Measuring the Quality of the First/Last Mile Connection to Public Transport

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ABSTRACT

The first and last mile of the public transport trip is an important component of the overall quality experienced by a transit user. While individual modes used during the first/last mile (1LM) trip, such as walking and feeder buses, have been widely studied, the multimodal and diverse nature of the 1LM environment is rarely dealt with. The paper presents a methodology for assessing the quality of the 1LM environment that combines objective measures with user perceptions into a single index that can be applied at a route, station, or system level. Firstly a survey is undertaken to understand passengers' requirements for the 1LM environment, from which importance weightings are derived for its different aspects. An environmental audit methodology is used for assessing 1LM quality, incorporating walkability, pedestrian level of service, and feeder bus metrics. The methodology is tested for the Gautrain rail service in Gauteng, South Africa. We find that passengers highly value security from crime on the 1LM trip, and that aspects of travel time and cost of the access trip are most in need of improvement. 1LM quality varies substantially between locations, especially between suburban and urban core areas, indicating areas that might be prioritised for attention.

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1. Introduction

Interest is growing in the first and last mile part of the public transport journey. This acknowledges that the passenger experiences the trip from origin to destination as a whole, and that the quality of the first/last mile (1LM) part may determine the overall satisfaction with the trip. This has important implications for sustainable transport goals, as the success with which passengers are attracted to and retained on public transport modes may have little to do with the quality of the modes themselves if the rest of the journey is unattractive. This might have implications for both the effectiveness and the equity of transport systems (Boarnet et al., 2017).

At present the research on the first/last mile and its role within the transit offering is fairly thin. While a considerable amount of research on the non-motorised environment has provided robust insights into what pedestrians and bicyclists require, this has less often been extended specifically to the analysis of the first/last mile. Little is known, for instance, on whether public transport users have the same preferences for and behaviour during the off-vehicle part of a multimodal journey as for a trip entirely made on foot or by bicycle, given that trip distances, purposes, and constraints might differ significantly between the two cases. The 1LM trip may consist of several modes, and may include a feeder bus or taxi trip in addition to a walk or cycle component. This multimodality of the 1LM trip creates several methodological questions, including how to judge the quality of the 1LM experience consistently, and how to draw valid comparisons across different cases.

The paper aims to help answer these questions by suggesting a general methodology for assessing the quality of the 1LM environment, and testing it using a case study. We develop a single index that captures the average quality of a 1LM environment, and that is flexible enough to be applied at a route or precinct level. Based on the premise that it is important for the index to reflect what passengers want from various aspects of the 1LM trip, we embed in it a user-derived importance weighting, and we undertake primary research to derive this weighting from a user population. The paper thus makes a methodological contribution, as well as an empirical one. The results demonstrate how priorities for intervention in the 1LM environment can be set using the insights gained from the analysis.

The paper first provides a short overview of existing methods for measuring the quality of aspects of the first/last mile environment, including walkability and multimodal quality of service. We then introduce the proposed methodology for deriving a composite 1LM index, and describe the steps followed in implementing it. Then follows a description of the case study among rail and Bus Rapid Transit (BRT) passengers in Tshwane and Johannesburg, South Africa, and the results of the experiment. Finally a discussion and conclusions are presented.

2. Background: The quality of the first/last mile trip

Most of the research on the first/last mile of the transit trip to date has focused on individual access modes. This includes a large body of knowledge on the walking and cycling environments, a segment of which has focused on walking and cycling access to public transport (see for instance Van Soest et al. (2020) and Wang and Liu (2013) for recent overviews). More recently interest has also shifted to shared mobility as a provider of first-last mile services, based on the argument that these might help to extend the catchment area of

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public transport to include those not traditionally served, reduce the costs of feeder bus services and parking infrastructure, and reduce private vehicle use (Shaheen and Chan, 2016; Zellner et al., 2016), despite some conflicting evidence as to the attainability of these goals (Tirachini, 2019). The roles of both car-based and bike sharing (Liu et al., 2012) have been examined in this context.

In the transit literature 1LM issues are included in measures of overall transit service quality. For example, the Transit Capacity and Quality of Service Manual (Kittleson & Associates Inc. et al., 2013) considers 1LM issues in terms of the proximity of stations and stops to origins and destinations, as well as safety, security, door-to-door travel time, and passenger amenities. Although the idea of a multimodal service quality indicator is appealing, it is less useful for studying the 1LM environment by itself as it conflates the 1LM measures with those relating to the transit service. Access distances are also an important aspect of transit network design where it relates to route and station spacing, as optimal design requires trading off access time with total trip time (Ibarra-Rojas et al., 2015; Kuah and Perl, 1988).

Many studies have examined relationships between the built environment and walkability or bikeability more explicitly (e.g. Saelens and Handy, 2008; Talen and Koschinsky, 2013), and developed methods for systematically assessing conditions in the field. Typical measures such as the walkability index developed by Frank et al. (2010) use a multicriteria rating to combine aspects such as sidewalk availability, ease of street crossing, terrain, and connectivity into an overall index. Other indices such as Walkscore™ use walking distances to points of interest to construct a gravity-based measure of access to opportunities (Carr et al., 2010). These tools are now widely used in planning practice (Phillips and Guttenplan, 2003). Importantly, although the walkability indices vary in scope and data requirements, they have generally been found to correlate well with actual walking behaviour for a variety of trip purposes (Manaugh and El-Geneidy, 2011), suggesting that the 1LM aspects captured by the indices reflect something of importance to the mode choice of commuters (Meng et al., 2016; Park et al., 2014; Ryan and Frank, 2009).

3. Methodology for first/last mile quality assessment

3.1 Composite index for first/last mile quality

The goal of the paper is to develop an approach to evaluate the overall quality of the first/last mile (1LM) environment, taking all aspects into account that are relevant from the point of view of the passenger. This draws substantially on the forementioned walkability literature, but adds aspects that go beyond walkability to address multimodal issues peculiar to the 1LM trip.

The approach is derived as follows. For a given public transport area of interest, for instance the 1LM environment serving a certain rail station, all relevant final origins or destinations are identified. These are the trip ends which are connected to the public transport system via a set of first/last mile routes. The set of routes, M, may cover multiple modes, including walking, bicycling, and the use of other public transport modes as feeder modes. Identifying this set may therefore not be trivial, as several modes may serve the same trip ends. Furthermore, identifying the routes might involve application of some route choice principle (e.g. shortest distance) to select the most likely route to be included. A route may also serve more than one origin/destination along its path.

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The combined first/last mile index (1LMI) for this area of interest is simply defined as a weighted average of the audit scores for all the routes within M. The use of a weighted average allows for the fact that some routes may be more important than others, because they serve more origins/destinations. The weight may be derived from the number of origins/destinations served, or the number of people using a given route.

The composite index for a particular area of interest is thus calculated as:

$$1LMI = \frac{\sum_{all\ i}(D_i R_i)}{\sum_{all\ i} D_i} \qquad \ldots [1]$$

D_i = origin/destination weight for 1LM route i

R_i = audit score for 1LM route i ϵ M

In order to calculate the audit score for a given route *i*, the route is first divided into a number of elements. These could be either link-based elements, such as street segments, or node-based elements, such as bus stops or street crossings. Each element is scored in terms of a set of attributes (e.g. lighting, obstructions, travel cost), and each attribute is associated with a weight that reflects the importance of that attribute from the user's perspective. The attribute score may come from a visual audit, desk-top assessment, or other measurement, using a standard scoring system, while the importance weight could come from a user survey. The importance weight allows some attributes to count more towards the overall score; the sum of weights across all attributes should be equal to 1.

In the case of link-based elements, the link has a length that needs to be taken into account. This is done by weighting the link attribute score by a distance weight that is equal to the link length as a proportion of the total route length.

The route score is calculated as the weighted average attribute score across all elements:

$$R_i = \sum_{all\ j} \sum_{all\ s} (w_s . p_{ij} . a_{sij}) \qquad \ldots [2]$$

w_s = importance weight for attribute s of element j

p_{ij} = distance weight for element j of route i

$$= \begin{cases} \frac{n_{li}.d_{ij}}{n_i.d_i} & \text{if j is a } \textit{link} \text{ element} \\ \frac{1}{n_i} & \text{if j is a } \textit{node} \text{ element} \end{cases}$$

a_{sij} = attribute score for attribute s for element j of route i

n_i = number of elements in route i

n_{li} = number of *link* elements in route i

d_{ij} = length of link element j of route i

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d_i = total length of route i

3.2 Attributes of first/last mile elements

From the literature, 19 quality attributes of first/last mile environments were identified, and grouped into seven broad categories (Table 1). The categories go beyond those typically included in walkability or NMT-only indices (see Frank et al. (2010); Park et al. (2014)), as the first/last mile trip also potentially involves other modes such as feeder buses. Thus categories relating to feeder trip distance, travel time, and fare are also included, as is a category related to the waiting area (such as bus stops) where passengers wait for feeder vehicles.

Table 1 Categories and attributes included in first/last mile quality assessment

Broad category of first/last mile attributes	Specific attributes	Key References
Personal security from crime while waiting for and walking to public transport	o CCTV monitoring o Visible security and police o Emergency call box o Lighting of sidewalks and bus stops	Kim et al. (2007); Tilahun et al. (2016); Venter et al. (2014)
Comfort of waiting areas	o Overhead shelter (rain and sun) o Resting facilities o Wi-Fi provision at waiting areas	Kittleson & Associates Inc. et al. (2013); Coffel et al. (2012)
Ease of finding information	o Info on bus delays and arrivals o Alternative route information	Coffel et al. (2012)
Safety from traffic accidents while waiting and walking	o Safe road crossings o Sidewalks and waiting areas protected from vehicle traffic	Saelens and Handy (2008); Weinstein Agrawal et al. (2008); Fillone and Mateo-Babiano (2018); Department of Transport (2014)
Sidewalk comfort and quality	o Walkways wide and obstruction-free o Clean and pleasant street environment o Walkways flat, even and neat	Aghaabbasi et al. (2017); Cervero (2001); Park et al. (2014); Saelens and Handy (2008); Weinstein Agrawal et al. (2008)
Time and distance of access trip	o Short walking distance to/from final origin/destination o Short waiting time for feeder bus o Overall trip to Gautrain station fast	El-Geneidy et al. (2014); Ryan and Frank (2009); Van Soest et al. (2020)
Cost of access trip	o Cost associated with feeder trip o Pay point machines at bus stations and pickup/ drop off points	Fillone and Mateo-Babiano (2018)

To illustrate the application of the methodology, a two-step procedure was followed. Firstly, a user survey was conducted to derive the importance weights w_s for a particular 1LM user population. This was followed by a route audit exercise for determining the route audit scores via visual observation. The approach and results are reported in the following sections.

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4. Application in Gauteng, South Africa

4.1 Context

The 1LM assessment approach is tested in the metropolitan region of Tshwane and Johannesburg in Gauteng Province, South Africa. Tshwane includes the capital, Pretoria, while Johannesburg is the commercial hub of the country. The region has a combined population of some 6 million people. The case study covers the central business districts of the two cities, as well as some secondary commercial nodes and suburban locations.

The region's land use patterns are largely characterised by sprawl and car-oriented design; car travel comprises about a third of all trips (Gotz et al., 2015). Main public transport modes include the minibus-taxi informal mode (about 50% of all trips), commuter rail (5%), and bus (3%). Walking is also a major mode (8% of trips), but bicycle use is very low (less than 1%). The rail mode includes the Gautrain, a regional system opened in 2010 that connects Johannesburg, Tshwane, and OR Tambo International Airport with about 80km of track. It offers high-speed service at a higher fare than other transit options. Gautrain operates its own bus feeder system serving most of its ten stations via standard and midibuses and about 430km of bus routes.

In addition, the municipalities of Johannesburg and Tshwane have started implementing their own Bus Rapid Transit (BRT) systems, with exclusive bus lanes and stations and high design standards. The first BRT routes have been deployed in inner areas, where they largely overlap with Gautrain catchments. BRT users are primarily middle-income (Vaz and Venter, 2012), while Gautrain attracts both upper-middle and higher-income passengers.

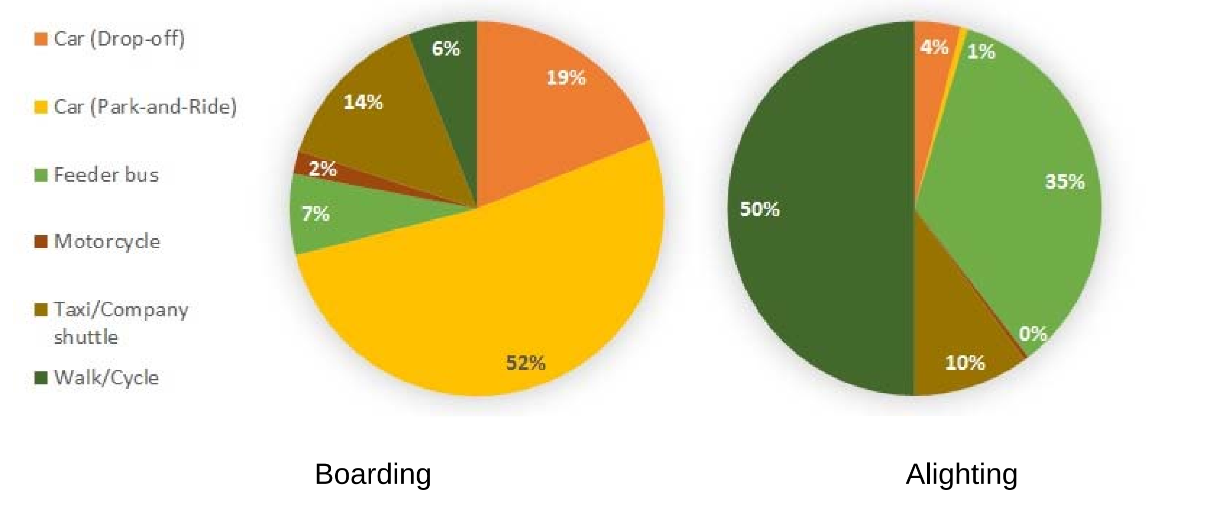

Figure 1 Access and egress modes of Gautrain passengers, Hatfield station (Source: Royal HaskoningDHV, 2017)

Figure 1 shows the distribution of access modes used by boarding and alighting passengers at Hatfield, the terminal Gautrain station in Tshwane. The car is the most important access mode: about three quarters of access trips are by car (either drop-off or park-and-ride), drawn from the terminal station's large commuter catchment area. Only 7% of passengers use

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Gautrain's feeder buses and 6% walk to the station. The mode use of alighting passengers looks very different. Walking (50%) and feeder buses (35%) dominate, as many educational and commercial destinations are located within walking distance of the station or its feeder bus route.

4.2 User survey

In order to derive the importance weights for the case study user population, a small user survey was conducted among Bus Rapid Transit and Gautrain passengers in December 2017 and January 2018. The intercept face-to-face survey recruited respondents at stations and bus stops, across a variety of Central Business District (CBD) and suburban locations in Pretoria and Johannesburg. The results are thus relevant to current users of these public transport systems, rather than potential non-users (such as car drivers) who may have different 1LM requirements.

The response rate was approximately 60%, and the total sample of 250 was split evenly between Gautrain and BRT users. The 1LM modes used by these passengers include walking, Gautrain feeder buses, and other public transport such as minibus-taxis as a feeder mode. For this first application of the 1LM methodology car-based feeder modes such as metered taxi, e-hailing, and kiss-and-ride were excluded, as was bicycling which has minimal use in this population.

Due to the fact that Gautrain and BRT are priced higher than other public transport systems, the sample is representative of the upper end of the transit-using population in Gauteng. The majority of respondents were employed (47%) or studying (44%), but only a quarter had a car available. Students are probably over-represented in the sample (24%) compared to the general public transport market, as the Gautrain and BRT service areas include many universities and colleges. Work (48%) and school/education (28%) were the most popular reasons for taking public transport in this sample; the majority of respondents are thus regular public transport users (44% use Gautrain or BRT daily).

The survey asked respondents to select (from the list in Table 1) and rank the three most important categories of attributes relating to the first/last mile part their trip. They were then asked to rate the importance of individual attributes using a Likert scale between 1 (very unimportant) and 5 (very important).

4.3 Results: Importance of first/last mile attributes to users

Figure 2 shows the results from the first ranking of broad categories of first/last mile criteria. The height of the bar shows the total number of mentions of each category within the top three, and the shading shows the breakdown by rank of each element.

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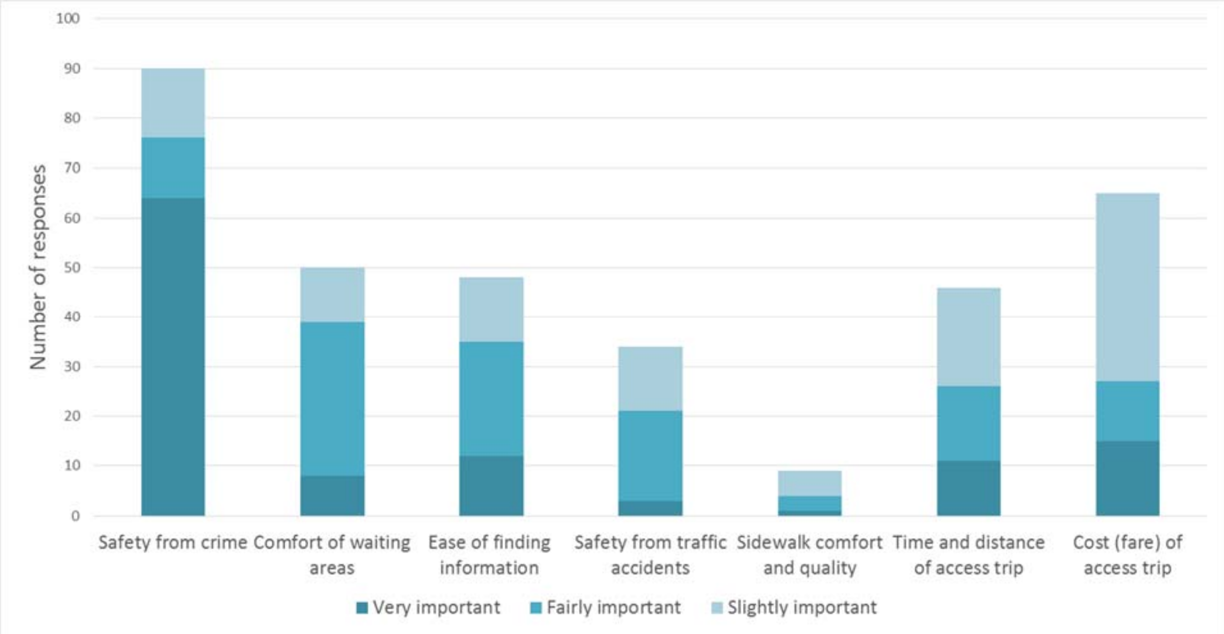

Figure 2 Results of user survey: Importance of broad categories of first-last mile attributes (n=750 responses)

A very clear ranking emerges (Table 2). Security from crime is considered the most important by far, with both the highest number of mentions, and the highest number of people selecting it as their most important criterion. About 73 percent of respondents selected security from crime to be among the top three concerns for them. The cost of the access trip is among the top three concerns of 55% of people and ranks second on the priority list. This is followed by three criteria with similar importance ratings, namely the ease of finding information, travel time/distance, and the comfort and convenience of waiting for the bus. Then follows traffic safety, which was included in the top three priorities by only a third of respondents. Finally, sidewalk quality and comfort is the least important issue to this group of users.

One-way Analysis of Variance (ANOVA) was performed to test the clustering of categories in terms of their importance ratings. It confirmed that the lowest and highest categories differ significantly (at a 95% significance level), but that the categories of comfort, information, time, and cost have similar importance levels. As a result, four clusters of importance levels ranging from low to high were identified, as shown in Table 2.

One reason for potential bias in the results is differing sample sizes – for instance, underrepresentation of passengers with experience walking to stops and stations could explain the low rating of the sidewalk attribute. To test for this the average ratings were compared between subsamples for the two access modes (walk and feeder bus). One-tailed t-tests revealed no significant differences in the average ratings for any of the attribute categories (95% significance) between the subsamples. The same test was also applied to test for differences between the main mode subsamples (Gautrain versus BRT passengers). It showed no significant differences except for the security attribute which is judged more important by Gautrain passengers. We conclude that, overall, perceptions do not vary substantially across the sample, supporting the use of the pooled data in further analysis.

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Table 2 Results of user survey: importance and inferred ranking of broad categories of first/last mile attributes

Broad category of attributes	Percentage of times selected within top three (%)	Percentage of mentions with most important (%)	Inferred ranking
Personal security from crime while waiting and walking	73%	67%	**HIGH**
Cost of access trip	55%	26%	**MED-HIGH**
Comfort of waiting areas	47%	21%	**MED-HIGH**
Time and distance of access trip	44%	27%	**MED-HIGH**
Ease of finding information	43%	22%	**MED-HIGH**
Safety from traffic accidents while waiting and walking	32%	15%	**MED-LOW**
Sidewalk comfort and quality	6%	13%	**LOW**

The average importance ratings were normalised to reflect the weight of each category of measures on a scale of 0 to 1, by dividing each by the sum of all average ratings (Table 3). These weights provide further insight into the desirability of individual attributes. For instance, overhead shelter and seating contribute more to the comfort of waiting areas such as bus stops, than the provision of wi-fi.

Table 3 Normalised importance weights (w_s) per individual attribute

Broad category of first/last mile attributes	Specific attributes	Importance weighting (out of 1)
Safety from crime	o CCTV monitoring	0.11
	o Visible security and police	0.11
	o Emergency call box	0.1
	o Lighting of sidewalks and bus stops	0.11
Comfort of waiting areas	o Overhead shelter (rain and sun)	0.07
	o Resting facilities	0.05
	o Wi-Fi provision at waiting areas	0.03
	o Info on bus delays and arrivals	0.05

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Ease of finding information	o Alternative route information	0.03
Safety from traffic accidents	o Safe road crossings	0.03
	o Sidewalks and waiting areas protected from vehicle traffic	0.03
Sidewalk comfort and quality	o Walkways wide and obstruction-free	0.004
	o Clean and pleasant street environment	0.01
	o Walkways flat, even and neat	0.001
Time and distance of access trip	o Short walking distance to/from final origin/destination	0.04
	o Short waiting time for feeder bus	0.06
	o Overall trip to Gautrain station fast	0.04
Cost of access trip	o Cost (fare) associated with feeder trip	0.06
	o Pay point machines at bus stations and pickup/ drop off points	0.05
	TOTAL	1.00

4.4 Route audits

A combined fieldwork and desktop approach was used to conduct the route audits. The steps followed were:

1. Identification of primary public transport modes and stations. These included seven Gautrain stations[1] in Tshwane and Johannesburg. The stations were selected to cover a range of urban core and suburban operating environments.

2. Selection of 1LM modes and areas of interest. Two first/last mile (1LM) modes were considered, namely walking and the Gautrain feeder bus service. The area of interest around each station was defined in terms of all major origins and destinations that could be accessed by either of the 1LM modes, separately or in combination, within a walking distance of 1km (or a walk time of about 20 minutes). The selection of catchment areas takes into account that maximum walk distances to transit vary considerably across the world (El-Geneidy et al., 2014; Van Soest et al., 2020); evidence indicates that passengers in some developing countries (Fillone and Mateo-Babiano, 2018; Jiang et al., 2012), and passengers accessing rail and BRT (Guerra et al., 2012; Jiang et al., 2012; Morency et al., 2011), are willing to walk considerably longer than the 400 meters typically used in US bus systems (Kittleson & Associates Inc. et al., 2013). This matches the experience in Gauteng, where surveys show that 82% of bus passengers walk up to 15 minutes to a bus stop (Statistics South Africa, 2014), which equates to

[1] The Gautrain stations included Hatfield, Pretoria, Centurion, Midrand, Sandton, Rosebank, and Park. The first and last are terminal stations.

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1,200m at an average walk speed of 3.5km/h. No comparable figure is available for Gautrain passengers, but these arguments support the choice of larger catchments for the purposes of 1LM analysis in Gauteng.

3. Identification of 1LM routes. High priority origins and destinations located within 1km from the stations and feeder bus stops were identified by examining land use maps, and based on the researchers' knowledge of the area. Detailed observed trip end data (e.g. from travel surveys) would be preferable to systematize this step, but were not available. The origins and destinations included all major educational, commercial, recreational, and employment nodes within the catchment. Shortest-distance 1LM routes connecting each station to the origins and destinations – either by walking only, or feeder bus plus walking – were identified from street maps. Field workers were allowed to adjust the routes as needed during the audits to reflect field conditions not taken into account by the desk-top exercise.

4. Development of audit criteria and scoring system. The categories and specific criteria used for auditing first/last mile route elements were chosen to closely match the attributes used during the importance surveys. A bespoke scoring system was developed based on qualitative and quantitative observational measures for each attribute, and drawing extensively on the literature listed in Table 1. The range of possible scores for each element varied between -2 and +2, with -2 being the worst case (i.e. not present or deficient/very poor), 0 being the minimum acceptable level, and +2 being best practice. Where minimum standards exist these were used: for instance, the attribute *walkway width and obstructions* received a score of +2 if the walkway was at least 1.8m wide and obstacle-free, 0 if it was 1.2m at its narrowest point (the minimum width prescribed in South Africa (Department of Transport, 2014)), and -2 if it was less than 1.2m wide or had obstacles like street furniture. In cases where no standard has been defined the researchers' judgment was used: for instance, *travel cost* was awarded either +2 (if an origin/destination was reachable from the station entirely on foot), or -2 (if reachable via a feeder bus trip with an additional fare). Further detail is provided in Venter and Cowper (2017).

5. Field audits. Engineering students at the University of Pretoria were trained to conduct the field audits, and supplied with maps and cameras. Before doing the scoring, field workers were asked to subdivide each route into nodes and links to reflect individual elements (such as bus stops and street crossings) of uniform condition. Link and node locations were captured on paper maps, as were audit scores and comments. These were later transferred to GIS for analysis. Consistency of scores was ensured by independent verification by a roving supervisor; field workers also took extensive GPS-tagged photographs to enable off-site verification and standardisation of scores. While it is also possible to obtain quality ratings directly from users, the use of trained auditors is common in environmental audits, for reasons of consistency, cost, and completeness (Adkins et al., 2012; Weinstein Agrawal et al., 2008).

6. Calculation of element, route, and station scores. Equations 1 and 2 above were used to calculate the summary scores at a route and station level. The importance weight values (w_s) used for each attribute are those shown in Table 3. The distance weight

(p_{ij}) for links are based on link lengths extracted via GIS. All routes for a given main station were weighted equally (i.e. all D_i = 1.0) as no information was available on the relative importance of individual origins and destinations.

About 40 origins and destinations were identified around each Gautrain station and its feeder bus routes. The audits covered a total of 129 1LM routes, which included 113 bus stops, 694 other walk route elements, and 350 kilometers of walk routes. The average length of the walk portion of a 1LM route was 500m.

Figure 3 shows an example of the extent of the feeder bus routes, bus stops, and walk routes audited around the Hatfield station in Tshwane.

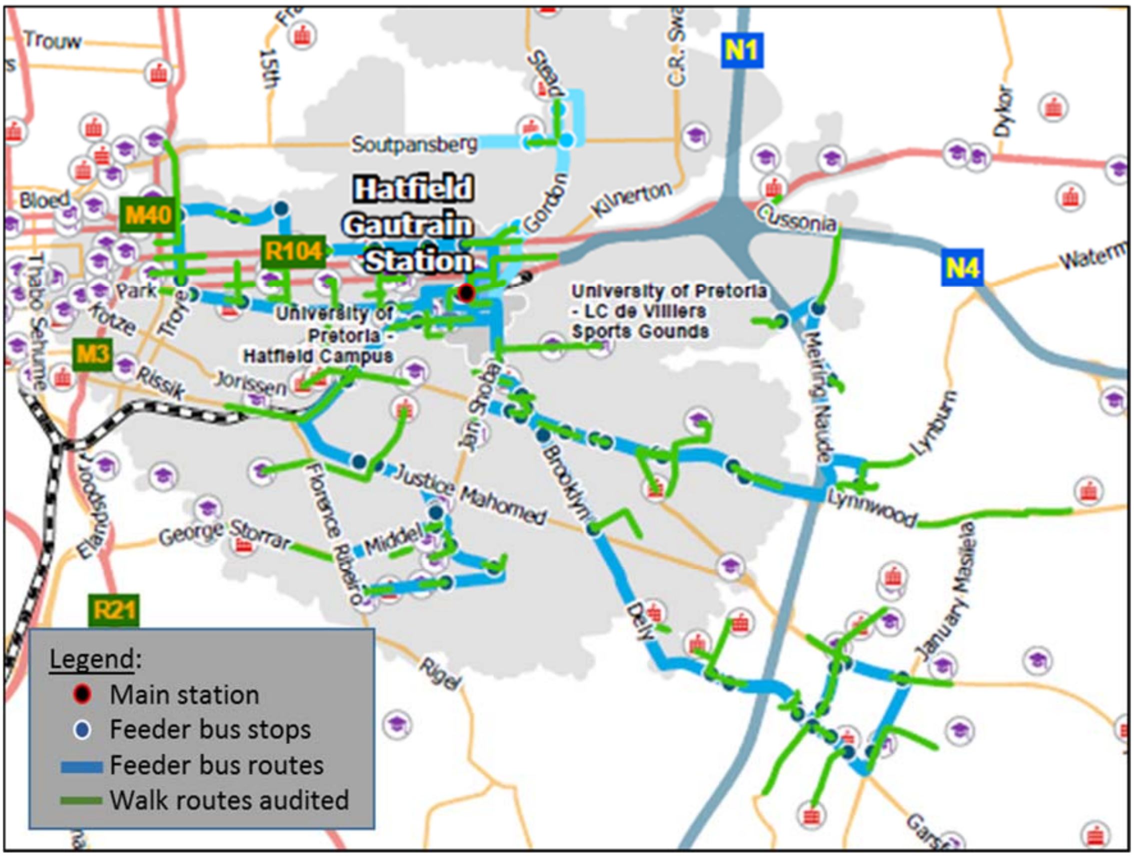

Figure 3 Area of interest around Hatfield station, including bus routes, bus stops, and walk routes *(Figure drawn by N du Plooy, Royal Haskoning DHV)*

4.5 Results: First/last mile quality assessment

Figure 4 shows the distribution of unweighted attribute scores (a_{sij}) for four of the stations, aggregated into the broad attribute categories. Using these four stations as examples, some general observations are made regarding the quality of the first/last mile environment.

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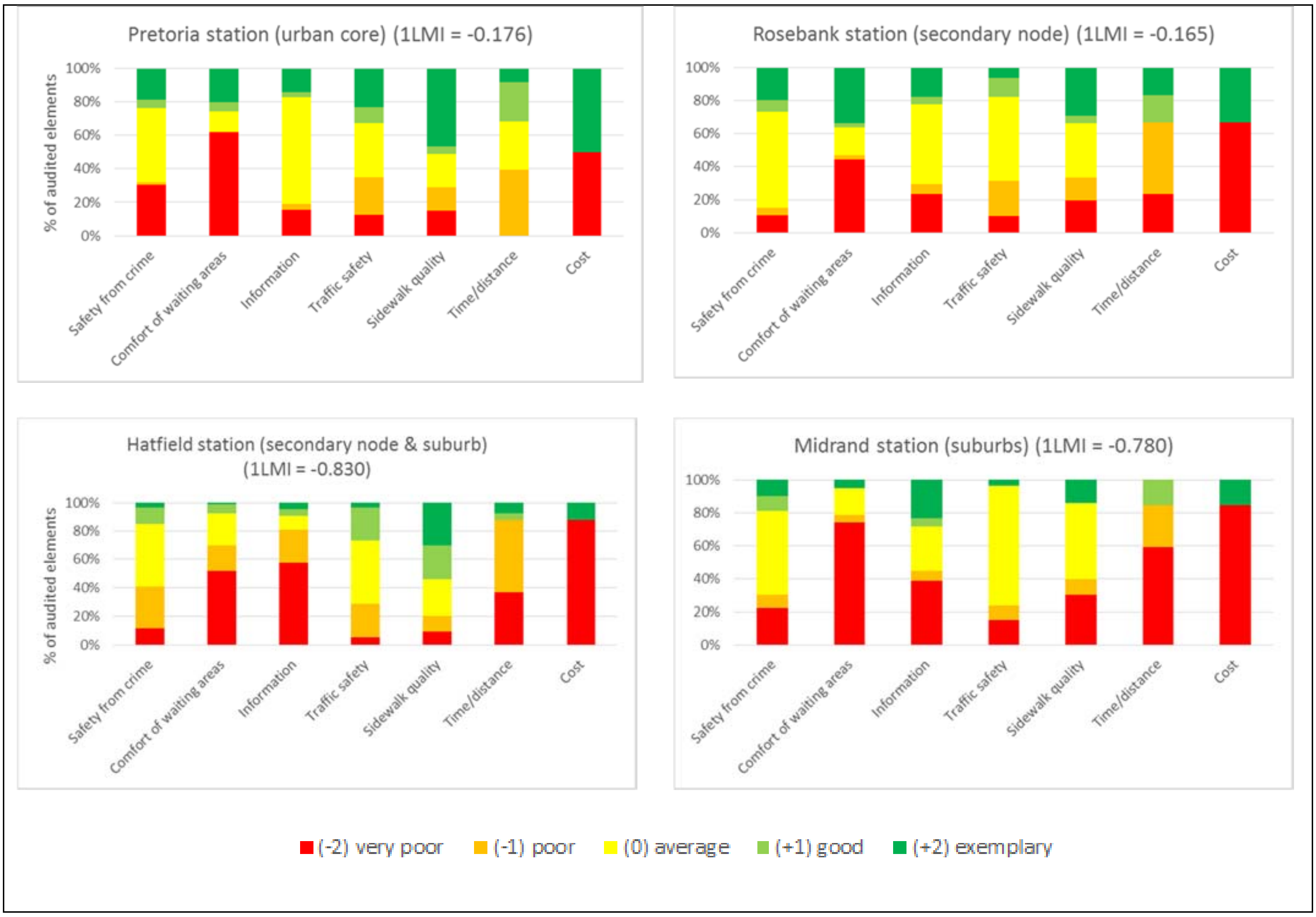

Figure 4 Unweighted audit scores for four example stations

Firstly, there is considerable heterogeneity across the broad categories of 1LM attributes. Categories that scored consistently lower than others included the comfort of waiting areas, time/distance to final destination, and cost. This reflects the fact that many bus stops are poorly equipped, lacking benches and shelter; and the fact that many origins/destinations can only be reached with a feeder bus trip, which raises the time and cost associated with the first/last mile connection. Stations that serve more suburban areas, such as Hatfield and Midrand, depend more heavily on feeder bus routes for 1LM access, and therefore score relatively worse on the time and cost attributes.

Interestingly, attributes associated with both safety from crime and from traffic accidents score relatively well – among these four stations, more than 60% of elements were typically rated at average or better in these two categories. This suggests that station precincts are already fairly well served in terms of elements such as street lighting and pedestrian crossings, although specific problem areas exist.

Despite this variation, the overall quality of 1LM elements as measured against minimum standards is relatively poor. Table 4 illustrates this point by showing the average audit score across all seven stations by attribute category. On average, the 1LM environment meets minimum standards (i.e. attribute rating at or above zero) only with regard to sidewalk quality

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(average score = +0.38), while traffic safety (-0.01) and safety from crime (-0.05) were very close to acceptable. Of greater concern are information provision (-0.74), the comfort of waiting areas (-1.08), and the time and cost of the 1LM trip (-0.92, -1.16).

Table 4 Average audit scores by attribute category

Broad category of first/last mile attributes	Average unweighted audit score
Safety from crime	-0.05
Comfort of waiting areas	-1.08
Ease of finding information	-0.74
Safety from traffic accidents	-0.01
Sidewalk comfort and quality	0.38
Time and distance of access trip	-0.92
Cost (fare) of access trip	-1.16
ALL ATTRIBUTES	-0.52

The results could be useful for identifying routes that are most in need of attention in terms of the first/last mile quality. Figure 5 plots the distribution of the route scores (R_i), calculated taking the user-derived attribute weights and the audit results into account. Routes are classified by the predominant type of environment as either suburban or urban core. It can be seen that the majority of routes (77%) lie below an acceptable score of zero, of which 14 routes (10%) are very poor (less than -1.0 on average).

There is a systematic difference between routes depending on the land use and development environment of each station's catchment area. The average route score for urban routes is higher than that for suburban routes (the difference is statistically significant at a 95% level, t-test). The reasons for this are suggested by comparing individual stations (Figure 4). The calculated index (1LMI) for Pretoria and Rosebank stations (-0.176 and -0.165), two urban core localities, are both higher than Midrand and Hatfield stations (-0.780 and -0.830), which are more suburban. While the suburban 1LM environments generally score somewhat worse in terms of bus stop infrastructure and information, it is especially time and cost of the 1LM trip that suffers in suburban locations. This is related to the low densities around suburban stations like Midrand, necessitating the need to take a feeder bus trip from the rail station in order to connect to final origins and destinations.

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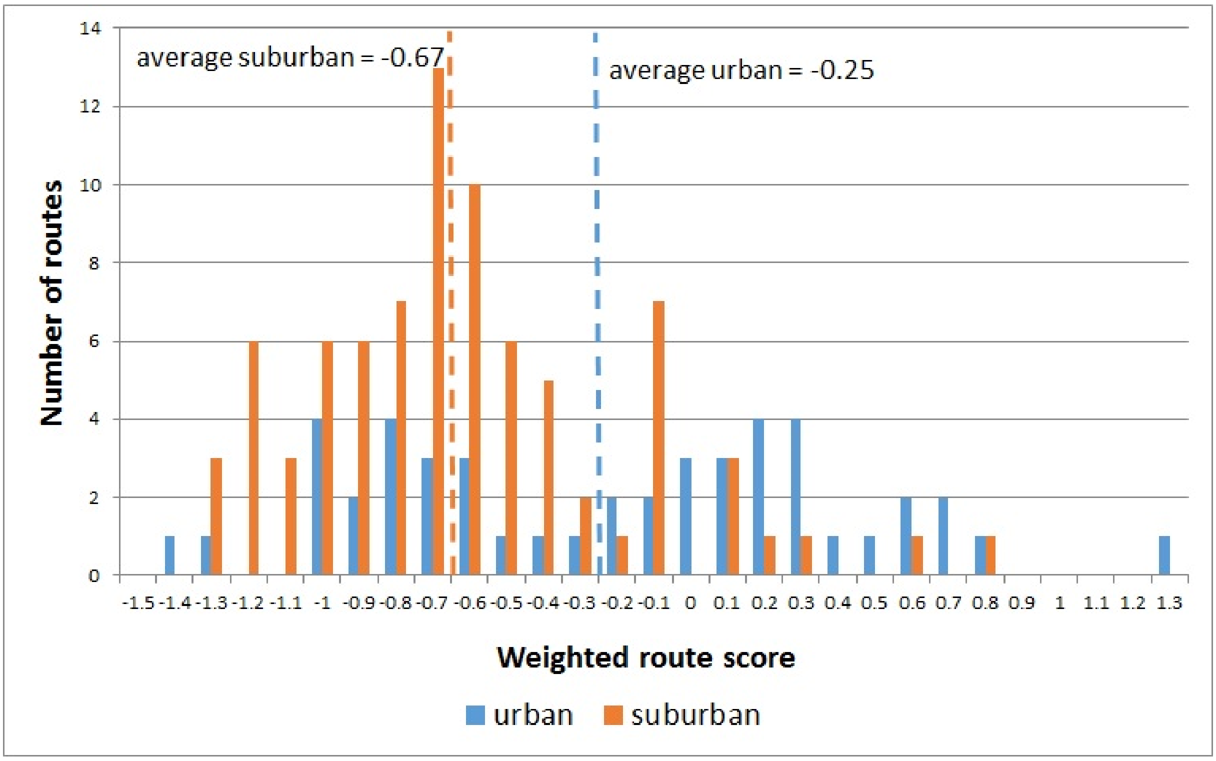

Figure 5 Frequency distribution of first/last mile route scores, all stations (n=129)

4.6 Discussion

The work reported here provides insight into what users value when considering the first/last mile part of their public transport trip, which could be of value when deciding on improvement actions. The results largely agree with the transport service quality and non-motorised literature, but also show the unique characteristics of South African urban environments. Distance and cost of the access trip is clearly an important issue that influences the likelihood of making the trip on foot or via some other mode (Ryan and Frank, 2009; Van Soest et al., 2020). However in Gauteng this factor is overwhelmed by the importance of security concerns, in line with the higher crime rates and crime perceptions observed amongst pedestrians (Venter et al., 2014). A recent province-wide survey shows that security on the walk to public transport and at stops is a major cause for dissatisfaction amongst bus and train users (Statistics South Africa, 2014). This is not unique to Gauteng, however: in Chicago, security issues such as violent crimes around transit stations can discourage walking to transit stops and use of public transport (Tilahun et al., 2016), while in the Bay Area safety from crime was found to be second only to walking distance in terms of importance to transit users (Weinstein Agrawal et al., 2008).

The importance of accessibility, sidewalk infrastructure, and traffic safety attributes on the attractiveness of the walking trip is well-established in the literature (e.g. Aghaabbasi et al., 2017; Koh and Wong, 2013; Saelens and Handy, 2008). The finding that people attach less importance to these aspects of the first/last mile environment in Gauteng is somewhat surprising, given the seriousness of the traffic safety problem in South Africa in general, and

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among pedestrians in particular. However it accords with the perceptions of Gauteng bus users in general: a recent perception survey shows traffic safety to be relatively low as a cause of dissatisfaction, behind issues such as security, punctuality, and fares (Statistics South Africa, 2014). This raises issues of transferability of the results, which is a topic for further study.

By simultaneously considering users' subjective requirements and the more objective findings of the environmental audits, it is possible to derive some priorities for action towards improving the first/last mile part of the Gautrain trip. Figure 6 plots the quality audit result (from Table 4) against the importance rating (from Table 2) for the main attribute categories across all stations. It appears that the most urgent priority would be to reduce the monetary cost of the feeder trip, as this attribute is very important to users but scores poorly, especially where such trips are taken by feeder bus. One effective strategy might be to introduce free transfers between the rail and the feeder bus. Like most other strategies this would raise the system's subsidy needs, and would therefore need to be considered within a broader conversation of trading off affordability with service quality and the achievement of broader social and environmental goals.

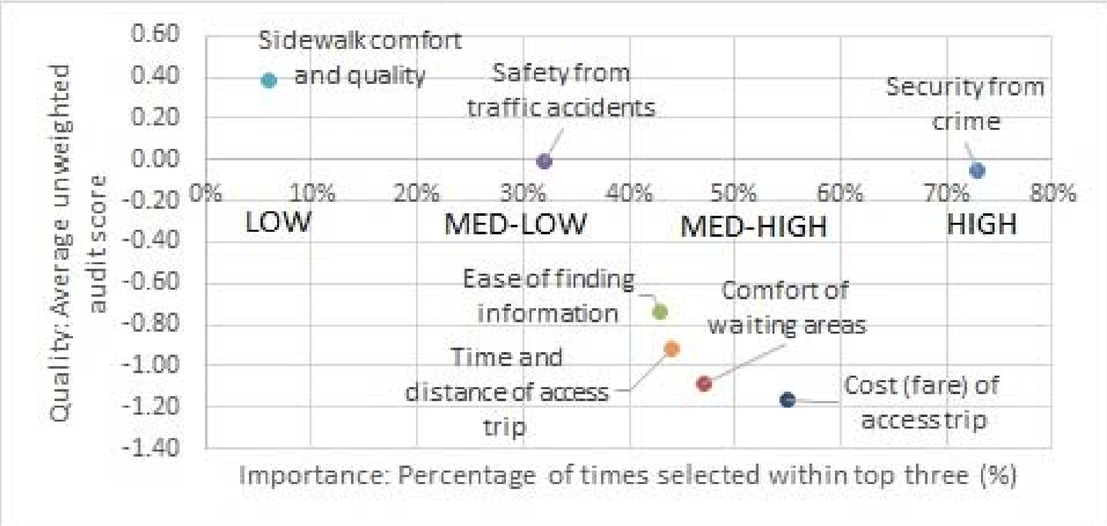

Figure 6 1LM audit scores and importance rating, per attribute category

The second priority would be to reduce the time required for the access trip, and to improve amenities at bus stops (both are of medium-high importance but score poorly).The time for the access trip could be reduced by better feeder bus strategies (such as increased frequencies or dedicated buslanes). In the long run, land use strategies that promote densification and development around Gautrain stations will reduce both 1LM cost and time issues as more trip ends migrate to within walking distance of stations. Bus stop infrastructure is relatively easy to address, and should be a short-term priority. Safety from crime is the next priority (high importance but reasonable current performance), and the audit results could give guidance as to which specific areas need attention. Passengers deem good lighting, visible policing, and security cameras equally important in raising the security of 1LM environments (see Table 3). Lastly, travel information, sidewalk conditions, and traffic safety are lowest on the priority list as they are either less important to passengers, or currently meet relatively high standards on average.

It is however important to note that these observations on prioritising actions are based on averages, and mask individual cases such as specific 1LM routes where action might be needed more urgently.

5. Conclusions and recommendations

The paper describes a technique for assessing the quality of the first/last mile (1LM) environment for public transport users of a specific transit system, based on both user valuations of the importance of various elements of the environment, and an objective audit of those elements. What is novel about the approach is that it incorporates aspects of the walking environment, bus stop infrastructure, and the time and cost involved in taking feeder modes to the main transport station into a single index. The technique was tested for Gautrain users in the cities of Tshwane and Johannesburg in South Africa. The results showed that it is possible to distinguish between specific stations, routes, and elements of the 1LM environment that perform better or worse, and that by considering both importance and performance a priority list can be developed for interventions to improve the 1LM experience for the user.

In this sample of rail and BRT users, security from crime emerges unsurprisingly as the most important issue, but as security features are currently at a reasonable standard authorities merely have to maintain this standard. Traffic safety is neither of major importance nor of low quality, and also not a priority for immediate action. The travel cost and time associated with some 1LM trips, particularly those involving the use of a feeder bus, are most in need of attention. Poor 1LM performance is generally observed in more suburban locations, where poor sidewalk and bus stop infrastructure combined with the extra cost and time needed to make longer 1LM trips using feeder buses contribute to low 1LM quality.

Future work required to improve the diagnostic power of the approach is to calibrate the scoring of 1LM elements against user expectations, in addition to field workers' assessments. For instance, acceptable costs and travel times for the 1LM trip need to be better understood, as considerable variation exists in these matters in different contexts (El-Geneidy et al., 2014). More research is needed on user preferences for other 1LM modes such as e-hailing, park-and-ride, and informal transit. This could be extended to behavioural research, in order to understand the elasticity of public transport demand to multimodal 1LM quality, which could in turn help planners to better measure, manage, and improve the 1LM environment. Behavioural insight is also needed to improve the valuation of the benefits of various 1LM improvement strategies, which can be useful when making the case for allocating public budgets to 1LM interventions.

While the 1LM method is flexible enough to be adapted to include different attributes, access/egress modes, and user-derived weights within the same framework, more work is needed to ensure the transferability and comparability of results. One way to do this might be to link the 1LM outcome (-2 to +2) to a universally understood scale such as the Level-of-Service concept (A to F) used in traffic engineering. Lastly, a limitation of the method is that it

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captures issues of the density of origins/destinations only indirectly via the travel time and cost of the access/egress trip. Alternative formulations incorporating cumulative accessibility measures might be a useful extension of this work.

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