I only get some satisfaction: Introducing satisfaction into measures of accessibility

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1- New satisfaction-based measure of accessibility is proposed

2- Satisfaction-based measure is compared to standard gravity-based measure of accessibility for cycling, walking public transport and car.

3- A dissatisfaction index that combines ratio between satisfaction-based and gravity-based accessibility measures with mode share is proposed.

4- The index highlights areas with potentially high proportions of dissatisfied commuters and where interventions for each mode could have the highest impacts on the quality of life of a given mode commuter.

5- Combined with a vulnerability index the dissatisfaction index can be used in equity analysis.

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ABSTRACT

Improving accessibility is a goal pursued by many metropolitan regions to address a variety of objectives. Accessibility, or the ease of reaching destinations, is traditionally measured using observed travel time and has of yet not accounted for user satisfaction with these travel times. As trip satisfaction is a major component of the underlying psychology of travel, we introduce satisfaction into accessibility measures and demonstrate its viability for future use. To do so, we generate a new satisfaction-based measure of accessibility where the impedance functions are determined from the travel time data of satisfying trips gathered from the 2017/2018 McGill Transport Survey. This satisfaction-based measure is used to calculate accessibility to jobs by four modes (public transport, car, walking, and cycling) in the Montreal metropolitan region, with the results then compared to a standard gravity-based measure of accessibility. We then offer a dissatisfaction index where we combine the ratio between satisfaction-based and gravity-based accessibility measures with mode share data. This index highlights areas with potentially high proportions of dissatisfied commuters and where interventions for each mode could have the highest impacts on the quality of life of a given mode commuter. Such analysis is then combined with a vulnerability index to show the value of this measure in setting priorities for vulnerable groups. The study demonstrates the importance of including satisfaction in accessibility measures and allows for a more nuanced interpretation of the ease of access by researchers, planners, and policy-makers.

Keywords: Gravity-based accessibility, Commuting, Trip Satisfaction, Equity, Vulnerable

INTRODUCTION

An increasing number of cities and transport authorities are developing accessibility measures to assess the performance of land use and transport systems (Boston Region Metropolitan Planning Organization, 2015; NSW Government, 2012; Transport for London, 2006). In gravity-based accessibility measures, professionals discount destinations with decay functions using travel times obtained from local travel surveys (Geurs & van Wee, 2004; Hansen, 1959). While this approach is effective in counting all possible destinations and adequately reflects traveler behavior, it does not capture the underlying psychology of travelers. Dissatisfaction with travel has been found to negatively impact an individual's quality of life and overall well-being, particularly when a dissatisfying trip becomes an unavoidable routine (De Vos & Witlox, 2017).

It is known that some trips are based more on necessity than convenience, with observed travel times captured in travel surveys in fact becoming a source of stress or inconvenience to individuals (Legrain, Eluru, & El-Geneidy, 2015; Manaugh & El-Geneidy, 2011). Inconsistent or lengthy travel times in a transport system can necessitate the inclusion of additional commuting time in personal time budgets. Increased amounts of time spent commuting have been found to not only negatively impact trip satisfaction (Loong & El-Geneidy, 2016), but also to reduce a commuter's well-being and social participation (Delmelle, Haslauer, & Prinz, 2013; Farber & Páez, 2011). Furthermore, satisfaction with travel time has been is associated with higher punctuality and energy levels at work (Loong, van Lierop, & El-Geneidy, 2017). This means that a population's high observed travel time tolerance should not suggest satisfaction with a transport and land use system, but rather their acceptance of these travel times under particular constraints. Given the importance of understanding trip satisfaction as one example of underlying travel psychologies, this study proposes a new measure of accessibility that incorporates travel time satisfaction. This satisfaction-based measure of accessibility adds a new tool to the professionals' toolbox for assessing a region's land use and transport systems.

LITERATURE REVIEW

Accessibility

Accessibility describes the ease of reaching destinations and is commonly used in urban geography and transport planning to measure the performance of land use and transport systems (Accessibility Observatory, 2016; Bocarejo & Oviedo, 2012; Geurs & Halden, 2015; Hansen, 1959; Manaugh & El-Geneidy, 2012; NSW Government, 2012; Transport for London, 2006). The most frequently-used measure of accessibility is location-based, which generates accessibility levels (typically to jobs) for specific locations using a given mode of transport. Location-based measures of accessibility have shown to be closely associated with the mode share on which it is generated (Legrain, Buliung, & El-Geneidy, 2015; Moniruzzaman & Páez, 2012; Owen & Levinson, 2015; Wu, Owen, & Levinson, 2018). Accessibility is also known to impact travel time and the prosperity of a neighborhood (Deboosere, Levinson, & El-Geneidy, 2018; Levinson, 1998).

A gravity-based (or weighted cumulative opportunities) measure of accessibility is considered the most reflective of individuals' travel behavior (El-Geneidy & Levinson, 2006). This measure values closer opportunities more than further ones through the use of decay functions. Decay functions are usually generated from travel behavior data specific to the region of analysis to ensure that the accessibility measures mirror local users' perception of travel time or distance (Geurs & van Wee, 2013). Decay curves are derived from the frequency of trips at different time or distance intervals, with more people willing to travel 10 minutes than 45 minutes to reach a job or any other desired destination (Iacono, Krizek, & El-Geneidy, 2010). Different types of curves have been used to fit this trend, including the negative exponential-decay function and the negative power-decay function (Ingram, 1971; Kwan, 1998; Östh, Lyhagen, & Reggiani, 2016). The negative exponential form is most commonly used, as it is generally more closely associated with travel behavior (Handy & Niemeier, 1997; Papa & Coppola, 2012).

Gravity-based measures account for travelers' perceptions of time (Ben-Akiva & Lerman, 1979; Geurs & van Wee, 2013; Kwan, 1998). These measures assume that all trips are undertaken willingly, ignoring that travelling individuals encounter a variety of constraints that influence their willingness to travel. More efforts are needed to introduce new decay functions that reflect willingness to travel by incorporating underlying psychologies like trip satisfaction in their development.

Satisfaction Measures

Satisfaction is related to a user's perceived discrepancy between their desired service delivery and the service they in fact received (Stradling, Anable, & Carreno, 2007). Travel satisfaction varies according to the unique identities and behaviours of individual users and their expectations (Friman & Fellesson, 2009). Many studies have sought to explain what causes trip satisfaction by identifying variables that increase dissatisfaction. Some variables are mode-specific, while others apply across all modes. For example, seasonality is significant in explaining cyclist satisfaction (2013) while the level of satisfaction with travel among bus and car users is affected by congestion levels (2011). While minimizing time and distance spent on a trip may follow a utility-maximizing function, frustration with commute times can be mitigated if individuals' perceive that this time can be used productively (Lyons, Jain, & Holley, 2007; Ory et al., 2004; St-Louis, Manaugh, van Lierop, & El-Geneidy, 2014) or an opportunity for taking personal time (Jain & Lyons, 2008). In line with this finding, it must also be recognized that personal attitudes towards traveling influence satisfaction levels among different mode users (Li, Wang, Yang, & Ragland, 2013).

Public transport specifically has taken a marketing approach to customer satisfaction and service provision in recent years (Molander, Fellesson, Friman, & Skålén, 2012). Ensuring high levels of customer satisfaction with public transport is key to increasing loyalty to the service (Olsen, 2007) and attracting potential riders. A unique factor to consider is captive riders, commuters who are limited in their choice of mode, whether by economic or personal conditions, to public transport (Krizek & El-Geneidy, 2007) and who are forced to continue their use of the mode despite their dissatisfaction (Jacques, Manaugh, & El-Geneidy, 2013). This group of users can be particularly dissatisfied, such as in London, UK, where riders from lower-income areas had the lowest levels of satisfaction of all users surveyed (Grisé & El-Geneidy, 2017).

A growing body of literature has been interested in analyzing trip satisfaction across transport modes. Trip satisfaction was highest for pedestrians, train commuters, and cyclists (2014). They found commuters of all modes saw satisfaction decrease as travel time increase. Other studies in America and China have found active modes to be among the most satisfying travel options while identifying several other commuting variables that impact overall satisfaction (Smith, 2017; Ye & Titheridge, 2017). With each mode possessing unique variables that impact overall traveller satisfaction, commuting time represents a common variable that may facilitate comparison. While accessibility measures often use time as a travel cost, no measure has of yet incorporated satisfaction with mode-specific travel times into its results.

METHODOLOGY AND DATA

Accessibility measures

In this study, gravity-based measures of accessibility to jobs are generated for four different modes relying on a negative exponential decay function. The standard measure of accessibility is expressed as follows:

$$A_{std,i} = \sum_{j=1}^{n} D_j e^{-ß_{std} c_{ij}} \qquad (1)$$

Where standard accessibility at zone i ($A_{std,i}$) is equal to the sum of opportunities (D) in each zone (j) multiplied by the negative exponent of movement cost between zones i and j (c_{ij}) multiplied by a cost sensitivity parameter determined with all trips ($ß_{std}$) (Geurs & van Wee, 2004). Opportunities are represented by jobs for this study and the travel time expressed in minutes. The sensitivity parameter ($ß_{std}$) is derived from a travel time decay function that includes all trips from the 2017/2018 McGill Transport Survey. The satisfaction-based measure of accessibility (A_{sat}) uses a different sensitivity parameter ($ß_{sat}$) derived in the same manner as above, albeit using only trips satisfied with their travel time, as described below. The formula is otherwise identical, as seen below:

$$A_{sat,i} = \sum_{j=1}^{n} D_j e^{-ß_{sat} c_{ij}} \qquad (2)$$

Three types of data are used to generate gravity-based and satisfaction-based accessibility measures: (i) location of jobs, (ii) travel times across the Montreal metropolitan region using different modes, and (iii) travel behavior and satisfaction data. The location of jobs *(D)* is obtained from the 2016 commuting flow from Statistics Canada (2016a), which provides information on the number of individuals commuting to each Census Tract (CT) to work in the Montreal Metropolitan region as well as their used mode of travel (public transport, car, walking, and cycling). Considering that each commuting destination corresponds to a job, we calculate the number of jobs in a census tract as equal to the total number of commuting to work trips ending in this CT. Mode share data is obtained separately from the 2016 Canadian Census (Statistics Canada, 2016b).

The second dataset consists of four travel-time matrices, one for each of the modes studied (public transport, car, walking, and cycling). The travel time matrices are generated by calculating the travel time from each census tract centroid to each other census tract centroid in the Montreal Metropolitan region. Walking travel times are calculated using ArcGIS's Network Analyst using a pedestrian-specific network and a walking speed of 5.47 km/h (a mid-range average speed derived by (2013) from a number of other studies). The bicycling travel time matrix is generated using the same network as above and a cycling speed of 15.62 km/h (representing the low-end of average cyclist speed found through GPS observation by (2007)). With respect to public transport, travel times are derived in ArcGIS from General Transit Feed Specification (GTFS) data for all transit agencies active in the region at 8 am. Finally, driving travel times are obtained from the Google API with an 8 am departure time using the pessimistic parameter to account for congestion. This dataset was used to derive the (c_{ij}) in equation *(1)* and *(2)*.

The final dataset comes from the 2017/2018 McGill Transport Survey, and is used to calculate the sensitivity parameters for both equation *(1)* and *(2)*. The Survey is conducted roughly every two years online, with a total of 4,859 respondents (students, faculty and staff) completing the 2017/18 version of the survey and answering questions about their most recent trip to McGill University. The survey had a response rate of 33.4%. Only respondents commuting to the

University's downtown campus are included in order to minimise variation in trip satisfaction ratings (St-Louis et al., 2014). Respondents are organised by mode: public transport, car, walking, and cycling. Public transport users include all users who used bus, metro, and/or train to travel to McGill. Respondents who identified using public transport in combination with walking or bicycling are categorised as public transport users, while respondents who identified using driving and public transport together were removed from the sample. The final sample included 3,794 respondents (2,142 public transport users, 403 drivers, 991 walkers, and 258 cyclists).

Respondents were asked for details about their last trip to McGill, including their departure time and arrival time in fifteen-minute increments as well as satisfaction with various aspects of the trip. The travel time of each trip is obtained by subtracting respondents' reported departure time from their reported arrival time. The overall travel time satisfaction is derived from the satisfaction questions related to travel time for each mode (Table 1). For each aspect, respondents were asked to rate their satisfaction from 1 to 5, with 1 being very unsatisfied and 5 being very satisfied.

TABLE 1: Questions selected from 2018 McGill Transport Survey to calculate overall trip satisfaction with travel time

<table>
<tr><th colspan="2">Mode</th><th>Thinking of your most recent trip, please rate your satisfaction with…</th></tr>
<tr><td rowspan="9">Public Transport</td><td rowspan="3">Bus</td><td>Length of time spent on the bus</td></tr>
<tr><td>Length of time spent to reach the bus stop</td></tr>
<tr><td>Waiting time for the bus</td></tr>
<tr><td rowspan="3">Metro</td><td>Length of time spent on the metro</td></tr>
<tr><td>Length of time spent to reach the metro station</td></tr>
<tr><td>Waiting time for the metro</td></tr>
<tr><td rowspan="3">Train</td><td>Length of time spent on the commuting train</td></tr>
<tr><td>Length of time spent to reach the commuter train station</td></tr>
<tr><td>Waiting time for the commuter train</td></tr>
<tr><td colspan="2" rowspan="2">Car</td><td>Length of time spent traveling in the vehicle</td></tr>
<tr><td>Length of time spent looking for parking</td></tr>
<tr><td colspan="2" rowspan="2">Walk</td><td>Length of time spent walking</td></tr>
<tr><td>Directness of route</td></tr>
<tr><td colspan="2" rowspan="3">Cycle</td><td>Length of time spent cycling</td></tr>
<tr><td>Directness of route</td></tr>
<tr><td>Continuous route with little or no stopping</td></tr>
</table>

The responses to questions listed in Table 1 are summed and averaged by respondent, with unanswered questions excluded. Respondents were considered as satisfied with their travel time when their overall travel time satisfaction was above three. Table 2 represents the average overall satisfaction with travel time and average travel time by mode.

TABLE 2: Summary statistics of travel time and overall satisfaction by mode

Mode	Number of respondents	Mean travel time (m)	Mean overall satisfaction	% of satisfied respondents
Public transport	2142	44.49	3.7	73%
Car	402	49.24	3.5	64%
Walk	991	21.31	4.2	85%
Cycle	258	26.2	4.1	90%

Respondents with an overall travel time satisfaction rating above three are used to derive the sensitivity parameter $(-ß_{sat})$ for equation *(2)*, while all respondents are used to derive the sensitivity parameter $(-ß_{std})$ for equation *(1)*. The respondents for each set are grouped by fifteen-minute intervals and expressed as a cumulative percentage of the whole (up to 105 minutes for public transport and car modes, and 60 minutes for walk and cycle modes), which allows for the generation of a decay curve as the percentage of all trips occurring at a given interval declines with increase in travel distance time. This process was conducted for each mode (public transport, cycling, walking, and car). Each data set is then fitted with a negative exponential curve with a set to an intercept of 1, and the decay factor of each curve is captured for use as the sensitivity parameter in the two accessibility calculations. Two decay curves were generated for each mode, which were then used to produce the accessibility measures, satisfaction-based and gravity-based, by each mode to jobs at the census tract level of analysis.

Accessibility Ratio

The results of the satisfaction-based measure are divided by the standard measure to generate an accessibility ratio for each mode, at the census tract level. A ratio of 100% means that the level of accessibility found using the satisfaction-based method is equal to that obtained using the standard method, while a lower ratio reflects significantly lower results found by the satisfaction-based method compared to the standard method. In other words, a low ratio suggests that the standard measure overestimates the level of accessibility a person is experiencing when not considering their satisfaction with travel time. The accessibility ratio is used to better understand the spatial patterns of overestimation by a standard gravity-based measure of accessibility to jobs, while also facilitating comparisons between modes.

Dissatisfaction Index

The next step was to build on the accessibility ratio to identify census tracts with potentially high dissatisfaction with each mode by combining the accessibility ratio with their respective mode share. Combining the accessibility ratio with mode share data allows us to identify areas where a large proportion of the population may be dissatisfied with their travel time to work by a given mode. For interventions based on satisfaction-based accessibility, including mode share will help in setting the priorities for each mode where there is a big accessibility ratio and a large number of users of such mode. Conversely, prioritising areas with very little existing mode share may not be the best use of limited resources.

For each census tract, we generate a standardized score (z-scores), by mode, of the accessibility ratio (Z_R) and mode share (Z_M), then subtract the accessibility ratio z-scores from the mode share z-scores using the following formula:

$$I_i = Z_M - Z_R ,$$

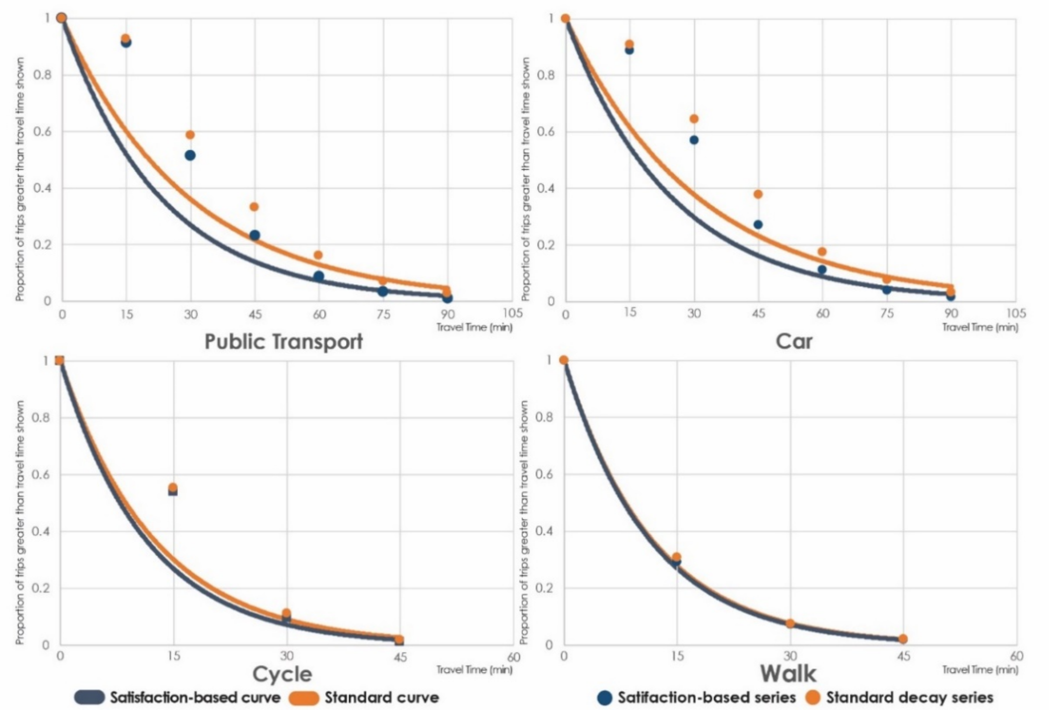
where the highest scores on the index are the result of a high relative mode share and a low relative accessibility ratio. Areas with a high dissatisfaction index are therefore areas with a potentially high proportion of dissatisfied commuters.

Given that lower-income commuters are more likely to be captive users, we compare the results of the dissatisfaction index to the top decile of census tracts on a social vulnerability index. Social vulnerability is determined through an index of four socioeconomic variables specific to the Canadian context, including median household income, the percentage of recent immigrants, the percentage of households spending over 30% of their income on housing, and the percentage unemployed (El-Geneidy, Buliung, van Lierop, Langlois, & Legrain, 2016; Foth, Manaugh, & El-Geneidy, 2013). Making improvements to areas that are high on both indices ensures that changes to the transport system are equitable and benefit users who are unable to change mode despite their dissatisfaction.

RESULTS

Satisfaction-based decay function

Figure 1 illustrates the satisfaction-based and standard travel time decay functions for each mode. The satisfaction-based method appears in blue, while the standard method appears in orange. For both walking and cycling, little difference is observed between the standard decay curve and the satisfaction-based decay curve (with β of -0.087 and -0.085 respectively for walking, and -0.087 and -0.080 respectively for cycling). This is likely explained by the fact that a very high proportion of these respondents were satisfied with their travel time (85% and 90% respectively). Conversely, fewer public transport and car users were satisfied with their travel times, and greater difference exists between the curves for each of these modes. Lower values are found for the satisfaction-based decay curve, particularly for public transport. For example, at 30 minutes the public transport decay factors are respectively 0.27 and 0.36, for a ratio of (0.75) whereas the factors for car are respectively 0.30 and 0.38 (ratio of 0.79).



Mode	Satisfaction-based decay factor	R^2	Standard decay factor	R^2
Public Transport	-0.034	0.916	-0.044	0.922
Car	-0.032	0.904	-0.040	0.916
Cycle	-0.080	0.943	-0.087	0.937
Walk	-0.085	0.999	-0.087	0.999

FIGURE 1: Travel-time decay curves by mode

Satisfaction-based accessibility

Using the above satisfaction-based and standard decay functions, we generate measures of accessibility to jobs for each mode. Figures 2 compare the results of both measures for car and public transport. As expected, accessibility by car is highest overall for both measures of accessibility. Accessibility by public transport is highest in the CBD and around metro and rail lines and decreases as distance from the core increases, while accessibility by car is more directly associated with distance to CBD.

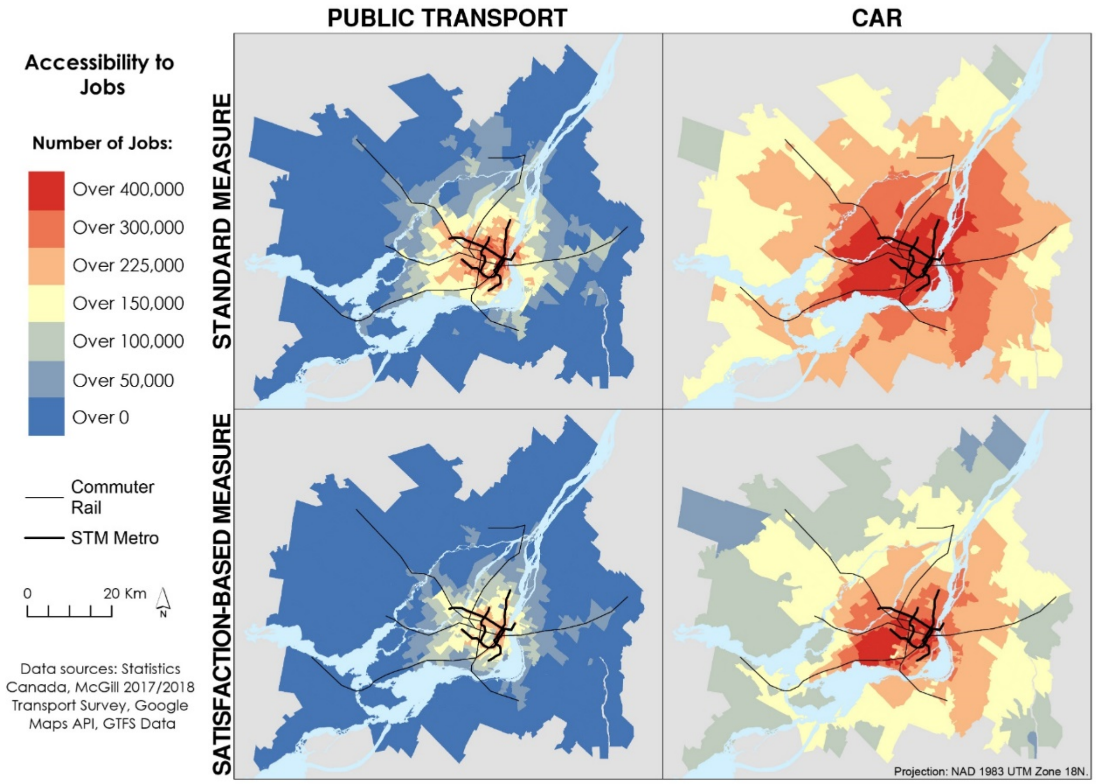


FIGURE 2: Comparison of accessibility to jobs by method, public transport and car modes

With respect to walking and cycling (Figure 3), accessibility is highly concentrated in the core of the region. When comparing the satisfaction-based measure with the standard measure, it is clear that significant changes occur in both public transport and car modes. For both modes, a reduction in accessibility occurs across the region when using the satisfaction-based measure, although the patterns remain similar. While there are some changes in cycling and walking between the satisfaction-based and the standard measure, they are not as visible as those observed for public transport and car.

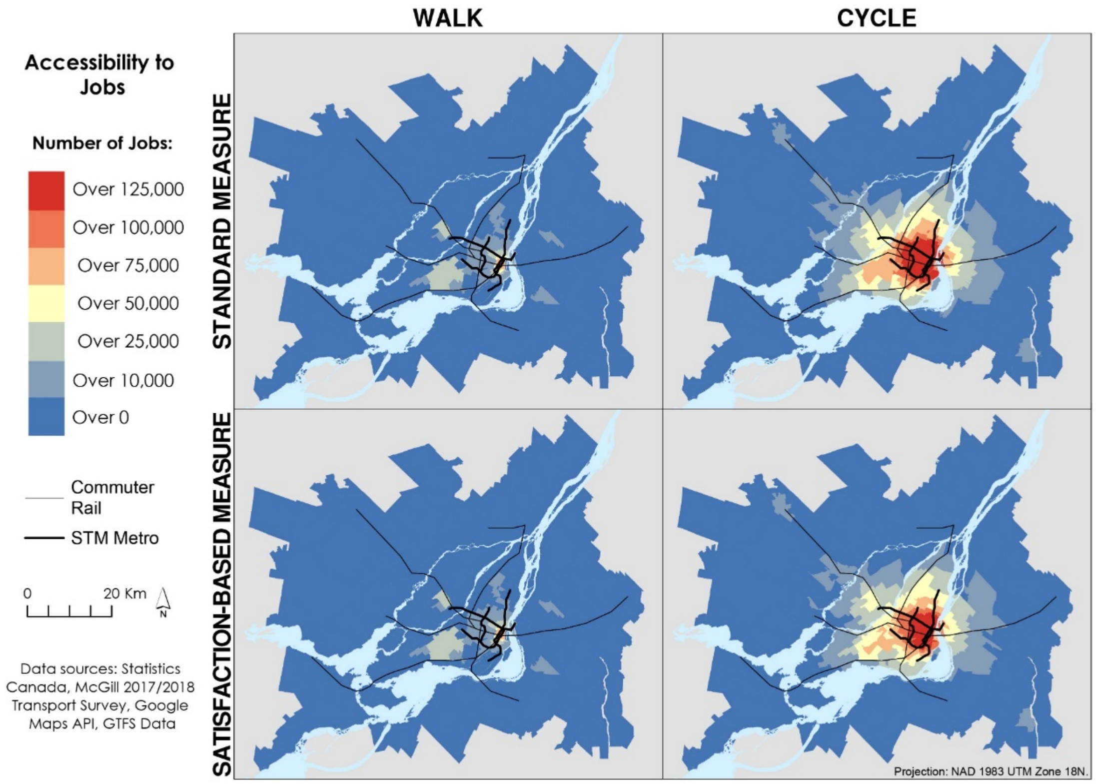


FIGURE 3: Comparison of accessibility to jobs by method, cycle and walk modes

Accessibility Ratio

In order to better understand the differences between both methods and clearly identify areas where this difference is most pronounced, we proceed by presenting the accessibility ratio (Figure 4). The largest ratios are found in walking and cycling, with most of the region maintaining 80% to 99% of accessible discounted jobs under the satisfaction-based measure. For cycling, some areas have a lower ratio (60%-79%), likely due to high travel times to employment clusters from these tracts. The standard measure compares favorably to the satisfaction-based measure when applied to active modes.

Accessibility to jobs by car is further reduced when using a satisfaction-based measure, with a ratio between 60% and 79% across most census tracts. This ratio is relatively consistent throughout the region, suggesting similar travel times to employment clusters corresponding to the largest gap between the satisfaction-based and standard decay curves. Accessibility to jobs by public transport, however, sees inconsistent ratios across the region, with significantly lower ratios than other modes (mainly between 20% and 59%). This reflects levels of service provision by public transport, as areas with higher levels of service and shorter travel times (such as those around the metro) have higher ratios. It is important to note that some peripheral census tracts have a high ratio due to a lack of public transport service – only local jobs are counted as accessible, with no change observed between methods.

The accessibility ratio demonstrates the magnitude of overestimation when using a standard accessibility measure, especially for public transport and car. Areas where the ratio is low are areas where many travel times can be expected to be dissatisfying. In other words, residents of these area are more likely to be dissatisfied with their travel time if using a given mode. Understanding what mode these residents are using, however, requires the addition of mode share data.

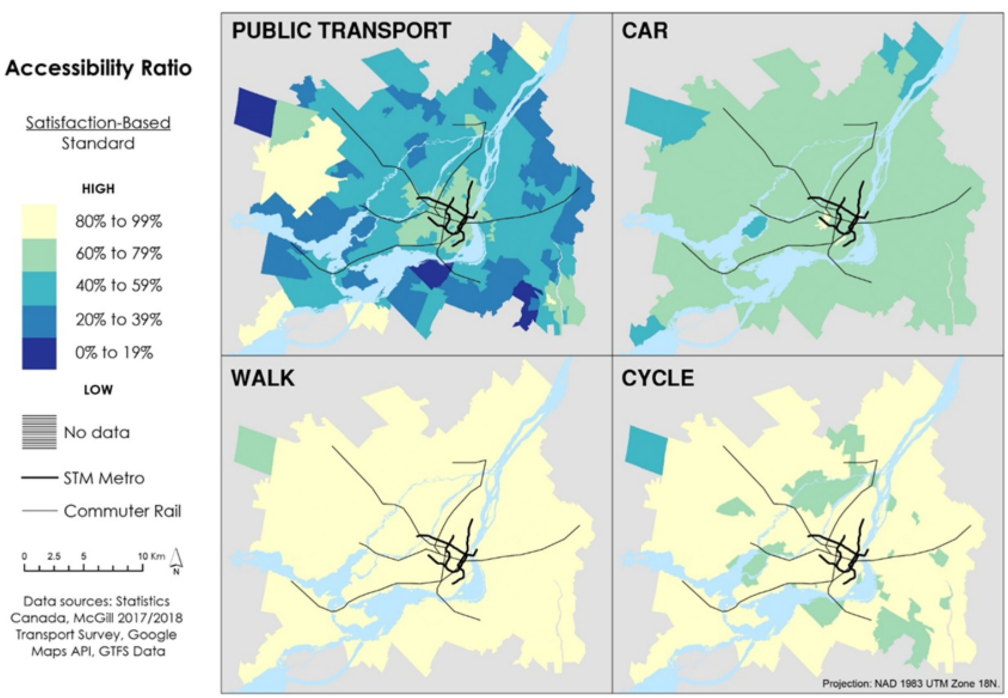


FIGURE4: Accessibility ratio to jobs, satisfaction-based method over standard method

Dissatisfaction Index

While the accessibility ratio highlights areas of potential dissatisfaction for each mode, it is unable to validate whether residents are in fact using the dissatisfying mode. The dissatisfaction index combines mode share data and the accessibility ratio to identify areas where both potential dissatisfaction and modal usage are high. The findings are presented in Figure 5, with the focus put on the center of the Montreal region where mode share is more divided between the four modes. Areas with a potentially high proportion of dissatisfied commuters appear in dark red across the region, alongside the 10% most vulnerable census tracts are surrounded with a black outline.

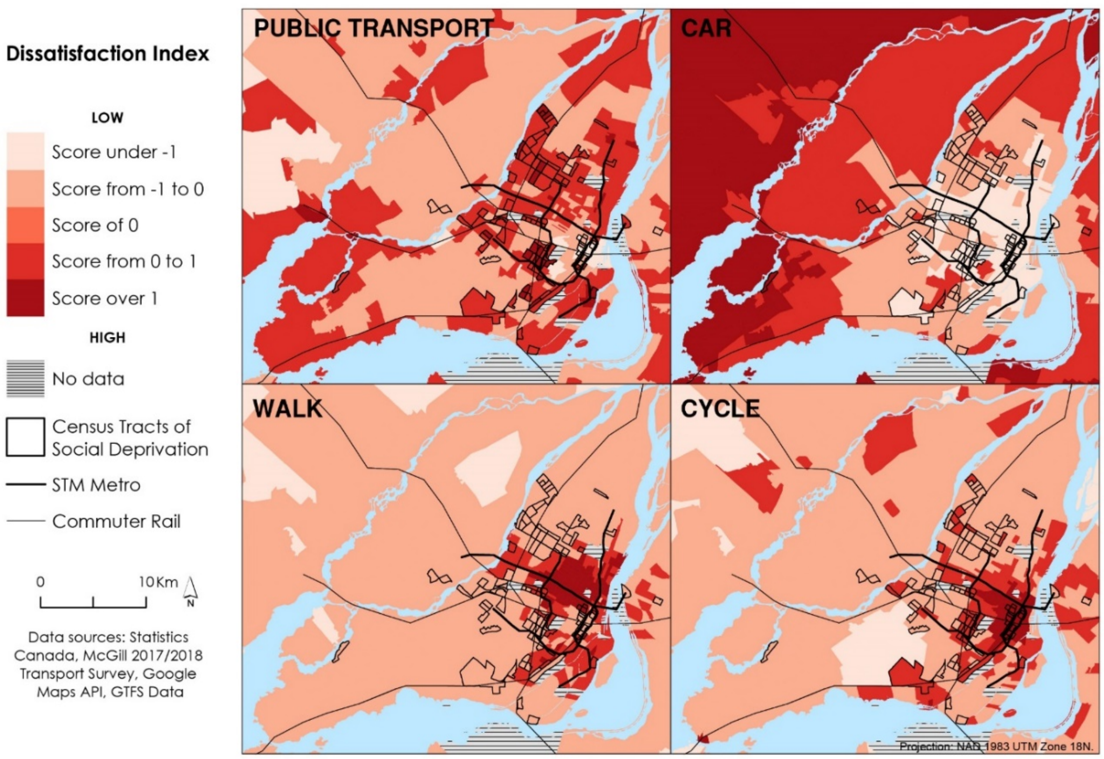


FIGURE 5: Dissatisfaction index by mode and census tracts of high social vulnerability

Clearly, the spatial pattern of the dissatisfaction index varies by mode. Areas with the highest potential dissatisfaction for cycling are concentrated in the core of Montreal, extending evenly to the north, east, and west. Areas with the highest dissatisfaction for walking lean towards the east. Both these areas have extremely high relative mode share for walking and cycling compared to the rest of the region, increasing their score on the dissatisfaction index. With the exception of some census tracts downtown for cycling, however, there is little overlap between high potential dissatisfaction and high social vulnerability. Improvements to travel times for both modes would reach the greatest number of walkers and cyclists by targeting these areas yet may not have a large effect on the most vulnerable residents of the region, except in some of the areas in the north of downtown for walking and in the north west of downtown for cycling, where there is a concentration of high vulnerable groups and high dissatisfaction index for these modes.

A similar conclusion may be drawn when considering the dissatisfaction index by car. Areas of high potential dissatisfaction are clustered in the periphery of the region, where the car represents the dominant travel mode. These areas do not overlap with the most vulnerable census tracts. Prioritising improvements in travel time by car for these areas may improve satisfaction for drivers, but will not affect the transport system's most vulnerable car users. Improvements to car travel must also be considered alongside the sustainability goals of the region and in mind of induced demand for car travel.

Lastly, public transport sees a dispersal of high potential dissatisfaction across the center of the region. There is a large correlation between areas of high potential dissatisfaction and highly vulnerable census tracts. With the exception of some tracts located in the core, most socially vulnerable census tracts have high levels of dissatisfaction by public transport. Areas with high dissatisfaction index and high social vulnerability suggests that riders from such location may be captive, unable to switch modes to get to their destinations and remaining dissatisfied as a result. Targeting these areas for improvements to public transport travel times would go furthest in improving the satisfaction and quality of life of commuters that are most in need, while also improving the equity of the broader region's land use and transport system.

DISCUSSION AND CONCLUSION

Our findings have shown that significant differences exist between a satisfaction-based measure and a standard measure of accessibility, especially for the public transport and car mode. This highlights the importance of considering satisfaction when aiming to identify areas in needs of improvements. The overestimation of accessibility by any one mode may discount the importance of facilitating its improvement as it assumes satisfaction of residents with the existing system. Using the satisfaction-based method is particularly viable for public transport, as it is the only commuting option available to some populations. As increasing public transport mode share can play a key role in meeting equity and sustainability goals for a regional transport system, using a satisfaction-based measure will more realistically demonstrate a population's willingness to use the system.

Increasing satisfaction-based accessibility can be achieved in two ways. The first, a traditional approach, is to reduce travel times to employment clusters for commuters. Shortening the travel times to jobs will increase the number of jobs accessible with a satisfying commuting time, and increase the satisfaction level of currently existing trips. This can be done by either creating more jobs closer to commuters' homes or improving the frequency of service, speed and directness of the transport system. The second approach consists of increasing satisfaction with travel time, which may include a variety of policies aimed at decreasing the displeasure of commuting. Providing clean and comfortable facilities, frequent service, customer information screens, and affordable fares are examples specific to public transport that can increase satisfaction, or reduce perceived travel time, without necessarily decreasing travel time (Fan, Guthrie, & Levinson, 2016; Lagune-Reutler, Guthrie, Fan, & Levinson, 2016). The use of the dissatisfaction index demonstrates a practical application of using the satisfaction-based accessibility measure in prioritising improvements to the regional transport system, where some of the psychology behind travel time is accounted for and not just the objective measure. The dissatisfaction index allows consideration of existing use of each mode as well as potential dissatisfaction with travel time in guiding transport investments. The inclusion of a social vulnerability index adds a final consideration of social equity in these decisions, particularly as it relates to improving the satisfaction and quality of life of the most vulnerable transport system users, which is a goal that many transport professionals are trying to achieve.

Our use of the McGill Transport Survey to generate satisfaction-based and standard measures of accessibility may not be broadly applicable due to the unique nature of the commute to McGill's downtown campus. Our method does however represent a simple and replicable approach to including satisfaction that may be made more or less complicated according to one's needs. We have demonstrated the viability of a method that may be applied by any interested agency or jurisdiction provided access to satisfaction ratings is available. Currently various municipalities around the world are collecting satisfaction surveys for different modes, while satisfaction surveys for public transport are commonly present at every public transport region around the world. The application of this method can be easily done through collaborations with local public transport authorities to highlight areas with dissatisfied riders. The study also highlights the need for adequate and consistent satisfaction ratings in transport planning, without which agencies would have difficulty generating a satisfaction-based measure or even evaluate their own land use and transport system from a user's perspective. Finally, including the trip satisfaction of commuters represents an important advance in generating accurate and equitable accessibility measures, which can prioritise improvements in the land use and transport planning for vulnerable groups.

This paper proposed a simple measure for including satisfaction in the generation of accessibility measures, while future research could test an alternative approach that would modify the travel costs between zones rather than the sensitivity parameter. By using satisfaction as a travel cost, jobs could be discounted according to the degree of dissatisfaction associated to the trip by a given mode. For example, two jobs reachable with a trip satisfaction rating of 50% may be worth one job reachable with a satisfaction rating of 100%. This would enable the use of satisfaction-based accessibility in an easily-understood cumulative opportunities framework. Combining perceived (or reported) travel time (as distinct from objectively measured travel time using GPS) with satisfaction in accessibility measures is another direction for future research. The issue, which cannot be addressed with current data sets, is the extent that dissatisfaction already embeds higher perceived travel times, or the degree to which they are two distinct phenomena.

COMPETING INTERESTS

The authors confirm no competing interests in their participation to this study.

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