Accessibility poverty:

Examining transit accessibility to jobs across the day in the Amsterdam region during the COVID-19 pandemic

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May 2022

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1. Introduction

The way we move around in cities is constantly evolving. Where the car was one of the most used means of transport over the past decades, cities around the world are now increasingly realizing that alternative means of transport can help to make cities more sustainable and provide equitable access for everyone that moves around cities. Amsterdam, the capital of the Netherlands, has been working for several years on policies with the goal of reducing car usage in the city (Gemeente Amsterdam, 2019a). This car-reducing policy also aims to create more space for pedestrians and cyclists and make the public transport network an important backbone of the mobility system. When cars are given less space on public city streets, other forms of mobility such as public transport must provide sufficient accessibility to reach destinations, such as jobs, shops, recreation, family, and friends, as well as other activities. The access to those destinations through the transit system is however lacking in Dutch cities, meaning that citizens are not able to reach activities at a reasonable time, ease, and cost (Rli, 2020). According to the national Council for the Environment and Infrastructure (Rli), current public transport policies in Dutch urban regions are primarily focused on the efficiency of the transit network rather than creating accessibility to activities. There is a focus on connections with clear nodes and corridors along which many people are transported, which mainly favours maximizing the number of people transported per kilometre (Rli, 2020). This approach has the disadvantage that it is relatively time consuming to travel crisscross through urban regions. At the same time, similarly to many metropolitan areas around the world, service cuts are often made on transit lines with lower ridership that connect the outer neighbourhoods and rural areas with the city centre as these are not as profitable (Schouten & Hendriksen, 2021).

Policies that focus on maximizing services along popular routes can lead to a situation in which captive transit users, those who have no alternative than using public transport to reach activities, are unable to reach those activities (Rli, 2020). When individuals do not have access to a car and the transit system does not provide access to the activities they wish to participate in, a situation is created which is often referred to as accessibility poverty (Lucas et al., 2016). Qualitative research by (Bastiaanssen, 2012) demonstrated how accessibility poverty negatively impacted socially vulnerable households in Rotterdam-south. In his 2012 research, Bastiaanssen found that members from socially vulnerable households with no car had a relatively more difficult time finding a job compared to households with car access, because of a mobility mismatch. The problem was not created by a shortage of jobs in the region, but moreover by a lack of crucial mobility connections and mobility supply at the appropriate time and destinations to jobs that matched the capacities of citizens of Rotterdam South.

The problem Bastiaanssen revealed in 2012 continues to be a problem ten years later, in 2022. In addition, the mismatch between where people live and where their potential jobs are located is not only present within socially vulnerable groups but is also becoming a problem for middle-income population segments such as teachers, nurses, and journalists as well (Rli, 2020). For example, nurses that do not have access to a car often experience problems reaching work in the early morning and on weekends, when public transport services are reduced. Similarly, cleaners often cannot reach their jobs after office hours, when many cleaning shifts begin. These examples clearly demonstrate that transport accessibility must be considered when developing mobility policy and measured at different time points throughout the day.

To gain a better understanding of the effects of the Dutch transportation policies on socially vulnerable groups, this research assesses the relationship between transit accessibility to jobs and social vulnerability of neighbourhoods in the Amsterdam region during the COVID-19 pandemic. Public transport companies in the region decreased the number of transit services as a reaction on the contact limiting measures taken by the national government to battle the pandemic (GVB, 2020, n.d.). Our goal is to better understand how the COVID-19 services provide transit accessibility to jobs for socially vulnerable groups that are reliant on transit to reach jobs on different moments of the day. We will assess the percentage of all jobs that can be reached, but also differentiate between multiple labour market segments as aggregating all jobs can inflate the actual opportunities of socially vulnerable individuals (Deboosere & El-Geneidy, 2018). The following research questions have been developed for this research:

- What is the relationship between neighbourhood sociodemographic characteristics and transit job accessibility in the Amsterdam region, and how does this vary across time during the COVID-19 pandemic?
- What is the spatial distribution of socially vulnerable neighbourhoods in the Amsterdam region?
- What is the spatial distribution of transit access to all jobs and specific labour market segments in the Amsterdam region and how does this relate to socio-economic characteristics of neighbourhoods?
- How does transit access to jobs change between daytime and night-time services in the Amsterdam region?

2. Literature review

For our study, it is important to understand how accessibility is defined. There is a vast body of literature which aims to define the term accessibility, such as 'the potential for interaction' (Hansen, 1959), 'the spatial distribution of activities and the ease of getting to those activities' (Handy & Niemeier, 1997), or 'the ease with which any land-use activity can be reached from a location using a particular transport system' (Dalvi & Martin, 1976). The most often used and complete definition of accessibility is that of Geurs and Van Wee (2004) who define accessibility as '*the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)*' (p.128). Central to Geurs and Van Wee (2004) definition is the operationalisation of accessibility into four components: land-use, transportation, temporal, and individual. The components interact with each other and together influence the accessibility of an individual. Through feedback loops accessibility also influences the four components. The four components of accessibility as described by Geurs and Van Wee (2004) are further used to better understand accessibility poverty in the Amsterdam region.

Central within our study is the concept of accessibility poverty, a sub-concept within the transport poverty literature. According to (Lucas et al., 2016), it is difficult to construct a concise definition for transport poverty as multiple definitions are used interchangeably to describe almost the same phenomenon. Definitions of transport poverty partly overlap but also look at a different parts of transport poverty. At the same time, it is still relatively underexplored. Examples of used definitions to describe transport poverty are accessibility poverty (Martens & Bastiaanssen, 2014; SEU, 2003), involuntary transport disadvantages (Jeekel, 2019), and transport affordability (Litman, 2015; Lucas et al., 2016). All the above

definitions can be seen as distinct, interrelated concepts that together describe transportation poverty (Lucas et al., 2016). In our study, the access to jobs that is provided through the transit system is the central topic. It mostly relates to the definition set by (Martens & Bastiaanssen, 2014), who use accessibility poverty as the definition for their research.

The key component of accessibility poverty is the difficulty in accessing key activities that are essential to take part in society at a reasonable time, ease, and cost (Martens & Bastiaanssen, 2014; SEU, 2003). These key activities include paid work, education, healthcare services or visiting friends, family, and shops (Burchardt et al., 1999). Individuals that are not able to access these key activities can be defined as access poor individuals. Transport accessibility is also related to the concept of transport related social exclusion, which looks into difficulties in participating in normal activities of society that have an important spatial manifestation (Preston & Raje, 2007). The mechanism behind accessibility poverty can be described by the entitlement theory of Sen (1983). As an example, Sen explains how famines are not caused by a lack of food but moreover by a lack of access to food. The same mechanism occurs with accessibility poverty. There is no shortage of key activities in urban regions, but a lack of access to those activities. For example, there are more job vacancies in a labour market segment in a region than the number of people who have the qualifications for the jobs, but many of the un- or underemployed have no viable transportation options to access the open job positions.

A population segment that is especially vulnerable for accessibility poverty are captive transit users. Literature on transit users often makes a distinction between two groups of users: captive and choice users. Choice riders use transit because it is most convenient for them even though they have alternative modes (often a car) available to them (Krizek & El-geneidy, 2007). Captive users are those that use transit because they have no alternative options as a result of income, age, disability, or family circumstances (Beimborn et al., 2003). Van Lierop and El-geneidy (2016) identify an additional group of users which they refer to as captive-by-choice users, which they define as a group that does not own an alternative mode of transport (private car) but does have the financial means to use an alternative mode of transport such as a rented car, taxi, etc. Captive transit users, those who lack the financial means to own or use a privately owned car or take a taxi, are often the most socially vulnerable populations of society. As a result, this group has no other option than to make use of the public transit network as well as low-cost active transport (walking and cycling) to reach key activities (Krizek & El-geneidy, 2007; Van Lierop & El-geneidy, 2016). Our study will specifically pay attention to captive transit users that belong to the more vulnerable groups in society, not those who are captive-by-choice.

According to Martens and Bastiaanssen (2014), within modern western societies those with no access to cars have less access to key activities because of the way we constructed our transportation network and the land use pattern of urban regions. Bastiaanssen et al. (2021) show how those citizens that depend on transit access to jobs face more difficulties in accessing jobs because of a combination of decentralisation of jobs and services in regions and the concentration of transit services on the main corridors of urban regions in Great Britain. This trend of decentralisation of jobs and concentration or transit services on main corridors is also reported in the Netherlands (Rli, 2020). Public transport companies focus on improving the efficiency of their network to lower their costs and increase the number of passengers per kilometre. Main corridors of the public transport network connect the outer parts of regions with the centre of the region. Connections with lower ridership between the outer parts and business clusters at the edges of regions are

lacking and are often the first to be cut (Schouten & Hendriksen, 2021). The reality that outer parts of urban regions have les transit services with lower frequencies and fewer routes compared to the central parts of a region in itself does not have to be a problem, if those living in the outer parts have other modal alternatives available to them. The problem, however, is that due to socio-economic segregation of European cities, socially vulnerable groups, which includes captive transit users, are the ones that have been pushed to these edges of urban regions (Musterd et al., 2016). This leads to what is referred to as a modal mismatch (Blumenberg & Manville, 2004): the distance between urban areas that must be covered is not the problem, but the lack of viable transit services between those areas is (Foth et al., 2013).

Qualitative research by Bastiaanssen (2012) clearly demonstrated how a modal mismatch due to transit policies that focus on efficiency led to accessibility poverty for captive transit users in the Dutch context. The problem Bastiaanssen found was that many residents of Rotterdam-south did not have access to a car, while the locations with jobs that matched their capacities were difficult to reach by public transport. Many residents of Rotterdam-south searched for low-skilled jobs that were mainly to be found at the edges of the urban region. The city's public transport network however mainly connects Rotterdam's neighbourhoods to the city centre via radial routes and provides less transit services to the edges of the region in which most low-skilled jobs are located. Therefore, residents without access to a car had a more difficult job reaching potential jobs within a realistic time compared to residents with car access. It was almost impossible for captive users to find a job. Not the absolute distance to jobs, but the lack of transport options to jobs was causing difficulties in finding an appropriate job. The example set by Bastiaanssen (2012) shows how current transit policies in The Netherlands fail to provide a fair distribution of accessibility to key activities for those citizens that are most vulnerable. For these vulnerable citizens, there are systemic problems of accessibility to employment, potentially leading to transport related social exclusion (Martens & Bastiaanssen, 2014).

The modal mismatch that is experienced by captive transit users has an important temporal component that is underexplored in the literature. Literature on accessibility acknowledges the effect of the temporal component on accessibility (Geurs & Van Wee, 2004; Miller, 2018). It acknowledges that travel times, and with that the potential accessibility of jobs, greatly depend on both the modal options available to an individual as well as the time of day when trips are made. To the knowledge of the authors, accessibility to activities is often studied across years to monitor chances in accessibility based on chances in the transport system and land use patterns (For example see Klumpenhouwer et al. (2021) and El-Geneidy and Levinson (2007)). Limited attention has been given in the literature to understand how chances in accessibility across the day influence access to jobs in different labour market segments. When the frequency and number of transit services decreases at night, it is likely that the number of jobs that can be reached will also decrease. This is problematic for captive transit users that still must reach their night-time jobs in labour market segments that have many jobs starting or ending at night. These citizens that greatly depend on public transportation have almost no options in reaching these jobs at night, because a focus on efficient transit policies leaves no room for a fully functioning night network that gives access to many places in the region. It creates even fewer opportunities for the most socially vulnerable in our society to work their way up the socio-economic ladder.

3. Study context, methods & data

3.1 Study context

We selected the city of Amsterdam and all adjacent municipalities that data on the number of jobs was accessible for. At the time that the analysis was conducted, the total number of jobs in the region was 815.817, and the population was approximately 1.2 million (CBS, 2018a; Gemeente_Amsterdam, 2021). All municipalities that are included in the analysis are connected to the transit system of the city of Amsterdam by train, bus, tram, and/or metro. No data was available for the municipality of Haarlemmermeer, which borders Amsterdam on the west, and includes the employment hub associated with Schiphol International Airport. The study includes all neighbourhoods located in the selected municipalities, including those which are less connected to jobs by the transit network such as rural areas. As illustrated in figure 1, the region and particularly the city of Amsterdam are well served by public transport. Bus and tram lines connect the outer parts of the region with the main job clusters in the city of Amsterdam. The metro and light rail network connect Amsterdam, Diemen, and Amstelveen.

The modal split in the city of Amsterdam has slightly changed in recent decades. People are increasingly using bicycles and public transport to move around the city, while car use has been declining (Gemeente Amsterdam, 2019b). Car ownership is relatively low in the city of Amsterdam, with an average of 0.4 cars per household. The surrounding municipalities have a higher average number of cars per household of around 1 which is comparable to the national average (CBS, 2021a). In 2019, the city of Amsterdam has opted for a policy that aims to give less space to cars in the city which focuses on alternative forms of mobility, such as cycling, walking and public transport (Gemeente Amsterdam, 2019a).

In many urban regions, access to transit services at night or early in the morning is limited. Transit lines stop running around midnight because the demand for transit naturally decreases after this time and as a reaction, the efficiency of the network decreases with it. The COVID-19 pandemic intensified this movement as there were fewer passengers on public transport overall and especially at night. GVB, the largest public transportation company in the Amsterdam region reduced their services during the COVID-19 pandemic for cost savings, possibly leading to a decrease in the access that is provided through the transit system (GVB, 2020, n.d.).

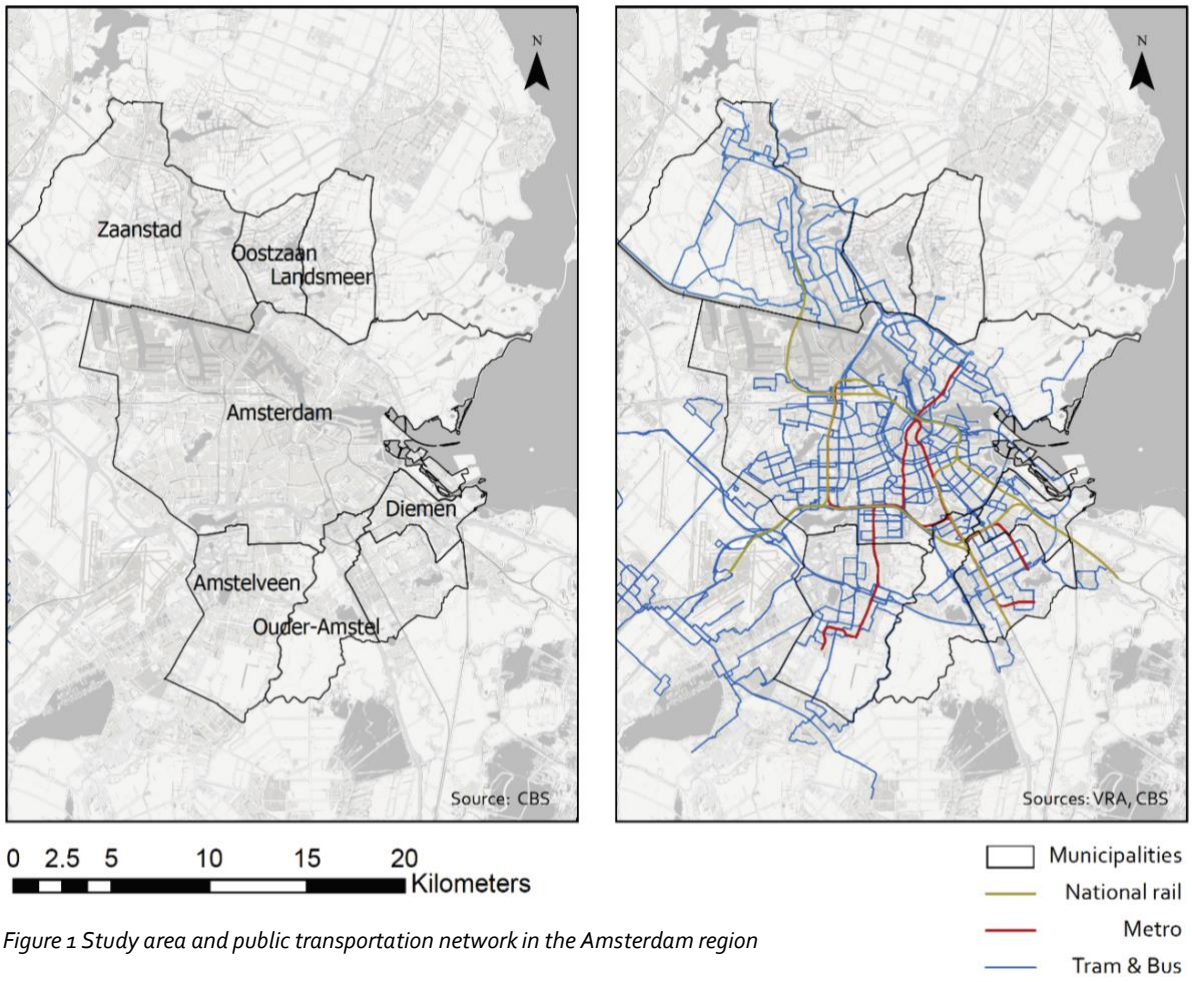

Figure 1 Study area and public transportation network in the Amsterdam region

3.2 Spatial analysis

3.2.1 Calculating accessibility to jobs

This study uses the percentage of potential jobs in the region that can be reached within 35 minutes via transit as a measure of accessibility. The 35-minute threshold was chosen as this is the average one-way commuting time in the Amsterdam region (Eurofond, 2020). We make use of a cumulative opportunity model to assess accessibility as suggested by Palacios and El-geneidy (2022). The cumulative opportunity model has the advantage that it is easy to interpret and operationalize. All jobs that can be reached within 35 minutes are equally weighted. Employment numbers in the region were provided by the city of Amsterdam (Gemeente_Amsterdam, 2021). It contains information on the location of jobs as well as the number of fulltime and parttime jobs in every firm and the labour market segment the firm is active in. Transit travel data was obtained from Transitfeeds.com in the form of General Transit Feed Specification (GTFS) (OpenMobilityData, 2021). The GTFS data contains data on the services of all public transportation companies in the region on December 30th, 2021.

Accessibility to jobs in the region was estimated using the GTFS dataset in combination with a street network layer of the region and the data on employment numbers. The GTFS dataset and the street network layer were transformed into a network dataset by making use of the GTFS To Network Dataset Transit Sources tool in ArcGIS Pro from ESRI (n.d.). The tool calculates walking time to transit stops, waiting time at the stop,

in-vehicle time, transfer time, and walking time to a final location. It is possible to create service areas showing the area reachable within 35 minutes from a starting location by public transport, including access and egress time. Service areas were calculated for the morning peak hour (8am) and during the middle of the night/ early morning (3am). As a starting location, centroids of 100 by 100-meter areas in the region as provided by the Central Bureau for Statistics (CBS) of The Netherlands were used (CBS, 2018c). The CBS only included areas with more than 20 inhabitants due to privacy considerations. The service area layers were then spatially joined with the employment data layer to estimate the percentage of all jobs and percentage of jobs per labour market segment. Even though the 100 by 100-meter areas already contain some socio-economic data, we chose to calculate the mean job accessibility per neighbourhood. Information about household income, education level, and land use mix is only publicly available at the neighbourhood level. As the size of each neighbourhood varies greatly and the distance between the edge of a neighbourhood and the centre can sometimes already be several hundred metres, we measured accessibility to jobs per neighbourhood by calculating the mean accessibility to jobs of all the 100 by 100-meter areas that make up a neighbourhood.

3.2.2 Social indicator

To identify places in the Amsterdam region that potentially house large groups of socially vulnerable inhabitants who are more often captive transit users, we made use of a social indicator. According to Foth et al. (2013), a social indicator should include variables that are country appropriate and relate to the social phenomenon that you aim to analyse. Foth et al., who conduct their research within a Canadian context, used the percentage of the population that has immigrated within the last five years as a variable in their social indicator on employment accessibility, because this group often work for lower wages and are employed in lower skilled jobs in their study area, Toronto. In the case of Amsterdam, we use four variables that relate to social disadvantages in accessibility to jobs that also have been identified by Kobus et al. (2021) for the Dutch context. All variables were converted to percentages to compare neighbourhoods with differing population sizes. Data was retrieved from the CBS (2018a, 2020). The four used variables are:

- Percentage low educated per neighbourhood;
- Percentage inhabitants that receive social assistance per neighbourhood;
- Percentage of social housing per neighbourhood;
- Percentage inhabitants belonging to the national 40% with the lowest personal income per neighbourhood.

In The Netherlands, low educated populations tend to have a higher chance on being unemployed compared to middle and highly educated populations (UWV, 2017). This is caused by various reasons, the most important being high competition among job seekers. More than one third (34%) of all low-educated people in the Netherlands are not active on the labour market, which is considerably higher compared to the average in the country (18%). Next to more competition among lower education job seekers, educational attainment has much influence on your income. Higher educated earn around twice as much as lower educated in The Netherlands (CBS, 2021b). Lower educated therefore more often belong to the group with the lowest income, just like those receiving social assistance, or living in social housing.

As discussed in the literature review, a low income can negatively impact the modal options of an individual as well as the location you can afford to live. Socially vulnerable individuals more often belong to the group that do not have access to a car (CBS, 2018b). It therefore seems logic to use car ownership as one of the variables in the social indicator. However, forced car ownership is more common in socially vulnerable neighbourhoods in peripheral parts of cities (Johnson et al., 2010; Kobus et al., 2021). It is therefore not clear whether there is real access to car use in neighbourhoods with high car ownership. Even when low-income groups have access to a car, high operating costs of car usage can restrict these groups of using their car to access work. Therefore, we have chosen to use variables that relate to income which potentially restrict modal options instead of car ownership in our study.

Apart from a direct effect on the modal options of individuals, the variables also relate to groups that potentially have difficulties in accessing jobs due to the process of socio-economic segregation. We see that European cities show increasing socio-economic spatial segregation (Musterd et al., 2016) in which socially disadvantaged groups are pushed to the edges of cities (Boterman & Van Gent, 2015). These places often lack viable transit connections to other parts of urban region regions in which socially vulnerable groups look for jobs, restricting the modal options of these groups (Bastiaanssen, 2012).

We tested the variables of the social indicator on their relatedness using a correlation matrix, which showed all variables in the social indicator are significantly related to each other. The correlation analysis shows that the variables are observing the same group and do not relate to different populations. Variables were all awarded an equal weight in the social indicator as suggested by Foth et al. (2013). The average of the four variables combined is re-ranked in quantiles, with neighbourhoods that are the most socially vulnerable in the highest quantile, and those with the lowest social vulnerability in the lowest quantile. The resulting quantiles will be used for further analysis.

3.3 Regression analysis

The final step of the research assesses the relationship between transit job accessibility and the social indicator. This was done using a linear regression analysis which included the social indicator as the dependent variable, and the percentage of jobs accessible as independent variable. The urbanity per km^2 population density, average house value, percentage housing built after 2000, number of shops within 1km, number of cars per household, percentage non-western immigrants were all added as independent socio-economic and land use variables to test if a relation would still exist when controlling for other factors that potentially have a relationship with the variables in the social indicator.

4. Results

This section will present the main findings of the paper. We start with a spatial analysis on the distribution of socially vulnerable neighbourhoods, followed by the distribution of transit accessibility to jobs in the region for both day (8am) and night (3am). Next, we turn to the regression analysis in which we will first address questions regarding the relationship between the social indicator score and job accessibility. Then, the findings on temporal chances in job accessibility are presented. Finally, the last paragraphs will answer if specific labour market segments are better accessible via transit than others in the region.

4.1 Social indicator

Figure 2 shows the spatial distribution of all neighbourhoods in the study area when ranked by the social indicator. Dark blue areas show the most vulnerable neighbourhoods. Some areas in the research are (see figure 1) have no colour because there is no data available. These areas are often not residential and have a different usage, such as parks and industrial areas.

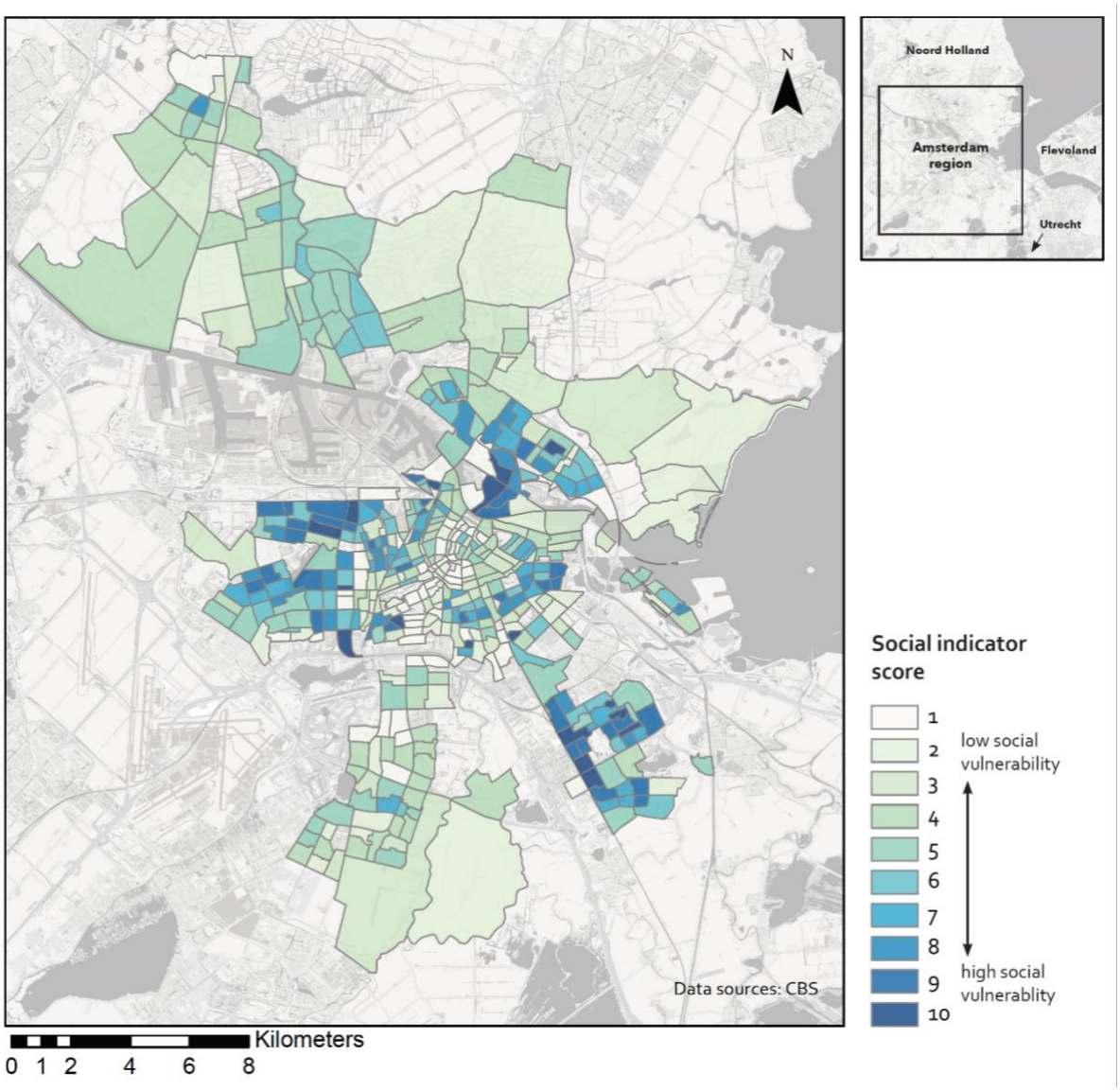

Figure 2 Social indicator map

The spatial distribution of neighbourhoods based on the social indicator shows the region is made up of three rings. In the centre of the region, the central area of Amsterdam, the south side of Amsterdam and the north side of Amstelveen, neighbourhoods have a predominantly low social indicator score and form the inner and first ring. The suburbs of Amsterdam that form a second ring around the city centre on the north, east, south-east, and west sides of the city score higher on the social vulnerability scale. The peripheral parts of the region in the northwest and south form the third ring of neighbourhoods. These neighbourhoods are in the middle of the social vulnerability scale. On the north and south side of the region a few more neighbourhoods can be found with a low social vulnerability score. These are rural areas that are large in terms of surface area but small in terms of population.

According to our social indicator, the socially most vulnerable neighbourhoods can be found at the edges of the city of Amsterdam, whereas the centre of the city of Amsterdam is the least socially vulnerable. These findings are in line with the findings of others, such as Boterman and Van Gent (2015) and Hochstenbach and Musterd (2018). Both studies found a process of sub-urbanisation of vulnerable populations to the outer neighbourhoods of the city of Amsterdam. The suburbanisation of these groups leads to a situation which we also observe by using our social indicator.

4.2 Spatial distribution of transit access to jobs at 8am

Figure 3 illustrates the percentage of all jobs in the region that can be reached within 35 minutes' travel time via transit at 8am per neighbourhood. It clearly shows large differences per neighbourhood as the percentage of accessible jobs varies between .2 and 81 percent with an average accessibility of 45 percent throughout the region. This means that the neighbourhood with the highest transit job accessibility can reach 81 percent of all jobs in 35 minutes, whereas the neighbourhood with the least transit job accessibility can only reach .2 percent of all jobs in 35 minutes. The pattern can to a large extent be explained by the spatial distribution of jobs and the structure of the public transportation system in the region. Job clusters are predominantly located in the centre of the region in the city of Amsterdam. They are mainly located in the centre, the south side, and the south-east edge of Amsterdam. Neighbourhoods in the centre or close to the centre of the region, in the centre, east and south of the city of Amsterdam therefore have the highest percentual accessibility to jobs via public transport. In these parts of the region, more than 65% and on average 72% of all jobs can be reached within 35 minutes via transit. Around these neighbourhoods, there is a second ring of neighbourhoods with transit accessibility to jobs between 30 percent and 65 percent of all jobs with an average of 50 percent. These are mainly neighbourhoods on the outskirts of the city of Amsterdam and in the municipalities of Amstelveen, Diemen, and Ouder-Amstel. Neighbourhoods on the North and South sides of the region in the municipalities of Amstelveen, Landsmeer, and Zaanstad have the lowest accessibility to jobs via transit in the region. Here, the accessibility ranges from 0 to 30 percent and has an average of 13 percent.

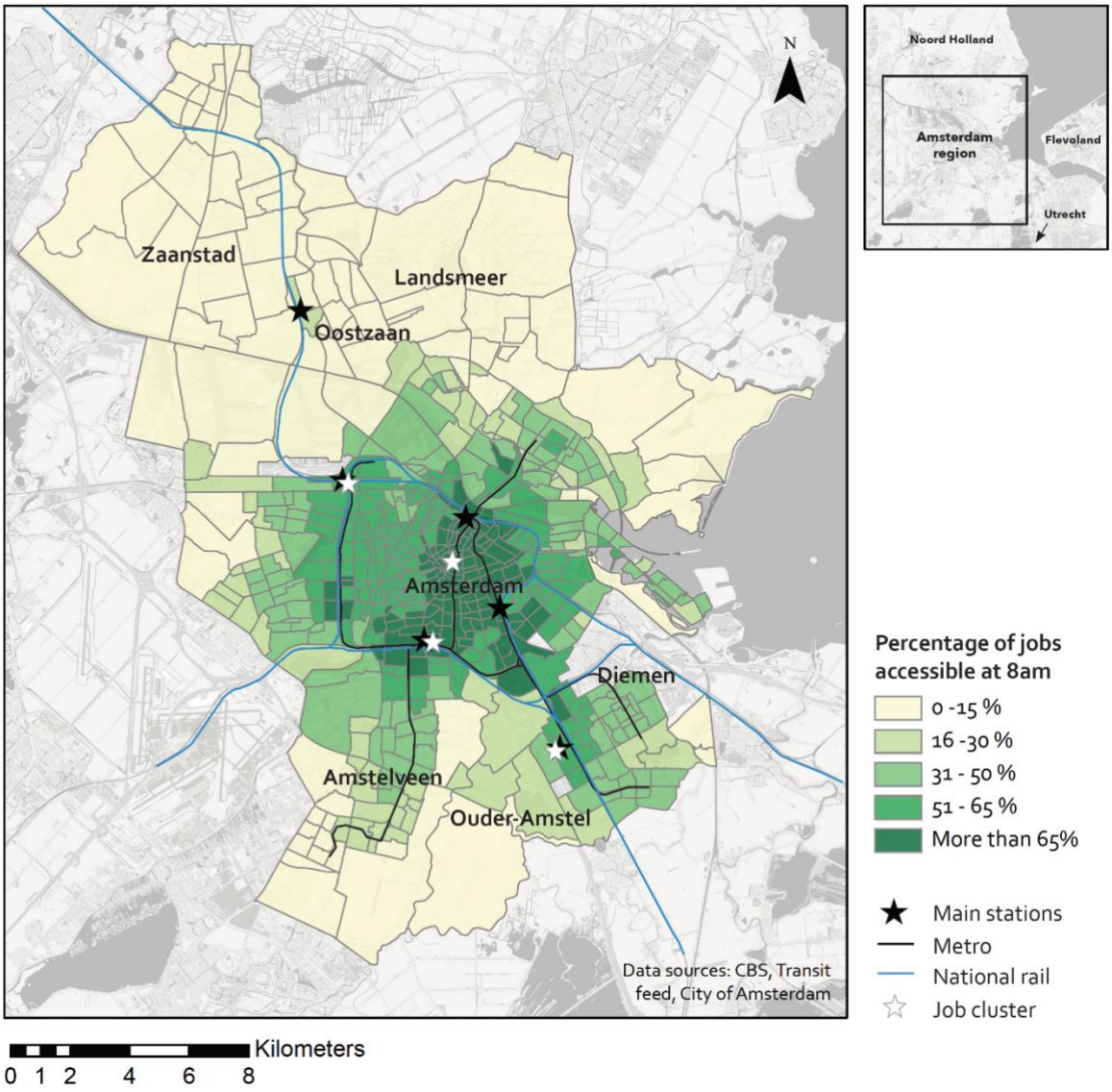

Figure 2 Transit access to jobs at 8am

4.3 Spatial distribution of transit access to jobs at 3am

Figure 4 shows that at night, the accessibility of jobs via transit in the region plummets for each neighbourhood. There is only one public bus at 3 a.m. in the entire region and this is reflected in the percentage of jobs accessible. As a result of the low frequency and number of transit services at night, the overall transit access to jobs in the region is low. Neighbourhoods close to job clusters have the highest accessibility to jobs compared to neighbourhoods more distant from job clusters. The relatively high accessibility to jobs for these neighbourhoods is mainly created through walking access, as inhabitants of these neighbourhoods close to job clusters can still walk to many jobs within 35 minutes. Neighbourhoods further away from job clusters cannot reach a high number of jobs within 35 minutes walking. Therefore, neighbourhoods that are not closely located to a job cluster or the only transit service at night have considerably lower job accessibility.

Neighbourhoods in the central part of the region have the highest job accessibility. Here, a maximum of 31 percent of all jobs can be reached by transit and/or walking with an average of 22 percent. Some neighbourhoods in the south-east of Amsterdam also have a

relatively high accessibility compared to the region, with an average of around 15 percent of all jobs being accessible by transit. Neighbourhoods in the other parts of the region all have low accessibility to jobs via transit at night as there are no job clusters or transit services to job clusters at 3am in these parts of the region. Here, a maximum of 15 percent of all jobs can be reached by transit with an average of 6 percent.

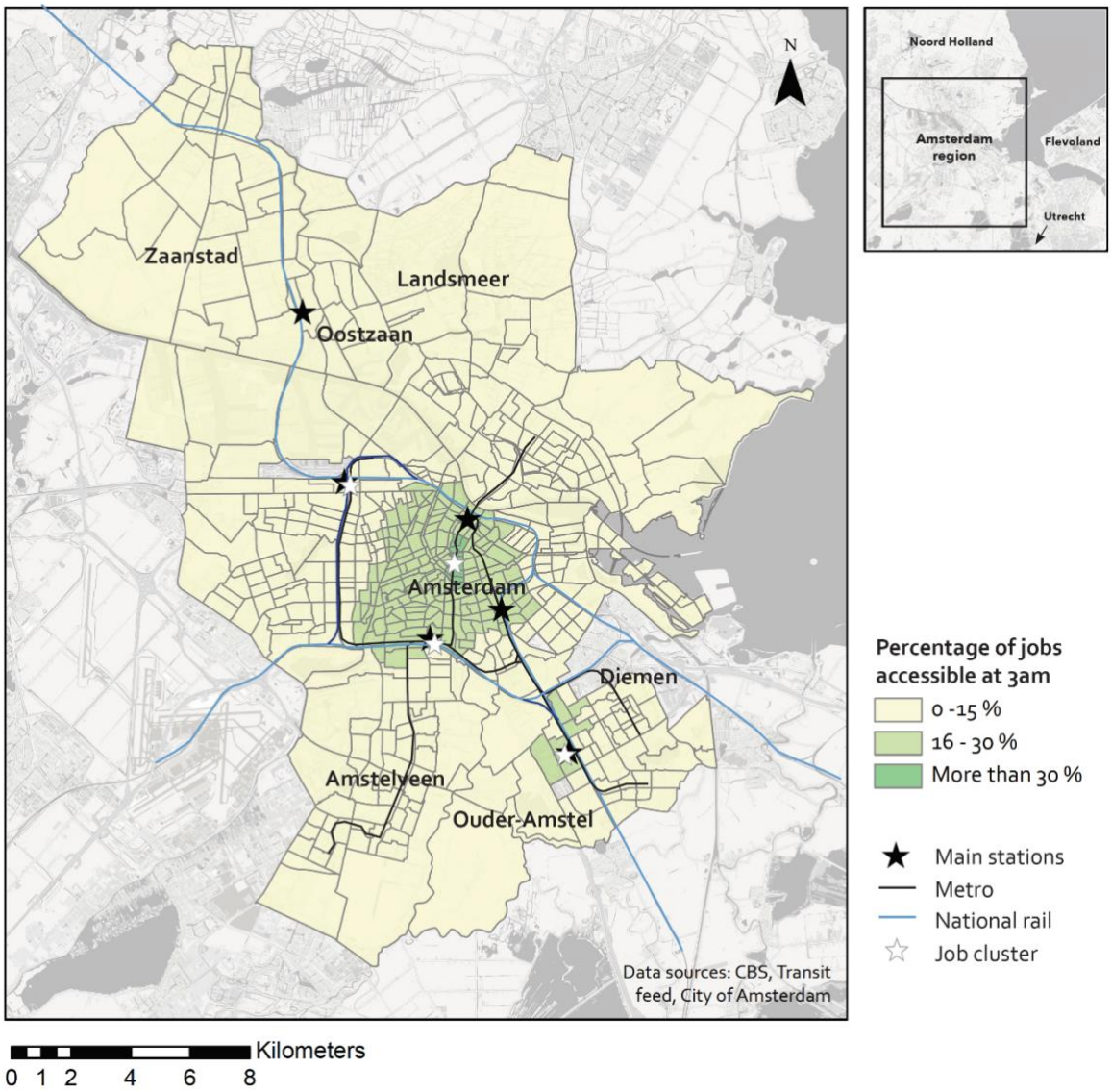

Figure 3 Transit access to jobs at 3am

4.4 Relationship between transit job accessibility and the social vulnerability score of neighbourhoods at 8am and 3am

In addition to the examination of the spatial distribution of accessibility to jobs via transit, we also examined the relationship between the social vulnerability score of neighbourhoods and the accessibility to all jobs for both day and night-time using a linear regression analysis. Other socio-economic and land use variables that could influence the relationship were also included. For both day and night, a significant negative relationship was found between the social vulnerability score of a neighbourhood and the percentage of

jobs that can be reached within 35 minutes by transit. This means that neighbourhoods with a high social indicator score predominantly have lower transit job accessibility than neighbourhoods with low social indicator scores. The relationship is slightly stronger at night than during the day. In addition to the relationship between transit job accessibility and the social vulnerability score, a positive relationship was also found between the social vulnerability score and the urbanity per km^2 (only at night), the population density per km^2, the percentage of non-Western immigrants in a neighbourhood and the percentage of houses built until 2000 in a neighbourhood. This shows that as a general trend, neighbourhoods with a higher degree of urbanisation are more likely to be socially vulnerable compared to rural neighbourhoods in the region. Neighbourhoods with a higher percentage of non-Western immigrants also have higher social vulnerability scores compared to other neighbourhoods. Finally, there also appeared to be a relationship between the age of the built-up environment and social vulnerability. Neighbourhoods built after 2000 have on average lower social indicator scores than neighbourhoods built before 2000. The average number of shops within 1km that was used as an indicator for urban mix of a neighbourhood as well as the average house value and the number of cars per household show no relationship with the social indicator value.

Table 1: Regression analysis of the social indicator and transit job accessibility, land use and transport variables

Coefficients[a]

	3am	8am
Constant		
Percentage of jobs accessible via transit	-.166***	-.137**
Urbanity per km2	.093*	.078
Population density per km2	.220***	.216***
Percentage non-western immigrants	.716***	.744***
Average house value	.024	.019
Percentage housing built after 2000	-.159***	-.148***
Number of shops within 1km	.087	.052
Number of cars per household	-0.026	0.021

Note: R^2 3am = .574, R^2 8am= .576
Significance levels: *P ≤ 0.05%, **P ≤ 0.01, ***P ≤ 0.001.
a. Dependent Variable: Social indicator

When we assessed the transit job accessibility in the region per quantile of the social indicator, we found a more nuanced result. Despite the negative relationship, both during day and night, neighbourhoods that fall within the higher quantiles of the indicator do not have the lowest accessibility to jobs via transit in the region at day. During the day, the neighbourhoods in the 4th and 5th quantiles that are mainly to be found at the edges of the urban region have the lowest accessibility to jobs via transit. Approximately 40 percent of all jobs can be reached from these neighbourhoods via transit. Neighbourhoods in both the higher and lower quantiles of the social indicator can all reach around 50 to 60 percent of all jobs in the region via transit. Neighbourhoods with a high social indicator score are predominately found on the edges of the city of Amsterdam. Here, transit job accessibility is only slightly lower than in the centre of the region and sometimes even comparatively high.

At night, the pattern shifts. Neighbourhoods in the lowest three quartiles have higher accessibility to jobs than all other neighbourhoods in the region. This is a result of the spatial distribution of jobs and the transit services at night. At night, almost no transit services are available. We only considered transit and walking as transportation options. Therefore, for most neighbourhoods, walking is the only option to access jobs at night, meaning that neighbourhoods near job clusters or the only transit service at night have higher access to jobs than neighbourhoods further away from these places. Most neighbourhoods in the first three quantiles are closely located to job clusters, whereas many neighbourhoods in the other quantiles are less close to job clusters.

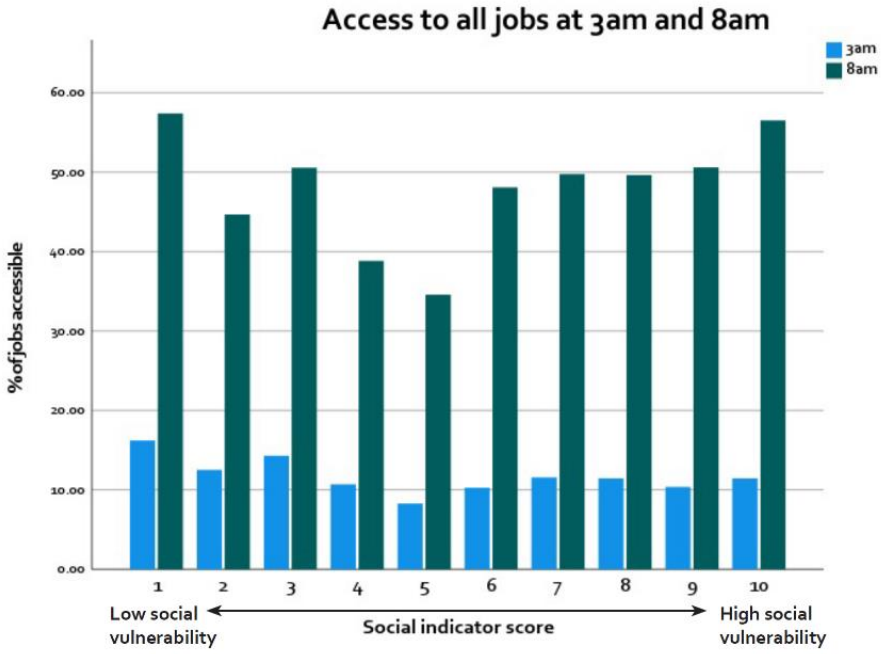

Figure 4 Transit access to jobs per social quantile at 3am & 8am

4.5 Differences in transit access to labour market segments at 8am and 3am

Our results show that transit accessibility to jobs shows great differences between day and night in the Amsterdam region. At 8am, on average 45% of all jobs can be reached via transit, whereas at 3am this percentage drops to 11%. The low percentage of all job that can be reached at night does not necessarily have to be a problem, if those segments that offer many night-time jobs have relative high access. Research by the Rijksinstituut voor Volksgezondheid en Milieu (RIVM) reports that most night-time jobs that have shifts starting or ending in the night in The Netherlands are found in the healthcare, transportation, and industry segment (RIVM, 2020). When examining transit access per labour market segment at night, our analysis reveals that within the industry and healthcare segment, 1 in 10 jobs and in the industry segment only 1 in 14 jobs can be reached via transit at 3am, revealing a mismatch between segments with many night-time jobs and the access that is provided by the transit system at night to these jobs.

Table 2: Mean percentage of jobs per labour market segment accessible at 3am & 8am in the Amsterdam region

	Mean percentage of jobs accessible at 3am	Mean percentage of jobs accessible at 8am
Agriculture, forestry & fishing	1.3%	3.7%
Industry and energy	6.9%	32.0%
Commerce & hospitality	13.0%	45.0%
Transport, information & communication	10.0%	40.8%
Financial services & real estate	11.5%	52.4%
Corporate services	11.2%	47.1%
Culture, leisure & other services	16.9%	52.6%
Public services	10.4%	47.3%
Education	11.7%	47.8%
Healthcare services	10.3%	44.1%
All jobs	11.0%	44.5%

4.6 Transit access to labour market segments throughout the social indicator score

Our analysis reveals that there are not only differences in transit access to jobs over the day, but also between social deciles. The regression analysis showed a negative relationship between the social vulnerability score of neighbourhoods and transit access to jobs, for both day (8am) and night (3am). This result seems to differ from other studies such as Foth et al. (2013), and Deboosere and El-Geneidy (2018), who showed that socially vulnerable groups have on average higher access to jobs via transit compared to other groups in the Canadian context. However, when looking per quantile, it becomes clear that during the day, the relationship is not linear and more in line with other studies. During the day, the socially most disadvantaged segments (deciles 8 – 10) have higher access to all labour market segments compared to other populations segments in the region. Only the socially least disadvantaged decile (1) shows higher access to most labour market segments (see figure 6). This indicates that people living in socially vulnerable neighbourhoods in the Amsterdam region do not have lower transit access to specific labour market segments than people living in less socially vulnerable neighbourhoods.

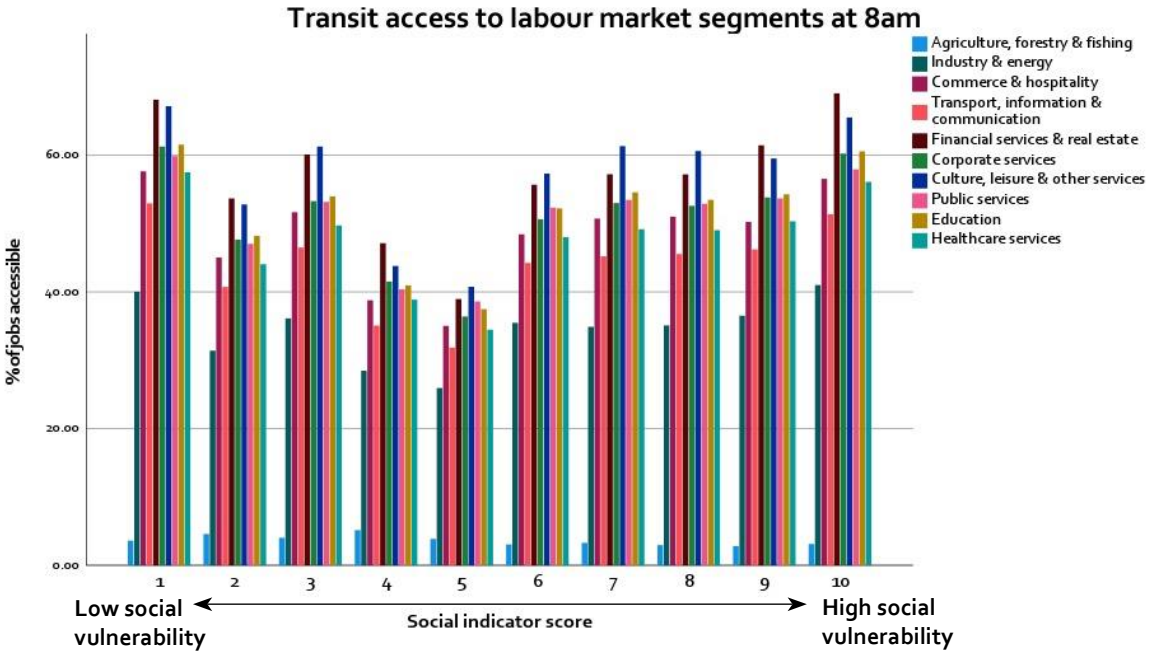

Figure 6 Transit accessibility to different labour market segments at 8am

Our research also examined the relationship between access to labour market segments and social vulnerability at night. This showed that the pattern is rather different at 3am, as the most socially disadvantaged deciles (8-10) have the least access to all jobs in the region (see figure 7). Labour market segments that offer many night-time jobs are poorly accessible for every decile, but especially for the socially most vulnerable deciles. This indicates that people living in neighbourhoods with a high social vulnerability have less access to most labour market segments at night. The healthcare, transportation, and industry segments, that according to the RIVM have many night-time jobs that have shifts starting or ending at night are all poorly accessible for people living in socially vulnerable neighbourhoods.

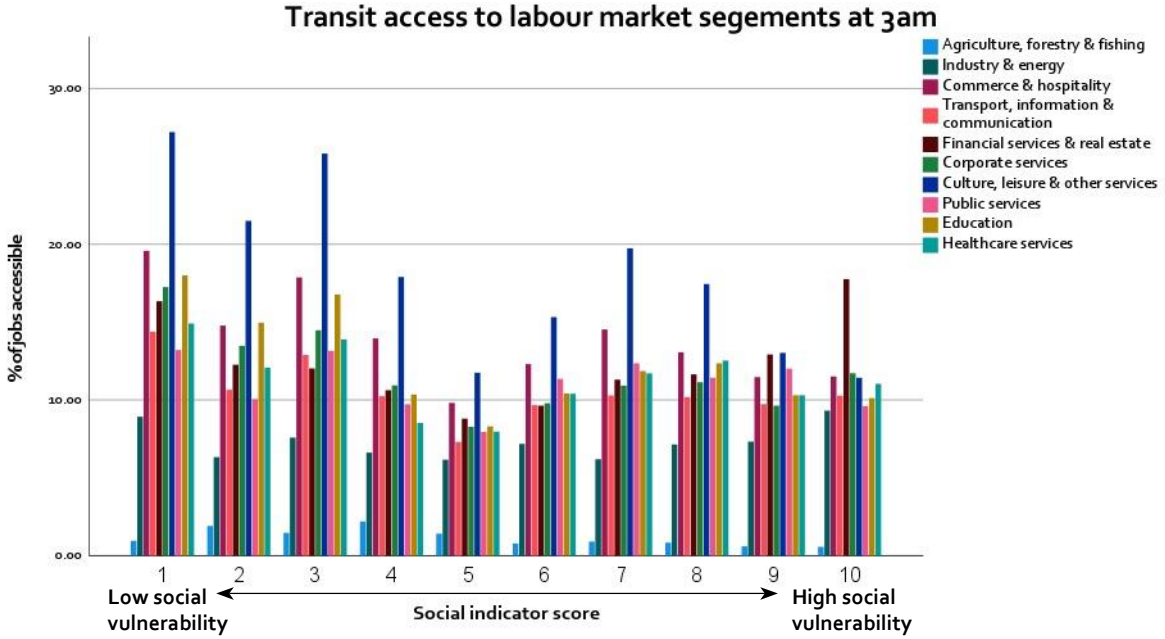

Figure 7 Transit accessibility to different labour market segments at 3am

5. Discussion

Many others have examined the distribution of access to jobs across different socio-economic groups (Deboosere & El-Geneidy, 2018; Martens & Bastiaanssen, 2014) or assessed transit accessibility to jobs over time (El-Geneidy & Levinson, 2007; Foth et al., 2013; Klumpenhouwer et al., 2021). And, while literature on accessibility acknowledges the existence of the temporal component of accessibility (Geurs & Van Wee, 2004; Miller, 2018), to the knowledge of the authors, no other studies have taken an interest in differences in access to labour market segments over the day for different socio-economic groups. Therefore, we attempted to fill this knowledge gap and examined differences in accessibility to labour market segments between day and night throughout the socio-economic spectrum simultaneously.

5.1 Modal mismatch and potential accessibility poverty at night

The results of this study reveal a clear modal mismatch for captive transit users that have night-time jobs. Captive transit users are more often part of the socially most vulnerable groups of society (Beimborn et al., 2003), which relates to the higher deciles of our social indicator that have low transit job access to almost every labour market segment. At day, we see that socially vulnerable groups have relatively high levels of transit access to jobs, which is in line with other studies such as Foth et al. (2013) and Deboosere and El-Geneidy (2018). Even when socially vulnerable citizens are captive transit users, they can still use the transit system to reach many jobs in almost every labour market segment in the region. Other studies overlook the changing relationship between social vulnerability and transit access to jobs over the day which, as we showed, impacts the modal mismatch. At night, the accessibility to jobs by transit plummets for every neighbourhood, especially for neighbourhoods with many socially vulnerable citizens. They cannot use the transit system to reach their night-time job and will have to use private transportation (a car) to reach their night-time jobs. Even though car ownership did not correlate significantly with most of the variables of our social indicator, high operating costs combined with overall low car ownership in Dutch cities can still lead to a problematic situation for groups in the higher quantiles that work at night. Especially nowadays, as fuel prices are rising to levels never seen before caused by the war in Ukraine (consumer, 2022), more people will be reliant on transit to reach jobs. However, the transit system does not provide access to night-time jobs and the car is too expensive to use or they have no access to a private car at all.

The combination of low access to a car, high operating costs for those with a car, no financial means to pay for a taxi or rental car, and poor access via transit to labour market segments with many night-time jobs will be problematic for citizens in the higher deciles of the social indicator. The modal mismatch that is created can potentially lead to accessibility poverty for those citizens as there is no viable transport option at night to reach a job.

It is important to note that in addition to using transit or the car, people in the Netherlands often cycle to work. In Amsterdam, approximately 50% of the inhabitant's use a bike to commute to work (KIM, 2017). While biking is a viable alternative transport mode at day, it is questionable whether this is a real alternative for transit at night. TNO (2010) found that many night workers experience safety issues because of the dark when commuting by bike at night. Safety issues when cycling at night can be related to cycling alone, cycling without proper street lighting or poor bicycle lighting (Ravensbergen et al., 2020). It is also debatable whether accessibility to jobs at night by walking 35 minutes can be counted as real accessibility to jobs at night. Here again, safety issues must be taken into

account, especially when talking about the female perspective on the safety of walking at night in urban streets (Ganjavi et al., 2000).

5.2 Urban type and transit access to jobs

Apart from the social vulnerability of neighbourhoods, the result of our analysis indicates that the urban type of neighbourhoods plays an important role in transit access to jobs. Neighbourhoods with high levels of urbanisation have better accessibility to jobs than the less urban neighbourhoods, both during the day and at night (see figure 8). Especially at night, the differences in access to jobs between urban types is great. These findings are in line with the findings of other studies on accessibility in the Amsterdam region who found that less urban parts of urban regions have lower access to activities than more urban parts (Martens & Bastiaanssen, 2014; Rli, 2020).

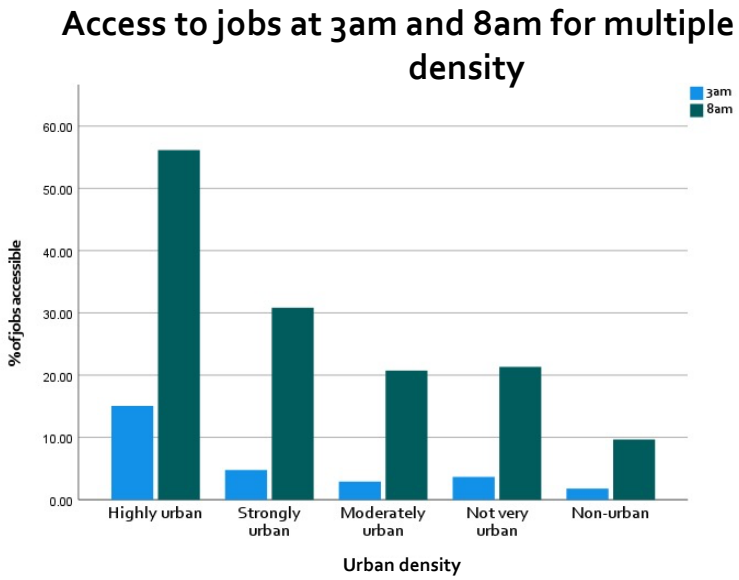

Figure 8 Transit access to jobs at 3am and 8am for multiple levels of density

5.3 Using car ownership as a variable of social vulnerability

An important difference with other studies is that we did not use car ownership as one of the variables of our social indicator, whereas others such as Foth et al. (2013) did. Car ownership is often used as a variable as it tends to be higher in high income groups, therefore indicating social vulnerability when ownership is low. Johnson et al. (2010) questions the usability of car ownership as an indicator of social vulnerability. They showed that using car ownership as a variable can distort the real picture of the distribution of advantages and disadvantages in western cities. Kobus et al. (2021) also question the usability of car ownership as a variable of social vulnerability in the Dutch context, as forced car ownership is more common in socially vulnerable neighbourhoods in peripheral parts of cities. It can therefore give a biased impression of the actual access to cars. A correlation analysis between the variables used in our study and car ownership in the Amsterdam region showed that car ownership was only positive related to one out of four of the used variables of this study. Therefore, we feel that including car ownership as a variable would have distorted the real situation of social vulnerability in our study. Apart from distorting the real situation, using car ownership as a variable to define groups with social

disadvantages in accessibility to jobs in cities that try to limit car usage seems contradictory. An increasing number of places in the city are becoming less accessible by car by car limiting policies, and parking fees in the city are so high that many socially vulnerable people would never be able to pay them. As cities focus on making transit the backbone of their transport system, it would seem logic to better incorporate transit accessibility to jobs as a variable within social indicators.

6. Conclusion

This study has helped to better understand how transit access to specific labour market segments changes over the day and how this relates to social vulnerability in the Amsterdam region during the COVID-19 pandemic. Like other studies, this study did not find clear signals for a modal mismatch at day, even when looking at separate labour market segments in the region. The socially most vulnerable neighbourhoods in the region have relatively high access via transit to all segments. The examination of a modal mismatch for captive transit users at night that is often overlooked in other studies can be seen as the primary contribution of this study. Despite the absence of a different relationship in the linear regression analysis, a decile level analysis showed that the socially most vulnerable neighbourhoods have the lowest access to jobs via public transport at night, especially to segments that offer many night-time jobs. This is mainly caused by a lack of transit services at night in the region. The combination of poor access to segments that offer many night-time jobs and already existing difficulties in accessing work can potentially lead to high levels of accessibility poverty for the socially most vulnerable groups in the Amsterdam region.

In addition, we have attempted to further develop a social indicator that correctly identifies socially disadvantaged groups in urban regions that face difficulties in accessing work. Whereas other studies include car ownership as one of the used variables for potential problems in accessing work, we deliberately chose not to use car ownership as a variable. Forced car ownership in socially vulnerable neighbourhoods and high operation costs of car usage together make car ownership a variable that can distort the real situation when evaluation difficulties in accessing work, as owning a car can differ from being able to use a car to commute work.

Our study has some limitations, mainly related to the availability of data. First, we would ideally have used data that distinguishes between low, medium, and high paid jobs as, for example, Deboosere and El-Geneidy (2018) have done. However, this data was not available or unavailable to the authors, meaning that we could not distinguish between incomes within labour markets. Second, our study was conducted at a time that the COVID-19 pandemic had major influence on transit services in Europe. Because of low ridership, transit companies lowered their services. It is not clear how services will be adjusted post-pandemic. .

Future research could focus on a comparison between accessibility to different types of jobs in the region via public transport and other forms of mobility. This would help quantify the accessibility that is provided by the transit system compared to other modes. In addition, it would be interesting to use qualitative research to assess whether inhabitants of socially vulnerable neighbourhoods that have low transit access to jobs at night truly experience difficulties in accessing jobs at night. We can only comment on neighbourhoods in the region that possibly experience accessibility poverty, not to which extend inhabitants actually experience it.

This research has helped to better understand the temporal character of accessibility poverty. It therefore helps to better understand the problems that socially vulnerable groups experience when looking for jobs on multiple moments on the day. The outcomes of this research can be used by policy makers to improve job accessibility for socially vulnerable groups and increase the equity of the transport system of cities. The needs of socially vulnerable groups should be better incorporated when making transport policies for cities, which will benefit society as a whole but especially those who need it the most.

Acknowledgement

The authors would like to thank the City of Amsterdam for providing detailed employment data of the region, and Jeroen Bastiaanssen for the valuable feedback.

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