The Physical Elements of Car Dependency

Observing the Degree of Required Car Utilization by Proximity of GOWs, Primary Facilities and Transportation Stops within Outer Neighborhoods in Groningen.

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Abstract

The increased amount of vehicles on the road since the 2000s in the Netherlands and the striving towards public transport and increased walkability in cities has created a paradox of how car-dependent people truly are in this day and age. Along with economic and social factors, the spatial layout of places can change the degree of car dependency. For this research, a set of criteria were combined to evaluate the extent of needed car utilization, based on four physical elements: GOW coverage, transportation stop coverage, primary facility types within the neighborhood and the distance to primary facilities in surrounding neighborhoods. The neighborhoods of Gravenburg, Meerstad and Beijum are compared in a quantitative analysis that illustrates the differences and similarities of the physical characteristics that influence private vehicle dependency. Furthermore, the relationships between the analyzed physical variables (GOW percentage, amount of transportation stops and presence of primary facilities) are investigated, to find links that make it possible to further research the dynamics of car dependency in outer neighborhoods. The research results show that the relationships between the variables should be further studied on a more extensive scale to come to a better understanding of the exact dynamics of car dependency in these types of neighborhoods.

Keywords: Car dependency, GOW, Proximity, Facilities, Distance, Transportation, Bus stop, Neighborhood

17 June, 2022

Cover page: Images by author.

List of Abbreviations

GOW	Gebiedsontsluitingsweg (collector road)
SW	Stroomwegen (arterial road)
ETW	Erftoegangsweg (local road)
GP	General practitioner

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1. Introduction

The influence of the car during the 20th century has been one of the key factors in spatial infrastructure and urban design. With rising congestion levels and safety concerns, urban sprawl and newly constructed neighborhoods at the outer parts of cities has now become one of the dominant issues within the field of spatial planning (Richardson & Chang-Hee, 2016; Saelens et al. 2003). Nowadays, new theories involving walkability and public transportation provide a greener, more sustainable and less car-dependent view with closer proximity to destinations (Fishman, 2016). In Dutch cities, spatial plans to further decrease car dependency by new institutional laws and urban design are currently in development (Gemeente Groningen, 2018). For the city of Groningen, car restraint policies, public transportation and further preference towards bicycle-usage and walkability are main focus points for future infrastructure development (Binnenstad Groningen, 2021).

1.1 The contradiction of car dependency

Within the city of Groningen, private motorized vehicles are prohibited to enter the city center since the implementation of the Traffic Circulation Plan (Verkeersplan) in 1977 (Tsubohara, 2007). By pushing citizens towards other options for traveling, dependency on other modes of transport instead of motorized private vehicles should increase. However, car-oriented infrastructure still serves a major role in the transportation of citizens and within the field of infrastructure design today. According to Statistics Netherlands (CBS, 2022), the amount of vehicles on the road has increased every year since 2004 (fig. 1). A case study by Cullinane (2003) showed that if citizens obtain a private car, it is considered an essential part of their lifestyle. On the other hand, with this aim towards increased car-free movement of citizens, there may be a possibility that infrastructure design will be further altered towards less car-centric development, and more bicycle paths and car-free zones. The increasing number of motor vehicles and new theories towards car-free design are two processes that together form a contradiction (Curiel et al, 2021). Increased amount of cars could indicate increased car dependency, while car-free design and sustainable infrastructure should indicate decreasing car dependency. This paradox may cause issues within spatial and urban design, if the amount of cars on the road continues to increase, while spatial design is oriented towards other ways of transportation. Therefore, it is essential to explore the reasons behind this paradox, looking at the physical elements within infrastructure that play an important role for car dependency.

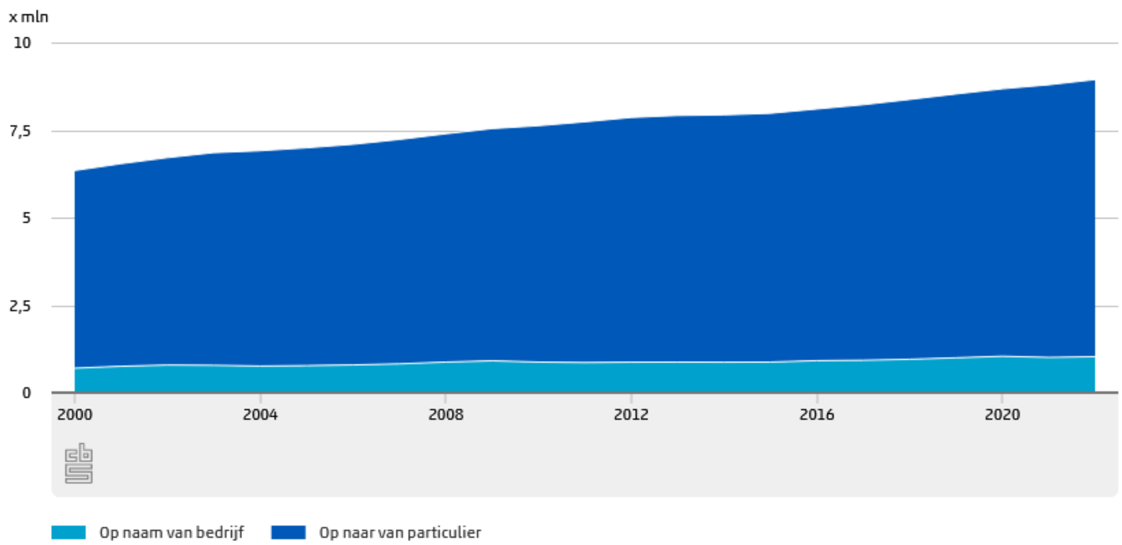


Figure 1: Yearly increase in the amount of registered car ownership. Light blue represents cars registered by a company, dark blue indicates private registers (CBS, 2022)

1.2 Scientific and societal relevance

The shift towards different modes of transportation and new urban design theories raises the question to what extent private car-ownership within cities for citizen travel behavior is still relevant. For example, previous research indicates a correlation between the access of traveling options to major travel places and walkability (Saelens et al. 2003). The physical layout and the locations of points of interests of neighborhoods within Groningen may have an impact on whether or not citizens remain using private vehicles. According to Bopp et al. (2013), whether a mode of travel to work is passive or active has significant different health outcomes. Furthermore, the increased amount of cars comes with a lot of environmental costs (Shafiei et al., 2018). Therefore, limiting the extent of car dependency should have positive effects on society.

1.3 Research questions and objectives

In this research, the goal is to analyze the level of car dependency of people in cities, by calculating the proximity of *Gebiedsontsluitingswegen* (abbreviated as GOWs) and observing primary facility types and transportation stops within three different neighborhoods in Groningen. Ultimately, this will provide indicators to further understand the mechanics behind car dependency. Therefore, an attempt is made to answer the following research question:

- *How and to what extent do the physical elements in the spatial environment influence car dependency in outer neighborhoods in Groningen?*

The GOWs within the neighborhoods of Gravenburg, Beijum and Meerstad are examined, and to what extent at which the GOWs cover the road infrastructure will be analyzed. Secondly, the destinations and travel behavior of citizens is determined. What kind of facilities are within each neighborhood? Furthermore, to what extent is the quantity of other transportation modes, in particular bus stops, contributing to decreasing car dependency? Lastly, it is important to understand how the different physical variables that determine car dependency relate to each other. The result of this case study could provide insights to what extent the use of private motorized vehicles is still necessary today within cities.

Therefore, the following sub questions will be covered:

1. What are GOWs and to what extent are they present within the analyzed neighborhoods of Gravenburg, Beijum and Meerstad?
2. To what extent are transportation stops contributing to a different level of car dependency in the analyzed neighborhoods?
3. How is the amount of primary facility types within and outside the neighborhoods influencing car dependency?
4. To what extent are the variables that influence car dependency interrelated?

1.4 Structure of the thesis

In the theoretical framework, four physical elements that influence car dependency are elaborated. In the conceptual framework, the possible correlation between certain variables is mentioned. The process of scoring the four physical elements into categories is explained in the methodology. Finally, in chapter 5 and 6, the results are analyzed and discussed. The thesis ends with a conclusion that discusses the limitations of the research and provides suggestions for future research on car dependency.

2. Theoretical Framework

The choice of transportation mode between private motorized vehicles and other options are dependent on a number of different factors, including infrastructure and neighborhood layout, proximity to amenities, quality and quantity of the public transport in a neighborhood, along with other physical, economic and social elements. This makes it a complex concept to study. In this section, an attempt is made to explain the significance of four physical elements of the spatial environment on car dependency.

2.1 Natures that influence car dependency

The vision of ideal transportation has shifted throughout history, from a car-oriented approach towards more walkability and sustainability: "*It is unchallenged that many people have built their present way of life around their cars, and depend on them for many regular and occasional journeys*" (Goodwin, 1995, p. 151). This meaning of car dependency by Goodwin suggests that in the 90s the car was still the most vital instrument of transportation within many countries. However, his analysis also showed that one-third of people would prefer to lower their dependence on a vehicle if conditions for other options would flourish or proximity to destinations would be lowered (Goodwin, 1995). This shows that social encouragement from citizens was there, but the physical layout and car-oriented plans at the time obstructed the possibility of decreasing car dependency. Goodwin provides three different natures that influence car dependency. Firstly, for some people, a private vehicle is simply the only possibility of travel due to limitations of other modes of transport. Certain locations could be problematic to reach by the use of other transportation options. Secondly, people may perceive the instant private access to transportation as a cost saving in time. Lastly, citizens may be disengaged from driving due to certain preferences. Some individuals could interpret driving as unsafe or as a waste of energy compared to public transport. Remarkable is that the three natures do not only involve people's preferences and experiences, but more importantly, also involve the proximity of destinations and access or distance to transportation links and nodes. Since Goodwin's research, spatial planning has become less car centric, although car usage has risen each year. In Groningen, the necessity of a private motor vehicle should have decreased (Binnenstad Groningen, 2021). Therefore, it provides the question if the car is still a vital instrument of transportation, or whether the car is merely a simple way of travel that people have incorporated in their daily behavior.

2.2 GOWs within the field of spatial planning

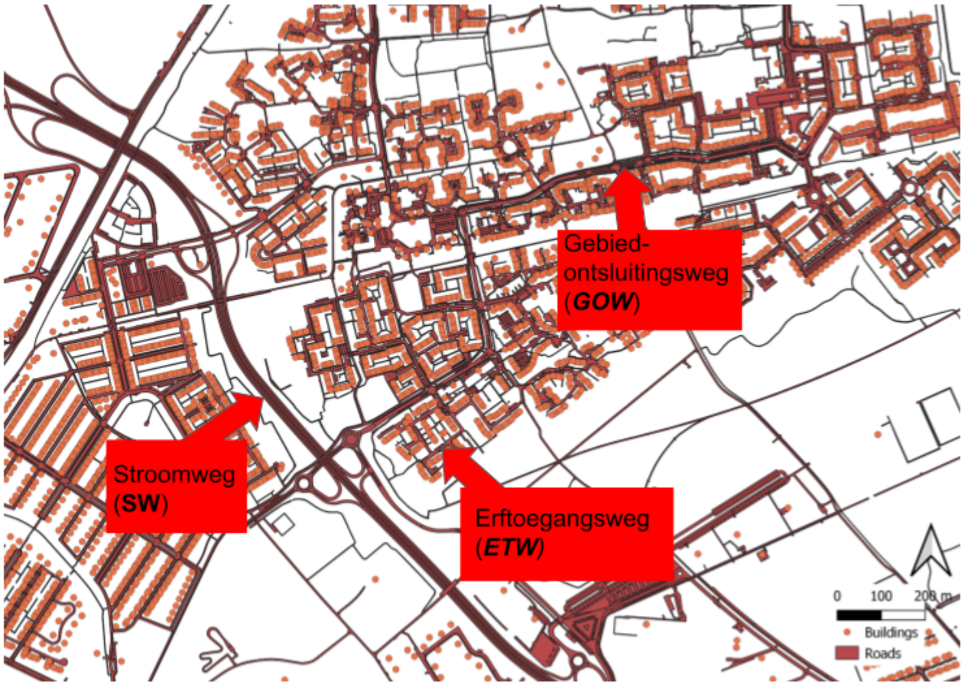


Figure 2: Examples of the classification of the Dutch road network. Location: West-Beijum.

To distinguish major roads from the rest of the infrastructure, road networks in the Netherlands are divided into SWs (stroomwegen/arterial roads), GOWs (gebiedsontsluitingswegen/collector roads) and ETWs (erftoegangswegen/local roads), that each have specific characteristics as displayed in figure 2 (SWOV, 2009). The categories are similar to the road classifications by the U.S. Department of Transportation (2000). SWs serve to guide traffic flows from A to B as uninterrupted as possible across and between cities, while ETWs are local roads within neighborhoods, consisting mostly of the final destinations of travel. GOWs fill the gaps between SWs and ETWs. GOWs are identifiable by their 50 or 70 km/h speed limit within cities and the interconnection between these roads (SWOV, 2009). The purpose of GOWs is to bring citizens conveniently from ETWs to SWs and vice versa, and frequently contain the busiest roads within neighborhoods and cities. GOWs play an important role within traffic flows and urban processes and could explain to some extent the level of car dependency within the neighborhoods of Gravenburg, Beijum and Meerstad. More GOWs decreases walkability, as these roads tend to be less safe for pedestrians, especially when crossing a road. However, a high level of GOWs does not automatically suggest increased car dependency, since transportation stops for public transport are also located at GOWs in most cases. Therefore, the amount of transportation stops at these GOWs should be studied as well.

According to Napieralski & Giroux (2019), urban roads have an important role within urban processes to comply with efficiency. These roads are the most efficient because of their higher speed limit and usually being classified as a priority road. With the rise of spatial theories oriented towards public transportation and walkability, especially within the city of Groningen, the attraction of making new plans involving the use of private vehicles has shifted downwards. For neighborhoods further separated from the inner city, this new trend establishes a compelling discussion to what extent the use of the car remains essential. For the neighborhoods of Gravenburg and Beijum, the physical road layout has remained unchanged since their respective establishments. With Meerstad still under construction, some of the layout has changed in this neighborhood. It is required to analyze the GOWs within these neighborhoods and investigate the extent to which the roads influence travel behavior of citizens.

2.3 The effects of transportation stops

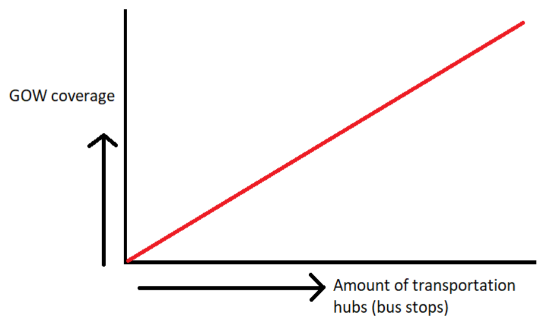
In a neighborhood, different transportation modes provide options for traveling. As mentioned earlier, Saelens et al. (2003) identified the correlation between walkability and accessibility to transportation options. If distances to most vital facilities are long, traveling by foot becomes unappealing for people. It is undesirable that people need to travel more than 400 meters by foot to a bus stop (Hess, 2012). Furthermore, several Dutch papers mention the aim to have 90% of the transportation stops covered within a 800m radius (Vervoerregio Amsterdam, 2020; Rekenkamer Amsterdam, 2016). Transport inaccessibility is associated with social exclusion, which further motivates private car ownership as it eliminates social interaction (Lucas, 2012). All of this considered, it follows that the distance to bus stops and other modes of transport have a plausible contributing role in citizen behavior and car dependency. To analyze the level of car dependency influenced by today's infrastructure design, transportation stops need to be taken into consideration. Increased number of transportation stops does not immediately indicate that people increasingly use this public transportation option, but it may at least indicate that people are less car dependent within the physical field.

2.4 Facilities within and outside the neighborhood

Lastly, the presence of and distance to vital facilities and its effect on human decision for transport mode is essential in developing an understanding about car dependency. If some primary facilities are non-existent within a neighborhood, the level of car necessity increases. For example, Mackett (2002) concludes that considering car dependency for schools, distance is one of the main factors. If distances to facilities are above a certain tipping point of the service range, the only options for traveling to most destinations are by private car or bicycle. Furthermore, there is a strong relationship between increased urban density and lower fuel usage, which suggests less use of the car and more primary facilities within a certain area (Newman & Kenworthy, 2015). If the distance to primary facilities is closer, the level of car necessity is therefore decreased. Additionally, it is beneficial for citizens if these facilities are located in clusters. This is the final component of the physical elements that influence car dependency.

2.5 Hypothesis

The expected result of this thesis is that the four researched elements all have a substantial influence on car dependency of residents. Furthermore, it is expected that the variables are to some degree dependent on each other (fig. 3&4).



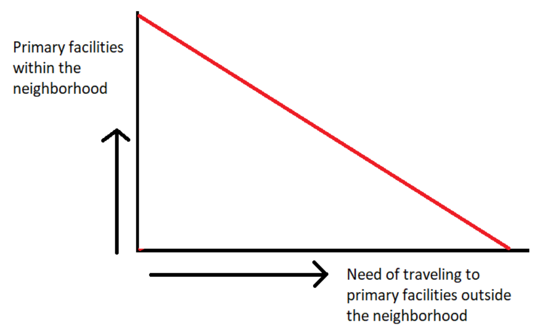


Figure 3 (left): The expected relationship between GOW coverage and bus stops.
Figure 4 (right): The expected relationship between facilities within and outside the neighborhood.

3. Conceptual Framework

3.1 The four physical elements of car dependency

As mentioned earlier, the level of car dependency within the physical environment in this research is determined by: (1) The percentage of GOWs coverage compared to the total road network within a neighborhood, (2) the amount of transportation stops, in particular bus stops, (3) the amount of primary facilities (schools, supermarkets, general practitioners) within the neighborhood and (4) the distance to facilities outside the neighborhood that are lacking within the neighborhood (fig. 5). However, car dependency is a complex study as it also contains social and economic elements, but this research focuses on the physical viewpoints of Saelens and Goodwin. This research therefore can only provide insights to what extent car dependency is influenced by the physical environment and infrastructure design.

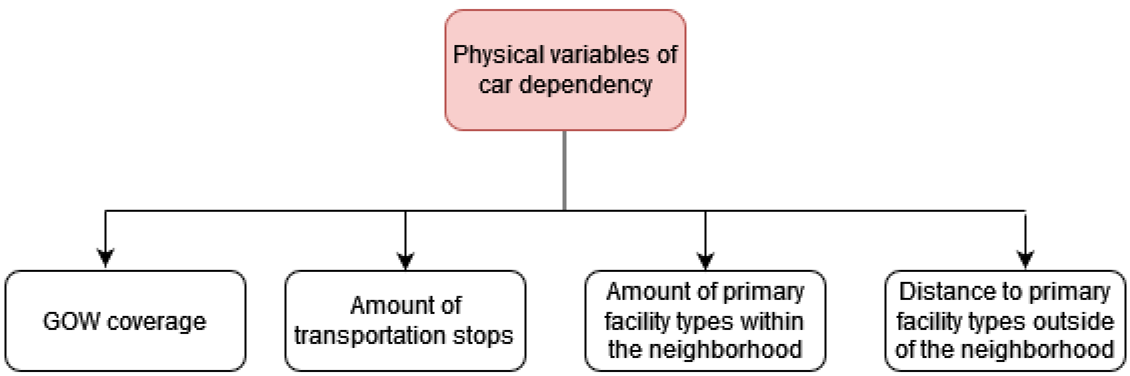


Figure 5: The four studied physical elements of car-dependency.

3.2 The correlation between physical elements of car dependency

In this research, determining whether the variables are independent or dependent will allow awareness on how to overcome car dependency in the future. The level of car dependency is a dependent variable of the aforementioned physical variables. However, the four variables that determine the necessity of the car could be interrelated, meaning these can be dependent on each other as well. It is expected that the location of bus stops mostly corresponds with GOWs, as main roads frequently are the optimal choice to reach the most number of people within walkshed of 400m mentioned by Hess (2012), without a significant loss of traffic flow (Ibeas et al., 2010). Furthermore, the amount of facilities within a neighborhood directly influences the amount of facilities outside of the neighborhood of which the distance is required to be analyzed. Some facilities need to be distributed as evenly as possible (for instance schools), but other facilities tend to develop in clusters (supermarkets, stores). The expectation is that the four elements of car dependency are related to some extent. Therefore, it is possible to tackle car dependency by focusing on one of the elements, which may automatically influence other variables.

If the correlation between the variables can be proven in the case of the three neighborhoods in Groningen (fig. 6), the different levels of car dependency can be better understood. This is essential for future urban development of cities and understanding traffic flows. Within the physical approach of analyzing and calculating dependence of a vehicle, the relationship between variables may show more or less complexity than expected.

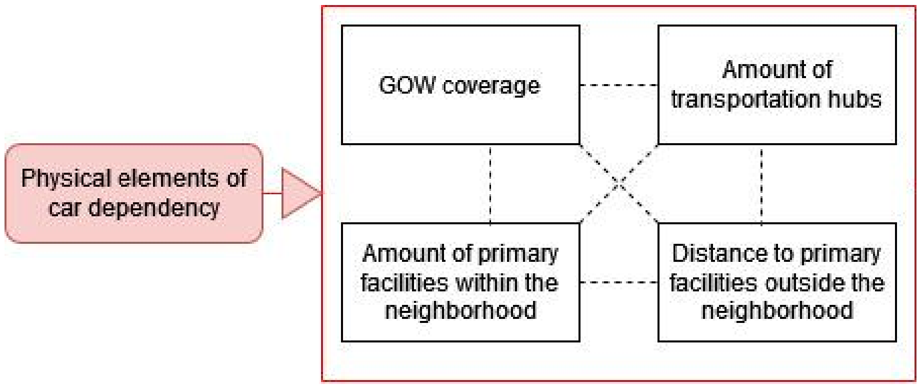


Figure 6: The expected relationship between the variables of car dependency.

4. Methodology

4.1 Case Selection

The three neighborhoods of Gravenburg, Beijum and Meerstad have been selected for this research by the following criteria:

- The analyzed neighborhoods are located at the outer region of the city of Groningen (more than 3 kilometers from the city center)
- The neighborhoods each have distinctive characteristics (size, population, building age) from each other, to be able to compare the influence of the physical variables for different types of neighborhoods.
- Information from the neighborhoods regarding GOWs, transportation stops and primary facilities should be recent and publicly available.

Each of the analyzed neighborhoods have distinctive characteristics which could provide insights to what specific characteristics may influence car dependency (fig. 7). Beijum was constructed in the 1980s, while Gravenburg was realized around the year 2000. Interestingly, the neighborhood of Meerstad will still be in construction as of 2022, which started as early as 2011 (Parallel, 2020). According to CBS (2019), the average number of cars per person differs a lot per neighborhood. Beijum scores 0,8 regarding the number of cars per person, while Gravenburg (1,0 cars per person) and Meerstad (1,3 cars per person) could be more car dependent because of this higher number.

Figure 7: Images of the three analyzed neighborhoods. Left to right: Gravenburg (Magnusstraat), Beijum (Stoepemaheerd), Meerstad (Wierdijk). Images by author.

The locations of the neighborhoods are each at a distance of 4 to 6 kilometers from the city center (fig. 8), and therefore are dependent on close proximity to facilities or transportation stops within or close to the neighborhood. Because of this, these three neighborhoods are chosen to be analyzed.

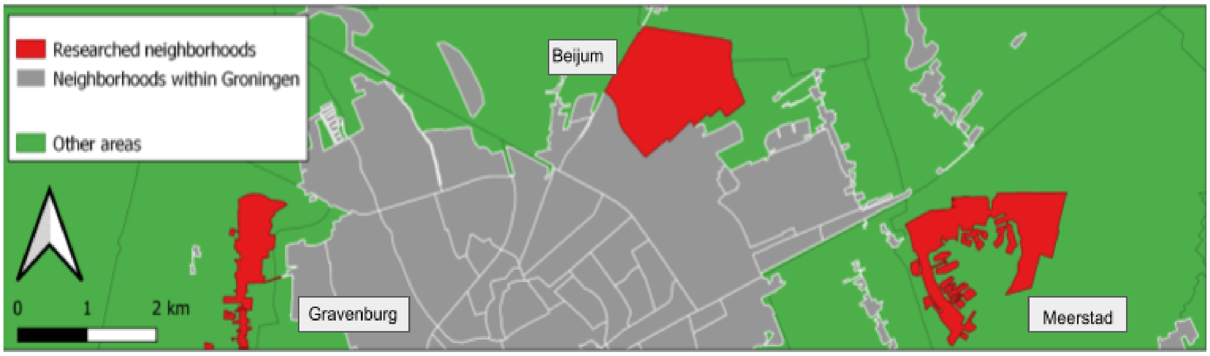


Figure 8: Gravenburg, Meerstad and Beijum neighborhood locations in the city of Groningen.

4.2 Research methods

To measure and understand the level of car dependency, a score table is utilized for each physical variable. Layers of quantitative data and observations will be examined to calculate numbers that serve as indicators for dependence of a private motor vehicle. This method is preferred instead of a statistical analysis because of the small data sizes and different characteristics of each neighborhood. Only if the social factors of car dependency would be included, a survey of citizens would be recommended. Instead, with the use of an observational analysis, the data becomes practicable and it is possible to use previous research as guidelines for the different categories.

4.3 Data collection & analysis

Firstly, for the data collection, data regarding GOWs within Groningen was required. Geographic data from ESRI and PDOK (see appendix 2) provided information about GOWs and road speeds within the Netherlands. GIS data containing GOWs was merged with the total road network. To convert the percentage into a classification needed to visualize car dependency, the percentage outcome is positioned within one of the three categories: insufficient, average and sufficient. A sufficient score is given if a neighborhood has the optimal conditions for private car-free travel. According to the U.S Department of Transportation (2000), collector roads (which are the American equivalent of GOWs) should not exceed 20% of the total road coverage in urban areas, but lower GOW coverage could indicate decreased mobility. Hence the classification is made between the values of 10% to 20% (table 1). Even though the American road system is different from neighborhoods in Groningen, this is one of the few sources about the ideal percentage of GOWs compared to the total road system.

Table 1: the GOW coverage score table that indicates mobility within a neighborhood.

GOW coverage (total length of GOW roads / total road network within neighborhood)	**Insufficient car mobility**: Less than 10% of the total road network	**Average car mobility**: 10-15% of the total road network	**Sufficient car mobility**: 15-20% of the total road network

Next, the amount of transportation stops is computed. Since the analyzed neighborhoods are dissimilar in surface area, the zone is divided by the amount of bus stops. The outcome then is again put into the same three categories. It is important to mention that all bus stops with the same label count as one bus stop location, as buses usually go both directions. Hess (2012) mentioned in his paper that the rule-of-thumb-distance to a bus stop is 400m. Additionally, two studies by Vervoerregio Amsterdam (2020) and Rekenkamer Amsterdam (2016) concluded that 400m is the maximum coverage distance for Dutch cities as well. By multiplying the distance in 2 axes, the ideal surface area for this study should be below 16 hectares. However, in the same papers it is mentioned that 90% of addresses should be within a 800m radius from a transportation stop and 100% of addresses for urban areas. Therefore, the aim is to keep the surface area per bus stop at least below 64 hectares. The aforementioned rules are applied for the categories (table 2). It is important to note that the surface area of the neighborhoods are based on the area that contains the built environment, as presented in the Basic Topography Register (PDOK, 2021). Neighborhood area datasets also cover the wide open fields within the boundaries of the neighborhood that serve limited to no role towards car dependency. Therefore, open fields within the neighborhood are not included in the surface area.

Table 2: The transportation stop score that displays the amount of surface area 1 bus stop has to cover.

Surface area (in hectare) / amount of transportation stops	**Insufficient**: More than 64 ha surface area per stop	**Mediocre**: 16-64 ha surface area per stop	**Sufficient**: 0-16 ha surface area per stop

For facilities within the neighborhood, the presence of schools, supermarkets and general practitioners (GPs) is analyzed (table 3). These are the main reasons for traveling next to commuting. Since destinations to work vary for each individual and could be seen as a social factor as well, this is left out of the research, to avoid an overabundance of complexity. More primary facilities within the neighborhood is associated with less car dependency.

Table 3: Facilities within the neighborhood score

Amount of primary facilities types (school, supermarket, GP) within the neighborhood	**Insufficient**: 0-1 facilities	**Mediocre**: 2 facilities	**Sufficient**: 3 facilities

Lastly, if any of the primary facilities is absent within the neighborhood, the distance to the closest facility outside of the neighborhood is studied. This is measured by using the shortest route along the GOWs. If certain primary facilities are relatively close to the neighborhood, the increase in car dependency is limited. Along with the previous physical elements, this fourth element is also separated into three categories (table 4). The location of primary facilities is acquired from the municipality, as well as the data site PDOK.

Table 4: (Distance to) facilities outside the neighborhood score.

Distance to missing primary facilities (school, supermarket, GP) outside the neighborhood	**Insufficient**: > 1000m	**Mediocre**: ≤ 1000m	**Sufficient**: No missing facilities

Now all variables and categories are explained, the full criteria for the car dependency score is displayed (table 5). The list of the used data sources is mentioned in the appendices.

Table 5: Methodology table to score the 4 physical elements regarding car dependency.

GOW coverage	**Insufficient car mobility**: Less than 10% of the total road network	**Average car mobility**: 10-15% of the total road network	**Sufficient car mobility**: 15-20% of the total road network
Surface area (in hectare) / amount of transportation stops	**Insufficient**: More than 64 ha surface area per stop	**Mediocre**: > 16 ≤ 64 ha surface area per stop	**Sufficient**: 0 ≤ 16 ha surface area per stop
Amount of primary facilities types in the neighborhood	**Insufficient**: 0-1 facilities	**Mediocre**: 2 facilities	**Sufficient**: 3 facilities
Distance (in meters) to missing primary facilities outside the neighborhood	**Insufficient**: > 800m	**Mediocre**: ≤ 800m	**Sufficient**: No missing facilities

- Gow coverage: A sufficient score indicates that the neighborhood is well designed considering road efficiency (as there are enough GOW roads to generate traffic flow). This may indicate that a private motor vehicle is actually more appealing, but the use of buses is also increased. GOW coverage in this research is therefore a double-edged sword.
- Transportation stops: A sufficient score indicates that the use of buses becomes more appealing because the bus stops are relatively close by proximity.
- Amount of primary facility types: A sufficient score indicates that the neighborhood provides the most needed facilities within pleasant proximity, therefore not needing a private vehicle.

- Distance to missing facility types: An insufficient score indicates that people need to travel further to reach most needed facilities. This means that they are more likely to use a car (or bus depending on the location of bus stops).

4.4 Limitations of the research

For this research, it is necessary to point out the limitations of the methodology. The structure of the car dependency score table makes the data practicable, but the value of the results is limited to a certain extent. If a score falls barely into a certain category, the validity can be questionable. The categories are based on both Dutch laws and American research, but it is uncertain to what specific extent these are applicable for the studied neighborhoods. Therefore, this research can only provide insights into the level of car dependency in suburban neighborhoods, but is limited regarding the contemporary state of car dependency in the Netherlands. The 20%-rule for GOWs based on American guidelines may not be as applicable for Dutch cities. Furthermore, as Meerstad is still under development, maps with information are continuously changing for this neighborhood. To keep the gathered data information useful, the neighborhood of Meerstad is analyzed based on the situation of January 1st, 2021. The other two neighborhoods have had no mentionable changes since this timeframe.

4.5 Ethical considerations

For this research, publically available datasets from PDOK and ESRI were used. Self-made images of the neighborhoods were carefully taken to protect the privacy of the citizens. Therefore, the images do not contain people, license plates of cars or house numbers. For this thesis, the code of research integrity as set by the University of Groningen has been followed.

5. Results

5.1 Gravenburg

Table 6: Table of the car dependency score of Gravenburg.

GOW coverage score	Transportation stop score	Facilities within neighborhood score	Facilities outside neighborhood score
High car mobility (15,4%)	Mediocre (37,8 ha)	Insufficient (1)	Insufficient (3200m)

The surface area used in this research instead of the official neighborhood boundaries is displayed in table 7. With an adequate GOW score of 15,4% (fig. 9), the traffic flow in the neighborhood of Gravenburg can be considered satisfactory. However, with GOWs only located at the western and southern edge of the neighborhood, eastern and northern parts of the neighborhood are relatively distant to the GOWs. All transportation stops are located at a GOW (fig. 10). From personal observations at the location, it is clear that the stops are at unsafe locations without sidewalks, which decreases walkability (fig. 11). With 4 bus stops distributed across 151 hectares of surface area, the neighborhood scores mediocre considering the coverage of bus stops. The amount of facility types within the neighborhood is insufficient, as the neighborhood only contains two primary schools out of all primary facility types. The distance to the closest GP is limited with 700m of distance, but there is no close proximity to any supermarket within the neighborhood, with 2500m being the closest road distance to the first supermarket.

Overall, the neighborhood of Gravenburg mostly scores insufficiently when it comes to providing a private car-free environment. With the lack of primary facility types, people depend on other neighborhoods and their proximity to Gravenburg. Although transportation stops are available, the distance to them depends on the household's position due to the western location of all bus stops. With high GOW coverage, the road network is well designed for vehicle travel.

Figure 9: Map of the surface area and buildings of Gravenburg.

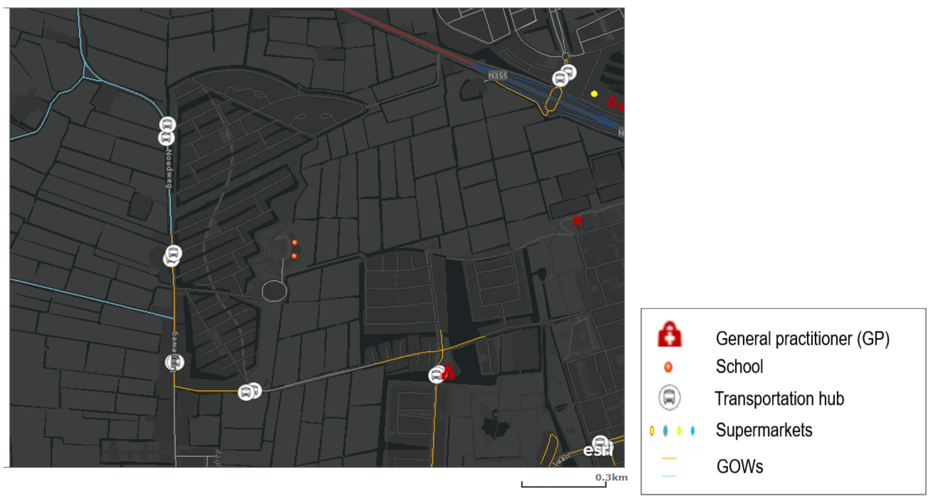


Figure 10: Map of the transportation stops and facilities within and outside the neighborhood.

Figure 11: Bus stop location at the north-western border of the Gravenburg neighborhood.

5.2 Meerstad

Table 7: Table of the car dependency score of Meerstad in 2021.

GOW coverage score	Transportation stops score	Facilities within the neighborhood score	Facilities outside the neighborhood score
Low car mobility (0%)	Insufficient (129 ha)	Mediocre (2)	Insufficient (2500m)

As mentioned earlier, the neighborhood of Meerstad is still under construction. The surface area of the eastern section (table 7) counts as a part of the living environment of the neighborhood according to the latest CBS datasets (PDOK, 2021). However, development in this area is for a large part still non-existent. Therefore, the results of this neighborhood analysis regarding transportation stop coverage may be inadequate to some extent.

With a GOW coverage score of 0%, the design of the Meerstad is struggling to generate a well established traffic flow for some sections of the neighborhood. However, one road may be changed from a 30km/h-zone to a GOW in the future, when construction is completed. Regardless, if these roads are included, the neighborhood remains in the same category. Within the neighborhood, transportation by bus is less optimal. The locations of the bus stops do not correspond with the GOWs (fig. 12&13), until the aforementioned road has been classified differently. The distance to other transportation stops at Middelbert (west of Meerstad) are too far for traveling by foot, with more than 800m, from the studied western edge of Meerstad. A general practitioner (GP) is located at the southern tip of the neighborhood. For citizens living in the northern section, and new citizens that will live in the eastern section, the distance to the GP can still be troublesome, especially with current constructions (fig. 14). During 2021, the neighborhood lacked a supermarket location, with the nearest being at a distance of 2500 meters in the neighborhood of Ulgersmaborg. However, plans to open a supermarket by the end of 2022 are already in development (Meerstad, 2021).

The neighborhood of Meerstad was still in its construction phase during the beginning of 2021. Since facilities are still yet to be built, people living in Meerstad should be more car dependent, especially before the implementation of the new extra bus stop in the northern section. With the absence of any bus stop in the southern section, this part of the neighborhood suffers the most regarding car dependency according to the score table.

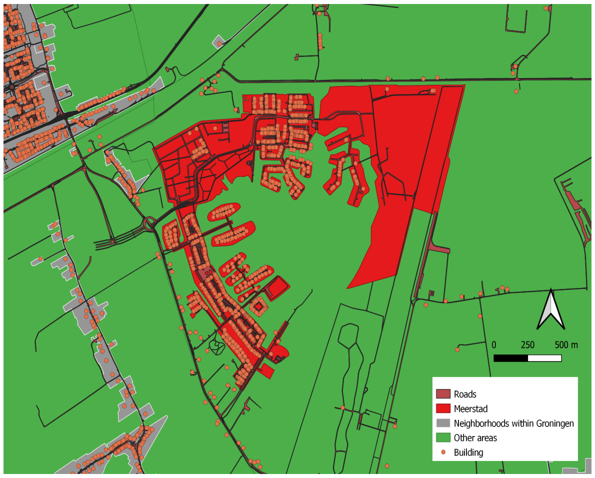


Figure 12: Map of the surface area and buildings of Meerstad.

Figure 13: Map of the transportation stops and facilities within and outside of the neighborhood of Meerstad.

Figure 14: Construction works decrease walkability to bus stops in Meerstad. Image by author of the yet to be completed supermarket hub.

5.3 Beijum

Table 8: Table of the car dependency score of Beijum.

GOW coverage score	Transportation stops score	Facilities within neighborhood score	Facilities outside neighborhood score
High car mobility (15,2%)	Mediocre (25,2 ha)	Sufficient (3)	Sufficient (N/A)

The neighborhood of Beijum is by far the most densely populated area of the analyzed neighborhoods (fig. 15). With a GOW coverage of 15,2%, the traffic flow is satisfactory. In this case the GOWs are spread evenly across the neighborhood, rather than being the border of the neighborhood. Despite a mediocre transportation stop score, the average distance for a household to a bus stop in the neighborhood is shorter than in Gravenburg thanks to the central GOW layout (fig. 16). The neighborhood of Beijum features all the primary facility types covered in this research. These are usually located in clusters at the center of the neighborhood (fig. 17). Therefore, citizens of the neighborhood have less reasons to need a car because of close proximity to these facilities. With high car mobility, overall frequent bus stops and a sufficient number of primary facilities, the neighborhood of Beijum is by far the least car dependent out of the analyzed areas.

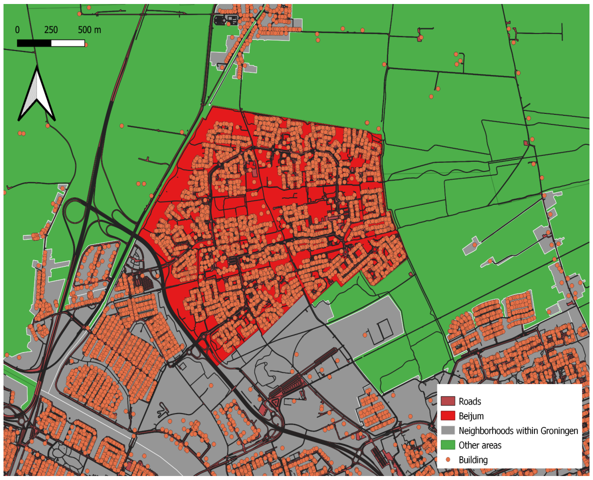


Figure 15: Map of the surface area and buildings of Beijum.

Figure 16: Map of the transportation stops and facilities within and outside the neighborhood of Beijum.


Figure 17: Cluster location of primary facilities in Beijum.

5.4 General results

The general results of the research display differences between the three neighborhood locations considering the degree of car dependency (table 9). The three neighborhoods are differentiated by the amount of inhabitants, size and construction era, which affect the level of car dependency. Gravenburg and Beijum are overall well connected with the rest of Groningen thanks to the average to high percentage of the GOWs. The surface area score of transportation stops in Gravenburg and Meerstad is insufficient compared to the Dutch guidelines of 400m (16ha) and an absolute maximum of 800m (64ha) distance. The distance for some households in Gravenburg and Meerstad to transportation stops is also discouraging the use of public transport as they are located at the western boundary of the neighborhood. The amount of primary facilities types within the neighborhood corresponds to the amount of buildings and households of the neighborhood.

Table 9: Research outcomes of the analyzed case study neighborhoods.

	Gravenburg	Meerstad	Beijum
GOW coverage (total length of GOW roads / total road network within neighborhood)	**Sufficient car mobility** 1200m/7800m=0,154 15,4%	**Insufficient car mobility** 0m/19000m=0,0 (700m/19000m=5,7% if GOW next to neighborhoods is included) 0%	**Sufficient car mobility** 3900m/25600m=15,2 %
Surface area (ha) / amount of transportation stops	**Mediocre** 151ha/4= 1 bus stop per 37,8 ha surface area	**Insufficient** 258/2= 1 bus stop per 129 ha surface area	**Mediocre** 227/9= 1 bus stop per 25,2 ha surface area
Amount of primary facilities types (schools, supermarket, GP) within the neighborhood	**Insufficient** (=1)	**Mediocre** (=2)	**Sufficient** (=3)
Distance to missing primary facilities types outside the neighborhood	**Insufficient** 700m (general practitioner) 2500m (supermarket) = 3200m	**Insufficient** 2500m (supermarket)	**Sufficient** - (All facility types within neighborhood)

6. Discussion

The vision of Goodwin (1995) that the car was the main mode of transportation because a lack of alternatives is still lingering in the outer neighborhood structure of Groningen. Alternatives for a private vehicle are available, but for some households the distance to a bus stop is still above the preferred guideline of 400 meters. Especially for people living in Meerstad, which is a neighborhood that is still dependent on facilities in other neighborhoods, this can be an issue. This makes a private vehicle for some people a necessity to get access to primary facility types.

Regarding the four physical elements of car dependency, there are several points to be made. In the neighborhood of Gravenburg and Beijum, there is an adequate design for traffic flow as GOW coverage is satisfactory. Because of this, car mobility is increased which could suggest preferences towards private motor vehicles. If GOW coverage becomes too low, driving a car is less efficient for leaving the neighborhood. It is therefore less practical, but the effect of becoming car dependent is minimal at most. The other variables seem to have a more direct effect on car dependency in these neighborhoods as it influences the options of travel and destinations, while GOW coverage only influences the flow of movement itself. The GOW coverage score for Beijum is optimal for traffic flow, yet the amount of cars per person is by far the lowest of the three neighborhoods, with a 0,8 cars per person (CBS, 2019). Meerstad on the other hand, with less facility types, less GOW coverage, and less optimal transportation stops scores 1,3 cars per person. Even with Meerstad being a wealthy neighborhood compared to Beijum, which could also be a reason for the difference to a certain degree, the necessity of getting to primary facilities and lack of transportation alternatives seems to be the primary cause of this higher number.

For Beijum and Gravenburg, the transportation stops are located along GOWs. For Gravenburg this results in long walking distances to transportation stops for some households because of the GOW position, while Meerstad has transportation stops far from the GOWs. Because of this, some traffic flow may be lost, but citizens have better proximity to their bus stops depending on their position. Furthermore, walking distances in Gravenburg and Meerstad can be unappealing as mentioned by Saelens et al. (2003), which is strengthened by lack of pavements, while traffic flow will be lower regardless of desired GOW coverage because of construction in Meerstad. The correlation between GOW coverage and the amount of transportation stops can be suggested based on the results, but more data of different neighborhoods is needed to perform a statistical analysis to prove their correlation. If all primary facilities are within the neighborhood, not only does this mean that travel to other neighborhoods becomes less necessary, but surrounding neighborhoods may become more car dependent because of the agglomeration effect of store clusters and other primary facilities.

The effect of physical elements of car dependency may therefore be a more complex study than initially expected, even without economic and social values taken into account. Schools are located in all neighborhoods, which is a major car influencer if the distance to these primary facilities becomes too long, according to the aforementioned study by Mackett (2002). Supermarkets and GPs may be generally less visited and therefore may be relatively less vital (or not present yet) in the neighborhoods of Gravenburg or Meerstad. In Beijum, primary facilities are clustered in and around shopping centers. This also raises the query if supermarkets, GPs and schools should be studied at the same level of importance. Furthermore, the results suggest that the four physical elements are more interrelated than mentioned in the framework. If GOW coverage is low, some traffic flow is lost. Primary facilities that rely on customers like supermarkets prefer space with the highest amount of traffic to attract people, for example close to the GOWs and transportation stops of Beijum. On the other hand, (primary) schools prefer a safe environment far away from GOWs. Therefore, the interrelatedness of GOW coverage and primary facilities is dependent on the type of facility, making a correlation more complex to analyze. Instead of strict connections between the physical elements, the relationship between the different physical variables can vary and is structured in a complex way (fig. 18).

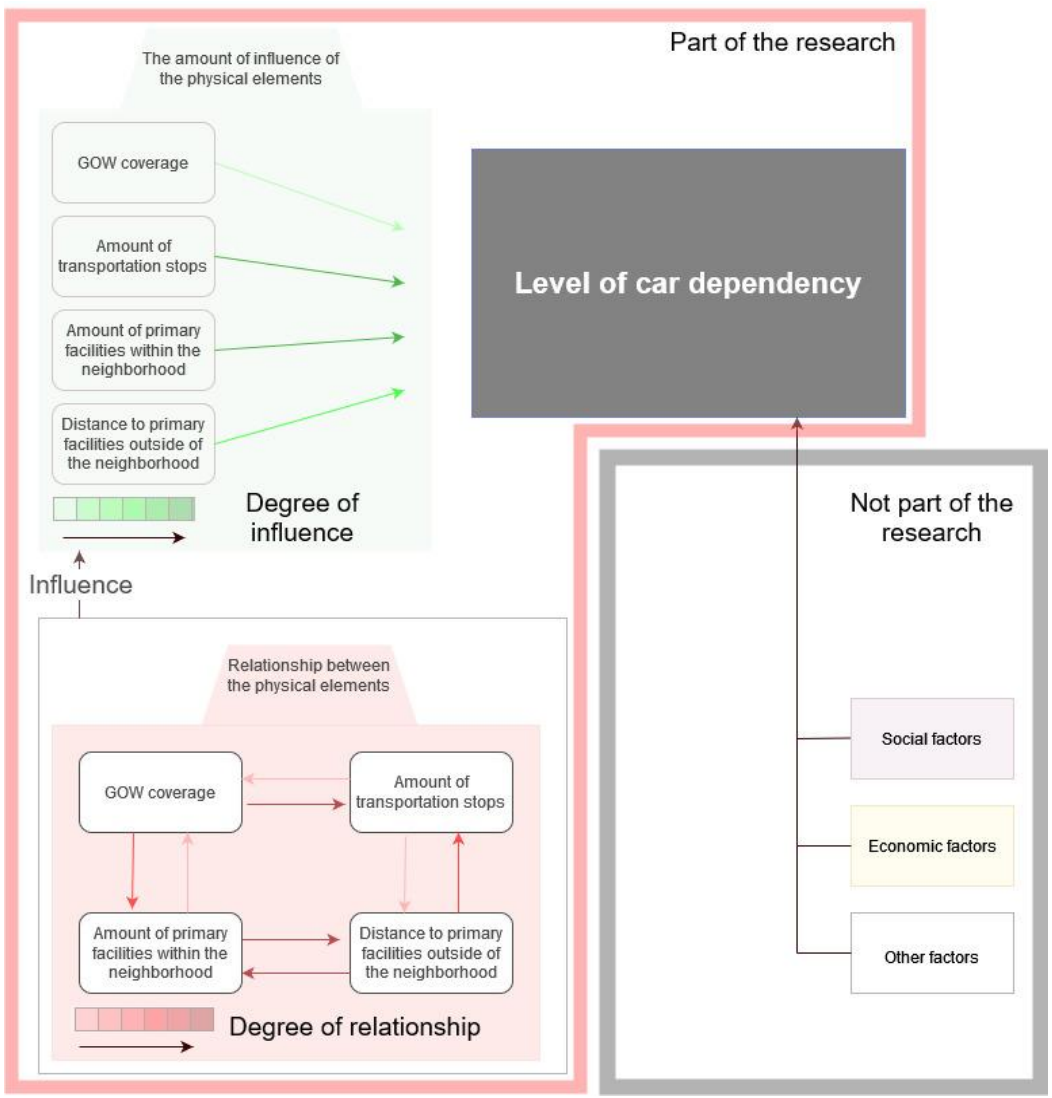


Figure 18: The relationships between the four discussed elements of car dependency and their individual impact on car dependency. Other factors of car dependency will also influence car dependency, but only the red squared area is covered for this research.

7. Conclusion

By comparing the three neighborhoods in Groningen, a conclusion can be drawn that the spatial environment and facilities can influence the need and degree of car utilization like social and economic factors. The four physical elements of car dependency seem to be interrelated in a highly complex manner. Although GOW coverage is a minimal factor regarding car dependency, the presence of these roads affects the preferred locations of transportation stops and primary facilities, as well as affecting other surrounding neighborhoods. Overall, the neighborhoods of Gravenburg and Meerstad still remain car-dependent despite popular trends of sustainable transportation in Groningen. The hypothesis is mostly accurate for these neighborhoods excluding the expected importance of GOWs as a variable for car dependency. Further research at which threshold a certain neighborhood is able to generate these facility clusters for these suburban neighborhoods is recommended. Additionally, new result outcomes when the development of Meerstad is completed may provide more information about car dependency in this neighborhood. If more outer neighborhoods are analyzed, statistical correlations may also be found. Therefore, this research could be seen as a starting point for supplemental and in depth understanding of the complex study of (the physical elements that influence) car dependency.

This research solely focused on the physical factors of car dependency, and if these four factors are just as important to analyze as other factors analyzed in previous research. Social and economic factors contribute to car dependency as well. Further studies focusing on these factors may relativize the strength of the physical factors on car dependency.

The process of this bachelor project was accomplished according to the predetermined goals and deadlines set by the author and supervisors. For future research projects, the theoretical framework of a study can be improved by more emphasis on the societal and scientific relevance of the project. Furthermore, a more in-depth study instead of observational methods could result in stronger valuable results. Due to health issues of the author, which were communicated to the supervisors and study advisor, the thesis is less in-depth than originally aimed by the author.

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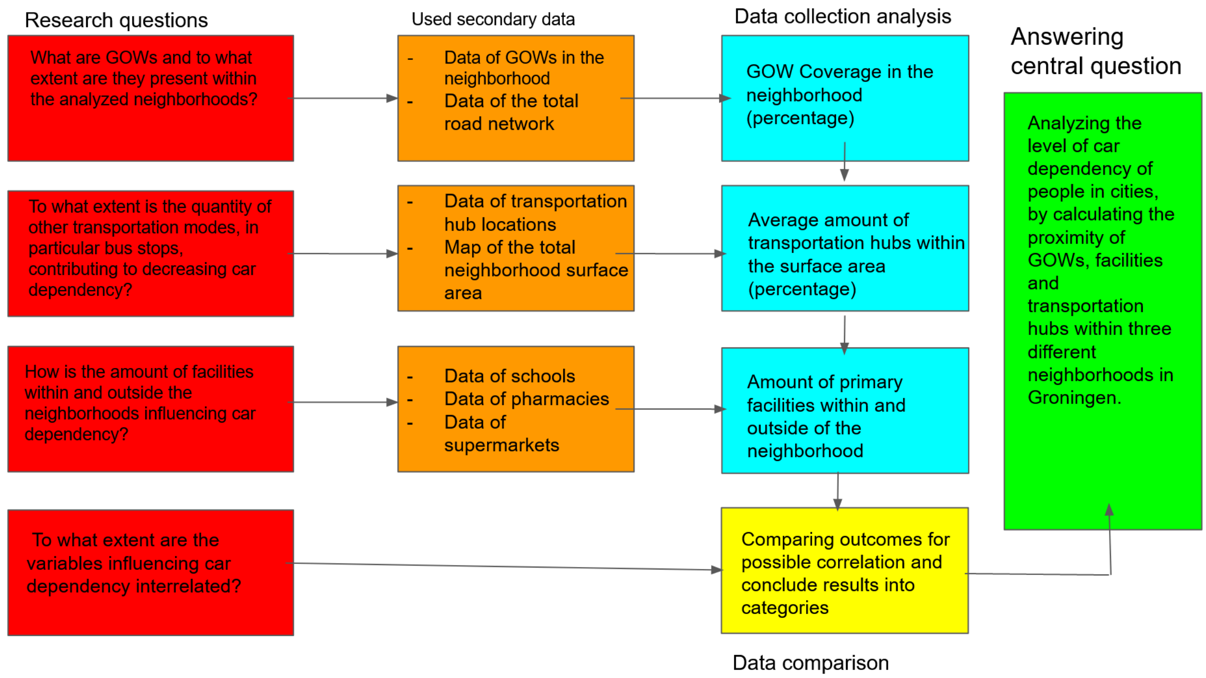
9. Appendices



Appendix 1: Full data analysis scheme (version of 1st of April 2022).

List of all datasets used or analyzed for this research in alphabetical order:

- *Alle Supermarkten NL* by fkeijzer_esrinederland (ArcGIS)
- *Basisregistratie Grootschalige Topografie (BGT)* by CBS (PDOK)
- *Building Ages in the Netherlands* by TU Delft (Parallel)
- *Maximum Snelheden kmu* by Andnol1r (ArcGIS)
- *Openbaar Vervoer Nederland - Haltes* by University of Groningen (ArcGIS)
- *Openbaar Vervoer Nederland - Lijnen* by University of Groningen (ArcGIS)
- *OpenStreetMap - Points of Interests* by ESRI Nederland (ArcGIS)
- *OV Haltes* by Vries Companen (ArcGIS)
- *Schoolfietsroutes Groningen BO Scholen* by 907142_rhdhv (ArcGIS)
- *Schoolfietsroutes Groningen VO Scholen* by 907142_rhdhv (ArcGIS)
- *Wijk- en Buurtkaart 2021 versie 1* by CBS (PDOK)

Appendix 2: Secondary data within ArcGIS and PDOK used or accessed for this research.