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Right to the city: Applying justice tests to public transport investments

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ABSTRACT

Many policy-makers are grappling with the twin challenges posed by growing travel demands and persistent socioeconomic inequality. To address these issues, numerous studies propose and apply "justice tests", which relate the effects of transport policies to prevailing socioeconomic deprivation. While the theoretical foundations of justice tests are well-established, there exists less agreement on methodological aspects and empirical specifications. In this paper, we propose a new criterion for evaluating the results of justice tests—namely the correlation coefficient—and explore its sensitivity to empirical assumptions by way of a case study of a major public transport investment. In comparison to other criteria identified in the literature, our proposed criterion appears to generate relatively stable results while being simple to calculate, interpret, and communicate.

1. Introduction

The sustained growth of cities is placing increasing pressure on urban infrastructure (United Nations, 2014; World Bank, 2014). In response, policy-makers in many jurisdictions have proposed major investments in public transport (PT) infrastructure and services.

At the same time, persistent socioeconomic inequality has received increasing attention (Glaeser et al., 2008). Organisations such as the World Bank, the International Monetary Fund (IMF), and the Organisation for Economic Co-operation and Development (OECD) have adopted policies designed to mitigate socioeconomic inequality (International Monetary Fund, 2014; OECD, 2013; World Bank, 2013).

Growing travel demands and persistent inequality give rise to new policy questions. Ideally, major PT investments would be efficient—in that their economic benefits exceed their costs—and equitable—in that they disproportionately benefit the less well-off. Several studies propose the use of accessibility-related "justice tests" to analyse the effects of PT investment on inequality (Lucas et al., 2016; Martens, 2012; Soja, 2010). While their theoretical basis is well-stablished, evidence suggests justice tests have had only limited influence on policy.

In this study, we seek to build on the existing literature in two ways. First, we propose a new criterion for determining "just" outcomes: The correlation coefficient between the *change in accessibility* and *prevailing socioeconomic outcomes*. Second, we use a case study to explore the sensitivity of our criterion to its empirical specification. Compared to other criteria identified in the literature, we find the correlation coefficient is relatively stable, while being simple to calculate, interpret, and communicate.

The following sections of this paper are structured as follows: Section 2 reviews the literature; section 3 outlines our research methodology; section 4 introduces our case study; sections 5 and 6 present and discuss our results, respectively; and section 7 concludes.

2. Literature review

Our paper draws on a broad and rich body of literature from fields as diverse as economics, sociology, geography, and public policy. In the interests of succinctness, here we focus on findings that are most relevant to our research methodology.

2.1. Urban economics – Attraction and segregation?

The urban economics literature suggests that cities can simultaneously *attract* and *segregate* low-income households. Low-income households are attracted to urban areas due to the socioeconomic advantages they confer, such as agglomeration economies (Glaeser et al.,

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2008).[1] Within cities, however, high-income households will—holding other factors constant—tend to out-bid low-income households in areas with higher amenity, leading to spatial segregation of households by income (Mieszkowski and Mills, 1993; Roback, 1982). The heterogeneous spatial distribution of households by income and amenity levels is a common feature of cities globally (Fujita et al., 2001; Massey and Eggers, 1993). If "accessibility" is an amenity that people generally value, then, ceteris paribus, we expect low-income households to be concentrated in areas that have less of it, and vice versa.

2.2. Sociological concepts of spatial justice – "The Right to the city"

While concepts of justice date back to Greek city-states, it is largely in the last two centuries that legal systems have mandated justice at the individual level (Johnston, 2011, pp. 3-4). A theoretical milestone was reached with John Rawls' "Theory of Justice" (1971), which argues that policy settings should be based on how they affect the least fortunate. A large body of literature expounds sociological concepts of spatial justice. Lojkine (1972), for example, argues that urban policies tend to increase distances between working class jobs and housing, an issue potentially compounded by inequitable access to transport systems. Harvey (1973) identifies the risk of dynamic effects: Policy settings may—either intentionally or unintentionally—reinforce prevailing socioeconomic inequalities.

Lefèbvre first coined the "right to the city" concept in *Space and Politics* (Lefèbvre, 1973), which he expanded on in subsequent publications, namely, *The Right to the City* and *The Production of Space* (Lefèbvre, 1991; Lefèbvre, 1986). In the latter, Lefèbvre calls for a focus on understanding the political economy of cities and the effects of policies implemented therein. Dikec (2001) treats similar issues. Recent work by Soja (2010) recommends "amplifying and extending the geographical approach to justice into new areas of understanding and political practice" (p. 5). Space is not, in Soja's view, an "empty void", but is rather "filled with politics, ideology, and other forces shaping our lives" (p. 19). Notably, Soja (2010) advocates for the use of a "justice test" to measure whether policies benefit more deprived areas.

Several recent studies consider how to reflect sociological concepts of spatial justice within transport policy settings. Martens (2012) focuses on accessibility and explores principles for determining an ethical distribution. After eliminating several well-known distributive principles, including a Rawlsian approach, Martens (2012) recommends maximising average accessibility subject to a constraint on the maximum allowable range between the most and least well-off. A focus on accessibility is supported by Van Wee and Geurs (2011), which recommends complementing utilitarian welfare economics with egalitarian ethical principles. Similarly, Lucas et al. (2016) blend "egalitarianism" and "sufficientarianism", as measured by Gini coefficients and accessibility thresholds, respectively.

Our methodological approach adapts and extends Martens (2012) and Lucas et al. (2016). We diverge from Martens (2012) in two key respects. First, we disregard the latter's goal of maximising average accessibility, which we consider to be an indicator of effectiveness rather than equity. Second, instead of focusing on the *range in accessibility* between the most and least well-off, we consider the *change in accessibility* across the entire distribution of socioeconomic deprivation. Our methodology is perhaps closest to Lucas et al. (2016), but differs in the use of correlation coefficients rather than Gini coefficients. The former is, in our view, simpler to calculate, interpret, and communicate.

2.3. Geographic concepts of accessibility – mobility and opportunity

Our study is heavily influenced by the large body of literature on geographic concepts of accessibility. Following Hansen (1959), we interpret accessibility as people's overall ability to reach socioeconomic opportunities.[2] Abley and Halden (2013) identify three distinct components of accessibility: namely, *transport mobility*, which defines the area one can reach in a certain travel-time or distance; *socioeconomic opportunities*, which relates to an indicator, such as employment, in a defined area; and *personal capability,* which describes one's financial and physical ability to use the transport system.[3] We define transport mobility and socioeconomic opportunities using travel-time and employment, respectively.[4][5]

Numerous studies relate PT accessibility to socioeconomic outcomes. Delbosc and Currie (2011) use Gini coefficients to measure access to PT services in Melbourne, where access is defined in terms of the number of PT services per day utilising nearby stops. In contrast to Delbosc and Currie (2011), we measure access to employment opportunities provided by PT services, rather than the number of PT services themselves. We agree with Manaugh et al. (2015) that PT service is merely a "means to an end" (p. 174).

Bocarejo and Oviedo (2012) investigate PT accessibility in Bogota using distance-decay, or impedance, models that take travel-time and travel-cost as inputs. For each zone, model parameters are estimated by way of regression analysis. Using these models, the authors assess the effects of transport policies, such as changes in PT fares and new PT infrastructure, on accessibility for each zone. The approach of Bocarejo and Oviedo (2012) is somewhat novel, and informs some aspects of our empirical testing. Compared to Bocarejo and Oviedo (2012), however, we focus on the criterion used to determine whether an outcome is just. Our empirical specification also avoids the need for micro-data or regression analysis and, moreover, we devote considerable attention to understanding the sensitivity of our results to our chosen specification.

Foth et al. (2013) relate socioeconomic deprivation to changes in the distribution of PT accessibility in Toronto in the period from 1996 – 2006, and find that the most deprived areas enjoy high levels of accessibility. El-Geneidy et al. (2015) also consider the distribution of PT accessibility in Toronto. Two employment-based accessibility measures are computed for each census tract, where employment is segmented into low and high wage jobs. El-Geneidy et al. (2015) conclude "residents in socially disadvantaged areas have equitable if not better transit accessibility to jobs than socially advantaged groups …" (p. 17). While both Foth et al. (2013) and El-Geneidy et al. (2015) inform our study, we note

[1] "Agglomeration economies" is a general rubric used to describe the (net) socioeconomic benefits of physical proximity (Glaeser et al., 2001; Head and Mayer, 2004). Agglomeration economies exist in both consumption and production, and operate via several microeconomic channels, such as knowledge spill-overs, labour market frictions, and input/output linkages (Anas et al., 1998; Glaeser et al., 2009; Glaeser, 2011).

[2] A large number of studies relate transport accessibility to various socioeconomic outcomes (see, for example, Cervero, 2001; Currie and Delbosc, 2010; Gibbons and Machin, 2005). Åslund et al. (2010) present a novel longitudinal analysis of accessibility and employment for refugees in Sweden and find that those initially housed in locations with lower levels of accessibility (measured in employment) are more likely to be unemployed nine years later. Such studies suggest accessibility is relevant to socioeconomic outcomes and tend to support Soja's contention that— in the absence of policy intervention— spatial inequalities may persist over time.

[3] Transport policy has typically emphasized mobility, as exemplified by investments designed to reduce travel times (Metz, 2008). In contrast, land use policy has tended to focus on increasing socioeconomic opportunities by influencing the location and intensity of development (Aldous, 1992; Calthorpe, 1993; Dantzig and Saaty, 1973; Leccese and McCormick, 2000; Meck, 2002). Finally, social policy has traditionally sought to mitigate differences in personal capability, for example by offering discounts (Asensio et al., 2003; Jones et al., 2012).

[4] Travel-times using PT comprises three distinct components, namely, walking to/from stops, time spent waiting at the stop for PT services, and time spent travelling in the PT vehicle itself (Walker, 2011).

[5] For detailed discussions of accessibility metrics see El-Geneidy and Levinson (2006); Geurs and van Wee (2004); and Handy and Niemeier (1997).

two primary points of difference: first, we adopt a different criterion for determining whether a change in accessibility is "just" and, second, we test the sensitivity of results to our adopted empirical specification.

Golub and Martens (2014) assess the equity of regional transportation plans in the San Francisco Bay Area. Their indicator of choice is the ratio of accessibility between car and public transport, which they analyse under different transport investment scenarios. In contrast to Golub and Martens (2014), we seek to compare justice test criteria while avoiding the use of bespoke transport model outputs. El-Geneidy et al. (2016) considers the effects of PT travel-time and estimated fares on PT accessibility in Montreal. In the absence of micro-data, we focus solely on measurements of travel-time.

To finish, some accessibility studies have been criticised for using resource-intensive and/or context-specific methodologies. Lucas (2006), for example, concludes government agencies may be "reluctant to make the necessary calculations", because "gathering the data and carrying out the initial assessments of accessibility is both a time consuming and frustrating process" (p. 805). Several existing studies rely, to varying degrees, on jurisdiction-specific and/or privately-held models or data (see, for example, Anderson et al. (2013)). Recent years have seen a trend towards greater reliance on open PT data, as discussed in Kuhn (2011), Qu et al. (2016) and supported by institutions, such as the World Bank (World Bank, n. d.). For these reasons, our application makes use of commonly-available, open-source data.[6]

2.4. Public policy frameworks for evaluating public transport investments

Do the policy frameworks used to appraise PT investments reflect the theories and methods discussed in previous sub-sections?

Wallis et al. (2014) review policy frameworks in the U.K. Australia, and New Zealand and identify two common evaluation frameworks: *an economic approach*, which applies social benefit-cost analysis (SBCA), and *a strategic approach*, which uses multi-criteria analysis (MCA). The economic approach produces measures of value that can be readily compared between projects and across jurisdictions. The strategic approach, in contrast, more flexibly accommodates complex objectives, such as considerations of inequality. Based on their review, Wallis et al. (2014) recommend that the economic approach (i.e. SBCA) be incorporated within a wider strategic approach (i.e. MCA), noting that this "blended" approach is already used in some jurisdictions, such as the UK (Department for Transport, 2013). The MCA approach seems well-suited to incorporating the results of justice tests.

Several organisations have reflected the "right to the city" concept in high-level policy settings (see, for example, the Department for Transport (2004) and the Federal Transit U.S. Department of Transportation Federal Transit Administration (2012)). A 2001 statute in Brazil, for example, enshrined the concept within law (Polis Inclusive, 2011). Whether such high-level policy direction influences transport investment priorities remains something of a moot point. Reviewing the distributional goals articulated in transport planning policy documents in the U.S. Martens et al. (2012) finds little explicit guidance and conclude that most agencies "all but ignore the distribution of transport-related benefits in the evaluation of plan alternatives" (p. 693). Manaugh et al. (2015) undertake a similar review and reaches similar findings, which they attribute to the lack of specific measures supporting the stated social equity goals. In echoes of Wallis et al. (2014), Manaugh et al. (2015) recommend incorporating specific, accessibility-based, easily-communicated measures of equity into the MCA that are used to appraise transport investment options.

Similar findings are reported in the U.K. context. Lucas (2006) considers the origins of transport policies on social disparities, which Lucas (2012) subsequently evaluates in terms of their effectiveness. Notwithstanding promising theoretical and methodological progress, Lucas (2012) observes "… there appears to be relatively poor take-up of the transport and social exclusion agenda amongst local transport authorities …" and calls for improved tools "at every level of governance." (p. 112). We note the U.K.'s Department for Transport has recently produced relatively detailed guidance on the use of accessibility analyses in transport appraisals (Department for Transport, 2015). Section 8 of WebTAG Unit A4-2 considers the effects of PT on accessibility to key destinations, such as medical and educational facilities; recreational, leisure, and social facilities; and employment. As WebTAG Unit A4-2 is a relatively recent document, we could identify no research assessing its influence on PT investment priorities.

Looking further afield, analysis of distributional effects is considered in "T5 Distributional (Equity) Effects" of the Australian Transport Assessment and Planning (ATAP) guidelines (TaIC, 2016). ATAP expresses support for the use of accessibility analysis to ascertain the distributional impacts of proposals but provides little guidance on what is equitable and how analysis should be undertaken. In New Zealand, the "Economic Evaluation Manual" (EEM) devotes one of approximately four hundred pages to equity, noting "… analysis of the distribution of benefits and costs among different groups of people is not required for the economic efficiency evaluation of the project. However, reporting of the distribution of benefits and costs, particularly where they relate to the needs of the transport disadvantaged, is part of the funding allocation process" (p. 5-457). Our review uncovered no further guidance on how equity was considered within the "funding allocation process".

Based on this—admittedly brief—review of policy settings in the U.S. U.K. Australia, and New Zealand, there seems to be relatively broad-based interest in understanding the distributional impacts of PT investment, and a common focus on using accessibility-related indicators. Of the jurisdictions considered, the U.K. seems to have the most well-developed guidance. On the other hand, questions remain over the degree to which this policy support influences transport investment priorities, especially in the U.S. Australia, and New Zealand.

3. Research methodology

How does one determine whether a distribution of accessibility is just? As noted above, Martens (2012) proposes the range in accessibility between the most and least well-off. Under this criterion, if a proposed PT investment maintains or reduces this range, then it is defined to be "just". Alternatively, Lucas et al. (2016) recommends using Gini coefficients.

In our view, both criteria have limitations. The primary problem with the range criterion proposed in Martens (2012) is that it only considers changes in accessibility at the end-points of the distribution of socioeconomic outcomes. One can easily imagine a situation where a proposed PT investment causes this range to increase, subsequently failing the justice test, even though the preponderance of accessibility benefits falls to people who are less well-off. While Lucas et al. (2016) propose using Gini coefficients to analyse the full distribution of accessibility outcomes, how changes in the Gini coefficient for accessibility relate to deprivation are not immediately obvious, nor necessarily straightforward to calculate, interpret, or communicate.

Here, we propose an alternative criterion for determining whether the change in accessibility caused by PT investment is just: The Pearson correlation coefficient, ρ_{XY}, relating the change in accessibility Y to prevailing socioeconomic deprivation X. Formally

$$\rho_{XY} = \frac{cov(X, Y)}{\sigma_X \sigma_Y},$$

where $cov(X, Y)$ denotes the covariance of X and Y, and σ_X and σ_Y denote the standard deviation of X and Y, respectively. Usefully, ρ_{XY} considers the change in accessibility across the full distribution of socioeconomic outcomes and lends itself to straightforward interpretation. Where $\rho_{XY} >$

[6] Our methodology is transferable where there is (1) a GTFS feed; (2) Open Street Maps; and (3) population data. Although GTFS feeds have limited coverage, they are now available for over 500 locations worldwide.

0 and is statistically significant, then we have evidence the benefits of the proposed PT investment tend to fall in less well-off areas, and vice versa when $\rho_{XY} < 0$.[7] The correlation coefficient is also relatively easy to calculate, interpret, and communicate using scatter plots and associated trend lines. Finally, because it is normalised to lie between -1 and +1, it may be possible to compare ρ_{XY} between projects and across jurisdictions. The main downsides are that ρ_{XY} is sensitive to outliers and non-linearities.

Our research thus concerns itself with understanding the relative merits of using the correlation coefficient, ρ_{XY}, as a criterion for determining the results of justice tests. To answer this question, we adopt a relatively straightforward methodology: specifically, we evaluate our justice test criterion for a proposed PT investment. To understand the robustness of our criterion to the chosen empirical specification, we repeatedly evaluate the same case study using alternative definitions of (1) accessibility; (2) spatial units; and (3) socioeconomic deprivation. To finish, we compare results for our criterion to those identified in Martens (2012) and Lucas et al. (2016).

4. Case study

4.1. Context

Our case study is the "City Rail Link" (CRL) in Auckland, New Zealand.[8] Auckland Transport (2010) describes how the CRL (1) supports three new stations at Aotea, Karangahape Road and Parnell; (2) enables more direct rail access to the city centre, especially from the west and south; and (3) increases capacity and allows for higher frequencies, reducing wait-times across the entire rail network. The effects of the CRL on Auckland's PT network are summarised in Fig. 1.

In analysing the effects of the CRL, we assume other transport and land use factors remain constant, which may underestimate its effects on accessibility.[9]

4.2. Data

We model Auckland's PT network using the "General Transit Feed Specification" (GTFS feed), as shown in Fig. 2. A GTFS feed consists of standardised text files containing PT network information, such as stop locations, route alignments, and schedules (Google, 2015).

Fig. 3 shows how we edit Auckland's GTFS feed to model the effects of the CRL, including new rail stations and route alignments.

Population and employment data is sourced for 10,094 census "meshblocks" (Statistics New Zealand, 2013). The area of meshblocks is approximately equivalent to an urban block, although varies with population density. Similar spatial units exist in other jurisdictions (see, for example, the Australian Bureau of Statistics (2011) and Canada Statistics (2011)).

We measure deprivation using the New Zealand Deprivation Index (NZDep), which combines various aspects of socioeconomic deprivation into a single indicator (Atkinson et al., 2014). Fig. 4 illustrates NZDep percentiles for the 2013 census data for meshblocks in Auckland, where a higher percentile indicates higher deprivation. Getis-Ord tests reject the null hypothesis of no clustering in the distribution of deprivation (p-value < 0.01).

Finally, we develop a PT routing tool to generate data on travel-times (and by extension accessibility) for various locations.[10] The time required for a PT journey includes walk (access/egress) time, wait-time, and in-vehicle time.[11]

5. Results

We split our results into four sub-sections. The first three consider the sensitivity of our justice test to definitions of accessibility, spatial units, and deprivation, respectively. To finish, we compare the results of our justice test to two others identified in the existing literature.

5.1. Accessibility

Accessibility functions differ primarily in terms of how they attenuate socioeconomic opportunities with distance. Here we consider two approaches that are commonly-used in the literature: namely, a "binary"approach and a "distance-decay" approach.

A "binary" approach to measuring accessibility, which is sometimes referred to as "cumulative opportunities", requires that the analyst specify a maximum travel-time T_{max}. The accessibility of a location is then defined as the sum of socioeconomic opportunities, E, which can be reached within T_{max}. Formally, the accessibility A_i of a location $i \in N$ in relation to all other locations $j \in N$ is

$$A_i = \sum_{j=1}^{N} I\left(t_{ij}; T_{max}\right) E_j,$$

where $I\left(t_{ij}; T_{max}\right)$ denotes an indicator function that equals one when travel-time t_{ij} from i to j is less than T_{max}, and zero otherwise.

In contrast, a "distance-decay" approach to measuring accessibility requires the analyst to specify an accessibility function $f(t_{ij}; \beta)$, which weights the contribution of socioeconomic opportunities, E_j. The function $f(t_{ij}; \beta)$ decreases with travel-time t_{ij}, whereas parameters β are identified by the analyst. Formally, we define distance-decay accessibility as

[7] In large samples, the Pearson correlation coefficient is an asymptotic approximation of the Chi-squared test, which in turn represents a second-order Taylor series expansion of a likelihood ratio test.

[8] The CRL is a useful case study for two reasons. First, local policies seek to increase PT use and reduce deprivation (Auckland Council, 2012). Second, there is a spatial dimension to accessibility and deprivation in Auckland. Third, the CRL is a large project with an approximate cost of €1.5 billion (Auckland Transport, 2010). Construction of the CRL is currently underway, and it is expected to be operational by circa 2023.

[9] First, we do not consider the potential for complementary changes to the PT network, such as the optimization of bus services to connect with rail services. Second, we assume the distribution of population and employment remains constant with and without the CRL, when we might expect intensification around rail stations post-CRL. Third, we do not consider the potential for the CRL to cause a mode shift from car to rail, which would likely reduce traffic congestion and improve accessibility for road users, including bus passengers.

[10] Two existing tools are commonly-used for PT routing problems. The first is "AddGTFStoNetwork" by Esri (Morgan, 2016). Examples of publications using the Esri tool include Fransen et al. (2015) and Widener et al. (2015). The second is the "Open Trip Planner" (OTP) developed by TriMet, Oregon's transport agency (TriMet, 2009). Examples of publications using the OTP tool include Boisjoly and El-Geneidy (2016) and El-Geneidy and Levinson (2006). In contrast to the Esri tool, our approach returns access/egress time, wait-time, number of transfers, or walking between transfers. In contrast to the OTP tool, our approach calculates the average wait-time to eliminate random variation in time-specific queries, while remaining computationally efficient. Accessibility calculations were programmed in Python, and the toolbox is made available for download with this paper.

[11] Walk distances are calculated using data from the Open Street Map (OSM) project, which includes some links that are traversable only by pedestrians (Open Street Map, 2013).We estimate access/egress time by assuming an average walking speed of 4.8 km/h. Several studies (e.g., Bohannon et al., 1996; Dewar, 1992; Knoblauch et al., 1996) report average walk speeds between 4.51 and 5.43 km/h. Wait-time is calculated as half of the headway for the relevant PT services at a PT stop. In-vehicle time is calculated from the GTFS feed. We impose a maximum of 2 transfers per journey. Following El-Geneidy et al. (2015), who notes PT accessibility varies over the day, we calculate average accessibility in 5-min increments for the period 7:00am to 9:00am on a typical weekday.

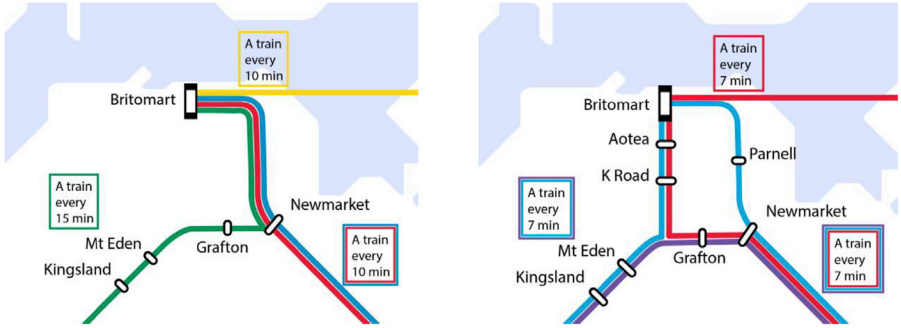

Fig. 1. Rail infrastructure and services with and without the CRL.

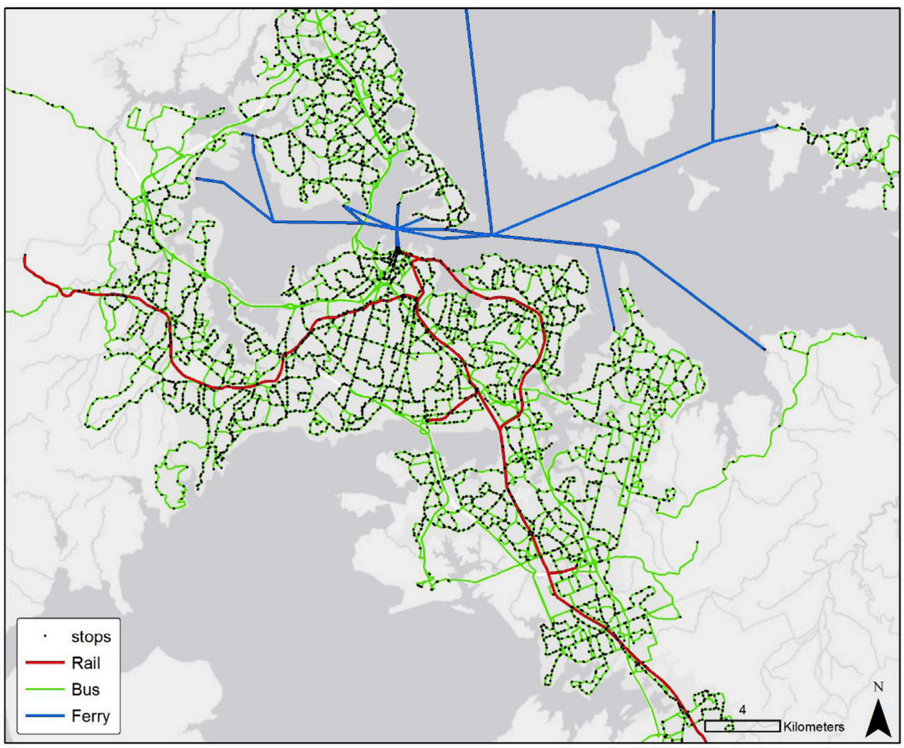

Fig. 2. Auckland's GTFS feed. Bus, rail, and ferry routes in green, red, and blue respectively; black circles denote stops and stations. (Auckland Transport, 2014b). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

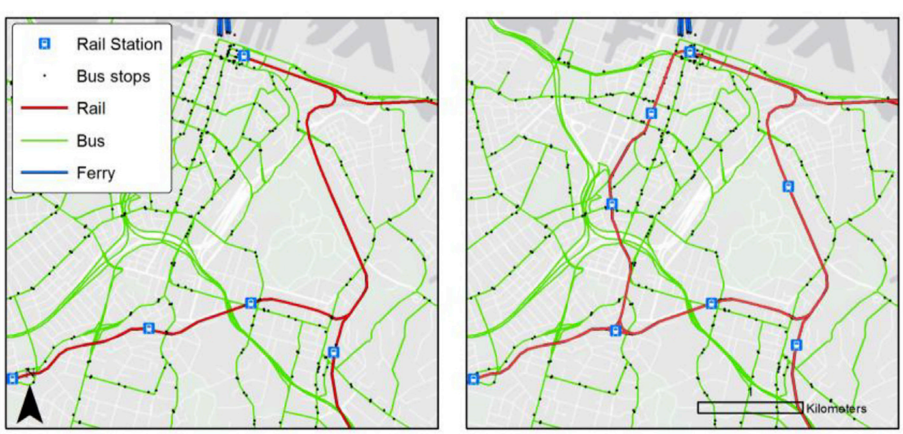

Fig. 3. Editing Auckland's GTFS feed to model the effects of the CRL.

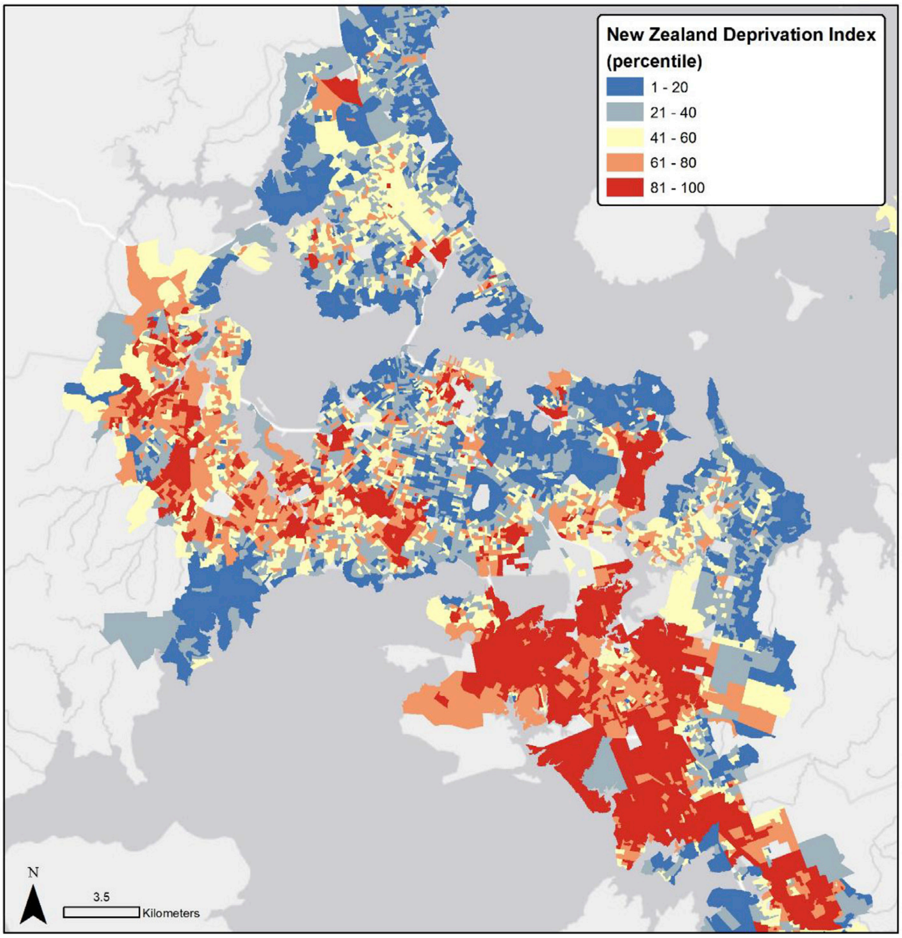

Fig. 4. New Zealand Deprivation percentile scores (NZDep).

$$A_i = \sum_{j=1}^{N} f(t_{ij};\beta)E_j,$$

where $f(t_{ij};\beta)$ is taken to be the following sigmoidal function [12]

$$f(t_{ij};\beta) = \frac{1}{(1+\exp(\beta_1(t_{ij}-\beta_2)))}.$$

The parameter β_1 controls the steepness at which $f(t_{ij};\beta)$ decays with t_{ij} and β_2 defines the mid-point, that is, when $f(t_{ij};\beta) = 0.5$.

We then calculate the change in accessibility caused by the CRL for values of T_{max} and β_2 varying from 20 – 60 minutes.[13] Fig. 5, for example, illustrates the change in accessibility for binary accessibility when T_{max} = 45minutes. We find increases in accessibility in the west, east, and south of the Auckland metropolitan urban area, which broadly align with areas of high deprivation illustrated in Fig. 4. Based on this informal visual analysis, one might expect in this particular case to find a positive correlation coefficient between the change in accessibility and deprivation, and so it proves.

Fig. 6 illustrates correlation coefficients for journeys where we vary the travel-time parameters in the range $20 \le T_{max} = \beta_2 \le 60$. In all cases, we find correlation coefficients that are positive and statistically significant ($p < 0.05$). Coefficients for the distance-decay function increase monotonically with travel-time parameter β_2, whereas coefficients for the binary function do not. Indeed, results for the distance-decay function are considerably smoother than those for the binary function. On this basis, the distance-decay accessibility function is preferred and provides a benchmark for the results that follow.

5.2. Spatial units

To gain more insight into the sensitivity of our criterion, we estimate correlation coefficients for two alternative spatial units: First, randomly-generated equally-sized hexagons (n = 391) and, second, official aggregations of meshblocks known as census area-units (n = 413). Fig. 7 illustrates the correlation coefficients for these two alternative definitions of spatial units.

We find that using fewer, larger spatial units results in larger correlation coefficients. The most obvious statistical explanation is that using fewer spatial units with larger areas reduces the variances σ_Y and σ_X proportionally more than the covariance $cov(X, Y)$. Even without a definitive explanation for what is causing the change in correlation coefficient, what can we conclude in relation to the sensitivity of our justice test? In this case, the correlation coefficients are significantly smaller using meshblocks vis-à-vis census area-units and hexagons. Nevertheless, the results of our justice test are unchanged, as under all scenarios $\rho_{XY} > 0$ and is statistically significant ($p < 0.05$). Whether this outcome reflects our empirical setting, or holds more generally, is left as an area for future research.

[12] Linear, polynomial, or exponential decay functions are also commonly-used.

[13] Analysis of ticketing data indicates the average morning peak rail journey in Auckland takes 30 min from entering to exiting the system (NB: This time represents the sum of wait-time and in-vehicle time), with a standard deviation of 15 min (Auckland Transport, 2014a). Combining data from our route planning tool with census JTW data allows us to calculate an average journey-time of 48 min, which seems reasonable once walking and wait time are allowed for, and remembering that JTW tend to be longer than average.

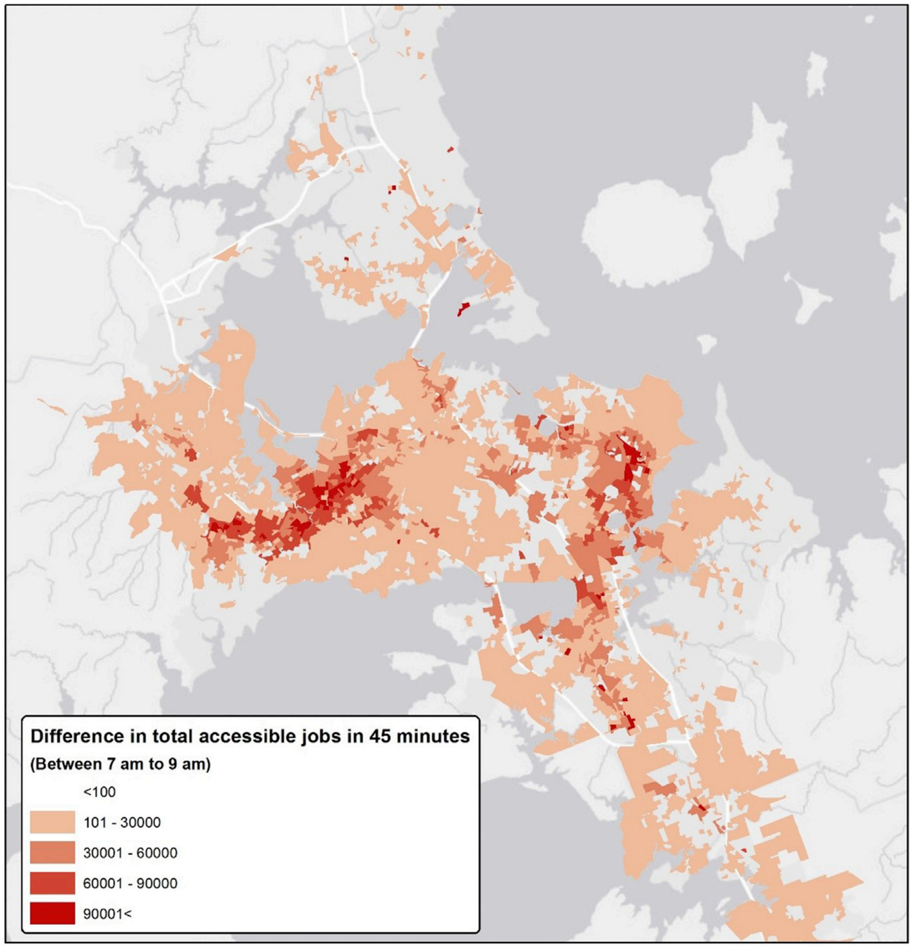

Fig. 5. Effects of the CRL on binary accessibility (meshblock level, 45-minute maximum travel-time).

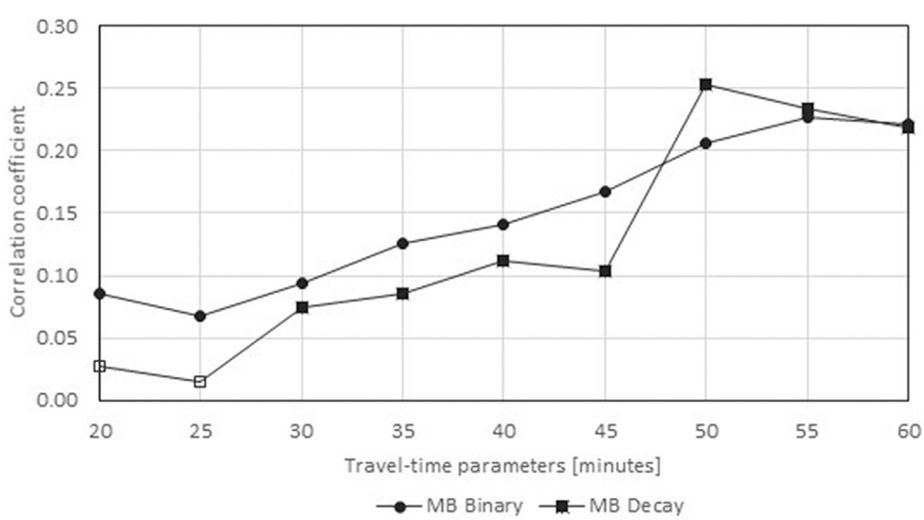

Fig. 6. Correlation coefficients – Binary and Distance-decay accessibility functions. Solid markers indicate statistically significant coefficients ($p < 0.05$).

5.3. Deprivation indicators

Although NZDep is a well-researched and widely-used indicator of socioeconomic deprivation in New Zealand, similar indices may not necessarily be available in other jurisdictions. For this reason, we test the sensitivity of correlation coefficients to another indicator of deprivation, specifically median household income. As deprivation tends to decrease with income, which we denote by z, the justice test for the former is reversed: That is, the CRL passes our (income-related) justice test when $\rho_{ZX} < 0$ and is statistically significant.

With this in mind, Fig. 8 illustrates the correlation coefficients when using median household income vis-à-vis NZDep.

The correlation coefficients for income are found to be significant when the journey-time parameter $\beta_2 \geq 35$. Above this time the correla-

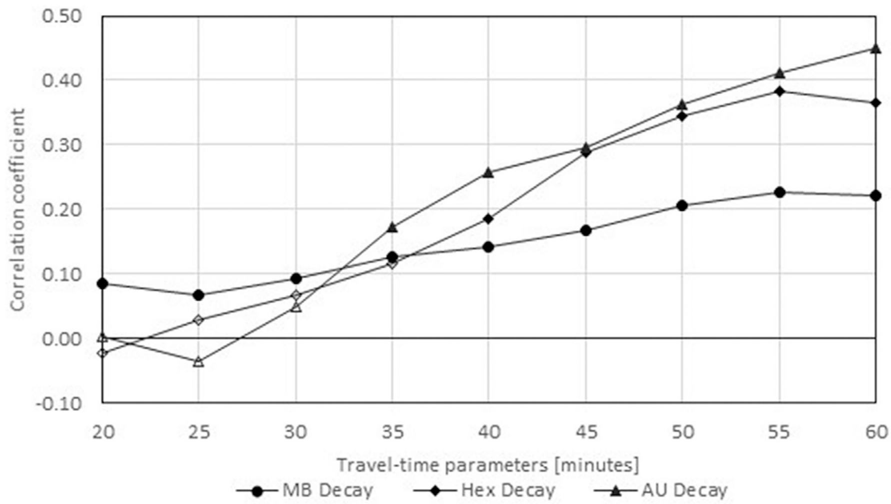

Fig. 7. Correlation coefficients – meshblocks (MB), hexagon (HEX), and census area-units (CAU). Solid markers indicate statistically significant coefficients ($p < 0.05$).

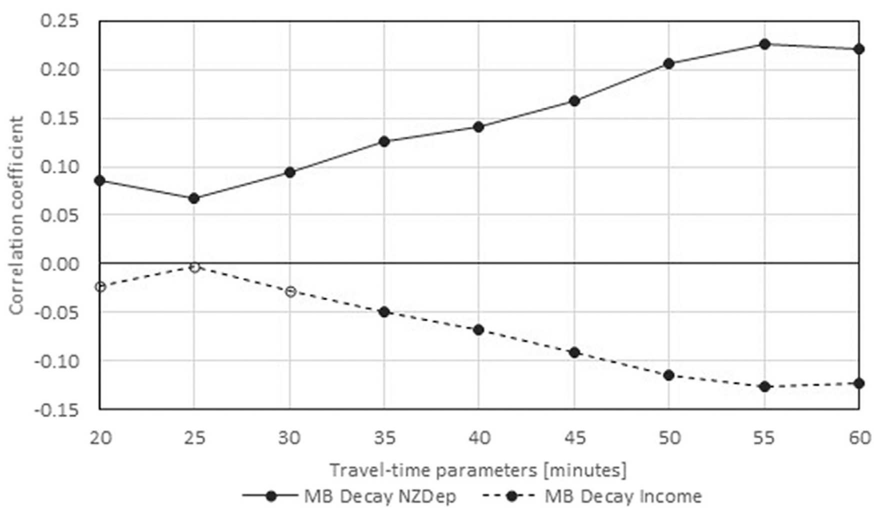

Fig. 8. Correlation coefficients – NZDep versus Median Household Income. Solid markers indicate statistically significant coefficients ($p < 0.05$).

tion coefficients continue to increase in magnitude, implying the CRL passes the income-related justice test. The magnitude of the correlation coefficients for the income-related test, however, is smaller than those found using NZDep, indicating reduced statistical confidence in the result. On this basis, we find the additional information contained in a specialised deprivation indicator, namely NZDep, strengthens the results of our justice test compared to the more readily-available but simpler indicator of median household income.

5.4. Comparing justice tests

We now compare our justice test to two other criteria identified in the literature, namely the range and Gini coefficient specified in Martens (2012) and Lucas et al. (2016), respectively.

In the case of Martens (2012), we calculate the average accessibility for the lowest and highest deprivation deciles with and without the CRL. We find the range between the average accessibility experienced in the highest and lowest deciles actually increases with the CRL. On this basis, the CRL would fail the justice test suggested in Martens (2012).

In the case of Lucas et al. (2016), we calculate Gini coefficients for accessibility with and without the CRL. The outcome of our proposed criterion vis-à-vis the Gini coefficient are summarised in Table 1, where "+" indicates a just outcome, and "-" otherwise. In the case of the correlation coefficient, an "-" denotes statistically insignificant result, whereas in the case of Gini coefficients an "-" denotes an increase in the inequality with which accessibility is distributed.

We find the correlation coefficient yields a definitive "pass" in all but four cases, which all relate to instances of binary accessibility, short journeys ($T_{max} \leq 25$minutes), and/or larger spatial units. In contrast, the Gini coefficient for the distribution of accessibility fails in the majority of cases, especially for travel-time parameters less than 40 min.

6. Discussion

How do we interpret our results? First, from a methodological perspective we find that our proposed justice test criterion, namely the correlation coefficient, performs well when compared to other potential criteria, insofar as it gives stable results that are relatively robust to changes in empirical specification.

On this basis, we suggest the correlation coefficient as an alternative criterion to more traditional measures, such as the range and Gini coefficient. The correlation coefficient considers changes in accessibility across the full distribution of socioeconomic outcomes while remaining easy to calculate, interpret, and communicate.

There are, in our view, two potential limitations from using the correlation coefficient as a criterion for justice tests in the way we have

Table 1
Comparing justice tests – Correlation coefficients versus Gini coefficients.

T_{max} and β_2	Correlation coefficient						Gini coefficient					
	Binary			Decay			Binary			Decay		
	MB	HEX	CAU	MB	HEX	CAU	MB	HEX	CAU	MB	HEX	CAU
20	+	-	-	+	-	+	-	-	-	-	-	-
25	+	+	+	+	+	-	-	-	-	-	-	-
30	+	+	+	+	+	+	-	-	-	-	-	-
35	+	+	+	+	+	+	-	-	-	-	-	-
40	+	+	+	+	+	+	-	-	-	+	-	-
45	+	+	+	+	+	+	+	-	-	+	+	+
50	+	+	+	+	+	+	+	+	+	+	+	+
55	+	+	+	+	+	+	+	+	+	+	+	+
60	+	+	+	+	+	+	+	+	+	+	+	+

described here. First, correlation coefficients may be sensitive to outliers and, second, they may not accurately capture non-linear associations. In this particular application, scatter plots of NZDep versus the change in accessibility indicated that neither of these two statistical issues were present.

As for empirical specifications, our findings support the use of distance-decay accessibility functions, detailed spatial units, and specific deprivation indicators. While more computationally and data intensive, these empirical attributes generated stable results and had high statistical power. Ultimately, the change in accessibility caused by the CRL appears to be positively correlated with prevailing socioeconomic deprivation, with a statistically significant effect across a range of travel-time values. It seems clear the accessibility benefits of the CRL are distributed in such a way that they favour the less well-off.

What are the weaknesses of our approach? First, we abstract from the demand for PT. This issue is common to most accessibility analyses, insofar as they consider *potential* rather than *existing* demand. The former can be motivated on logical and practical grounds. First, major PT investments can take decades to implement, reducing the relevance of existing demand. Second, detailed demand analysis requires access to ticketing data, which may be confidential.

Second, we analyse accessibility for walk-up PT users only, and do not consider other potential access modes, such as cycling, ride share, and park and ride. The degree to which this affects the results of our justice test depends on the proportion of users who access PT using those transport modes, which will be context-specific. In theory, it is possible to replicate our accessibility analysis for several access modes, and weight results, for example, by mode share.

Third, we do not incorporate information on the spatial distribution of travel times for PT journeys. Typically, we would expect travel times to increase as accessibility declines, for example, in locations that are remote from the city centre. To capture this effect, one could specify parameters that varied across the city, as per Bocarejo and Oviedo (2012), possibly drawing on census data on home and work locations. Such an approach, however, appears to be sensitive to issues with endogeneity between accessibility and travel patterns. Further econometric research into the issue of endogeneity, and whether it affects the travel-time parameters used in accessibility analyses, would seem to be warranted.

Fourth, we do not incorporate second-order land use and transport changes into the analysis. We do not allow for complementary changes to the wider PT network, such as optimization of bus and rail connections. Nor do we allow for changes in accessibility to affect land use or location choice. More specifically, our justice test is 'static' in that it assumes the distribution of inequality is independent of PT acessibility. In practice, changes in PT accessibility will change amenity levels (positively or negatively) and, in turn, the distribution of households and, by extension, inequality. The degree to which changes in accessibility affect household sorting is context-specific and may occur over long timeframes, but may impact on the results of such tests and thus be relevant to policy.

7. Conclusions

Many cities are grappling with the twin challenges posed by growing travel demands and persistent socioeconomic inequality. From a policy perspective, major PT investments would ideally be efficient—in that their economic benefits exceed their costs—and equitable—in that they disproportionately benefit the less well-off.

In this study we propose a new criterion for deciding ex-ante justice tests for PT investment: The correlation coefficient. To pass our justice test, there must exist a statistically significant positive correlation between the change in accessibility and prevailing socioeconomic deprivation. While relatively simple, we are not aware of prior studies that have investigated the use of this criterion in the context of justice tests.

We use commonly-available open-source data to apply this criterion to a case study of the "City Rail Link" (CRL) in Auckland.[14] Our proposed criterion generates definitive and stable results, particularly when using a distance-decay accessibility function, detailed spatial units, and a specialised deprivation indicator. We find our criterion performs well compared to others identified in the literature.

Some may question whether an all-encompassing justice test helps to understand the complex effects of PT transport investments. We hedge our bets on this front. Our literature review did identify a gap between policy and practice in relation to justice tests, which may be partly addressed by the application of a simple and well-understood test. That said, we do not believe there exists one justice test to rule them all and our results support a focus on careful specification and sensitivity testing.

The systematic application of ex ante justice tests to major PT investments seems to represent an appropriate adjunct to policy settings in those jurisdictions that seek to reduce inequality. The criterion presented in this study provides a relatively simple and stable method for determining the outcomes of such tests.

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[14] The tool used in our analysis is available for download with this paper. Users can use this tool to load and edit GTFS feeds and population data, and undertake their own accessibility analyses.

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