Accessibility and space-time differences in when and how different groups (choose to) travel

Jean Ryan a, b, *, Rafael H.M. Pereira c, Magnus Andersson b, d

a Department of Technology and Society, Lund University, P.O. Box 118, 22100 Lund, Sweden
b K2 The Swedish Knowledge Centre for Public Transport, Bruksgatan 8, 22237 Lund, Sweden
c Ipea Institute for Applied Economic Research, Brasilia, Brazil
d Malmö University, Department of Urban Studies, Nordenskiöldsgatan 1, 21119 Malmö, Sweden

ARTICLE INFO

Keywords:
Accessibility
Time geography
Public transport
Stockholm
Spatio-temporal Differences
Transport justice

ABSTRACT

A fair distribution of accessibility to key activities is a central concern for distributive justice in transport planning. This implies that disparities in accessibility and the negative effects associated with a lack of accessibility should be mitigated. However, even though accessibility is not purely spatial or static, it is conventionally treated as if it were. Several studies have significantly advanced the spatio-temporal representation of accessibility. However, there is still a lack of focus on how these dynamics affect different groups of people with differing socio-economic and demographic characteristics and how these dynamics might influence their travel mode choice. The aim of this paper is to analyse how differences in accessibility to the workplace by public transport during multiple times of the day are associated with the time period in which different groups of people commute to work, and how the flexibility of individuals’ time constraints might influence whether they can and do commute using public transport. Using a transport justice-focused time geography perspective, this study draws on the spatio-temporal aspects of people’s real activities based on travel survey data for the Stockholm Region. This study contributes to the literature by highlighting the differences in accessibility to the workplace by public transport across multiple departure time periods; showing how these results compare with mode choice (if there is a choice); and revealing which socio-economic, demographic and geographical factors characterise these differences. This study also illustrates how a transport justice-focused time geography approach could help researchers have a more detailed and nuanced understanding of the relationship between accessibility and sustainable travel behaviour, and how this relationship might change at different times of the day.

1. Background and aim

A fair distribution of accessibility to key activities is a central concern for distributive justice in transport planning (Pereira et al., 2017; Martens, 2017). This implies that disparities in accessibility should be limited and that the negative effects associated with a lack of accessibility should be mitigated. However, even though accessibility is not purely spatial or static, it is conventionally treated as if it were. It has been argued that it is more fitting to acknowledge and investigate the complexity inherent in the circumstances of people, living and working in different areas with varying schedules and different transport options, and the corresponding production of dynamic levels of accessibility (Miller, 2018). Even though a number of studies have significantly advanced the spatio-temporal representation of accessibility (e.g. Xu et al., 2015; Fransen et al., 2015; Boisjoly and El-Geneidy, 2016; Farber and Fu, 2017; Steg, 2019; Järvenpää et al., 2018), there is still a lack of focus on how these dynamics affect different people with differing socio-economic and demographic characteristics and how it might influence their travel mode choice.

In the transition to the use of more sustainable modes of transport it is important to consider how available such modes are to different groups in society, and how the freedom to choose sustainable options differs among different groups. Little is known about how the production of accessibility during different times of the day interacts with the ways in which different groups in society can travel, with respect to the flexibility of working hours, (gendered) familial and home commitments, negotiation between household members and modal options in particular (Boyer and Spinney, 2016; Fu and Juan, 2017; Hjorthol, 2001;
The flexibility to travel during different timeframes can be considered a significant advantage, as can the flexibility to work from home. These forms of flexibility tend to be concentrated in certain groups in society, often those with higher levels of education and living in the wealthier parts of cities (Elder, 2019; Elder, 2020). This can result in some groups in society being comparatively ‘forced’ to travel during tighter timeframes, while others have more freedom to work from home and/or decide when and more flexibility for how they want to travel. This can also relate to familial commitments, in terms of having to drop off/pick up children at specific times and locations (Schwanen, 2008).

Associations between accessibility and modal choice have been established in several studies (e.g. Yousefzadeh Barri et al., 2021; Cheng et al., 2020; Owen and Levinson, 2015; Cui et al., 2020), with these associations most likely mediated by self-selection processes (see Janke (2021) for an overview). However, these associations vary depending on income and car ownership (see Cui et al., 2020), suggesting that there may be disparities in modal options between social groups. Few studies have however explored temporal dynamics and how they make modal options differently available to different groups (with the exception of e.g. Boisjoly and El-Geneidy (2016) who draw on census tract data). Not only do some groups have less flexibility with respect to departure and arrival times and transport modes, but the necessity for some groups to be in certain places at certain times can result in the segregation of different kinds of commuters in time and space (e.g. Kwan, 2013; Wang et al., 2012; Abbasi et al., 2021).

The literature to date lacks an explicit focus on how different groups of people with varying constraints are affected by the transport and land use system(s) and differing provisions of public transport throughout the day. Different groups of people (have to) travel during different timeframes. Given that the supply of public transport services varies across the day, this variation could affect not only accessibility levels, but also the capability of individuals to use more sustainable modes. With this study, we explore the extent to which variations in accessibility during different time periods are related to the use of public transport among different groups while accounting for individuals’ socioeconomic characteristics and indicators of time constraints.

The aim of this study is two-fold. Combining estimates of travel time to the workplace with travel survey data for the Stockholm Region in Sweden (Stockholm Travel Survey, 2015), we first examine how differences in accessibility to the workplace by public transport during multiple departure time periods are associated with the time of the day during which people commute. Second, we analyse how the temporal flexibility of people’s real activities is associated with using public transport as part of their commute. Both socio-economic and geographical factors characterising these differences are analysed from a transport justice-focused time geography perspective. The present study aims to advance the existing body of literature by highlighting how temporal differences in accessibility are associated with including public transport as an element of the commute trip. This paper also contributes to the literature by putting forward a transport justice-focused time geography approach to interpret how the relationship between accessibility and mode choice (if it is a choice) is mediated by socio-economic, demographic and geographical factors.

2. Literature overview

2.1. The links between accessibility and modal choice

The most prevalent definitions of accessibility emphasise the ‘potential’ for interactions (Boisjoly and El-Geneidy, 2017; van Wee, 2016; Geurs and Osth, 2016). Alongside the increasing centrality of the concept of accessibility has come a greater emphasis on the distribution of the social effects of transport policies and projects (Martens and Di Ciommo, 2017; Pereira and Karner, 2021), an area which has been traditionally largely neglected (Geurs et al., 2009; Bocarejo and Oviedo, 2012). The concept of accessibility is central in the conceptualisation of justice because potential tells us more about a ‘fair’ distribution of opportunity (comprising freedom of choice) than realised travel behaviour does (see Ryan et al., 2019). Nonetheless, accessibility needs to be understood in relation to a notion of freedom of choice that is bounded by personal characteristics, time constraints, housing and transportation costs, among other things (Tiznado-Aitken et al., 2022).

In recent years, several studies have examined the links between accessibility and modal choice. In particular, one study examined the disparities in accessibility by public transport as a potential reason behind the differences between travel behaviour among urban and suburban residents (Cheng et al., 2020). Expectedly, they found that low public transport accessibility levels in suburban areas were associated with lower levels of public transport use. A study based in the Greater Toronto and Hamilton Area explored the relationship between public transport accessibility and public transport use depending on household income and vehicle ownership (Yousefzadeh Barri et al., 2021). The study focused on whether investments in public transport in low-income areas might result in a greater proportion of trips by public transport, through the generation of new trips among existing public transport users or through a modal shift to public transport. Previous studies in the same region found that low-income households rely on public transport to a greater extent and make fewer trips that tend to be shorter (Allen and Farber, 2020), implying that those who are often referred to as ‘captive riders’ (those with no other option but to travel by public transport) are more likely to be found in this group. Other studies have found a positive association between accessibility to jobs by public transport and a higher modal share of public transport (e.g. Owen and Levinson, 2015), with another recent study finding that increases in both local and regional accessibility were associated with a greater likelihood of using sustainable modes, with local accessibility more closely associated with a decrease in car use (Lussier-Tomaszewski and Boisjoly, 2021). It has been reasoned that groups with limited mobility options and lower incomes could end up with no alternatives if public transport provision were to be reduced (Cui et al., 2020), thus reinforcing the importance of public transport provision for social inclusion.

2.2. Factors affecting freedom of choice

However, the links between accessibility and modal choice vary across groups. Janke (2021) found that household members influence each other’s travel behaviour. However, the study highlights how only women’s travel attitudes seemed to influence choice of neighbourhood, and link this to previous research finding that women’s travel behaviour tends to be more affected by built environment and neighbourhood characteristics than that of their male counterparts. Janke (2021) emphasises how most previous research on residential self-selection overlooks the possibility – and probability – that residential location is a result of negotiation between household members with differing views and values. Minnen et al. (2016) highlight how non-standard working hours can be the result of greater autonomy over one’s working hours (e.g. self-employed workers) or of fixed working schedules and shift work (among e.g. factory workers). Non-standard working hours can also be the result of either part-time or overtime work, with the former being more common among women (ibid.) and the latter more common among men. Non-standard working hours have been linked to poorer health outcomes among workers and/or their families (e.g. Jamal, 2004; Fenwick and Tausig, 2001, respectively, cited in Minnen et al., 2016). How these non-standard hours are distributed among the day’s 24 h and the week’s seven days has consequences for the timeframes during which, and the ways in which, a person can travel to work, and possibly the amount of time it takes to get to the workplace. De Vos et al. (2021) cite and detail several studies in their findings that attitudes tend to predict modal choice, often to a greater extent than built environment factors and residential location, with satisfaction with modal choice also a predictor of the use of that mode in future.
2.3. Dynamic accessibility giving a more nuanced picture of accessibility and freedom of choice

Accessibility has until recent years most commonly been analysed as a static phenomenon. All conventional accessibility measures are cross-sectional, and give only a representation of a snapshot in time (Miller, 2018), and a glimpse of how this is experienced by individuals. Several studies have highlighted the inherent limitations with analysing accessibility as a static phenomenon (e.g. Jonsson et al., 2014). Some argue that approaches adopting a static equilibrium view of the world tend to overlook the complexities surrounding the ways in which people adapt to changing conditions within the transport and land use system. One such aspect relates to unimodal, bimodal, intermodal, or multimodal combinations, and how people tend to draw on a variety of these combinations in meeting their travel needs (Jonsson et al., 2014; Oostendorp et al., 2019; Groth, 2019). Several studies have used a static accessibility perspective to examine accessibility inequalities across income and ethnic groups, mostly focusing solely on accessibility levels during peak-time (Deboosere and El-Geneidy, 2018; Geurs et al., 2016; Wu et al., 2021; Smith et al., 2020).

The introduction of a range of different analytical tools and open data sources has led to a more nuanced perspective and facilitated dynamic accessibility analyses (Stepniak et al., 2019; Pereira et al., 2021). This has meant that it has now become easier for accessibility analyses to account for temporal variations in the provision and frequency of public transport, moving away from simpler proximity-based analyses (Kwan, 2013). Lei and Church (2010), Farber et al. (2014) and Xu et al. (2015) were among the first to highlight and exemplify spatio-temporal variability in accessibility analyses based on public transport, while others have highlighted how the dynamic spatio-temporal concentration and dispersal of different social groups can be problematic (e.g. Le Roux et al., 2017).

One of the key examples of time-dependent accessibility analyses is Fransen et al. (2015), where gaps in provision were identified by drawing on analyses of dynamic accessibility levels to key activities, calculated at regular time intervals and producing synoptic metrics across various peak and off-peak timeframes. They argue that such approaches allow for the production of more reliable representations of accessibility, finding that on average 11% less jobs were accessible during off-peak timeframes and that public transport provision corresponded to the ‘traditional’ rhythm of life. This could in turn be considered to disproportionately disadvantage those travelling (and required to travel) outside peak hours. Farber and Fu (2017) assess dynamic public transit accessibility to jobs using travel time cubes to calculate at regular time intervals and producing synoptic metrics across various peak and off-peak timeframes and that public transport provision corresponded to the ‘traditional’ rhythm of life. This could in turn be considered to disproportionately disadvantage those travelling (and required to travel) outside peak hours. Farber and Fu (2017) assess dynamic public transit accessibility to jobs using travel time cubes to compare the effects of investments/disinvestments in infrastructure over time, arguing that such analyses are necessary to determine whether social equity objectives are met (see also Foth et al., 2013). Lee and Miller (2018) measure the changes of new public transport services for space-time accessibility to jobs and healthcare in an underserved neighbourhood of Columbus. They address temporal fluctuations in accessibility considering multiple departure times while accounting for the operating hours of workplaces and healthcare services, although their representation still results in relatively coarse estimates and may not reveal full temporal dynamics in transit accessibility. The perils of focusing on one specific period (e.g. peak) for accessibility analyses are highlighted in Fayyaz et al. (2017). They argue that such analyses produce overly optimistic estimates of accessibility by public transport, and propose a more realistic approach by drawing on estimates from each minute of the day. Jarvis et al. (2018) discuss the pros and cons of dynamic accessibility modelling and contribute to the development of location-based accessibility research by proposing a conceptual framework that allows the incorporation of time into three of the core components of accessibility (people, transport, and activity locations). Their case study illustrates how conventional static accessibility models tend to overestimate accessibility levels, while simultaneously potentially underestimating inequalities.

2.4. Variations in accessibility levels and temporal segregation

A recent study examined temporally differentiated segregation, revealing that the level of segregation to which different social groups are exposed differs depending on the time of the day and day of the week (Abbasi et al., 2021). The potential for interaction between groups (categorised by fare type i.e. standard fare and special fares for passengers with disabilities, older people and children and young people) at the destination was higher during peak hours on weekdays. From the inverse perspective, this meant that segregation was lowest during the morning and evening peak on weekdays. This differed depending on the social group. Similarly, another recent analysis of travel survey data in the Paris region examined the ways in which different groups concentrate and disperse during the day’s 24 h, based on the analysis of travel survey data in the Paris region, finding that the most spatio-temporally segregated group was the upper class (Le Roux et al., 2017).

For the current study, close attention is paid to the ways in which the representation of accessibility to the workplace differs when different timeframes and supply levels are considered, and how the estimates differ between groups and across timeframes. This approach provides a more detailed, dynamic and nuanced representation of accessibility for different individuals and their respective characteristics.

3. Conceptual framework

The conceptual framework for this study draws on both transport justice and time geography. As the backdrop of a person’s activity programme is considered central for the investigation of people’s accessibility and mobility (Neutens et al., 2011), we draw on the time geography concept of constraints (Hagerstrand, 1970; as elaborated upon by e.g. Miller (2005) and Schwane et al. (2008)). Constraints are conceptualised as the limits to which a person is subject. These constraints affect their spatio-temporal opportunities to carry out everyday activities and can be sorted into three categories according to the time geography framework: coupling constraints; capability constraints; and authority constraints (Hagerstrand, 1970).

A person’s coupling constraints refer to their obligation to be present at a particular place during a specific timeframe (Hagerstrand, 1970; Hagerstrand, 1989). These coupling constraints in turn mean that a person’s opportunities to participate in other activities simultaneously or elsewhere are limited or non-existent (Hagerstrand, 1970). The spatio-temporal fixity of a person’s activities determines the tangibility of their coupling constraints, that is, people with more fixed activities will have tighter coupling constraints, while people with more flexible activities and perhaps the possibility to virtually participate in activities are conceptually more free to move in time and space (Miller, 2005; Ellöd, 2020). However, some have argued that the fixity of a person’s activities is actually a highly subjective phenomenon (e.g. Schwane, 2008). Coupling constraints are also largely considered to be a gendered phenomenon (Kwan, 2000; Scholten et al., 2012; Schwane et al., 2008), with balancing activities and tasks and struggles between commitments particularly evident in the everyday life of women.

Capability constraints encompass the limits of a person’s physical or cognitive capacity, tools, skills and material resources (Hagerstrand, 1970; cf. Ellegård and Svedin, 2012), while authority constraints encompass the limits a person faces externally such as working hours, opening and closing hours, areas people are prohibited to enter (often during specified timeframes) (ibid).

From a transport justice perspective, accessibility and its distribution as a social good is the key concern (Martens, 2017; Pereira et al., 2017). The concept of constraints interacts with many factors that shape and are shaped by accessibility such as the need or opportunity to trip chain, job opportunities, childcare commitments, access to different transport modes, working hours, public transport provision, etc. These factors in turn interact with the three components of accessibility: transport, land use and the individual (Geurs and van Wee, 2004), making constraints
and the mechanisms surrounding their production a central concept for transport justice.

For this study, we are interested in the interaction between people’s constraints and their possibilities to reach their workplace during different time periods and using sustainable modes of transport. Constraints include (but are not limited to) the fixity/flexibility of the individuals’ working hours, proxies for childcare commitments (having children in the household), financial constraints expressed as household income per household member, and a lack of access to certain modes of transport, estimated as a lack of access to a bike or car.

4. Material and methods

4.1. Study area

This study is based in the Stockholm region, Sweden, which comprises both an administrative and functional urban region, officially defined as the large metropolitan region of Stockholm (Statistics Sweden, 2005). The Stockholm region encompasses Sweden’s capital and largest city, with a population of 2,392,000 inhabitants (Statistics Sweden 2020). There is a notable uneven distribution of population in the region, where population densities and income levels tend to be higher close to the city centre (see Rubensson et al., 2020). See Fig. 1 for a reference map of the region. See Fig. 2 for a map of the distribution of population densities in the region.

Stockholm has a strong reputation as a city-region for its investment in and use of public transport (Lundin and Gullberg, 2011). The public transport system facilitates 2.9 million boardings on an average weekday on four different public transport modes (underground, bus, commuter train, light rail) (see Rubensson et al., 2020). The current policies pursued by the Stockholm Regional Planning Authority focus on facilitating a change from a more monocentric structure to a more polycentric one comprising sets of sub-centres (ibid.).

4.2. Combination of travel survey data and travel time estimates

This study comprises the analysis of accessibility estimates generated through the r5r package in R (Pereira et al., 2021) combined with travel survey data (Stockholm Travel Survey, 2015) to identify potential disparities in the provision of public transport, and the corresponding distribution of accessibility and travel mode choice among groups with differing socio-demographic characteristics during the peak, pre-peak and post-peak periods.

Travel behaviour data comes from a regional travel survey conducted between September and October 2015 (Stockholm Travel Survey, 2015) on behalf of the Stockholm Regional Authority. Using a random stratified sample representative of the Stockholm Region, the survey gathered data on 45,445 respondents (response rate of 35.2%). Respondents were asked about individual and household socioeconomic characteristics and information on all trips carried out on the specified day. This information was collected in a travel diary format. The survey was conducted using three methods: a paper survey, an online survey, and then a telephone survey for the last proportion of the sample not yet reached using the first two survey methods (Region Stockholm, 2016). First, the pre-peak, peak and post-peak periods for work trips on weekdays were identified based on the distribution of reported work trips during the same days in the travel survey data. The analysis of this distribution showed that 73% of work trips take place during the peak period (06:00–08:59), with 21% taking place during the pre-peak (05:00–05:59) and post-peak (09:00–13:59) periods.

We employed ‘travel time’ in minutes as a surrogate indicator of accessibility, linked to the definition of accessibility as the ease with which one can reach locations (see, e.g. Hansen (1959) for the definition and Bertolini et al. (2005) for a discussion), here the ease with which people can reach their workplace. The travel time accessibility estimates were calculated by drawing on public transport data in the General Transit Feeder Specification data (GTFS) format from December 2015, road network data from OpenStreetMap from November 2016, and real departure time periods mentioned above. These estimates were generated using the R5 multimodal routing engine accessed through the r5r package in R (Pereira et al., 2021). Because base areas can vary a lot in size between low- and high-density areas, we estimated the travel time matrices by walking and public transport between the population-weighted centroids of all base areas within the Stockholm region. These population-weighted centroids were calculated using population estimates at high spatial resolution (a 100 × 100 meter-grid) generated by Bondarenko et al. (2020). Accessibility estimates can vary greatly at different departure times because of how public transport service levels vary across the day (Conway et al., 2018; Stepniak et al., 2019). To reduce this uncertainty for our accessibility estimates, we considered the median travel time for each origin-destination pair in each period. These median estimates were calculated for each period after generating hundreds of travel time matrices with multiple departure times (five random departure times per minute) during each period time window. Differences in the overall accessibility conveyed by the public transport system (combined with walking) across these time periods were then examined by comparing the different descriptive statistics of the travel time estimates for the three periods.

Using the travel survey data, origin-destination (OD) pairs were then generated for each work trip reported by respondents. The OD pairs comprised the respondents’ home base areas as the origins and workplace base areas as the destinations. As we did not have the exact geolocations of the respondents’ homes or workplaces, we used the population-weighted centroids of base areas as origins and destinations. Travel time estimates were produced for all trips for all three time periods, based on a combination of walking and public transport. This was regardless of whether the work trip actually took place during the peak, pre-peak or post-peak period, and regardless of the mode(s) the respondents reported using. This was in order to capture how the ease of accessing their employment activity might be affected by differences in transport service supply during the different periods.

Groups with tendencies to travel during the respective time periods were identified through developing two binary logistic regression models, with socio-economic and demographic variables from the travel survey data employed as independent variables. Our units of analysis in these models were the work trips conducted within one of the specified timeframes: pre-peak, peak and post-peak. The first model compared the peak to the pre-peak, with the second comparing the peak to the post-peak. The dependent variable was configured as a binary variable with the respondent travelling during the pre-peak period forming the reference category of the binary variable in the first, and during the post-peak period in the second model. We tested a range of independent variables that reflect personal characteristics and/or constraints which may affect individuals’ opportunities to travel during certain timeframes and use certain transport modes. The variables producing significant
results (p-value <0.05) and acceptable models were ultimately kept. These variables are presented in the Results section. While the industry sector within which one works can influence flexibility (and constraints), the travel survey did not collect information on the respondent’s type of profession/employment. However, the survey gathered information on respondents’ own perceptions of the flexibility of their working hours and the flexibility of their departure time, which were tested in the models, with only the former ultimately included. Because it is not possible to determine the built environment characteristics around interviewees’ home locations, we included in the regressions the location in the region of the municipality in which the respondent lives.

A third binary logistic model was then developed to analyse the extent to which including some form of public transport during the trip to work is associated with socio-economic and demographic variables, as well as the travel time estimate for the respondent’s trip to the workplace during the specified timeframe and the timeframe during which the respondent travels to work. The dependent variable comprised all trips to work during the selected timeframes with an element of some form of public transport, with trips not comprising any element of public transport comprising the reference category.

5. Results

5.1. Differences between travel time estimates for the different time periods

Our analysis of the differences between the travel time estimates for
the different time periods indicates that accessibility by public transport and walking is lower during the pre- and post-peak periods (means of 82.5 and 83.3 min from all base areas to all other base areas, respectively). This is compared to the representation of accessibility during the peak (mean of 79.9 min). For work trips among this sample, that is, the specific OD-pairs under consideration, the mean travel time estimate for the pre-peak period was 45.59 min (SD = 24.73), for the peak, 43.62 min (SD = 24.96), and for the post-peak, 46.10 min (SD = 27.07). This indicates, as expected, that public transport supply during the peak is most likely more frequent and more highly connected. The differences between these mean values may not appear to be dramatic but they indicate a qualitative difference in the accessibility conveyed by the public transport system overall.

5.2. Accessibility and travel to the workplace during different time periods for different groups

As detailed in the Methods section, we used two binary logistic regression models to identify which characteristics are associated with travel during the different time periods. To capture how differences in accessibility levels could influence the period of the day in which people travel, we also included in the model an indicator of the differences in travel time estimates between periods, with the peak estimate expressed as a percentage of the travel time estimate for the respondent’s period of travel. A higher value indicates a greater ease of reaching the workplace during the pre-peak and post-peak periods, respectively. The first model compared travel during the peak to travel during the pre-peak with this forming the dependent variable, the latter the reference category, with the second model comparing travel during the peak to travel during the post-peak, the latter forming the reference category in this case too. See Table 1 for a summary of regression results.

The results show that respondents whose trips to work were associated with a greater travel time estimate (indicating a lower level of ease of reaching the workplace) during the peak were less likely to travel during the peak. This is a rather intuitive result, suggesting that people travel when the accessibility conveyed by the (public) transport system for their specific trip is best. Those living more centrally in the region, those with higher household incomes per household member (above the median), those with access to a bicycle, those with a driving license, those with more flexible working hours, in the age category 25–39, those with children living in the household, and women were more likely to travel during the peak. Women were in fact estimated to be more than twice as likely to travel during the peak, indicating a gendered difference in travel. Those with partly or fully flexible working hours were more than twice as likely to travel during the peak, indicating that even with flexible working hours the peak is still deemed an optimal time to travel. This could also be influenced by social and personal norms or by e.g. childcare provision or school hours.

The second model compared the peak to the post-peak, with travel during the former forming the reference category (Table 1). Most of the results from the second model were comparable to those from the first model. However, there were some key differences. In the case of the second model, the residential location of the respondent in the region did not produce a significant result. The flexibility of the respondent’s working hours produced a lower odds of travelling during the peak, with a significant result only produced for those with fully flexible working hours. This underscores the argument that only partial flexibility (perhaps coupled with constraints related to childcare provision and/or school hours) may still result in peak travel. This also indicates that the preference might be to travel later rather than earlier (than during the pre-peak) when there is more flexibility in working hours. The results from both models indicate that individuals with more resources in general (financial, spatio-temporal, mobility) travel during the period conveying the greatest accessibility i.e. the peak, not least in relation to their trip in particular.

In our third model we analysed how socio-economic and demographic variables and differences in accessibility between time periods, and travel during different time periods are associated with using.
Table 1
Binary logistic regression results.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Model 1: Peak compared to pre-peak travel</th>
<th>Model 2: Peak compared to post-peak travel</th>
<th>Model 3: Inclusion of public transport as an element of the commute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Odds ratio (95% confidence interval)</td>
<td>Odds ratio (95% confidence interval)</td>
<td>Odds ratio (95% confidence interval)</td>
</tr>
<tr>
<td>Accessibility to the workplace</td>
<td>0.976*** (0.963–0.988)</td>
<td>0.969*** (0.960–0.979)</td>
<td>.</td>
</tr>
<tr>
<td>Travel time estimate for the respective period of travel (in minutes)</td>
<td>-</td>
<td>-</td>
<td>1.002* (1.000–1.003)</td>
</tr>
<tr>
<td>Time period of travel (peak = 1; other = 0)</td>
<td>-</td>
<td>-</td>
<td>1.707*** (1.538–1.895)</td>
</tr>
<tr>
<td>Location of respondent’s municipality in region (central location = 1; less central/more peripheral location = 0)</td>
<td>1.979*** (1.625–2.409)</td>
<td>n.s.</td>
<td>1.394*** (1.280–1.517)</td>
</tr>
<tr>
<td>Household income per household member (above median = 1; up to median = 0)</td>
<td>2.114*** (1.736–2.574)</td>
<td>1.183** (1.061–1.319)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Household income per household member (above 90th percentile = 1; up to 90th percentile = 0)</td>
<td>-</td>
<td>-</td>
<td>0.788** (0.668–0.929).</td>
</tr>
<tr>
<td>Bicycle access (always = 1; no, never or yes, sometimes = 0)</td>
<td>1.305** (1.077–1.582)</td>
<td>1.178** (1.050–1.323)</td>
<td>0.751*** (0.686–0.822)</td>
</tr>
<tr>
<td>Driving license (holding a driving license = 1; no driving license = 0)</td>
<td>1.433** (1.095–1.877)</td>
<td>1.214* (1.031–1.429)</td>
<td>0.254*** (0.220–0.292)</td>
</tr>
<tr>
<td>Reported flexibility of working hours (fully flexible working hours or shift = 0; fixed working hours or shift = 0)</td>
<td>2.090*** (1.724–2.533)</td>
<td>n.s.</td>
<td>1.306*** (1.201–1.419)</td>
</tr>
<tr>
<td>Reported flexibility of working hours (fully flexible working hours = 1; flexible with limitations, fixed</td>
<td>-</td>
<td>0.529*** (0.451–0.620)</td>
<td>.</td>
</tr>
</tbody>
</table>

Variable not included in model due to the inclusion of another closely-related/correlated variable or irrelevance for the model. ***p < 0.001; **p < 0.01; *p < 0.05; n.s. not statistically significant at p < 0.05 threshold. Nagelkerke R² Model 1: 0.104; Model 2: 0.027; Model 3: 0.123.

The results indicated that people with a higher household income per household member (here, a significant result produced above the 90th percentile) were significantly less likely to travel using an element of public transport, despite perhaps having a greater opportunity to (choose) to do so. Those with access to a bicycle and those with a driving license were also perhaps unsurprisingly less likely to use public transport. Those living in central parts of the region, those with more flexible working hours (partly and fully flexible), those with a lower level of accessibility during their time period of travel, those travelling during the peak, those in the age category of 25–39, and women were more likely to travel using some form of public transport as part of their trip. Conversely, people with children in the household were less likely to use an element of public transport. The results from this model also suggest that individuals with more resources (with the clear exception of high levels of financial resources) are more likely to travel using public transport. The association between gender and temporal resources is unclear here. However, those with children in the household were less likely to travel using public transport which could be linked to a lack of temporal resources and/or coupling constraints.

5.3. Spatio-temporal patterns for different groups

To help contextualise the household travel survey data in Stockholm, Fig. 3 shows some of the differences in the spatio-temporal patterns of travel behaviour for different groups. The visualisation in Fig. 3A indicates that the commuter flows of those with lower incomes (here, a household income of up to 30,000 SEK) are more geographically dispersed throughout the region. This is compared to the middle- and higher-income groups, whose commuter flows appear to be more highly concentrated in the centre. The flows observed in the middle-income category connect the central location of the labour market with housing locations dispersed around the Stockholm region. This pattern reflects recent housing developments largely comprised of newly built detached and semi-detached single-family dwellings targeting the middle-income category located further from the city centre (Region Stockholm, 2020). The flows of those in the middle-income category are more spatially dispersed than those in the higher, with the latter clustered in and around the centre to a greater extent. This might in turn suggest economies of scale and agglomeration effects for higher-income jobs, with those with said incomes more likely to be able to afford to live in more central locations.

The visualisation in Fig. 3B shows that trips using unsustainable modes of transport (here, any trip including a car) are spatially more...
dispersed, possibly involving greater trip distances than those travelling more sustainably. There are no obvious concentrations in the centre for the former, perhaps reflecting the dispersal of residential and/or job locations for this group. In turn, the radial public transport network may not facilitate these trips. Meanwhile, the flows of those using more sustainable modes of transport are more concentrated in the centre and along the large capacity public transport corridors, with the peak more spread to far-flung locations. In general, these patterns seem to be very similar during the peak and post-peak, but more apparent during the peak.

6. Discussion and conclusions

The aim of this study was to analyse the differences in accessibility to the workplace by public transport combined with walking across multiple departure time periods. These results were then compared with
modal choice, drawing on the spatio-temporal aspects of people’s activities. The socio-economic, demographic and geographical factors characterising these differences were then analysed from a transport justice-focused time geography perspective.

From our regression analyses, we found that those with more resources (financial, spatio-temporal, mobility) yet still with coupling constraints tend to travel during the peak, or during the period conveying the greatest levels of accessibility for the person’s specific trip. The flexibility to travel during different timeframes and to work from home tends to be concentrated in higher-income groups living in the wealthier parts of cities (Gildé, 2019). This comprises a double advantage for some groups: a temporal advantage in terms of being able to optimise departure times and a financial advantage in terms of transport cost savings.

Coupling constraints are often considered to be a gendered phenomenon, with balancing activities and tasks and struggles between commitments particularly evident in the everyday lives of women (Gil Solà, 2016; Priya Uteng, 2021). Given that women were more than twice as likely to travel during the peak indicates a gendered difference in travel. This could be related to a gendered difference in employment type and the timeframes during which one travels to the workplace, in time geography terms, the authority constraints of a person’s work.

Having children in the household was significant, with this category being more likely to travel during the peak compared to the pre-peak and post-peak. This suggests that those with children in the household are generally more likely to travel during the peak than those without. This finding could be related to coupling constraints linked to familial commitments such as dropping off/picking up children at specific times and locations (Schwanen, 2008).

Intra-household interactions, negotiation processes, gendered differences, and the freedom and flexibility of different household members to travel have been studied by several researchers. Interactions and negotiations between household members have been found to be paramount in influencing travel and location choices (Janke, 2021; Schwanen et al., 2007; Gil Solà 2016; Priya Uteng, 2021). Further research is required establish the ways in which household interaction affects not only the gendered differences in modes used, but also the gendered differences in available modes and the temporal flexibility with which a person can travel.

The results from the third model suggest that those with fewer palpable constraints are more likely to travel using an element of public transport. This suggests that the opportunity to travel sustainably is concentrated among some groups in society. This is, however, with the exception of financial constraints, where those with higher incomes were found to exclude public transport despite arguably having greater freedom to (choose to) do so. Associations between accessibility and modal choice have been found in several studies (e.g. Yousefzadeh Barri et al., 2021; Cheng et al., 2020; Cui et al., 2020), with one recent study finding that increases in both local and regional accessibility were significant differences in job accessibility between modes (Wu et al., 2022). One study in particular found that job accessibility by public transport was lower during the pre- and post-peak periods. This constitutes a qualitative difference in the accessibility conveyed by the public transport system across these periods, with better accessibility during the peak owing to a higher frequency and level of connectivity during these hours and with these differences more concentrated in some parts of the region. Several policies focus on flattening peak demand and spreading this demand through differentiated pricing strategies (UITP, 2020). Another study has actually investigated how pricing affects demand for public transport during the peak in Stockholm, finding that revenues could be increased if a premium was charged for peak travel (Horn af Rantzien and Rude, 2014).

However, those who face fewer constraints and are more able to choose when they travel seem to choose to travel during the peak which suggests that (pricing) policies aimed at spreading this demand may not be effective. Instead, a combination of policy measures could be employed, such as reducing the supply during the peak and increasing it during the hours immediately before and after the peak. Furthermore, integration policies targeting wider societal issues such as working hours, labour markets and gender equality could be more effective in spreading peak demand.

Other studies have shown how improving accessibility by public transport during different timeframes could strategically be used to expand economic activity (McArthur et al., 2019). However, it was highlighted that the accessibility needs of night-time workers were not captured by the accessibility metrics used. This meant that those working non-standard hours and night shifts faced serious accessibility shortcomings in the form of low-frequency bus services and a lack of coverage in the Greater London area (McArthur et al., 2019). The development of more holistic night-time economy policies was considered a means of counteracting such issues (ibid.) and could be applied more broadly and in different cities and contexts to the same end.

Spatial patterns in the residential location of different groups have also been found to affect the accessibility of different groups, depending on the levels of segregation in different regions. We found that the commuter flows of those with lower incomes were more geographically dispersed throughout the region than those of the middle and higher-income groups, whose commuter flows appeared to be more highly concentrated in the centre. Rubensson et al. (2020) found that concentrations of population groups appeared to be less apparent in the case of Stockholm compared to North American city-regions. Cats and Ferrari (2022) found that in Stockholm there were clusters of different travel behaviour types who use the network and travel to different areas in different ways, complementing our findings. Furthermore, ‘reverse commutes’ are most difficult to cater for in terms of public transport provision (see Davidson and Ryerson, 2021), suggesting that those with lower incomes and with more dispersed commuter flows may have more difficulty commuting sustainably in the Stockholm region, although this is not the case in all contexts (ibid.).

Moreover, the decentralisation of jobs tends to worsen accessibility to jobs for socio-economically disadvantaged groups, especially those who rely on public transport, as extensively discussed in the spatial mismatch hypothesis literature (cf. Oh and Chen, 2022; Gobillon et al., 2007). One means of overcoming this trend is to promote the concentration of low-income job opportunities in close proximity to public transport stops and nodes. Oh and Chen (2022) further emphasise that progressive land use and transport policy efforts could work as a means of redistributing the agglomeration effects for lower income workers. However, this is rather complicated in that firms with specific characteristics tend to locate in areas suited to their business and labour market needs, and have a range of different limitations. Such targeted efforts may be context-dependent. Some studies have also found that there are significant differences in job accessibility between modes (Wu et al., 2021; Saraiva and Barros, 2022), with one study in particular finding that job accessibility by public transport (combined with walking) was 30 times lower than job accessibility by car (Boarnet et al., 2017). However, small-scale changes such as stop distribution and 'last mile'
solutions can have considerable effects for macro accessibility (see e.g. Hansson et al., 2021), and accessibility to jobs in particular (Boarnet et al., 2017). We have not tackled these particular issues in the current study. Furthermore, we have not addressed how self-selection processes are likely to affect the choice of home and job location, and indeed the extent to which the home and job locations can be considered to be ‘chosen’ among different groups. Built environment characteristics were not included in the models, comprising a further limitation. The travel time estimates produced were associated with spatial differences between the time periods. As these differences are rather complex and linked to a range of factors influencing demand and supply, we have not explored them in detail in this study. These processes could indeed be explored in future research.

Similarly, household negotiation processes are likely to be at play, and in turn influence the possibility of using sustainable commuting modes. Those working fixed non-standard hours, in part-time contracts and without the possibility to work remotely are likely to be particularly exposed (see Minnen et al., 2016), with respect to pressure on work and family commitments, particularly if longer commuting times are involved, but also with respect to the possibility to travel using sustainable modes of transport. A further step would be to investigate such facets in more detail.

Research on how the production of accessibility during different times of the day interacts with the ways in which different groups in society can travel is still limited. With this study, we have contributed to this literature by showing how a transport justice-focused time geography perspective could help researchers have a more detailed and nuanced understanding of the relationship between accessibility and sustainable travel behaviour and how this relationship might change at different times of the day.

CRediT authorship contribution statement

Jean Ryan: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Project administration, Writing — original draft, Writing — review & editing. Rafael H.M. Pereira: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing — original draft, Writing — review & editing. Magnus Andersson: Methodology, Visualization, Writing — original draft, Writing — review & editing.

Data availability

The authors do not have permission to share data.

Acknowledgements

This research was funded by a grant administered through K2 The Swedish Knowledge Centre for Public Transport (grant number 2020012). The authors acknowledge and thank the reviewers for helpful feedback.

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Journal of Transport Geography 111 (2023) 103665


