Evaluating Spatial Justice in Rail Transit: Access to Terminals by Foot

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Abstract: There has been a growing interest to improve urban rail services for increasing a city's economic competitiveness. While accessibility provided by rail services has been the focus of many studies, determining accessibility to rail stations is less investigated. The present study examines how accessibility to rail stations via walking has social justice implications. Accessibility can be measured by socioeconomic background, trip characteristics, self-selection, and neighborhood characteristics. Commuters from two rail stations in Auckland, New Zealand—a transit-oriented development (TOD) and a local station—participated in an interactive online survey. Spatial and statistical measures were used to assess the ease of access to the two stations. Under the developed framework, which evaluates social justice in transit, minimum accessibility should be provided (sufficientarianism) and accessibility should disproportionately benefit the less well-off (egalitarianism). The findings show that minimum accessibility was not met for either station, but the TOD station provides better access for low-income individuals. This study contributes by demonstrating the use of a developed framework to evaluate accessibility to rail stations via walking from a social justice perspective. This can be adapted to analyze the accessibility to rail stations in an urban environment of any city. **DOI: 10.1061/JTEPBS.0000419.**

Introduction

Most road networks worldwide support the use of cars as the main means of transport. Car-dependent cities have raised concerns about discriminatory geographies toward low-income neighborhoods such as higher unemployment rates (Korsu and Wenglenski 2010), social exclusion (Currie et al. 2009), and lower political engagement and participation in urban activities (Delbosc and Currie 2011). Recognizing these failures, a growing number of transport authorities (e.g., Brisbane City Council 2018; City of Melbourne 2018; Transport for NSW 2018), including those in Auckland (Auckland Council 2012), are promoting greater utilization of public transit, especially in the form of urban rail systems, thus making stations an important destination for everyday walking and cycling (Duany et al. 1991; Kamruzzaman et al. 2014; Southworth and Owens 1993).

Generally, commuter rail users walk longer distances to stations in comparison to bus users (Wasfi et al. 2013, pp. 23–24). In Auckland, people who use urban heavy rail services for commuting are more likely to walk than to drive, cycle, or be dropped off to a rail station (Wilson 2013). This study focuses on walking accessibility to urban rail stations, which is also known as the walkability index (Frank et al. 2005; Leslie et al. 2007; Southworth 2005). The desire to walk depends on the pedestrian friendliness of the urban environment surrounding the rail stations (Dittmar and Poticha 2004, pp. 20–24). Transit-oriented development (TOD), in particular, aims to improve the walkability around new or as an improvement to existing rail or rapid bus stations by creating compact, pedestrian-oriented, and mixed-use communities (Calthorpe 1993; Speck 2012). While walkability tends to examine the surrounding built environment, in this study the objective is to understand the ease of walking access to rail stations from the user's perspective. Therefore, the term walking accessibility to transit is used instead of walkability to highlight the difference.

While existing literature [for a review see Button and Rietveld (1999)] discusses that rail transport is an environmentally friendly alternative to cars, the social impacts of inaccessible rail transit stations are often overlooked. Accessibility is one of the main social benefits of transportation systems (Dodson et al. 2016; Levine and Garb 2002; Martens 2016; Vigar 1999), and often the social impacts of limited access to opportunities are ignored. This can increase economic disparities and harm socially and economically disadvantaged groups. These days, social justice is applied to regional plans and used to evaluate transport systems (e.g., Auckland Council 2012; Victoria State Government 2017). Well-established distributive justice theories (Dworkin 2000; Harvey 1973; Rawls 1971; Sen 2009; Soja 2010; Walzer 2008) are commonly adopted by transport planners (Lucas 2004; Martens 2016; Pereira et al. 2017) to develop a socially just transport system. However, lack of evaluation tools from a social justice perspective at a microlevel (such as walking to transit stations) can reduce the system-level impact.

Current studies on walking access to rail transit stations (Schlossberg and Brown 2004; Sun et al. 2017; Zhao et al. 2013) suggest interventions in urban form to improve walkability. However, these interventions affect different socioeconomic groups differently. Low-income minority communities are less likely to participate in physical activities (Taylor et al. 1998; Ministry of Health 2014) as they tend to reside in areas with poor walking infrastructure in comparison to neighborhoods where people from Caucasian backgrounds reside (Cassel et al. 1971; Cleland et al. 2010). If the benefit of walking facilities is a public good, then concerns over its socially just allocation fall in the domain of distributive justice theories. To date, there is a limited understanding of

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how accessibility to transit stations via walking can be evaluated from a social justice perspective.

The purpose of this paper is to adopt the perspective of distributive justice in justice theories and utilize it to evaluate walking access to rail stations. While the issue of walking to transit stations has been the focus of many studies, there is often limited engagement with the philosophical literature on social justice. The current paper differs from previous research by providing an approach to assess the walking access to rail stations by adopting justice theories and evaluates the social impact of accessibility to transit stations. The framework developed in a previous study by Adli et al. (2019) is adopted to investigate two rail transit stations in Auckland, New Zealand as the case studies. This framework benefits from a dialogue between sufficientarianism and egalitarianism theories of social justice. It accommodates universalist concerns about inequality of opportunities and basic needs regarding transport, along with considering the context-specific issues such as people's socioeconomic background, trip characteristics, self-selection, and neighborhood's characteristics. Without a robust framework to evaluate justice, it is difficult to define fair access to existing rail transit stations and thereby plan fair access for new stations.

This study contributes by providing an application of the framework which can be adopted by transport authorities to evaluate alternatives for walkability improvement at any urban transit stations.

The next section of this paper is a summary of the relevant literature. It is followed by the research methodology. The results are then presented, and it continues with a discussion of the findings. The paper concludes with the significance and originality of the proposed framework.

Literature Review

This section provides a summary of the key findings in current transportation justice frameworks and their relevance to walking accessibility to rail stations.

Transit Accessibility

Transit accessibility can be simplified to a medium that connects people and places in order to indicate the ability and freedom of choice (Talen 2001, pp. 30–31). To further simplify this, a city can be considered as a labor market; therefore, the main principle function of transit accessibility is the quantity that measures how well transit services connect people to jobs (Harvey 1973, p. 61; Ihlanfeldt and Sjoquist 2000, p. 123). This measure, however, focuses mostly on the time cost of accessibility rather than the several variables affecting the trip. Even if accessibility is calculated as a price index, different individuals value their journey differently, thus its price is unique to everyone. What can be agreed upon is that a journey is made only if the benefits of each journey outweigh its cost.

The literature on transit accessibility can be classified into two types: accessibility to transit and accessibility provided by transit (Geurs and van Wee 2004; Moniruzzaman and Páez 2012). This study focuses on the first. This does not mean that accessibility provided by transit is less important; on the contrary, a higher level of service tends to attract more commuters (Alshalalfah and Shalaby 2007; Cervero et al. 2009a, b; Johnson 2003; Taylor et al. 2003). In this study, accessibility measures are seen as the opportunity to participate in society.

Mass-transit stations such as train stations are a key element in TODs (Calthorpe 1993, p. 140). While accessibility to rail stations is key in a successful design, its concept is challenging theoretically and empirically. The surrounding land use of the train station and its accessibility are the main factors that create neighborhoods that are classified as "transit-oriented" (Beimborn et al. 1992; Cervero and Kockelman 1997; Guthrie and Fan 2016). A neighborhood with high density and diverse land use along with a connective street layout can improve accessibility, reduce journey time, and improve convenience for transport passengers (Bentley 1985). Recent studies show that unresponsive land-use planning and street design can lead to failure in mass-transit investments (Aggarwal and Jain 2016; Li et al. 2017; Wey et al. 2016). For example, if two stations have the same level of service and are connected to the same destinations, but they show different ridership, then it is very likely that the difference is due to varying accessibility to stations for environmental and socioeconomic reasons. For example, Nelson et al. (2013) found that controlling for other factors, property values generally increase around rail stations. The work by Cervero and Zupan (1996) shows that low-income groups primarily rely on bus services more than rail due to lower fare levels. Moreover, commuter rail is often zonal in fare structure and disadvantages commuters who live on the fringes of a city due to lower housing cost (Taylor and Morris 2015).

Accessibility to Rail Stations by Walking

While ad hoc measures of accessibility such as catchment analysis are becoming more available and may be informative (Boarnet 2017; Dong 2017; Sukaryavichute and Prytherch 2018), they are still incomplete measures of accessibility. Given that people are different in their personal preferences and travel needs, accessibility is a relative concept. For example, Mokhtarian et al. (2015) explain differences in individuals' travel purposes based on theories of motivation. Therefore, accessibility should ideally be measured individually, which requires data consisting of individual travel patterns and preferences.

To measure personalized accessibility, it is necessary to identify the variables associated with the level of access. The first step in the distribution of accessibility is identifying the groups of disadvantaged people. The existing literature on justice have debated for decades about the measures of social class and whether social identities can be categorized by income (Kuby et al. 2004; Pulugurtha and Agurla 2012; Thompson et al. 2012), occupation (Cordera et al. 2015), education (Rachele et al. 2015), ethnicity (Gutiérrez et al. 2011), age (Chiou et al. 2015), or some combination of these variables (Buehler and Pucher 2011; Taylor et al. 2009). However, many studies in transportation justice (Manaugh et al. 2015; Martens 2016; Peters and Gordon 2008; Thomopoulos and Grant-Muller 2013) follow Rawls to define the least-advantaged groups as those members of society with the lowest prospects of enjoying primary social goods over a life cycle. Similar to Rawls' society, this study uses the income levels to identify the worst-off and well-off population groups.

Second, the combination of walking pattern and distance varies for people according to trip purpose, the built environment, individual trip characteristics, socioeconomic characteristics, and self-selection preferences (Durand et al. 2016; El-Geneidy et al. 2014; Zhao et al. 2003). Some significant characteristics that are associated with neighborhood environment and walking include safety from traffic and safety from crime (Calise et al. 2012; Handy et al. 2006; Saelens and Handy 2008). For example, women prefer to choose walking routes which are perceived to be safer than the shortest path (Weinzimmer et al. 2015). Studies found that the willingness to walk can also be associated with age (Yang et al. 2011), gender (Agrawal and Schimek 2007; Rodríguez and Joo 2004), and income (Wardman et al. 2007). Preferences for travel are different spatially, which can at least partially explain the differences in travel behavior between locations as a consequence of self-selection (Boarnet and Sarmiento 1998; Chatman 2009; Van Wee 2009).

The present study follows the literature regarding the identification of socioeconomically disadvantaged groups and factors impacting the individuals' walking access to a train station. The contribution of the study is the approach and methodology that analyzes these factors by adopting justice theories to evaluate walking accessibility to a transit station.

Theories of Justice and Transportation Equity

In recent years, inspired by theories of social justice, some scholars (Lucas 2004, 2012; Lucas et al. 2001, 2016; Manaugh 2013; Martens 2012, 2016; Pereira et al. 2017) have attempted to define social justice in the context of transportation planning. Lucas's (2004) understanding of social justice in transportation is influenced by notions of "environmental justice" and "social exclusion." For Lucas, transport, or more specifically, the lack of adequate transport, causes certain groups of the population, such as minorities living in low-income communities, to be effectively "locked out" of the activities that enable a decent quality of life (p. 291).

Martens's transport justice theory (Martens 2012) is based on Dworkin's theory of equality of resources (Dworkin 2000). Dworkin's ideas fall under the label of sufficientarianism and suggest that a fair distribution of transport accessibility is when "all members of society should be guaranteed a sufficient level of accessibility under most, but not all, circumstances." Martens excludes expensive, high-access locations from his theory of transport justice. Instead, he focuses on a range of choice locations that offer a sufficient level of accessibility where "in the ideal situation" the dominant transportation mode can be used by all adults, regardless of their abilities. In this context, the main question is "What is a sufficient level of accessibility?" Martens argues that this question cannot be answered by theories of social justice, as it requires a process of democratic deliberation and selection.

Lucas's and Martens's focus on transport sufficiency can be problematic, because a transit service can improve the minimum services, but the real meaningful benefits could happen in high-income areas. According to Soja (2010), "Service provision almost always favored the wealthier residents even in the name of alleviating poverty" (p. viii). Pereira et al. (2017) addresses this risk by combining sufficientarianism and Rawlsian egalitarianism. Based on a review of the strengths and limitations of the social theories and their application in transportation, he concludes that studies addressing the distributive issues in transportation equity can benefit from a dialogue built between Rawls's egalitarianism and the human capability approach (CA). He argues that accessibility as a combined capability should be the main focus of distributive justice for transport planners. The moral principles of the distribution of transport accessibility, in Pereira's view, should first satisfy some minimum level of accessibility to key destinations as a basic provision for people, and then prioritize disadvantaged groups. Moreover, the concept of accessibility brings in the spatial dimension that is concerned with moral concerns over the equality of opportunities, which is lacking in Rawls' proposal for distributive justice. In this sense, accessibility is a necessary condition for promoting equality of opportunity.

While Pereira addresses the theory of transportation justice, the lack of attention on the unique definition of accessibility in transit systems makes his theory difficult to apply in the transit planning context. Adli et al. (2019), by combining sufficientarianism and egalitarianism, expand the transport justice theories of Martens (2016) and Pereira (2017) to develop a social justice framework for transit systems. The focus on transit systems makes Adli's transit justice framework the best match for the present study. Under this framework, (1) access to transit is a right; (2) the areas under a minimum level of accessibility and people with lower levels of income are a priority; (3) the distribution of transit accessibility will be evaluated spatially; and (4) the focus is on ranking the spatial distribution of justice for being less or more just rather than defining the perfect just arrangements.

This study builds upon the existing transport justice theories and extends them to better suit walking accessibility to transit stations. The present study utilizes Adli's transit justice theory to measure how just access to a rail station is for residents of the case-study neighborhoods. The next section provides a methodology that translates the abstract theory of transit justice into quantifiable measures. This will allow practitioners to track and compare the success of social justice policies in walking accessibility to transit stations.

Methodology

The methodology of this research implements the transit justice theory in access to rail stations. Following the proposed framework, justice can be achieved if a minimum level of accessibility is provided for people in the vicinity of rail stations and people with lower income have relatively better access to rail stations. As such, it is necessary to define the measures of accessibility and deprivation. While the literature agrees that income can be used as a measure of deprivation, there is less agreement about the measures of accessibility level. Studies use a range of factors to describe accessibility levels from quantitative factors such as different speeds of walking to qualitative factors such as perception of livelihood (Ewing and Handy 2009; Finnis and Walton 2008; Frank et al. 2010; Shamsuddin et al. 2012); however, the geometric distance is a key consistent factor of accessibility in most studies. Therefore, this study uses actual walking distance as a measure of accessibility level. Fig. 1 provides a summary of the steps of the methodology and how the steps link to the transit justice framework.

The first principle of the transit justice framework is to provide a minimum accessibility to residents. While a train station is merely a means to an end, the minimum access to a rail station only makes sense when comparing two or more stations with similar services, such as two stations on the same rail line. This way, under the transit justice framework, it can be argued whether a station is better or worse in providing minimum walking accessibility compared to the other station. Because it is necessary to agree on a minimum level of accessibility to transit services as a right for all residents, in the absence of a just and democratic process, a survey (Wilson 2013) undertaken by Auckland Council has been used to define the minimum level of accessibility for the rail stations in the case study. The study showed that people in Auckland typically walk to rail stations more than any other modes, and the median walking distance is about 1.2 km. Modern network analysis tools can easily estimate this catchment using isochrone analysis. An isochrone is a polygon showing the area that can be accessed given a certain starting point. The difference between the estimated isochrone by computer algorithms and the isochrone generated from the actual collected data can show where the minimum accessibility is not provided. In other words,

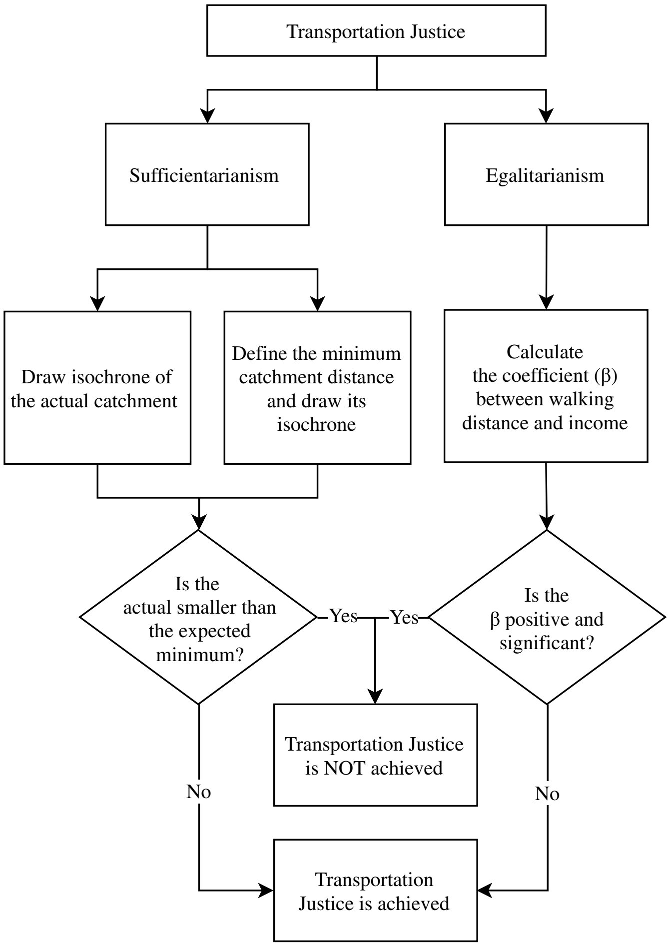

Fig. 1. Flow diagram of the methodology.

if the actual isochrone is smaller than the estimated isochrone, there are subjective and objective factors that prevent people from walking to train stations.

The second principle of the transit justice framework is to provide accessibility for the less well-off population. Therefore, the relationship between accessibility and deprivation needs to be statistically measured. For the present study, the relationship is measured by walking distance to the train station and income. An ordinary least squares (OLS) regression model can measure this relationship. Moreover, it is necessary to include other control variables that can influence walking distance to a rail station to better identify the impact of deprivation on accessibility. The regression model used in this study is described in Eq. (1)

$$A = \beta_0 + \beta_1(Income) + \beta_2(CV)_1 + \beta_3(CV)_2 + \beta_4(CV)_3 + \cdots + \beta_n(CV)_n + \varepsilon_i \quad (1)$$

where A = level of accessibility (i.e., the distance walked to get to the rail station); $Income$ = household income in thousands NZD; $(CV)_i$ = control variables; and β_i = coefficients. The control variables in this study are gender, age, household size, walking route, perceived safety from traffic, perceived safety from crime, and self-selection factor. One unit (NZ$1,000) change in the *Income* variable will result in β_1 unit (100-m) change in walking to the rail station ceteris paribus. Considering the fact that a minimum of 10 observations for each estimated parameter are required for the OLS model (Harrell 2001; Peduzzi et al. 1995, 1996), the sample size for this study should be over 90.

Survey Design

Survey Locations

Auckland currently has a population of approximately 1.5 million and is experiencing rapid population growth. In the next 20 years, Auckland is predicted to grow by one million residents. The government has adopted a spatial plan for the region which articulates the desire for a transformational shift to transit with a focus on rail transit as well as the adoption of policies to reduce socioeconomic inequality (Auckland Council 2012). This research focuses on the current conditions of two train stations as the case study, and the stations are located in a different urban context, as shown in Fig. 2. Both train stations are located on the Western Line, have the same level of services, and the main destination for all services is the city's business district. The New Lynn station's location was part of "the largest urban regeneration project" in New Zealand. It was transformed into a transit-oriented development (TOD). This project included densification, new apartment buildings, and improvement to the adjacent town center to improve the walkability of areas around the rail station. The station located on Baldwin Avenue, on the other hand, has not undergone any significant changes over the last two decades. The contrast between the TOD–walkable design of the New Lynn station and the cul-de-sac–low-density design of the Baldwin Avenue station makes them ideal case studies for this research.

This study focuses on the morning peak (7–9 a.m.) because this period has the highest ridership (Auckland Transport 2015) and many studies (Anas et al. 1998; Buehler and Pucher 2012; Santos et al. 2011) suggest that job-related transit trips are mostly made during this period.

Data Collection and Questionnaire

Fundamentally sociological research involves a constant interplay between observation and explanation. Questionnaires are the most common technique used in survey research for observation (de Vaus 2002). One limitation that emerged from literature on accessibility is that the methods used are often time- and resource-intensive. Lucas (2006) concludes that government agencies are reluctant to make the necessary calculations because "gathering the data and carrying out the initial assessments of accessibility is both time consuming and a frustrating process" (p. 806). This issue has informed the methodology developed in this study. In this research, the latest developments in smartphone technology are used to provide a low-cost and effective data-collection method. A web-based, self-administered, and anonymous questionnaire was developed for this study as a cheaper, faster, and more accurate way to collect data.

The questionnaire is designed to be completed within 5–10 min by participants using their own mobile phone while commuting. The questions can be categorized into socioeconomic, trip, and neighborhood characteristics. Table 1 provides the measurement items included in the questionnaire, categorized according to the themes.

While most of the questions are routine in social surveys, the questions on self-selection of neighborhood and questions with spatial data are relatively new. In order to identify the self-selection issues, four diverse urban forms in Auckland were identified: (1) a mixture of apartment buildings, offices, and shops; (2) detached houses mixed with units; (3) apartments and terrace houses; and

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Fig. 2. Case-study stations in their urban context.

(4) detached family houses in the cul-de-sac street network, shown in Fig. 3. Self-selection is established when the participants' existing and preferred neighborhoods are the same.

Questionnaires are usually limited to nominal, ordinal, and continuous forms of data, and the spatial dimension of walking route choices are difficult to capture. To overcome this limitation, a map was designed which allowed participants to draw the routes they walked to access the rail stations and pinpoint locations they found unsafe from traffic and crime.

This study required a sample of commuters who travel to New Lynn and Baldwin Avenue stations. Five students were hired to distribute survey invitations during the morning peak period (7–9 a.m.) outside the stations. The invitation included a participant's information sheet and a URL to do the questionnaire online (the developed web application).

Collected Data

Questionnaire Data

After distributing 5,000 invitations over 12 weekdays, only 298 people completed the survey. A possible explanation for the low response rate (5.9%) is that the potential respondents could not be reached by the surveyors because of restrictions by the transport authorities on where the surveyors can approach the commuters. From the 298 responses, 264 were deemed suitable for analysis. The most common trip purpose was the journey to work (93.9%), and most of the respondents were frequent users (84.8%). The collected data can be categorized into spatial and nonspatial. Characteristics of the nonspatial data (Questions 1–8 and 13–16) for each station are shown in Table 2.

Table 1. Measurement items in the questionnaire

Category	Question	Description	Response type
Socioeconomic	What is your gender?	—	Nominal
	Which age group do you belong to?	—	Scale
	What is your approximate annual household income before tax?	—	Scale
	How many people live in your household?	—	Scale
Trip characteristics	At what station do you get on the train?	—	Nominal
	How did you get to this train station?	Asks about the mode of travel to the rail station	Nominal
	What is the main purpose(s) of your trip?	—	Nominal
	In last month, how often have you used the train?	—	Ordinal
	Please provide the approximate address (street name and suburb) of your house.	These questions only appear if the respondent use walking for the travel mode to the case-study train station	Spatial
	Please draw the route you choose to travel to this station on the map.		Spatial
Neighborhood characteristics	Considering the route you took to get to the station, please point out the locations you DID NOT feel safe from traffic while walking.		Spatial
	Considering the route you took to get to the station, please point out the locations you DID NOT feel safe from crime		Spatial
Self-selection of neighborhood	Which of these images is more similar to the road layout of your neighborhood?		Nominal
	If you were to move, which of the images would be your preferred neighborhood?		Nominal

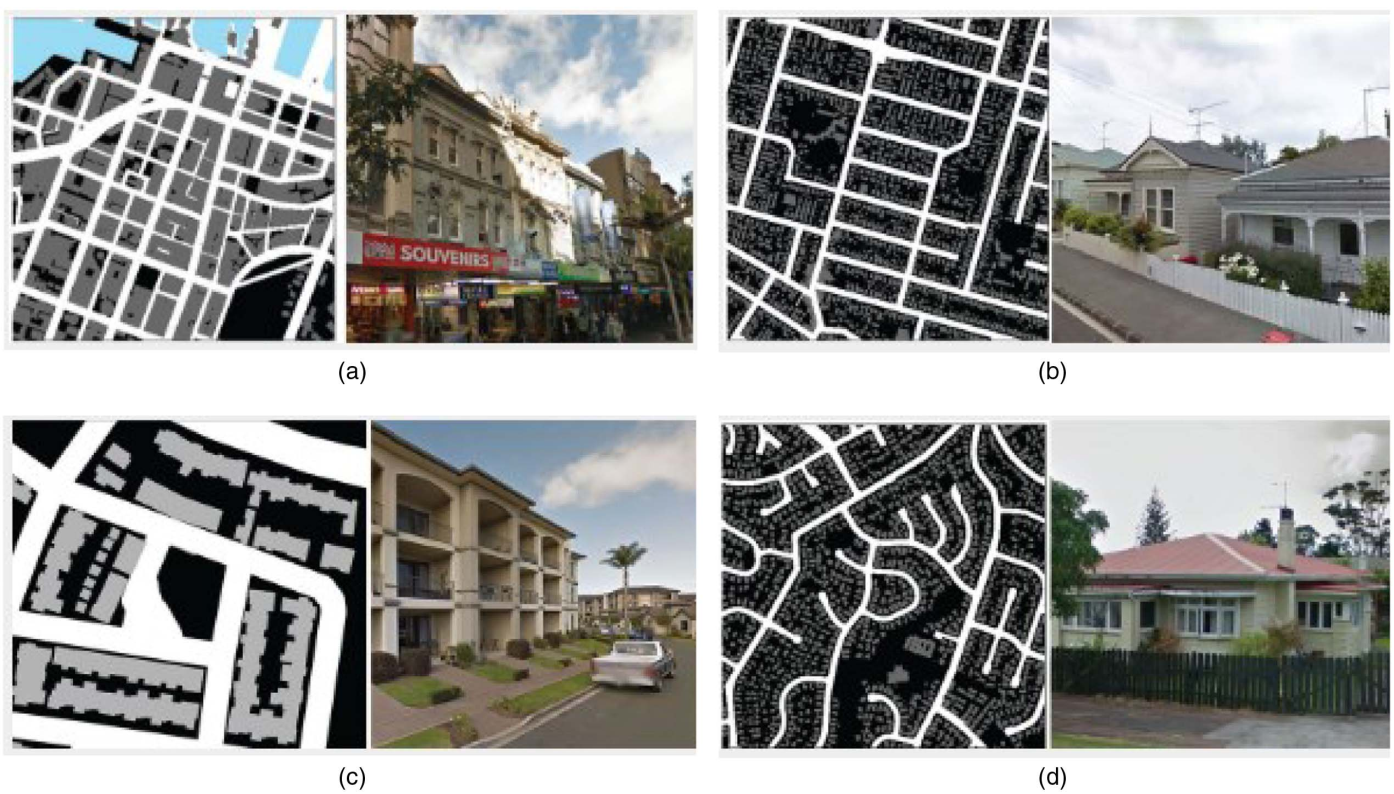

Fig. 3. Four diverse urban forms in Auckland: (a) a lively and active place (a mixture of apartment buildings, offices, and shops); (b) detached houses mixed with units (streets meet each other at a right angle); (c) apartments and terrace houses; and (d) mostly cul-de-sac and no through traffic (big detached family houses). [Google (2015), Streetview, Google Maps.]

Some data-cleaning processes are required before the collected data can be used for analysis. Following the theoretical framework, the collected data was cleaned to include only people frequently using train services for work. Moreover, records with incorrect spatial data needed to be removed from the analysis. After data cleaning, 27% of the participants for the Baldwin Avenue station and 74% of the participants for the New Lynn station were removed from the analysis.

The focus of this study is on walking access to rail stations to assess the urban form in the vicinity of the case-study train stations. Other modes of access are beyond the scope of this research.

Table 2. Description of participants

Socio-economic characteristics	Total number (%)	Baldwin Ave station (%)	New Lynn station (%)
Total samples	264	72	188
Mode of transport			
Bus	60 (22.7%)	0	60 (31.9%)
Cycle	8 (3.0%)	0	8 (4.3%)
Drive	36 (13.6%)	8 (11.1%)	28 (14.9%)
Walk	116 (43.9%)	60 (83.3%)	52 (27.7%)
Dropped off	44 (16.7%)	4 (5.6%)	40 (21.3%)
Gender			
Male	134 (50.8%)	33 (45.8%)	98 (52.1%)
Female	130 (49.2%)	39 (54.2%)	90 (47.9%)
Gender diverse	0	0	0
Age			
16–19 years	0	0	0
20–24 years	42 (15.9%)	10 (13.9%)	32 (17.0%)
25–29 years	37 (14.0%)	10 (13.9%)	24 (12.8%)
30–34 years	22 (8.3%)	6 (8.3%)	15 (8.0%)
35–39 years	42 (15.9%)	8 (11.1%)	34 (18.1%)
40–44 years	32 (12.1%)	9 (12.5%)	23 (12.2%)
45–49 years	31 (11.7%)	10 (13.9%)	21 (11.2%)
50–54 years	26 (9.8%)	6 (8.3%)	20 (10.6%)
55–59 years	18 (6.8%)	5 (6.9%)	13 (6.9%)
60–64 years	13 (4.9%)	7 (9.7%)	6 (3.2%)
65 years and over	1 (0.4%)	1 (1.4%)	0
Annual income			
NZ$20,000 or less	12 (4.5%)	2 (2.8%)	8 (4.3%)
NZ$20,001–30,000	10 (3.8%)	2 (2.8%)	10 (5.3%)
NZ$30,001–50,000	39 (14.8%)	7 (9.7%)	24 (12.8%)
NZ$50,001–70,000	33 (12.5%)	9 (12.5%)	32 (17.0%)
NZ$70,001–100,000	69 (26.1%)	17 (23.6%)	56 (29.8%)
NZ$100,001 or more	101 (38.3%)	35 (48.6%)	58 (30.9%)
Household size			
1	27 (10.2%)	4 (5.6%)	23 (12.2%)
2	59 (22.3%)	18 (25.0%)	38 (20.2%)
3	56 (21.2%)	17 (23.6%)	38 (20.2%)
4	68 (25.8%)	27 (37.5%)	43 (22.9%)
5	38 (14.4%)	6 (8.3%)	30 (16.0%)
6	16 (6.1%)	0	16 (8.5%)
Purpose of trip			
Entertainment/socializing/leisure	0	0	0
Personal/medical	0	0	0
Tertiary education (e.g., university)	16 (6.1%)	0	16 (8.5%)
Travel to work	248 (93.9%)	72 (100.0%)	172 (91.5%)
Frequency			
Only occasionally	28 (10.6%)	4 (5.6%)	8 (4.3%)
A few days (less than three times a week)	12 (4.5%)	4 (5.6%)	156 (83.0%)
Frequently (three times or more in a week)	224 (84.8%)	64 (88.9%)	24 (12.8%)
Self-selection, current neighborhood			
Type A	0	0	0
Type B	84 (31.8%)	50 (69.4%)	24 (12.8%)
Type C	8 (3.0%)	6 (8.3%)	8 (4.3%)
Type D	24 (9.1%)	4 (5.6%)	20 (10.6%)
Self-selection, preferred neighborhood			
Type A	16 (6.1%)	4 (5.6%)	12 (6.4%)
Type B	56 (21.2%)	35 (48.6%)	16 (8.5%)
Type C	4 (1.5%)	5 (6.9%)	4 (2.1%)
Type D	40 (15.2%)	16 (22.2%)	24 (12.8%)

Note: Percentages do not add up to 100% because of missing data.

Many people arrived at the New Lynn station by modes other than walking, such as being dropped off, driving, and cycling, which contributed to the high number of participants not being eligible for the study. There are bus-to-rail transfers and cycling options available at Baldwin Avenue station. However, none of the respondents used these options, most probably due to the impracticality of these options.

Spatial Variables

Questions 9–12 collected spatial data regarding the respondents' street and suburb, the route they walked to reach each of the stations, and locations identified as not being safe from crime and traffic. A summary of the collected data is shown in Fig. 4. The thicker lines indicate the routes that are commonly walked by the local transit users.

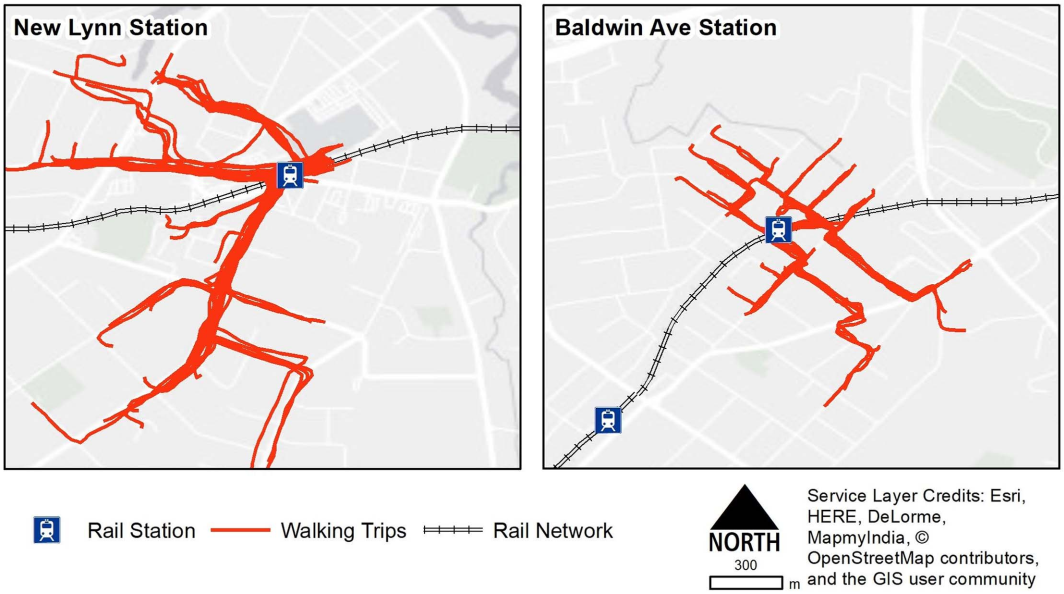

Fig. 4. Collected spatial data.

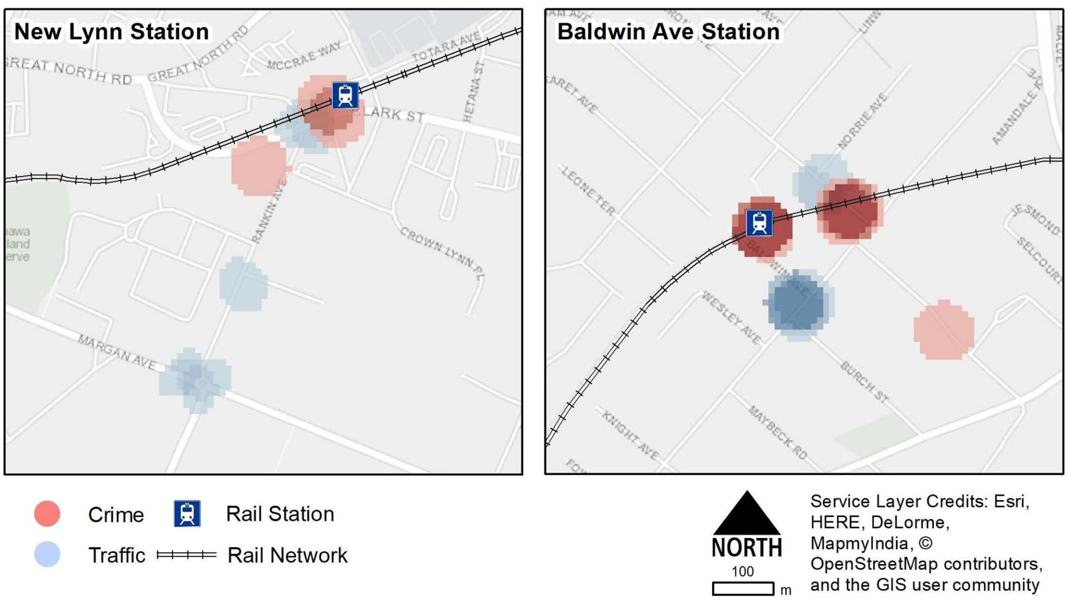

Fig. 5. Perception of safety issues in relation to traffic and crime. Note: Darker shading represents higher safety risks.

The collected spatial data cannot be used directly for the analysis. This information is used to generate four variables. First, collected routes to the stations are placed on the street network to measure actual distance in meters. Second, the routes taken by respondents were compared to the shortest routes to identify whether they used the shortest path. Third, a heat map was generated from the locations that participants identified as unsafe traffic to mark all respondents crossing the hot spots. Finally, another layer was added to the heat map to identify locations which were deemed as unsafe from crime by the participants, as shown in Fig. 5.

Analysis

The method proposed in this study follows two principles of justice under Adli's transit justice framework. The first principle is to provide a minimum accessibility to residents. Minimum accessibility can be evaluated by spatially comparing the actual and estimated walking isochrones. The second principle is to provide accessibility for the less well-off population, which can be evaluated by a regression model. The results of these analyses are explained in the following sections.

Spatial Analysis

This analysis is to address the first principle of the transit justice framework, which is to provide a minimum accessibility to residents. Based on a survey in Auckland (Wilson 2013), a distance over 1,200 m is considered below a minimum level of access for walking to a station. This analysis highlights routes with poor walkability that are within the rail station catchments and therefore do not provide the minimum level of accessibility.

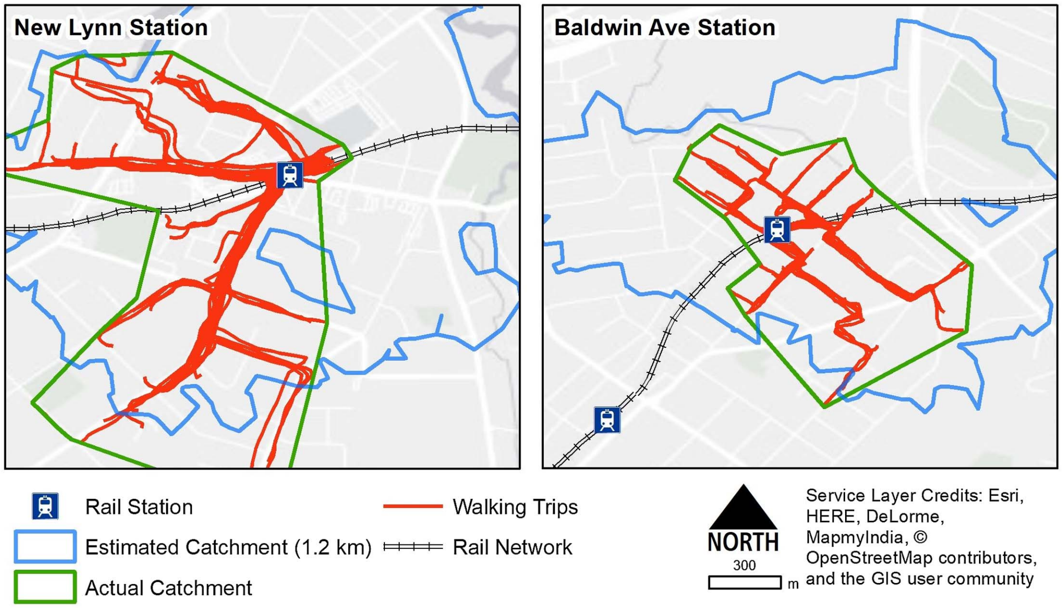

Fig. 6. Actual versus estimated catchments. Note: The estimated catchment is based on open street network data. Where there is more than one station available in a 1.2-km vicinity of a location, the catchment only includes the closest station.

Holistic accessibility measures such as catchment analysis tend to include all people who walk less than 1,200 m to a station as provided with minimum access. While this measure is informative and can be readily computed with modern mapping technologies, it remains unsatisfactory when compared to actual behavior. Findings show that the actual catchments of the stations are affected by more factors than walking distance/time. It can be seen that the actual catchments extend differently compared to the estimated catchment area using a radius of 1,200 m (Fig. 6).

Descriptive statistics for each station catchment are summarized in Table 3. The results show that both the area and the population covered in the actual catchments are considerably lower than the modeled catchments. The estimated median income, however, is not much different.

To better understand this difference, the access needs to be measured by a number of variables, not the time/distance of the trip. This is important, as different households value destinations differently, hence the social value of walking to a train station has a different meaning to each household and should ideally be specific to each one. In the case studies, some people tend not to use the station for their trips, while they are technically covered in the station catchment.

This shows, unlike what ordinary GIS network models assume, that the cost of accessing the stations is not evenly distributed, and the minimum accessibility is not spatially provided for all users in the modeled catchments. Collecting sample data from the commuters, on the other hand, provides more realistic catchments of rail stations.

Table 3. Descriptive statistics of stations

Station	Catchment	Area (km^2)	Population (1,000 people)	Estimated median income (NZ$1,000)
New Lynn	Actual	1.33	4.19	55.61
	Estimate	2.55	6	52.42
	Difference	−48%	−30%	6%
Baldwin	Actual	0.63	2.27	89.52
	Estimate	1.7	5.63	90.29
	Difference	−63%	−60%	−1%
Total	Actual	1.96	6.46	67.15
	Estimate	4.25	11.63	71.58
	Difference	−54%	−44%	−6%

Note: The population and income are based on 2013 census data (Statistics New Zealand 2013).

Regression Analysis

Multiple regression provides a way of examining the joint impact of a set of variables. The dependent variable for the analysis is the distance walked to the station (100-meter units) as a measure of accessibility. The spatial data collected via questionnaires makes this study unique. Spatial distribution of safety from crime and safety from traffic allows the hotspots to be identified, and the route to train stations allows for measuring distance and identification of the shortest paths. The coefficients show the relationship between accessibility and each independent variable. The adjusted R squared value shows that around 82% of the variation in accessibility is explained by the independent variables. The multiple regression analysis results are presented in Table 4. Variables that are not statistically significant are removed from the models.

The regression analysis for both stations ($n = 100$) shows that accessibility is significantly associated with the number of people in a household, age, gender, household income of the commuter, shortest path walked, feeling unsafe from traffic and crime, and finally the station itself. Using stations as a dummy variable allows (1) all responses to be included such that the coefficients are not station-specific and (2) to avoid a biased impact on the income variable as a consequence of omitting the station variable.

Including stations as a simple dummy variable means a fixed slope for regressing accessibility on income. Because each station has a different distribution of income, as can be seen by projecting the points onto the horizontal axis in Fig. 7, using a simple dummy variable inflates the size of errors. To address this issue, an

Table 4. Association of accessibility variables with income level for people using trains to go to work from 7 to 9 a.m.

Variables	Coefficient	Standard error	t	$P > \|t\|$
Intercept	8.2415	1.192	6.913	0.000***
Station (1 = New Lynn)	−3.1907	1.396	−2.286	0.025**
Annual income (NZ$1,000)	−0.0514	0.009	−5.471	0.000***
Station* annual income (NZ$1,000)	0.0968	0.014	6.777	0.000***
Gender (1 = female)	0.6394	0.355	1.800	0.075*
Age	0.0749	0.020	3.809	0.000***
Household size	0.3207	0.156	2.051	0.043**
Shortest path (1 = Yes)	−3.5468	0.565	−6.276	0.000***
Crossing traffic (1 = Yes)	1.1304	0.404	2.797	0.006***
Crossing crime (1 = Yes)	−1.3848	0.481	−2.879	0.005***
Self-selection (1 = Yes)	8.2415	1.192	6.913	0.000***
Observations	100	—	—	—
Adjusted R squared value	0.821	—	—	—

Note: The dependent variable is distance walked to station in 100-m units, ***p-value < 0.01, **p-value < 0.05, and *p-value < 0.1.

interacting dummy station variable with explanatory income variable has been added to allow for a difference in slopes.

The regression shows that people are expected to encounter more unsafe traffic crossings for longer paths. Concern over safety from crime has a negative impact on the distance people walk, and people who take the shortest path tend to walk less. Moreover, women, older people, and people in big households tend to walk more. The self-selection factor is not significantly associated with walking distance to the rail stations.

For the New Lynn station, the results show that the TOD provides better access to low-income households that are in close vicinity to the station. An increment of NZ$10,000 in income moves the pedestrian 45 m away from the station, ceteris paribus. Whereas, for Baldwin Avenue station those with the higher income are at closer proximity to the train station. An increment of NZ $10,000 in income brings the pedestrian 51 m closer to the station, ceteris paribus.

It is worth noting that these findings are correlations and the direction of causation could be either way. For example, it is possible that the higher accessibility for houses near Baldwin Avenue station, over time, has resulted in higher income for their residents. Or, people with higher income can afford prime locations near the station. From an urban planning perspective, the results for the Baldwin Avenue station flag a "potential" for changes in land-use policies, such as zoning, to allow for higher utilization. The objective of the analysis is to highlight where transportation facilities do not meet social justice principles. This can trigger a just and democratic discussion about why it is happening and what can be done.

Discussion

For the transport systems to be equitable, they need to provide a minimum level of accessibility for everyone and be just by disproportionately benefiting the less well-off. In terms of minimum accessibility (sufficientarianism), both stations should provide enough accessibility for people living in a 12,000-m catchment per station. However, the findings show that the actual catchments cover considerably less area than the traditionally estimated catchments and cover much less population. The New Lynn station, with 30% less than minimum population coverage, performs slightly better than the Baldwin Avenue station, with 60% less than minimum population coverage.

In terms of prioritizing the disadvantaged groups (egalitarianism), the land-use planning around a terminal should allow low-income households to have better access. While the TOD design in The New Lynn station allows for better access for commuters with low income, high-income neighborhoods benefit more from the Baldwin Avenue station, which is not in line with the justice framework. These results, however, need some careful consideration. The New Lynn station attracted more commuters compared to the Baldwin Avenue station, with significantly more ridership. Therefore, it was more difficult to attain participants at the Baldwin Avenue station. Moreover, many respondents reach the stations

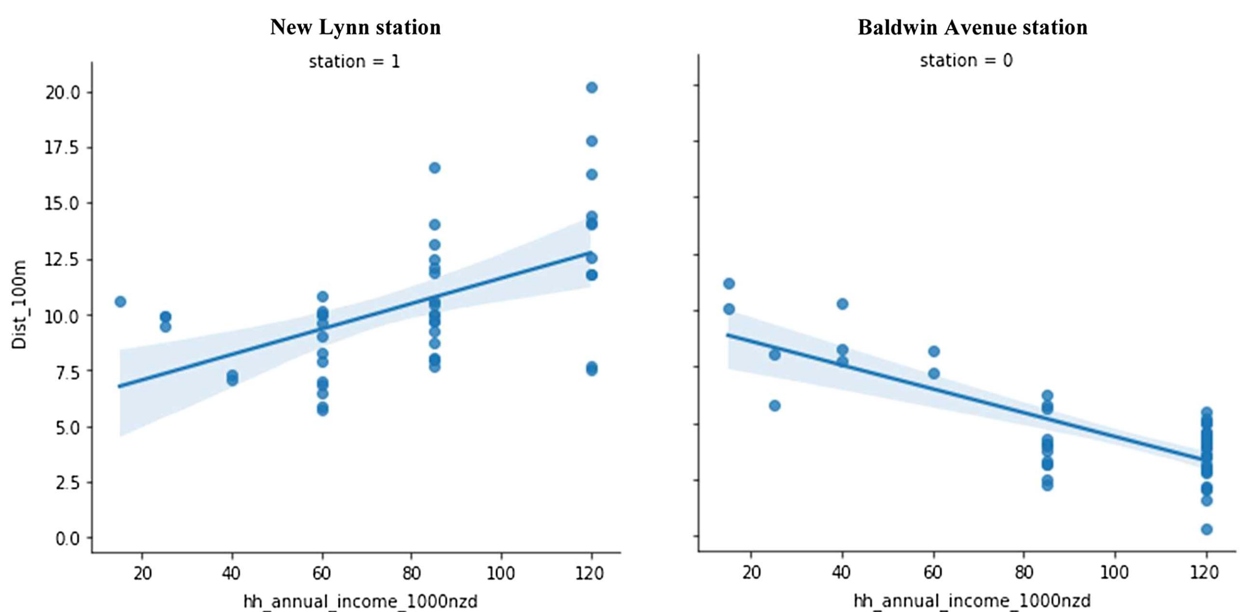

Fig. 7. Association between a household's annual income and distance walked to train stations. The shaded area shows the confidence interval of 95% for the regression estimate.

using modes than other walking (e.g., transit, cycling, driving, etc.) and they could not be included in this study. The interactive questionnaire, admittedly not without limitations, simplifies current difficulties in data collection.

The main goal of this research is to extend the transit justice framework, discussed by Adli et al. (2019), to be applicable at a detailed scale of planning and design of a rail station. The findings showed that both sufficientarian and egalitarian aspects of the framework are applicable and measurable. This addresses the "lack of tangible measures" issue, which is one of the main barriers of incorporating the social justice objective in transit plans. The results demonstrate that the transit justice framework has the potential to be extended and its measures can be quantified. The results, however, do not investigate why a setting is less or more just. Instead, it highlights (in)justice for the consideration of planners.

It may be questioned whether these objective measures can help understand the complex and diverse social effects of rail stations. In response, the literature identifies a gap between policy and practice in relation to social justice objectives. In this context, simple, quantifiable, and stable measures may be better than no measures. On the other hand, the aforementioned principals of justice cannot be considered as the only solution; careful application and interpretation are, as always, needed. Also, urban configurations that are flagged as unjust as the result of these justice measures may nonetheless be a valuable part of the city and do not require any planning interference.

The ready-to-use open-source codes, a more user-friendly interface, and the universal theoretical framework can assist transport authorities to replicate this study in their jurisdictions with minimal effort. This helps them to accommodate the social justice objectives in their investment evaluation processes and objectively measure its success.

The method is not without its limitations. First, a prime location can provide access to a combination of amenities and cannot be only defined by a good walkable distance to a rail station. Other methodological issues, such as the dynamic effects of households' location in response to accessibility, are also omitted. Second, the methodology relies on the participation of transit users. The result of the regression model in this study is based on 48 valid observations for the New Lynn station and 52 valid observations for the Baldwin Avenue station, which is the minimum required for the statistical analysis used. More advanced techniques such as sending an invitation via a text message or email can improve the response rate. Third, the method heavily relies on mobile internet infrastructure. Cities with limited telecommunication infrastructure or people with less internet knowledge may choose not to participate in a similar study.

Conclusion

More cities around the world are heavily investing in active modes, especially in the form of rail transit. Unfortunately, the investments focus on more tangible economic and environmental gains, and less tangible social factors such as justice are usually overlooked. In this study, the results show that neither station provides sufficient accessibility, because their actual catchments are much less than the estimated catchments determined by traditional approaches. However, New Lynn performs relatively better compared to the Baldwin Avenue station. In terms of prioritizing lower income transit riders, again New Lynn station performs better by allowing them to access the station from a short distance. While some recommendations can be made about achieving social justice in each case study, the main value of the proposed methodology is to compare rail stations and show which station is more or less just rather than defining the just ideal. The findings show that the transit justice framework not only works for high-level transit planning, as it was originally intended for, but also can be applicable at station planning and design levels.

The current study adds to the limited but expanding body of research in transit justice in four main avenues. First, this study expands the application of existing theoretical framework on transit justice to station planning and design. Second, this methodology is spatial and captures the mostly overlooked spatial dimension of a questionnaire survey to provide a better understanding of the travel patterns around stations. Third, the methodology is validated in that its conclusions are based on measures of statistical significance. Fourth, the method is flexible, as it can model a range of transit infrastructures and different jurisdictions. The paper encourages further research to develop the model by including other modes (such as cycling), different time spans (such as all day, evening peak, and interpeak), and specific job categories (such as industrial, office, and service jobs) to build on the present findings and to examine how a rail station can integrate with its context under the transport justice framework.

Data Availability Statement

All data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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