Applying Justice Tests to Public Transport

Saeid Adli[1] and Stuart Donovan[2] (presenter)

ABSTRACT

Many cities are grappling with the twin challenges posed by growing travel demands and persistent socioeconomic inequality. From a policy perspective, major transport investments would ideally be efficient – in that their economic benefits exceed their costs – as well as equitable – in that the distribution of benefits favour the less well-off. To this end, this study formulates and applies a justice test for public transport investments that relates accessibility to inequality. The specification of the justice test enables comparisons between projects and across jurisdictions. We apply the proposed justice test to Auckland's City Rail Link and test the sensitivity of results to changes in key assumptions. We conclude that well-specified justice tests are a straightforward adjunct to the policy frameworks that are currently used to evaluate public transport investments in many jurisdictions.

NOTE TO READER

An extended version of this paper has been submitted to the journal Transport Policy, where it has been conditionally accepted for publication subject to revisions.

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[1] PhD student, University of Auckland; MA (Urban and Regional Planning); IPENZ Transportation Group member;; sadli@gmail.com

[2] Principal, Veitch Lister Consulting; IPENZ Transportation Group member; BA (History), ME (Eng. Sci.), MPhil. (Economics); PhD student, Vrije Universiteit Amsterdam; stuart.donovan@veitchlister.com.au

1 INTRODUCTION

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

Socioeconomic inequality has also received increasing attention of late, especially in the context of urban development (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 persistent and increasing socioeconomic inequality (International Monetary Fund, 2014; OECD, 2013; World Bank, 2013).

Policy settings – both in New Zealand and internationally – have historically sought to prioritise transport investment on efficiency grounds, as measured using social benefit-cost analysis. The presence of growing and persistent inequality, however, gives rise to new policy questions. What are, for example, the distributional effects of transport investment? Such questions are the focus of this paper, for which policymakers and practitioners are the primary target audience.

To answer questions about the distributional impacts of transport investments, we draw on a large body of literature in economics, sociology, geography, and public policy, which identifies a role for so-called “justice tests”. While justice tests have well-established normative foundations, we find few instances where they have been systematically used to inform transport investment priorities. Our study seeks to close this gap between theory and practice; we are primarily interested in ‘how’ one might apply justice tests to public transport investments, rather than ‘why’.

This study advances the literature in two areas. First, we implement a methodology that is *flexible*, in that it can be used to model a wide-range of PT infrastructure and service investments; *robust*, in that it relies on measures of statistical significance; and *transparent*, in the sense that it relies on commonly-available, open-source data. These attributes ensure the results of our proposed justice test is comparable both between projects and across jurisdictions. Second, we test the sensitivity of our results to changes in key assumptions. We find that assumptions on accessibility, such as maximum travel-time, and level of spatial aggregation are particularly important.

The following sections of this paper are structured as follows: Section 2 presents our methodology; section 3 applies the justice test to a case study of the City Rail Link; and section 4 concludes.

2 METHODOLOGY

Our methodology draws on a large and diverse body of literature, which we summarise as follows:

- The economics literature identifies microeconomic channels through which urban areas can both attract and segregate low-income households;[3]
- The sociological literature advances normative concepts of spatial justice, and argues that policy should seek to mitigate prevailing socioeconomic inequalities;[4]

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[3] Findings from the urban economics literature suggest cities simultaneously attract and segregate low-income households. Low-income households are likely to be attracted by the socioeconomic opportunities that cities have to offer, while also being segregated into areas with less amenity. “Accessibility”, which Hansen (1959) defines as people’s overall ability to reach services and activities, would seem to qualify as one such amenity.

[4] A large body of literature considers sociological concepts of spatial justice. Lojkine (1972), for example, argues that many urban policies tend to increase distances between working class jobs and housing, which compounds inequitable access to transportation systems. Harvey (1973) identifies the potential for dynamic effects: Policy settings may – either intentionally or unintentionally – reinforce prevailing socioeconomic inequalities. Soja (2010) advocates for the use of a spatial justice test to measure the fairness of public policies.

- The geographic literature presents empirical methods for analysing the accessibility of transport networks, in general, and PT networks, in particular;[5] and
- Policy frameworks currently used to evaluate PT investments appear well-placed to incorporate the results of justice tests, even if they do not yet do so.[6]

We build on the justice test advanced by Soja (2010). Our (ex-ante) justice test relates changes in accessibility to inequality using the following four key steps:

1. Calculate existing levels of PT accessibility for areas within a city;
2. Adjust the PT network to simulate the impacts of the proposed PT investment;
3. Calculate new levels of PT accessibility with the investment, from which we subtract existing levels of PT accessibility to estimate the change in accessibility by area; and
4. Relate the change in PT accessibility to measures of prevailing socioeconomic deprivation.

Interpreting the results of our justice test is relatively straightforward: Where we find a statistically significant positive correlation between the change in accessibility and prevailing deprivation, the proposed PT investment "passes" our justice test; where we find no correlation, the PT investment is neutral with respect to our justice test; and where we find a statistically significant negative correlation, the PT investment "fails" our justice test. The strength of the correlation between accessibility and deprivation thus determines the result of the justice test, which is a standardised statistical measure and hence can be compared between projects and across jurisdictions.

We note that this methodology assumes all other transport and land use factors remain constant, which is likely to underestimate the overall effects of PT investments on accessibility for three reasons. First, we do not consider complementary changes to the PT network, such as the optimisation of bus services to connect with rail services. Second, we assume the distribution of population and employment remains constant with and without the proposed PT investment. Third, we do not consider potential mode shift from car to public transport, which may reduce congestion and improve accessibility for road users, including bus passengers.

Finally, we emphasise that the results of this justice test are not intended to be considered in isolation: Instead, we propose this justice test as an adjunct to – rather than a replacement for – existing policy frameworks used to evaluate PT investments. Even projects that fail our proposed justice test may nevertheless be worthy of funding, and vice versa.

3 APPLICATION: AUCKLAND'S CITY RAIL LINK

In this section, we apply our justice test to the "City Rail Link" (CRL) in Auckland. The purpose of the case study is, first, to illustrate how to apply the justice test to a proposed PT investment and,

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[5] Abley and Halden (2013) define accessibility as people's overall ability to reach socioeconomic opportunities. They conceptualize accessibility in terms of *transport mobility*, which is defined by transport infrastructure and services; *socioeconomic opportunities*, which is defined by land use patterns; and *personal capability*, which refers to an individual's ability (financial and physical) to use a transport system. Many studies consider relationships between accessibility and socioeconomic outcomes. Åslund et al. (2010), for example, present a longitudinal analysis of accessibility for refugees in Sweden. Refugees initially housed in locations with lower levels of accessibility (measured in terms of access to employment) are less likely to be employed nine years later. El-Geneidy et al. (2015) analyses the relationship between socioeconomic disparities and access to public transport (PT) in Toronto, and is perhaps the closest to our own study.

[6] 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 Administration (2012)). A 2001 statute in Brazil, for example, enshrined the concept within law (Polis Inclusive, 2011). Whether this high-level policy direction has influenced investment decisions is a moot point; our review of the literature revealed no instances where justice tests are systematically applied and/or used to inform transport investment priorities.

second, to investigate the sensitivity of the results to changes in key parameters.

The CRL presents a useful case study for several reasons. First, Auckland is a medium-sized city of approximately 1.5 million residents that is experiencing sustained population growth; over the next 20 years Auckland's population is predicted to grow by one million residents (Auckland Council, 2012). Second, local government has adopted policies that seek to increase use of PT and reduce socioeconomic inequality (Auckland Council, 2012). Third, and as we shall see in later sections, there is a spatial dimension to socioeconomic inequality in Auckland. Finally, the CRL is a major investment with an approximate cost of $3.0 billion (Auckland Transport, 2010).

The following sub-sections model PT accessibility in Auckland, quantify the change in accessibility caused by the CRL, and relate this change to prevailing levels of inequality. Finally, we summarise our results and test their sensitivity to changes in key parameters.

3.1 Modelling public transport accessibility in Auckland

Auckland's PT network is described using the "General Transit Feed Specification" (GTFS feed), which is illustrated in Figure 1.[7] Here, bus, rail, and ferry routes are illustrated in green, red, and blue respectively, while black circles denote stops and stations.

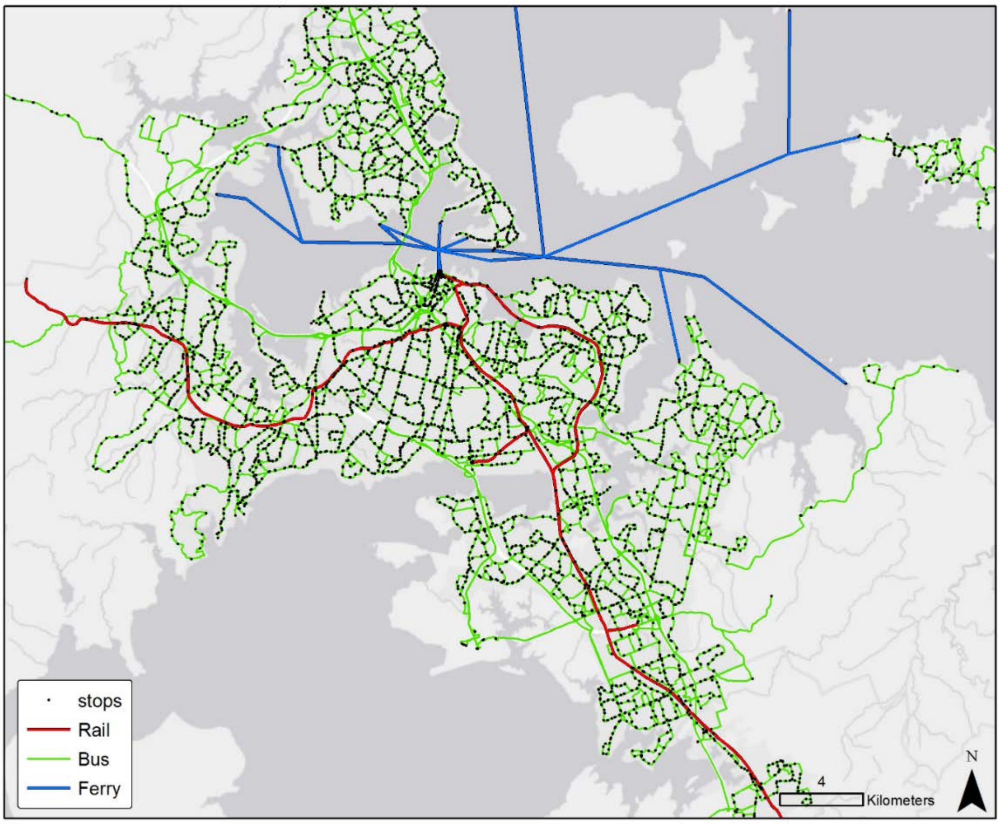

Figure 1: Visualising Auckland's GTFS feed (Auckland Transport, 2014b).

Population and employment data is available for 10,094 census "meshblocks" (Statistics New Zealand, 2013). Distances between meshblock centroids and PT stops are calculated using data from the Open Street Map (OSM) project (Open Street Map, 2013). OSM data includes some links that are traversable only by pedestrians, such as stairs and walkways.

We define meshblock q to be "accessible" from meshblock p if it is possible to use PT to travel from meshblock p to meshblock q within a specified maximum travel time. Formally, accessibility is

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[7] A GTFS feed consists of a set of standardised text files, where each file contains information on aspects of the PT network, such as the location of stops, the alignment of routes, and schedules (Google, 2015).

a directed graph in which edges are determined as follows:

1. For two meshblocks p and q, calculate the shortest-path (in terms of time) $t^*(p,q)$ that connects the centroids of p to q when travelling via foot and/or using PT; and
2. For a specified maximum travel time denoted by T_{max}, if $t^*(p,q) \leq T_{max}$, then meshblock q is defined to be "accessible" to meshblock p.

Figure 2 illustrates travel time components that make-up a hypothetical 42-minute journey between two meshblocks (MB).

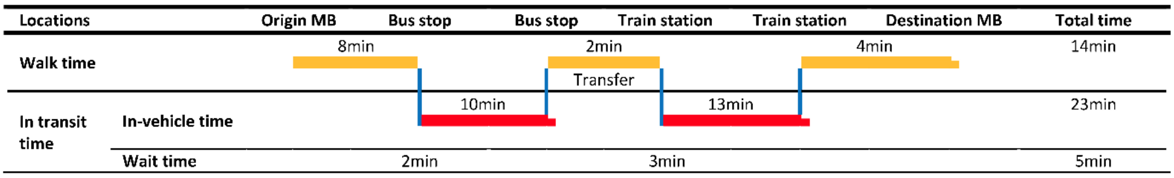

Figure 2: Hypothetical 42 minute journey between two meshblocks.

The time required for a PT journey includes walk (access/egress) time, wait-time, and in-vehicle time.[8] As PT accessibility varies over the day, we calculate accessibility in five-minute increments for the period 7:00am to 9:00am on a typical weekday, and average the results.[9]

3.2 Simulating the impacts of the City Rail Link on accessibility

Auckland's GTFS feed was modified to simulate the effects of the CRL.[10] Figure 3 and Figure 4 illustrate city centre rail infrastructure and services with and without the CRL.[11]

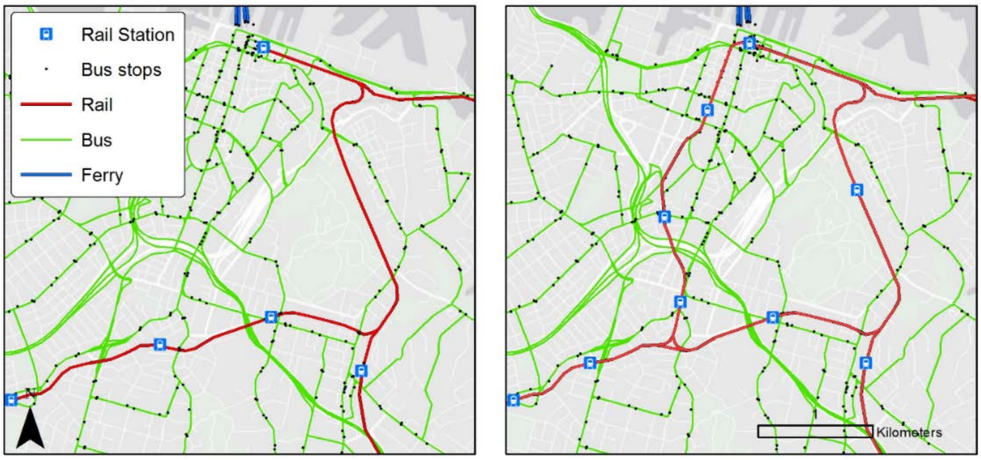

Figure 3: Rail infrastructure with and without the CRL.

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[8] We estimate access/egress time by calculating the distance between meshblock centroids and PT stops, including – in the case of transfers – the distance between PT stops. Total walking time is estimated by assuming an average walking speed of 4.8 km/h (Bohannon et al., 1996; Dewar, 1992; Knoblauch et al., 2007). Wait-time is calculated as half of the headway for the relevant PT services, and we impose a maximum of 2 transfers per journey. In-vehicle time is calculated directly from the GTFS feed.

[9] This case study took 13 hours running on a Windows 8.1 (64-bit) desktop PC with an Intel Core i7 processor and 16GB RAM. Two other tools are commonly-used to solve PT routing problems. The first is "AddGTFStoNetwork" developed by Esri (Morgan, 2016). Publications using the Esri tool include Fransen et al. (2015) and Widener et al. (2015). The second is the "Open Trip Planner" (OTP) developed in 2009 by TriMet, Oregon's transport agency (TriMet, 2009). Publications using the OTP tool include Boisjoly & El-Geneidy (2016), El-Geneidy & Levinson (2006), and Manaugh & El-Geneidy (2012).

[10] The CRL has three primary effects on Auckland's PT network (Auckland Transport, 2010). First, the CRL adds new stations at Aotea, Karangahape Road, Newton, and Parnell. Second, the CRL enables rail services to access the city centre more directly. Third, the CRL enables a reduction in headways from 10 to 7 minutes.

[11] Newton Station has been dropped by subsequent designs.

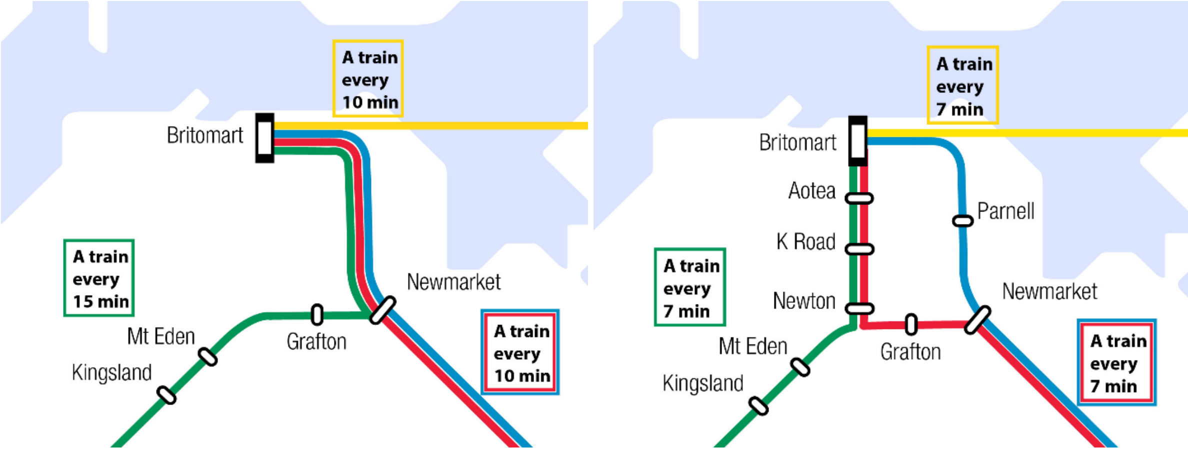

Figure 4: Rail services with and without the CRL.

Figure 5 illustrates the change in accessibility caused by the CRL assuming a 30-minute maximum travel time. The CRL is found to increase accessibility across much of Auckland's central urban area, as well as in those areas to the west and south that are close to rail stations.

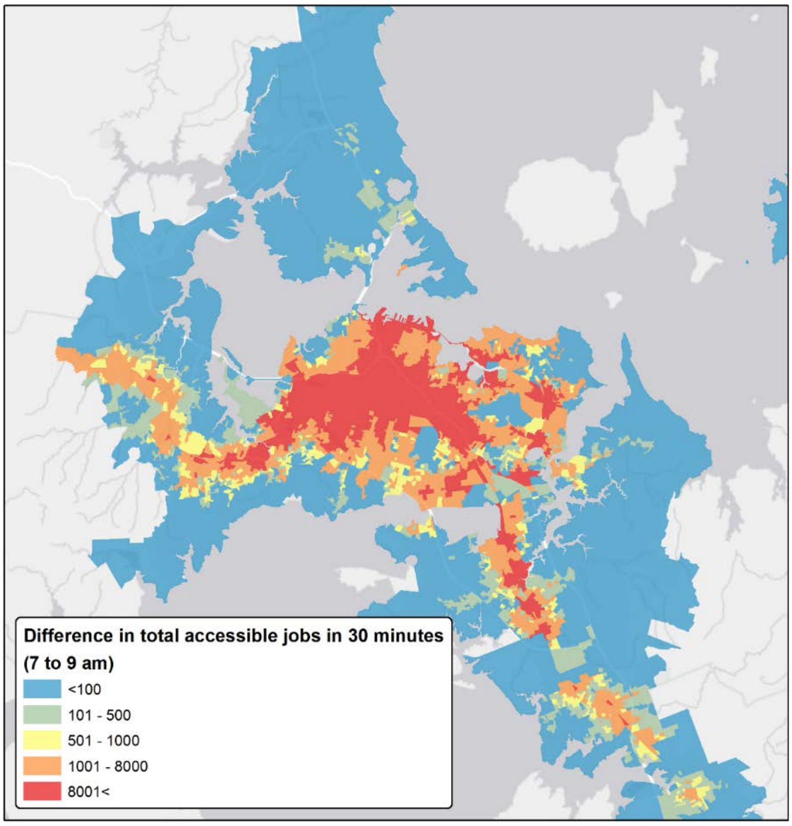

Figure 5: Change in accessibility caused by CRL (30-minute maximum travel time).

3.3 The spatial distribution of socioeconomic inequality in Auckland

We measure deprivation using the New Zealand Deprivation Index (NZDep), which combines various indicators of socioeconomic deprivation into a single indicator (Atkinson et al., 2014). Figure 6 illustrates percentiles of NZDep scores derived from the 2013 census data for meshblocks in Auckland, where a higher percentile indicates higher levels of deprivation. We observe concentrations of deprivation in the west and south. Statistical tests reject the null hypothesis of no clustering in the spatial distribution of deprivation in Auckland (Getis-Ord Gi* z-score = 14.46; p-value < 0.01), which is consistent with the segregation of households based on income.

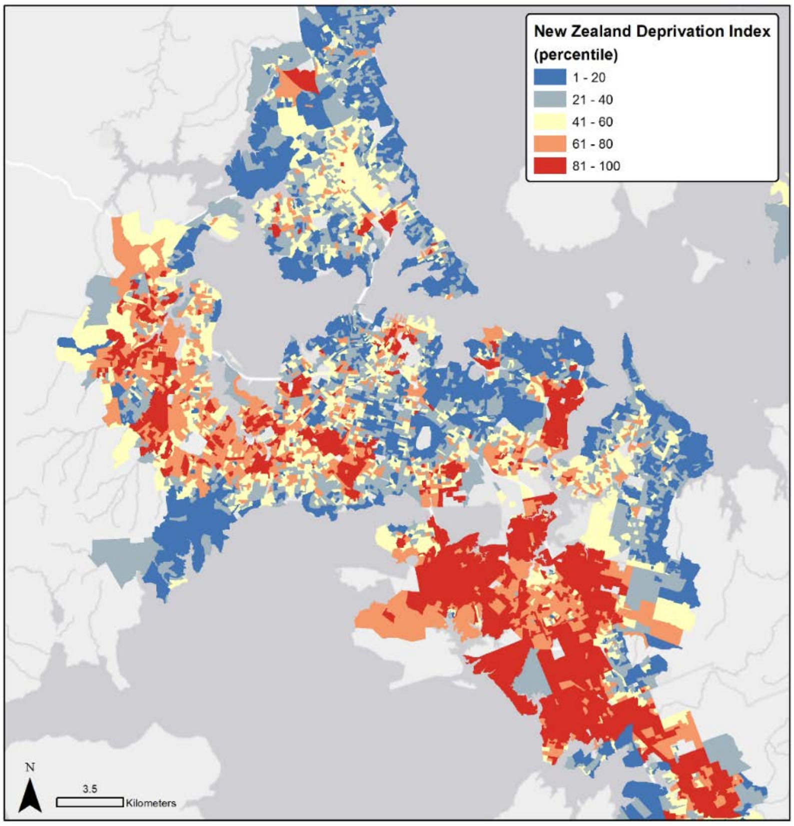

Figure 6: The percentiles of New Zealand Deprivation score (NZDep) for Auckland.

3.4 Results

3.4.1 Primary Results

Figure 7 shows the relative change in accessibility with and without the CRL. Accessibility increases for all deciles in all scenarios, although the magnitude of the increase varies with the deprivation index and the maximum travel time that is used to calculate the change in accessibility.

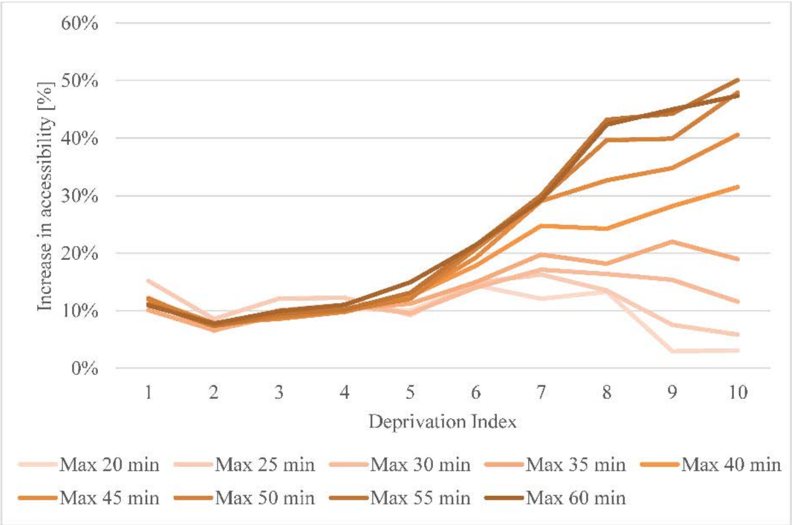

Figure 7: Percentage change in number of accessible jobs for deprivation deciles (1 to 10) in a specific PT travel time (5-minute intervals from 20 – 60 minutes).[12]

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[12] Ticketing data indicates the average morning peak rail journey in Auckland takes 30 minutes from entering to exiting the system (NB: This time represents the sum of wait-time and in-vehicle time), with a standard

As maximum travel time increases, the CRL is found to cause larger increases in relative accessibility, especially for higher deciles. This result suggests areas of high deprivation are located further from employment, as predicted by Lojkine (1972). Table 1 summarises changes in accessibility by NZDep decile and maximum travel time.

Table 1: Number of accessible jobs by deprivation deciles (1 to 10) and maximum travel time (10-minute intervals from 20 - 60 minutes).

	Average Access									
NZDep index	**20min**		**30min**		**40min**		**50min**		**60min**	
	Pre CRL	**Post CRL**	**Pre CRL**	**Post CRL**	**Pre CRL**	**Post CRL**	**Pre CRL**	**Post CRL**	**Pre CRL**	**Post CRL**
1	2,995	3,364	11,167	12,498	25,890	28,763	44,464	49,865	64,161	71,155
2	4,968	5,328	14,932	15,904	32,081	34,582	54,493	58,496	75,945	81,837
3	6,581	7,245	17,730	19,514	34,508	37,468	55,556	60,526	77,200	84,881
4	6,602	7,287	17,645	19,588	35,754	39,254	59,575	65,521	82,469	91,575
5	6,819	7,503	16,220	17,767	32,067	36,076	55,599	62,314	78,384	90,081
6	6,822	7,804	15,833	18,054	30,190	35,564	50,882	61,415	73,843	89,660
7	6,538	7,327	13,851	16,223	25,814	32,203	44,249	57,277	65,946	85,216
8	5,969	6,762	11,517	13,404	19,833	24,638	32,373	45,209	49,405	70,334
9	7,136	7,351	12,411	14,319	20,998	26,912	34,125	47,746	51,583	74,802
10	3,830	3,949	8,186	9,133	15,757	20,718	28,196	41,698	46,857	69,034

Figure 8 illustrates the correlation between the change in accessibility and the deprivation index for various maximum travel times. A clear trend emerges: when T_{max} is 35 minutes or less, when the increase in accessibility caused by the CRL is concentrated in areas with low levels of deprivation. The opposite result holds when T_{max} is 45 minutes or longer.

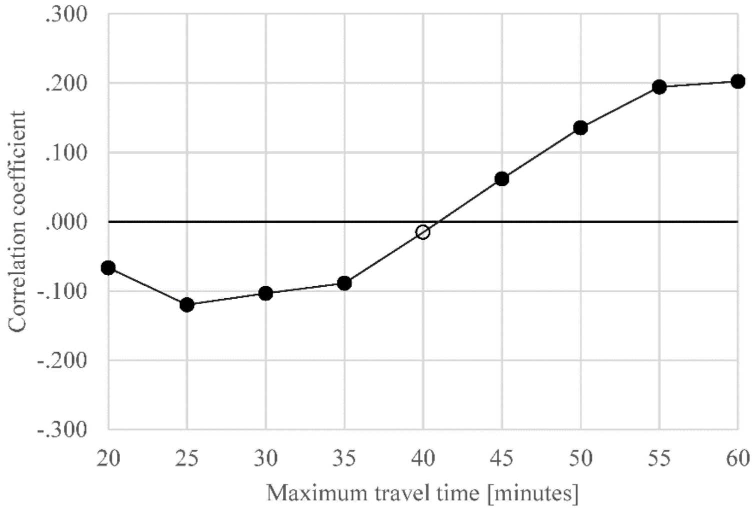

Figure 8: Correlation coefficients (vertical axis) between change in accessibility and deprivation index versus T_{max} at MB level (horizontal axis). Solid markers indicate statistically significant coefficients (p-values < 0.01).

This provides strong evidence that the results of our justice test are sensitive to the assumed value of maximum travel time, T_{max}. Identifying the role for T_{max} is a useful contribution of this study, which the existing literature on accessibility and justice tests does not consider in much detail.

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deviation of 15 minutes (Auckland Transport, 2014a). If we estimate total access/egress time at 10-30 minutes per journey, then a journey-time of 20-60 minutes captures approximately 72 percent of rail journeys.

3.4.2 Sensitivity testing

Aside from maximum travel time, two other assumptions underpin our analysis: 1) the spatial units used to aggregate data and 2) the indicator used to measure socioeconomic inequality. We now test the sensitivity of results to changes in these two assumptions.

First, we consider two alternative spatial units: A randomly generated mesh of uniform hexagons with a constant area of 0.5 sq.km (n = 3,096), and amalgamations of meshblocks defined by Statistics NZ known as "Area Units" (n = 342). Figure 9 presents the correlation coefficients associated with these two alternative spatial units.

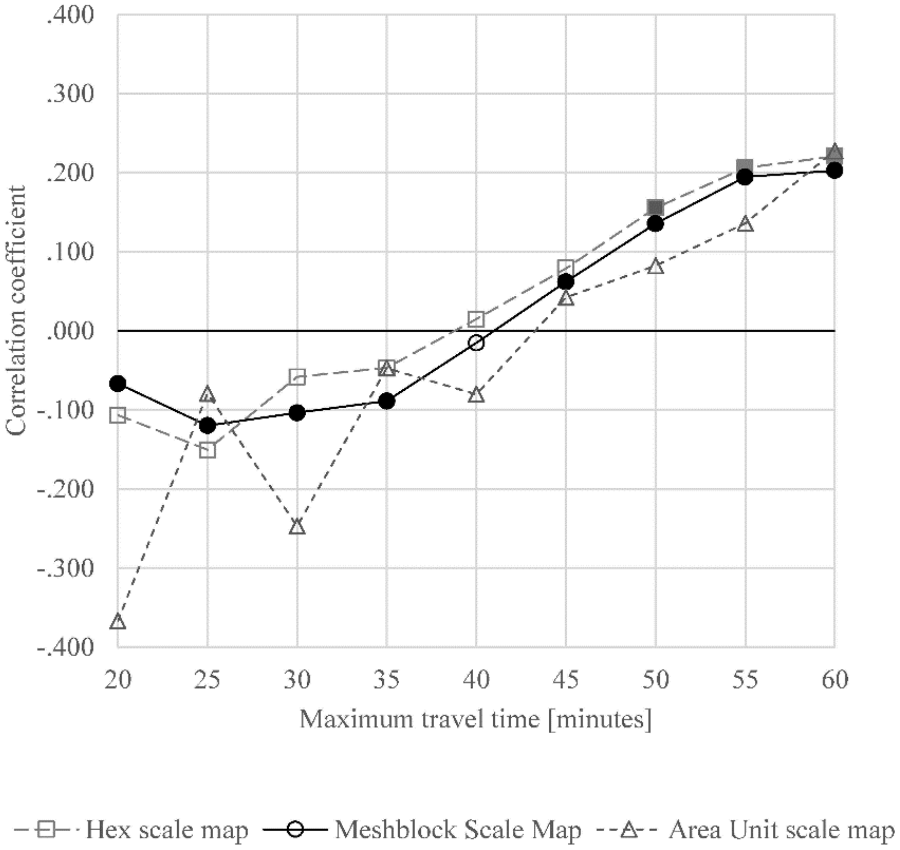

Figure 9: Correlation coefficients (vertical axis) between change in accessibility and deprivation index versus T_{max} at MB, hexagon, and area unit level (horizontal axis). Solid markers indicate statistically significant coefficients (p-values < 0.01).

Results for the alternative spatial units are generally consistent with those found using meshblocks, both in terms of the magnitude of the correlation coefficients and the trend as T_{max} increases. The number of spatial units, however, has a large effect on the statistical power of the justice test. Using area units, for example, does not return statistically significant correlations in any of the specifications that were tested. This suggests that the number of spatial units used in the analysis is important to the statistical power of the test, and hence the conclusions drawn therefrom.

Our second sensitivity test used median household income as the indicator of inequality. Data on median household income by meshblock was sourced from the 2013 New Zealand census (Statistics New Zealand, 2013). The results of this test produced similar correlation coefficients to those found using the deprivation index. Thus, the results of the justice test appear to be robust to the choice of indicator for socioeconomic inequality.

4 CONCLUSIONS

In this study, we formulate and apply an ex-ante justice test for PT investment. Our focus is positive (application-oriented) rather than normative (theory-oriented): We are interested in 'how' one applies a justice test to potential PT investments, rather than 'why'.

Our proposed test relates the change in accessibility caused by a PT investment to measures of prevailing socioeconomic deprivation. For a PT investment to pass the justice test, there must exist a statistically significant positive correlation between the change in accessibility and deprivation. The test is intended as an adjunct to, rather than a replacement for, existing policy frameworks used to evaluate PT investments.

This study advances the literature in two areas. First, we develop and implement a methodology that is *flexible*, in that it can be used to model a wide-range of PT infrastructure and service investments; *robust*, in that it relies on measures of statistical significance; and *transparent*, in the sense that it uses commonly available, open-source data. These attributes ensure our proposed justice test is relatively comparable, both between projects and across jurisdictions. Second, we apply our methodology to a case study of the "City Rail Link" (CRL) in Auckland and test the sensitivity of our results to changes in key assumptions. We find that assumptions on accessibility, such as maximum travel-time, and level of spatial aggregation are particularly important.

Notwithstanding its advantages, we note several opportunities to improve our analysis:

- First, rather than specifying a single value for maximum travel-time, one could incorporate information on the spatial distribution of travel times for PT journeys.[13]
- Second, rather than focusing only on the direct effects of the investment, one could incorporate second-order land use and transport changes into the analysis.[14]
- Third, rather than using a binary definition of accessibility, one could use a continuous accessibility function, such as an exponential distance decay function.[15]
- Fourth, rather than focusing on walk-up access, one could replicate our analysis for a variety of access modes, such as park-and-ride, and weight the results.
- Fifth, rather than abstracting from the demand for PT, one could use micro-data to link the use of public transport to socioeconomic deprivation.
- Sixth, rather than assuming socioeconomic deprivation is independent of PT investment, one could consider how changes in accessibility affect where households locate.[16]

Notwithstanding these limitations, the justice test developed and implemented in this study represents a relatively straightforward adjunct to the policy frameworks currently used to evaluate PT investments in many jurisdictions. In jurisdictions where policy settings seek to reduce prevailing inequality, the systematic application of justice tests may be a useful tool.

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[13] Typically, we expect PT travel times would increase as accessibility declines, for example, in locations that are remote from the city centre. Such information could be sourced from the census.

[14] In terms of land use change, we might expect those areas which experience an increase in accessibility to undergo intensification. Similarly, in response to a major PT investment, one might anticipate complementary changes to the PT network, such as optimization of bus and rail connections.

[15] Even a more sophisticated accessibility function, however, will be sensitive to underlying assumptions and may even introduce further complications. Careful justification of accessibility parameters is therefore likely to be an integral part of any application, regardless of the precise functional form that is adopted.

[16] In practice, PT investment will change amenity levels (positively and/or negatively), which in turn affects the distribution of households and, by extension, inequality. The degree to which changes in accessibility affect household sorting will be context-specific and occur over long timeframes but is deserving of further research.

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