	Yes - only in cities
	Mobility hub	• Encourages multi-mode transport • Increased accessibility • Increased comfort and provided services for travellers	• Implementation costs	No
	Personally shared	• Cost sharing • Better use of vehicles • Increased social contact	• Dependent on other road users • Not very reliable • Social safety issues • Difficult for government to act on	Yes
Automated systems	SAV	• Greatly improves feasibility by eliminating drivers costs • Sustainable • Increased coverage and timetable efficiency • Increased comfort	• High implementation costs • Juridical barriers	No

Table 2: *Overview of the mentioned alternatives*

5 Results data analysis Friesland

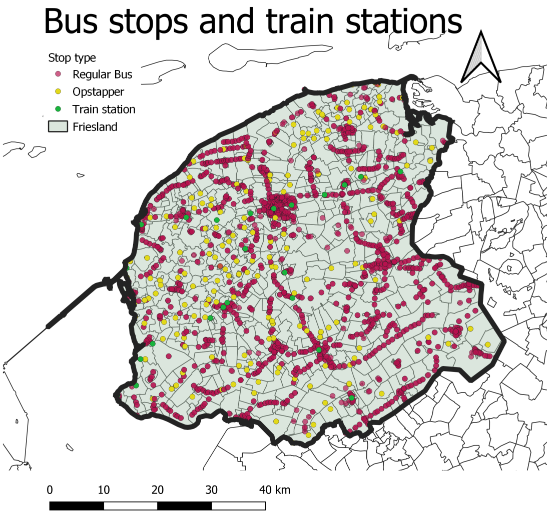
In this chapter a spatial data analysis is done on the availability of public transport and its alternatives in Friesland, The Netherlands. As a start, the locations of bus stops, Opstapper stops and train stations are given in section 5.1, and demographic data per district in section 5.2. Then, for every type of stop a map is created, displaying the availability per district. This is done for train stations in 5.3, for regular bus stops in 5.4, and for Opstapper stops in 5.5. Lastly, a combined map is made in section 5.6, displaying a total mobility score for each district. The districts with the highest and lowest scores are discussed. All maps displayed in this chapter can be found in a larger size as well in Appendix B.

5.1 Stops locations

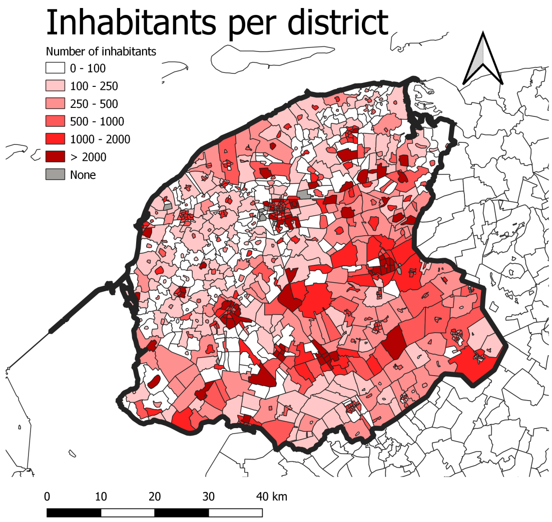
To give an overview of all the stops of public transport or the Opstapper DRT system, all these locations are displayed in Figure 8a. A distinction is made between train stations, regular bus stops and Opstapper bus stops, respectively visualised by a green, red and yellow dot on the map. Large stop clusters can be seen in the cities, such as Leeuwarden, Drachten, Heerenveen and Sneek. Furthermore, some bus lines can be distinguished due to their line-wise orientation.

5.2 Inhabitants

In Figure 8b the number of inhabitants per district is displayed. Districts with a low number of inhabitants are shown in white, for the other district the colour intensity is increasing along with the population size. Additionally, there are several districts with no inhabitants at all, these are displayed in grey. A correlation between the number of inhabitants and the number of transport stops present is clearly visible, as stop clusters often coincide with high-population districts.



(a) Transport stops



(b) Inhabitants

Figure 8: *Public transport stops locations and inhabitant amounts in Friesland*

5.3 Train stations

Firstly, the availability of the train as a transport mode is investigated more closely. Friesland has a total number of 23 train stations divided over 4 rail routes, all converging towards regional capital Leeuwarden. The amount of train stations per district is displayed in Figure 9.

All districts with a train station are displayed in dark blue. Additionally, districts with its geographical centre within a proximity of 1000m of a train station are considered to have a station.

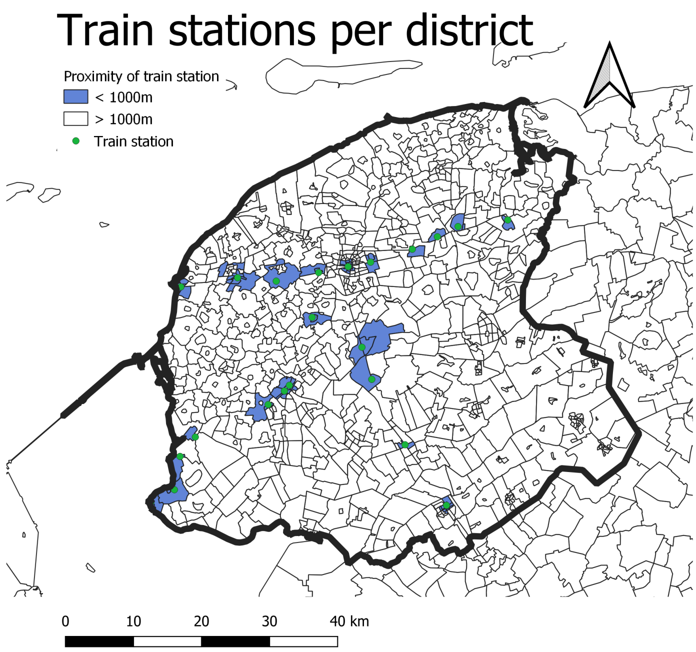


Figure 9: *Train stations per district*

5.4 Bus stops

Secondly, the bus stops availability of regular (non-DRT) busses is examined per district. In the map in Figure 10, the number of bus stops are shown. Regions with no bus stops at all are displayed in white. Regions with 1 or 2 bus stops are shown in a light orange. Districts with 1 or 2 bus stops are likely to just have one or two lines available, but due to the fact that busses mostly drive in both directions, two stops are often located rather close to each other, but for instance on the other side of the street. The same holds for regions with 3 or 4 stops, but then it is more probable that the number of bus lines is slightly larger. All districts containing more than 4 bus stops are displayed in dark orange. The interval of this group is 5 to 23 bus stops per regions. These are put together in one group as regions with a low amount are more relevant for this study than those with a high amount.

It can be seen that the south-east part of the province has many districts with more than 4 bus stops. In this area the population is generally higher as well. In the northern half of the province on the other hand, a significant proportion of the districts has a rather limited amount of bus stops in the area, except for the districts with a relatively larger population.

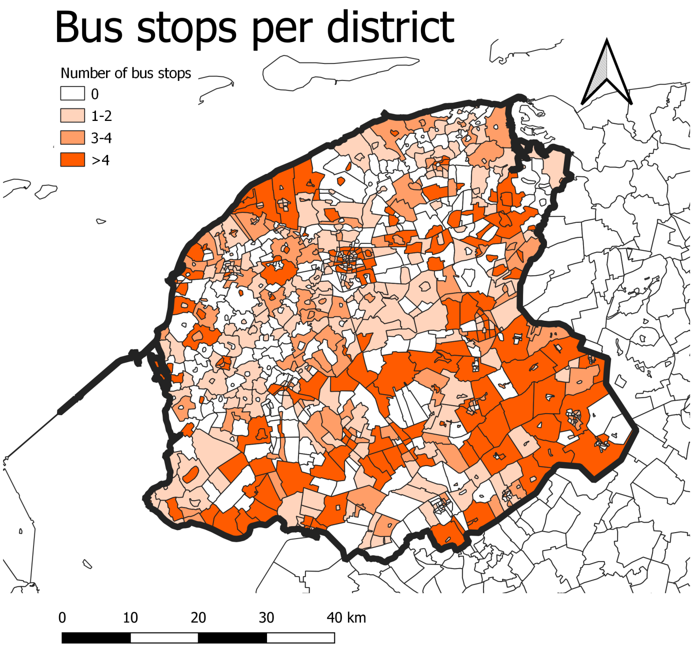


Figure 10: *Bus stops per district*

5.5 Opstapper stops

A last type of stop that is considered is the Opstapper, the largest DRT system in Friesland. The number of Opstapper stops per region can be seen in Figure 11. In this map the regions with no Opstapper stops are displayed in white and regions with 1-2 stops are displayed in yellow, which is the highest number of stops per district. It can be seen that the Opstapper is mainly operating in rural regions with lower amounts of inhabitants, and not so much in urban cores.

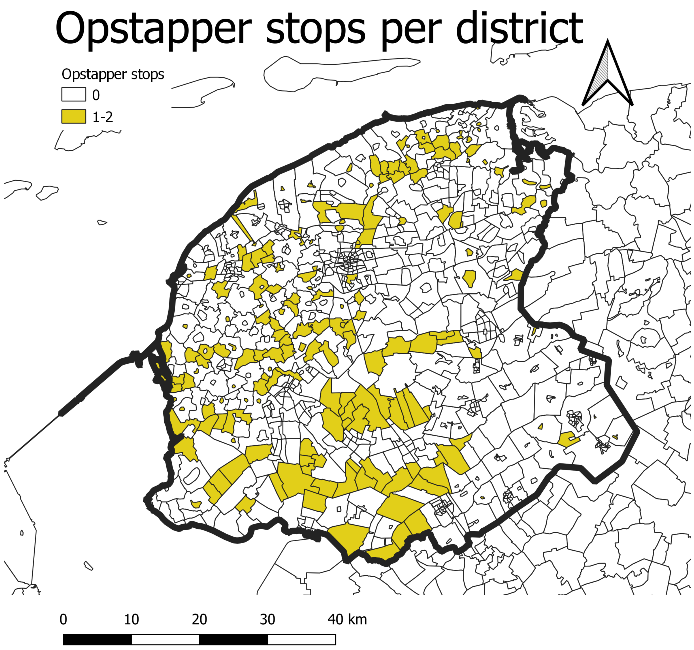


Figure 11: *Opstapper stops per district*

5.6 Combined map

In the previous sections of this chapter, a map has been made for every variable individually. Now every district is given a total score to indicate where the mobility options are rather limited. The scores per transportation type can be found again in Table 1, and the formula used to compute the mobility score is Formula 1. The results of the mobility score for every district are displayed in Figure 12. The minimum score is 0, districts with this score are displayed in white. Higher mobility scores result in a darker green appearance on the map. The highest mobility score is 46.

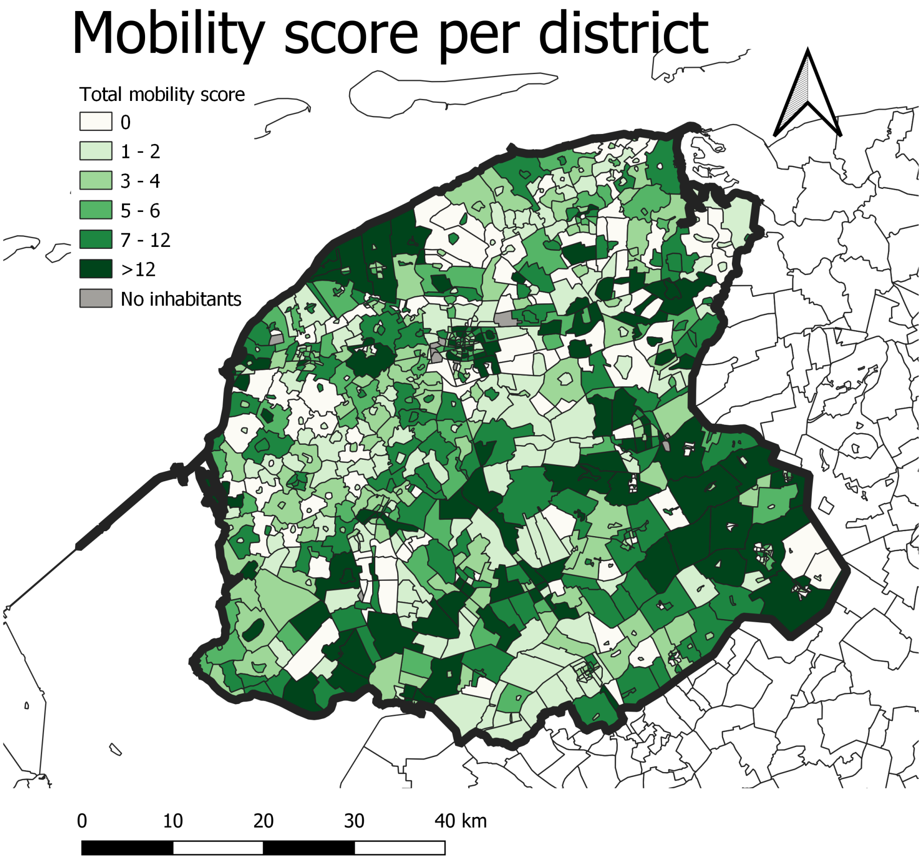


Figure 12: *Mobility score per district*

There are 138 districts (of the 877 in total) that have a mobility score of 0. This means there is not a single transportation stop available within the district. The 5 districts with lowest mobility score and highest inhabitant amounts can be found in Table 3. The rest of the 22 districts with a mobility score of 0 and a population above 500 can be found in Appendix C. In these districts the risk of people without access to public transport is the highest.

Name district	District code	Mobility score	Inhabitants
Skoatterwald	BU00740107	0	4975
De Trisken	BU00900013	0	3135
Ureterp-Buorfinne	BU00861602	0	1575
Oosterwolde-Maden	BU00851101	0	1380
Dokkum binnen de Bolwerken	BU19700000	0	1335

Table 3: *The five districts with the lowest mobility score and largest population*

The five districts the highest mobility score can be found in Table 4. This top 5 is established by filtering on the highest inhabitant amounts, as there were more districts with mobility score 38. The rest of the top 20 districts with a high mobility score can be found in Appendix C.

Name district	**District code**	**Mobility score**	**Inhabitants**
Jubbega	BU00740406	46	3280
Akkrum	BU00740901	44	3310
Ureterp-Buitengebied	BU00861607	42	1015
Buitengebied St.-Annaparochie	BU19491600	40	715
Surhuisterveen	BU00590200	38	5655

Table 4: *The five districts with the highest mobility score*

6 Discussion

The results of this research have provided some insight in the possible alternative forms of public transport in rural areas. Additionally, the research has tried to create a model for a spatial data analysis on mobility availability in a region. This chapter will address some limitations in the research and the corresponding impacts on the results.

The literature analysis was focused on academic papers and public reports from the governmental institutions. There is a possibility that some relevant reports or papers have not been found in the research, which could lead to less relevant or incorrect information. To mitigate this effect, more than one source has been used where possible.

A limitation in the data analysis of this research is the data gap: as described in the methodology, data about transport lines and corresponding frequencies that could be coupled to stops locations was not available in time. The consequence is that every bus or train station was treated as if they provide the same mobility services as the others. This is generally not the case: different stops have different lines with different amounts of departures. To account for the variability of mobility options per type of stop, a rather simple grading model was used, i.e. Table 1. This model can be improved, by using for instance the number of daily departures as a weight. Moreover, there is a large spread in the size of districts, which leads to more favourable scores for larger districts.

An inaccuracy in the available data is the bus stop type. Not in all cases was it possible to determine whether the stop was an Opstapper or a regular bus stop, again mainly due to the missing data. Some stops might not have been identified properly, making the mobility score of several regions in Figure 12 diverge somewhat from what they should be.

Lastly, there are several bus stops located near borders of districts, providing a bus service for the neighbouring districts as well. However, these districts do not get credit for this in the mobility score. In this study this was not possible to take this into account, because of the island effect in district locations, see also Figure 2.

The limitations in data gathering and processing of this study have a negative impact on the quality of the results, but it was still possible to identify the regions with the least amounts of mobility options in the area, and thus the results provide some base as to where more alternative forms of public transport can be implemented.

7 Conclusions and recommendations

7.1 Summary of findings

This research has aimed to identify possible alternative forms for public transport in rural areas and how these can be used more to increase the mobility availability, with a focus on the Dutch province of Friesland.

Three groups of relevant stakeholders have been identified: authorities, transport operators and travellers. Authorities have a big impact on the transport system via regulations and provided subsidies, they have the aim to keep inhabitants connected. Transport operators are responsible for providing transportation services to the public, while maximizing their own profits. Alternative forms of public transport already help doing so, and this can be increased in the future. There are many subgroups of travellers, but overall travellers want to be able to move efficiently from origin to destination, while maximizing comfort and minimising the costs and travel time. Alternatives for public transport can address this need by providing flexible first- and last-mile transport.

Based on literature study, several alternative forms of public transport have been found. The alternatives have been classified into three main groups: demand responsive transport (DRT), shared mobility and automated systems.

DRT systems are cost effective in areas with low demand, such as rural areas. It reduces unnecessary trips and empty buses, while providing a flexible service for travellers. However, the obligation to reserve a certain time before a trip, often by calling, imposes a significant threshold for users.

Shared mobility systems come in many different forms, but the general advantage is that users get the benefits of the transportation modes as needed, without the costs and responsibilities attached to (full) ownership. Mobility hubs can be a good way to increase the use of shared mobility options and combining those with regular public transport.

Automated systems, and more particularly autonomous vehicles (AVs), have not been widely adopted yet due to safety and juridical concerns. However, shared AVs (SAVs) have the potential to be an excellent public transport solution, for rural areas as well. They can improve cost-efficiency by eliminating driver costs and improved (timetable) efficiency, while increasing the patronage and thus enhance accessibility.

Of the aforementioned alternatives, only a DRT system called the 'Opstapper' is widely present in rural areas in Friesland. Shared mobility options are still limited to the few cities in the region, and AVs are still in development and not present yet.

To obtain more information about the availability of public transport and its alternatives, a data analysis was done on the province of Friesland. Every district was assigned a mobility score for the number of train stations, regular bus stops and Opstapper stops that are present in the area. Several districts have been identified that do not contain any public transport system while having a population of more than 500. These are high-risk districts, where the chance of having limited mobility possibilities for inhabitants is rather high.

7.2 Recommendations for Friesland

Several recommendations can be made for the province of Friesland, based on the outcomes of the literature and data analysis.

- While the Opstapper is already widely available in the more rural districts, its booking and payment method, and the need to reserve an hour ahead, are rather unfavourable for the users. Making booking available by app or online, and reducing the reservation time needed, can greatly improve the service for its users.
- Shared mobility could be used more in rural areas as well, providing last-mile transport for users of the public transport system. This can be encouraged by implementing multiple shared mobility hubs around existing bus stops and train stations or start a trial to investigate the impact locally.
- Friesland should take into account that the arrival of SAVs will change the public transport system in the next 10 to 30 years, with great a potential for rural areas as well. Therefore the first steps can already be investigated to be able to have a smooth introduction of SAVs in the near future.
- The results of the data analysis show 22 districts without any transportation options in the area while still having a significant population. Each of these districts should be investigated more closely, and actions should be taken to increase the mobility options for inhabitants, for instance by implementing more DRT stops or shared mobility options.

7.3 Recommendations for further research

Future research could further develop the model to analyse spatial mobility availability that was set up in this research. Implementing for instance the (daily) frequencies and routes could improve the model's representativeness of the mobility system, and thereby the accuracy of the recommendations for authorities. The model could also be applied onto different (rural) areas in the Netherlands or even abroad, to investigate mobility availability elsewhere.

Another interesting aspect of mobility availability that could be the topic of a new research, is the difference in availability of transport during the week versus the weekend, or day vs. evening, as weekends and evenings often have a rather different public transport scheduling. This can lead to a better understanding and overview of mobility availability gaps that are present only during a certain time span in the week.

Other research can be done on identifying the optimal locations for mobility hubs in Friesland, and how exactly these hubs should look like and what services should be offered to improve the quality of public transport, taking into account the wishes from local inhabitants.

7.4 Conclusion

This research has shown that alternative forms of public transport such as DRT systems, shared mobility options and autonomous systems can be applied in rural areas to increase the mobility availability for local inhabitants. Several of these systems are already used in Friesland, but they are not omnipresent yet. Districts in the province of Friesland with a low number of mobility options have been identified using a spatial data analysis model. In these districts transportation options should be increased, which can be done by expanding the current systems for public transport or DRT, or by implementing more shared mobility systems or other alternative forms of public transport in these regions. In general, mobility hubs could be implemented around existing train stations or bus stops, making it possible to use shared systems and to provide last-mile transport, in rural areas as well. The availability of transport options can be researched further, for example by improving the mobility model with more data, to better identify regions with a high risk for low mobility.

References

Alonso-González, M. J., Liu, T., Cats, O., Van Oort, N., & Hoogendoorn, S. (2018). The potential of demand-responsive transport as a complement to public transport: An assessment framework and an empirical evaluation. *Transportation Research Record*, *2672*(8), 879–889.

Arriva. (2021). https://www.arriva.nl/a/arriva-bikego.htm

Arriva. (n.d.-a). https://arriva-reisinfo.fis.nl/

Arriva. (n.d.-b). *Aanvullend vervoer friesland*. https://www.arriva.nl/friesland-en-waddeneilanden/reisinformatie-4/aanvullend-vervoer.htm

Arriva. (n.d.-c). Met de Arriva Vlinder. https://www.arriva.nl/over-je-reis/met-de-bus/met-de-arriva-vlinder/?regio=Frysl%5C%C3%5C%A2n

Austin, J. (2021). *Mobility hubs – a transport planning concept whose time has*. https://www.transportxtra.com/publications/local-transport-today/news/69431/mobility-hubs--a-transport-planning-concept-whose-time-has-come

Bastiaanssen, J., & Breedijk, M. (2022). *Toegang voor iedereen?* https://www.pbl.nl/sites/default/files/downloads/pbl-2022-toegang-voor-iedereen-4932.pdf

Blad, K., de Almeida Correia, G. H., van Nes, R., & Annema, J. A. (2022). A methodology to determine suitable locations for regional shared mobility hubs. *Case Studies on Transport Policy*, *10*(3), 1904–1916.

Boers, J. (2023). Je hebt op het platteland gewoon een auto nodig. *autoweek.nl*. https://www.autoweek.nl/columns/artikel/weblog-joost-je-hebt-op-het-platteland-gewoon-een-auto-nodig/

Bronsvoort, K. (2019). *Exploring alternative public transport in rural areas: What are the preferences of bus users in rural areas of the netherlands for a demand responsive transport service and a multimodal alternative that combines express bus and bike-sharing?* http://resolver.tudelft.nl/uuid:b64b3429-c521-430b-93bf-148944260281

Butler, L., Yigitcanlar, T., & Paz, A. (2020). Smart urban mobility innovations: A comprehensive review and evaluation. *IEEE Access*, *8*, 196034–196049. https://doi.org/10.1109/ACCESS.2020.3034596

Centraal Bureau voor de Statistiek. (2018). *Ruim kwart huishoudens heeft geen motorvoertuig*. https://www.cbs.nl/nl-nl/nieuws/2018/25/ruim-kwart-huishoudens-heeft-geen-motorvoertuig

Coutinho, F. M., van Oort, N., Christoforou, Z., Alonso-González, M. J., Cats, O., & Hoogendoorn, S. (2020). Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in amsterdam. *Research in Transportation Economics*, *83*, 100910.

CROW. (2020). https://www.crow.nl/thema-s/collectief-vervoer/flexwaaier/flexvervoer-in-nederland/15-flexsystemen-1

Frank, L., Dirks, N., & Walther, G. (2021). Improving rural accessibility by locating multimodal mobility hubs. *Journal of transport geography*, *94*, 103111.

Het Locov. (n.d.). *Landelijk overleg consumentenbelangen openbaar vervoer*. https://www.locov.nl/default.aspx

Iclodean, C., Cordos, N., & Varga, B. O. (2020). Autonomous shuttle bus for public transportation: A review. *Energies*, *13*(11), 2917.

Imhof, S., Frölicher, J., & von Arx, W. (2020). Shared autonomous vehicles in rural public transportation systems. *Research in transportation economics*, *83*, 100925.

Interprovinciaal Overleg. (n.d.). *Toekomst ov - ipo*. https://www.ipo.nl/thema-s/mobiliteit/toekomst-ov/#:~:text=Provincies%5C%20en%5C%20vervoerregio%5C%27s%5C%20zijn%5C%20verantwoordelijk%5C%20voor%5C%20regionaal%5C%20OV.,draagt%5C%20bij%5C%20aan%5C%20de%5C%20sociale%5C%20ontwikkeling%5C%20van%5C%20inwoners

Jobinder. (n.d.). *Opstapper | Jobinder*. https://www.jobinder.nl/opstapper/

Kesteren, G. v. (2007). *Gemeente en openbaar vervoer*. https://www.crow.nl/publicaties/rapport-gemeente-en-openbaar-vervoer

Knierim, L., & Schlüter, J. C. (2021). The attitude of potentially less mobile people towards demand responsive transport in a rural area in central germany. *Journal of Transport Geography*, *96*, 103202. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2021.103202

Krickel, O., & BRF. (2018). *Erste "Mitfahrbänke" in Raeren und Lontzen aufgestellt*. https://brf.be/regional/1212373/

Machado, C., de Salles Hue, N., Berssaneti, F., & Quintanilha, J. (2018). An overview of shared mobility. *Sustainability*, *10*(12), 4342. https://doi.org/10.3390/su10124342

Madani, N., Creemers, L., Moeinaddini, M., Saadi, I., & Cools, M. (2022). Low-cost shared mobility alternatives in rural areas: A case study of ride-sharing benches in the german-speaking community of belgium. *Case Studies on Transport Policy*.

Mageean, J., & Nelson, J. D. (2003). The evaluation of demand responsive transport services in europe. *Journal of Transport Geography*, *11*(4), 255–270.

Ministerie van Fininanciën. (n.d.). *3.4 artikel 16 openbaar vervoer en spoor*. https://www.rijksfinancien.nl/memorie-van-toelichting/2022/OWB/XII/onderdeel/1053599#

Ministerie van Infrastructuur en Waterstaat. (2023). Kamerbrief over hoofdlijnennotitie mobiliteitsvisie 2050. https://www.rijksoverheid.nl/onderwerpen/openbaar-vervoer/documenten/kamerstukken/2023/03/17/hoofdlijnennotitie-mobiliteitsvisie-2050

Mulley, C., & Nelson, J. D. (2016). *Shaping the new future of paratransit: An agenda for research and practice*. https://doi.org/10.3141/2542-03

@noth. (n.d.). https://at-north.nl/over-at-north/

NS. (n.d.). Ov fiets beschikbaarheid. https://ovfietsbeschikbaar.nl/

Plicht, J. (2023). Provincies bezuinigen op ov in landelijk gebied: 'er is bijna niks meer over'. *NU.nl*. https://www.nu.nl/provinciale-statenverkiezingen/6254435/provincies-bezuinigen-op-ov-in-landelijk-gebied-er-is-bijna-niks-meer-over.html

Provincie Friesland. (2023). https://cuatro.sim-cdn.nl/fryslan/uploads/programma_van_eisen_concessie_openbaar_vervoer_fryslan_2024-2034.pdf?cb=tGV5vO6q

Provincie Fryslân. (2022). https://cuatro.sim-cdn.nl/fryslan/uploads/friese_ov-monitor_2021.pdf?cb=zkjUV8Oe

Provincie Fryslân. (n.d.). *Openbaar vervoer*. https://www.fryslan.frl/ov

Räker, C. (2022). https://dutchreview.com/expat/shared-mobility-netherlands/

Rienstra, S. (2022). *Nederlandse overheidsuitgaven en -inkomsten verkeer en vervoer*. https://www.kimnet.nl/publicaties/rapporten/2022/01/17/nederlandse-overheidsuitgaven-en--inkomsten-verkeer-en-vervoer

Robberegt, I. (2020). https://circulairfriesland.frl/app/uploads/2021/02/201123_memo_routekaart_circulair_friesland.pdf

Schaefer, C., Stelter, A., Holl-Supra, S., Weber, S., & Niehaves, B. (2022). The acceptance and use behavior of shared mobility services in a rural municipality. *Smart Cities*, *5*(4), 1229–1240.

Sebah, I. (n.d.). https://theconversation.com/phone-call-anxiety-why-so-many-of-us-have-it-and-how-to-get-over-it-155798

Shaheen, S., Chan, N., Bansal, A., & Cohen, A. (2015). Shared mobility: A sustainability & technologies workshop: Definitions, industry developments, and early understanding.

Sörensen, L., Bossert, A., Jokinen, J.-P., & Schlüter, J. (2021). How much flexibility does rural public transport need?–implications from a fully flexible drt system. *Transport Policy*, *100*, 5–20.

Wiki OV in Nederland. (2022). Opstapper Friesland. Retrieved June 2, 2023, from https://wiki.ovinnederland.nl/wiki/Opstapper_Friesland

Zhu, J., Xie, N., Cai, Z., Tang, W., & Chen, X. (2023). A comprehensive review of shared mobility for sustainable transportation systems. *International Journal of Sustainable Transportation*, *17*(5), 527–551.

A Arriva Interview

An interview was conducted with T. (Thom) Lageveen, Development Advisor North from Arriva, the main public transport provider in Friesland, The Netherlands. The interview was originally held in Dutch, on May 31 of 2023. Lageveen has granted permission for his name and function to end up in this research. Firstly, the questions are enumerated in section A.1. Secondly, a short summary is provided in section A.2.

A.1 Questions

General

1. How does Arriva feel about the fact that everyone has the right to accessibility? How does the organization contribute to maintaining accessibility in rural areas?

2. How does Arriva view the use of alternative forms of public transportation?

Opstapper

1. Why was the Opstapper system chosen in Friesland? (to the extent that Arriva had influence)

2. More specifically, why were fixed departure times and locations chosen, with the option of being taken home?

3. Why can't the Opstapper be booked via the internet or an application?

4. Why are there fixed fares instead of distance-based fares like in regular public transportation?

5. What do drivers do if there are no or insufficient reservations?

6. Can reservations be denied? What are the reasons for refusal?

7. Is Arriva satisfied with the Opstapper? Why or why not?

Other alternatives / future

1. Are there any other alternatives to public transportation besides the Opstapper and Lijntaxi used by Arriva in Friesland, and are there expectations of transitioning to a new system in the coming years?

A.2 Summary of the interview

According to Lageveen, Arriva considers accessibility for all individuals as crucial. They believe in providing public transportation options to all areas, including rural ones. Arriva aims to strike a balance between profitability and affordability in the public transport system. They have agreements with the province of Friesland to ensure that every core area has access to public transportation.

Arriva recognizes the importance of alternative forms of public transport. In Friesland, they have implemented some alternative options, including the Opstapper and Arriva Vlinder. These alternatives have lower operating costs and offer different levels of service. The Opstapper and Vlinder require reservations and personal initiative from passengers. The Opstapper system was chosen for Friesland to address the unique challenges posed by its rural areas. Previous attempts with small buses were discontinued due to high costs. The Opstapper system connects small villages to existing bus lines or trains, allowing them to access higher-quality public transport connections.

The Opstapper system has fixed departure times and locations to comply with legal requirements imposed by the Province for being classified as public transport. While door-to-door service is available for an additional fee, the main goal is to connect passengers to public transport hubs. The lack of online booking capabilities for the Opstapper is due to its outsourcing arrangement and technical limitations. However, there are plans to explore the implementation of app-based reservations in the future.

Fixed fares are used in the Opstapper service instead of distance-based fares to simplify implementation and keep costs affordable. If demand significantly increases, the service may be scaled up to a regular bus line.

When there are no or insufficient reservations, Opstapper drivers may seek other work, while Arriva Vlinder drivers remain idle but still receive payment. Other forms of transportation, such as line taxis and neighbourhood buses, follow fixed schedules. Reservations for the Opstapper service cannot be refused unless there are exceptional circumstances. Passengers with multiple no-shows within a specific time frame may face restrictions.

Lageveen expressed that Arriva is generally satisfied with the Opstapper service as it allows them to offer public transportation in every village or core area. However, finding a balance between motivating people to use public transportation and managing rising costs is a challenge.

Besides the Opstapper and Lijntaxi, Arriva has introduced Arriva Vlinder as an alternative form of public transportation. There are no expectations of transitioning to a new system in the coming years, but the organization is evaluating the long-term viability of the current structure. The goal is to ensure minimal connectivity to every village with affordable fares. Lageveen also mentions the increasing trend of people seeking simpler transportation options and the changing labor market, which may contribute to future driver shortages. He highlights the importance of autonomous transport for rural areas and the potential cost savings associated with reduced labor expenses. However, current legislation requires a person to be present in autonomous vehicles, limiting their speed to 15 km/h. Arriva is lobbying for changes in legislation to enable fully autonomous transport.

B Results maps

All maps that have been created in this research that are shown in chapter 5, are displayed again in this appendix in order of appearance. The size is larger, so more details can be distinguished. Transportation stops locations are shown in Figure 13, inhabitants amounts in Figure 14, train stations in Figure 15, regular bus stops in Figure 16, Opstapper stops in 17, and lastly, the mobility score in Figure 18.

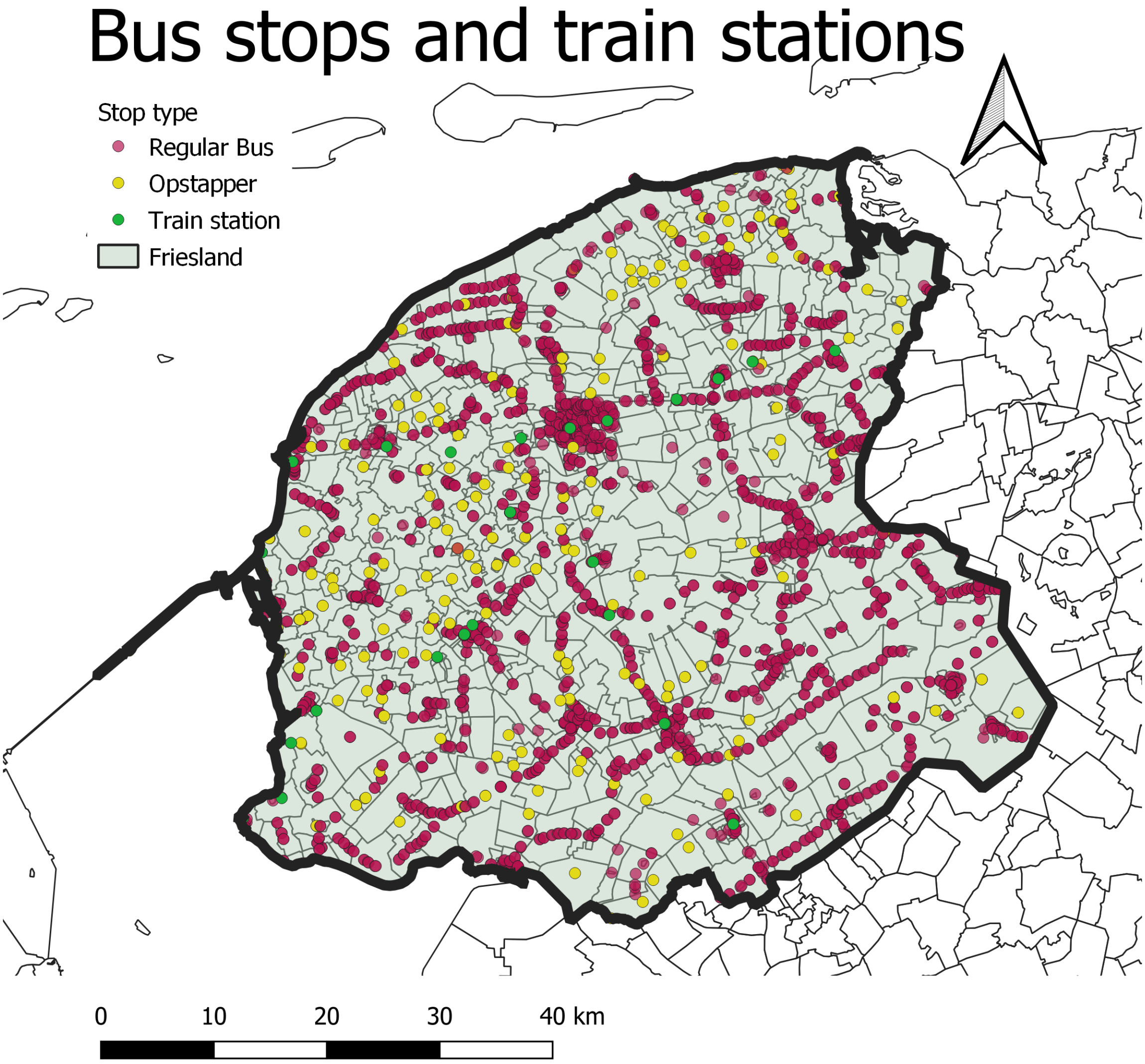


Figure 13: Transport stops

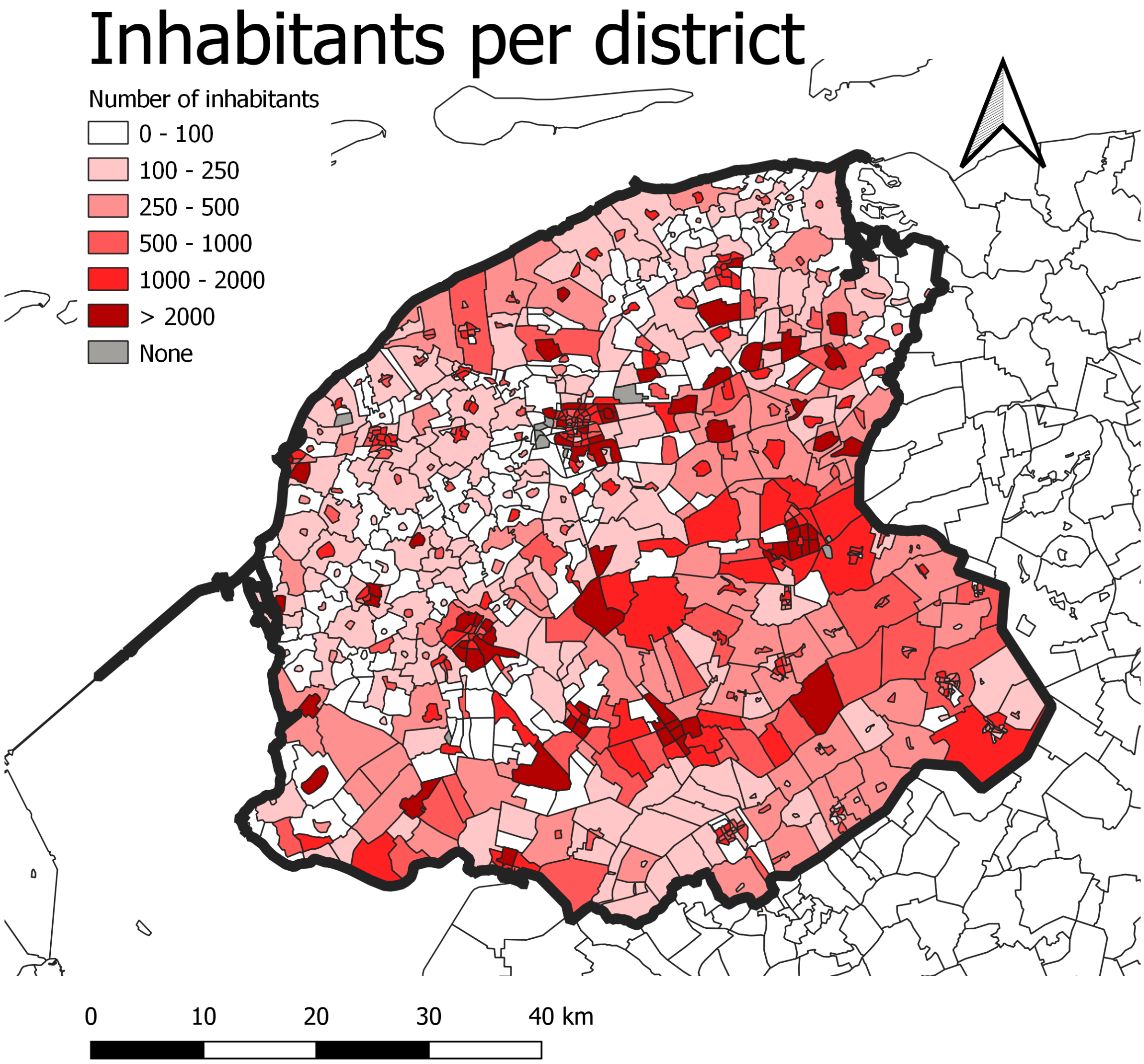


Figure 14: Inhabitants

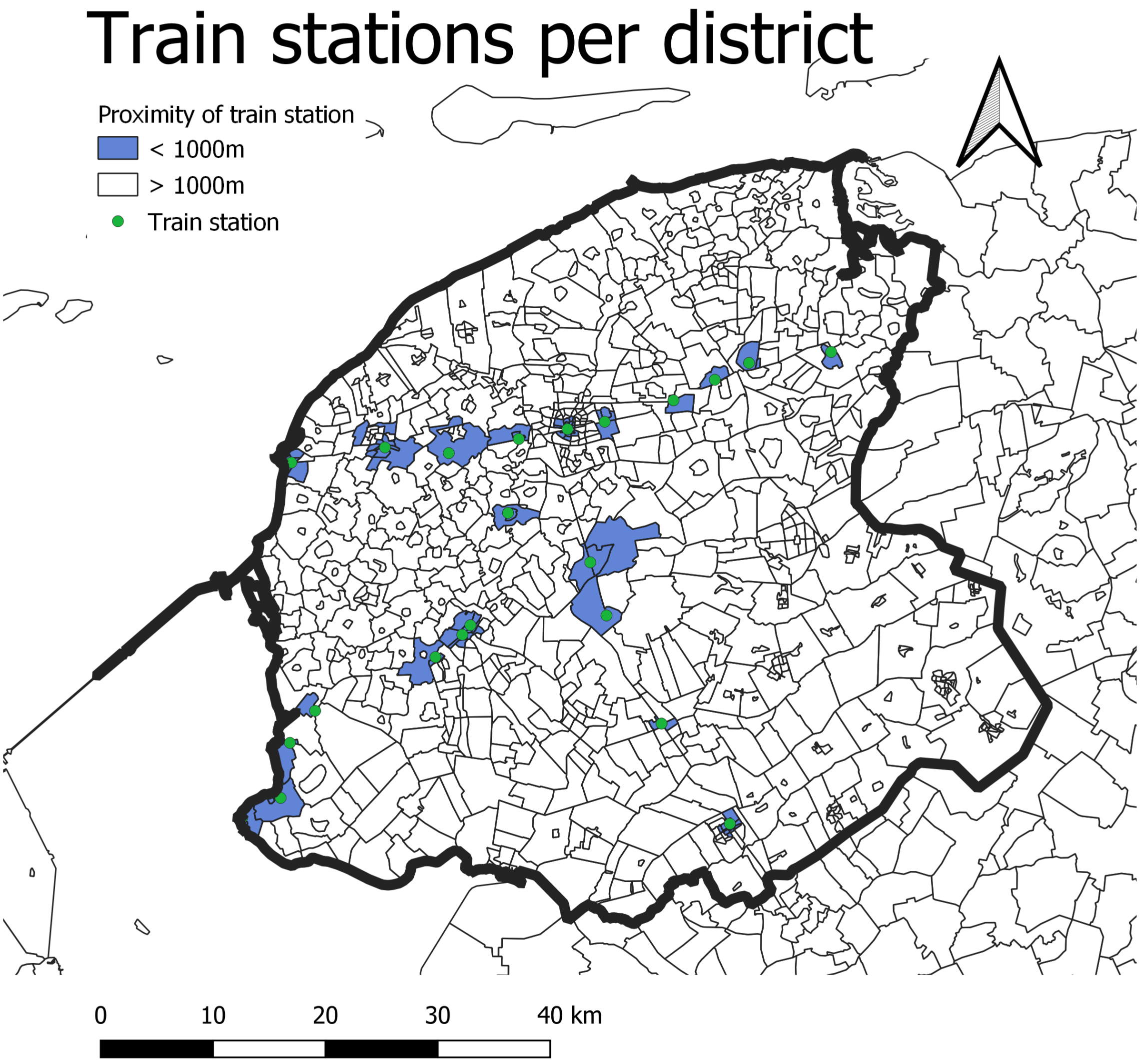


Figure 15: Train stations

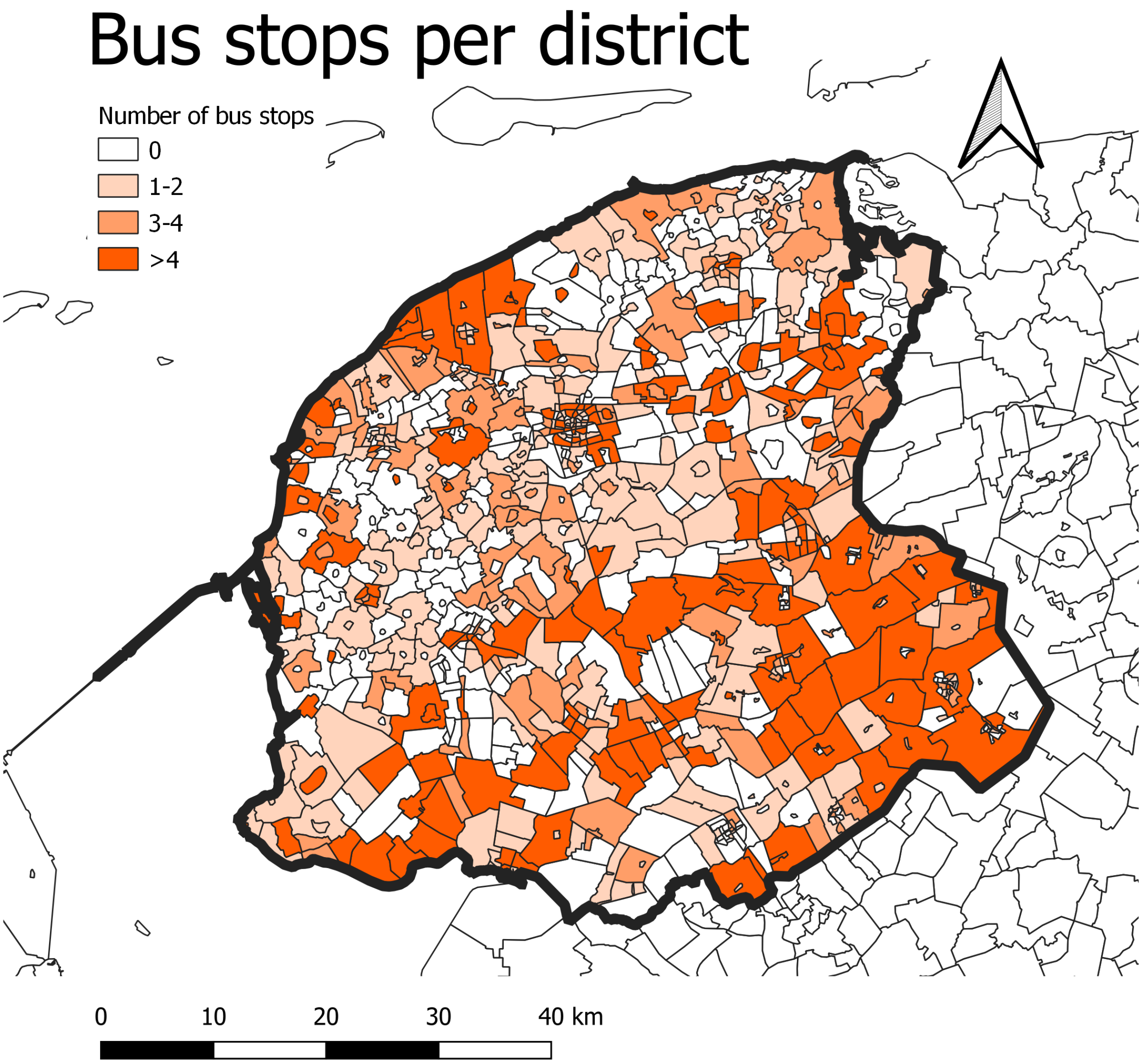


Figure 16: Regular bus stops

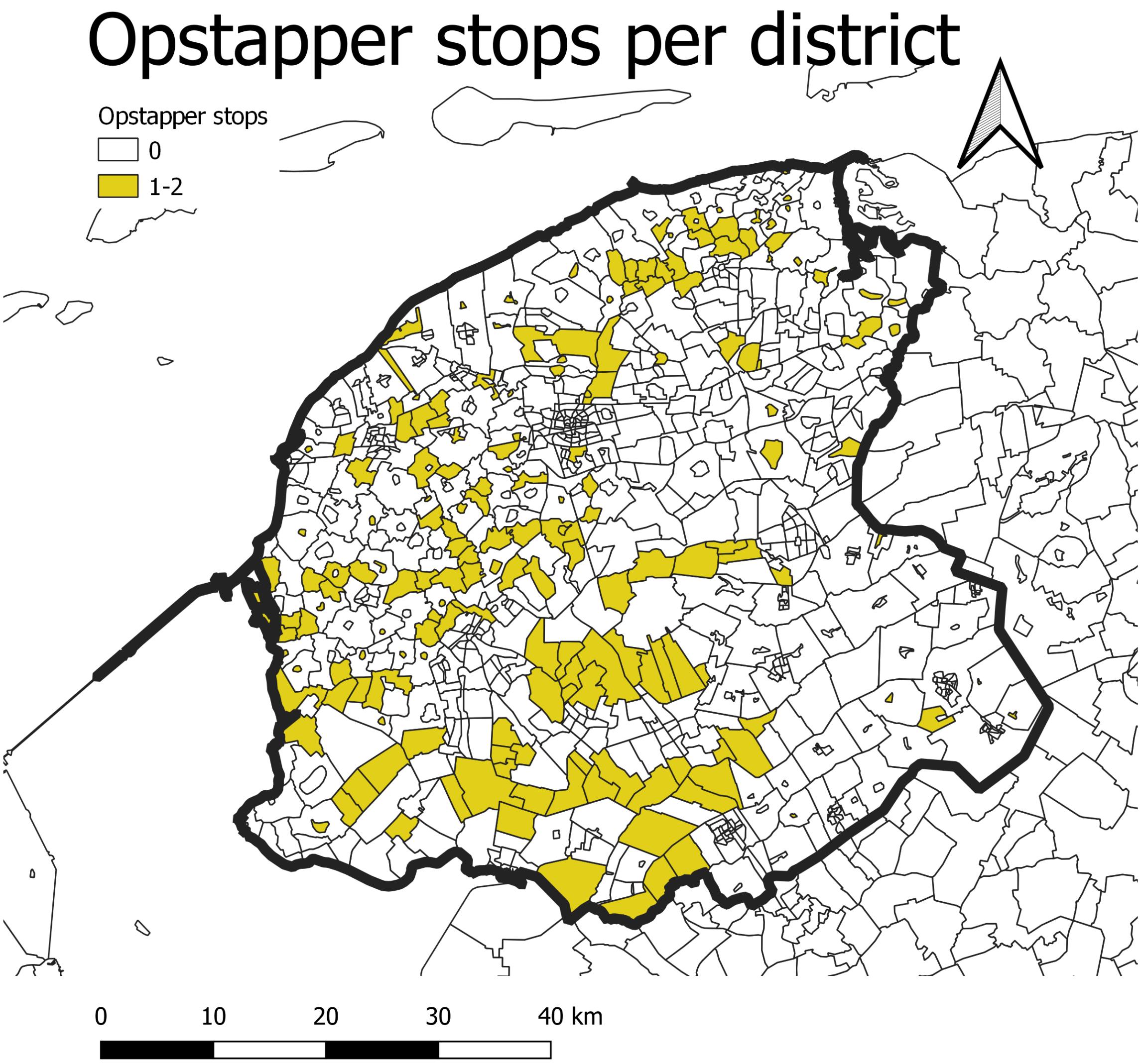


Figure 17: Opstapper stops

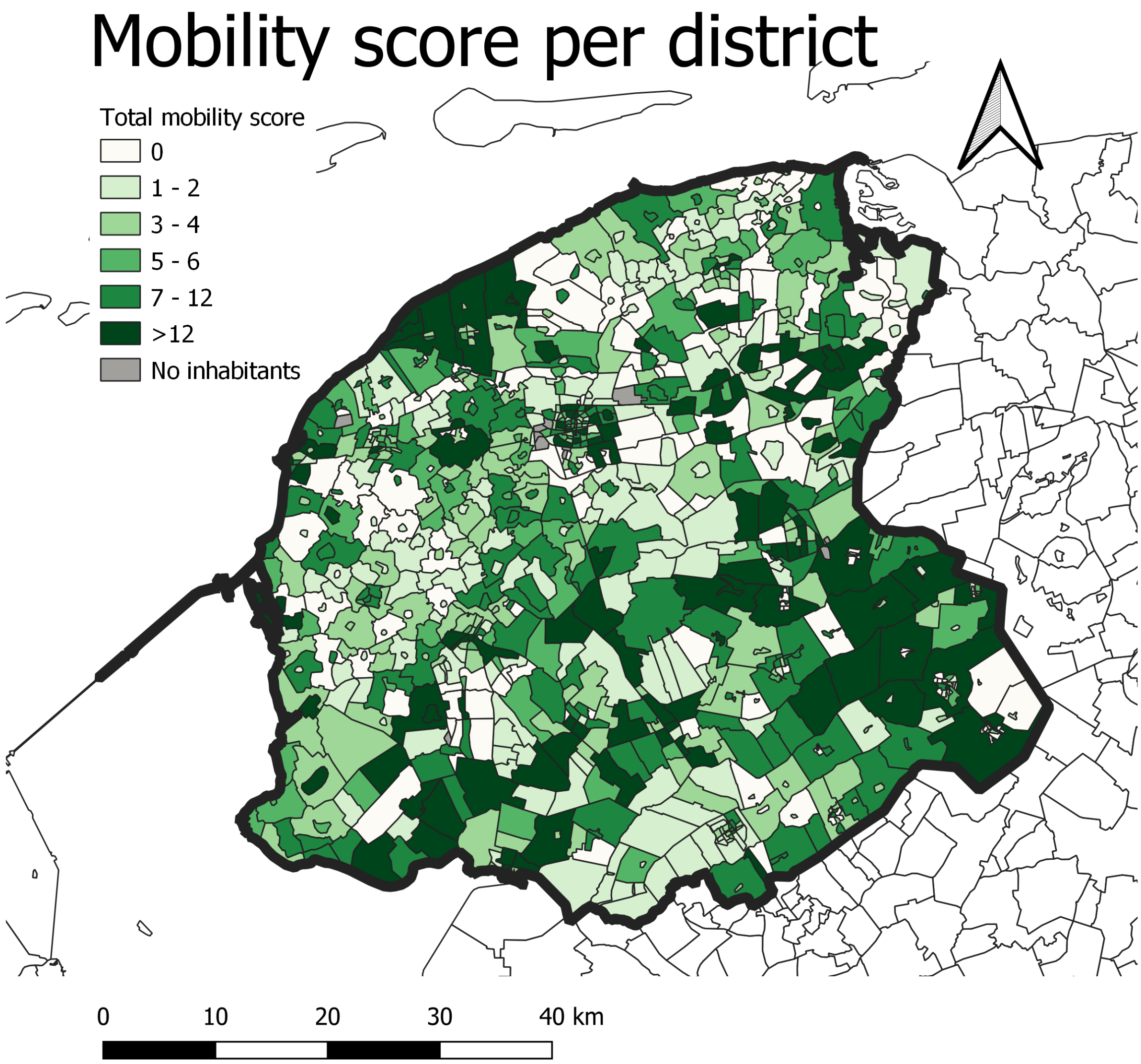


Figure 18: Mobility score

C Mobility score tables

In this appendix, the lists of special districts in Friesland that have been identified in chapter 5 are displayed fully. Firstly, the 24 districts that have a mobility score of 0 while having a population larger than 500 are displayed in Table 5. Secondly, the top 20 districts with the highest mobility scores are shown in Table 6.

C.1 Districts with low score and high population

Name district	**District code**	**Mobility score**	**Inhabitants**
Skoatterwald	BU00740107	0	4975
De Trisken	BU00900013	0	3135
Ureterp-Buorfinne	BU00861602	0	1575
Oosterwolde-Maden	BU00851101	0	1380
Dokkum binnen de Bolwerken	BU19700000	0	1335
Dronryp Oost	BU19492603	0	1260
Ureterp-Fûgelliet	BU00861605	0	1170
Lemmer-Kom	BU19402303	0	1130
Noordwolde-Rotanwijk	BU00860203	0	1085
Beetsterzwaag-Skeakel	BU00981005	0	1085
Gorredijk-Loevestein	BU00860505	0	960
Joure, Wyldehoarne	BU19401909	0	960
Wiarda	BU00807302	0	930
Sumar	BU07370600	0	905
Anjum	BU19700300	0	875
Oldeholtpade	BU00981501	0	815
Nijland	BU19001001	0	775
Bitgum	BU19491901	0	760
Donkerbroek-Zuid	BU00850202	0	715
Oosterwolde-Prandinga	BU00851103	0	710
Beetsterzwaag-Merkelân	BU00860202	0	700
Beetsterzwaag-Singels	BU00860206	0	605
Dronryp West	BU19492604	0	565
Ureterp-De Ekers	BU00861604	0	525

Table 5: Districts with a score of 0 and population of >500

C.2 Districts with the highest mobility score

Name district	District code	Mobility score	Inhabitants
Jubbega	BU00740406	46	3280
Akkrum	BU00740901	44	3310
Ureterp-Buitengebied	BU00861607	42	1015
Buitengebied St.-Annaparochie	BU19491600	40	715
Surhuisterveen	BU00590200	38	5655
Noord	BU00740100	38	3680
Damwâld	BU18910000	38	5530
Stationskwartier	BU00801008	38	770
Workum	BU19000200	36	4165
Haulerwijk-Buitengebied	BU00850608	34	775
Joure, Blaauwhof	BU19401901	34	2320
Zuiderburen	BU00807203	34	5575
Feanwâlden	BU18910201	34	3530
Buitenpost	BU00590000	32	5085
Stiens	BU00806301	32	7240
Sint Nicolaasga	BU19404101	32	3280
Centrum	BU00740101	30	2995
Nijlân	BU00804101	30	3715
Buitengebied Oudebildtzijl	BU19493900	30	300
Wijckel	BU19405101	28	635

Table 6: Districts with the highest mobility scores