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Public transportation accessibility: Comparing Auckland, Brisbane, Perth, and Vancouver

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Abstract

Accessibility is generally accepted as an important benefit of public transportation (PT) systems. Consistent measurement, however, remains a challenge. In this paper we propose methods for measuring accessibility, which we apply to cities in Auckland, Brisbane, Perth, and Vancouver. As our proposed method relies only on open data, meaningful comparisons are possible across a wide-range of jurisdictions. Our results indicate that Auckland performs relatively poorly in accessibility compared to Brisbane, Perth, and Vancouver. The methodology developed into this paper is provided as a GIS toolbox, providing planners and analysts with a simple and fast tool to calculate accessibility.

1. Introduction

While the social costs of public transportation (PT) vary, one of its universal benefits is accessibility (Vigar, 1999; Levine and Garb, 2002; Dodson *et al.*, 2016; Martens, 2016).

How can PT accessibility be measured? Despite a burgeoning body of research, existing tools and methods used to measure PT accessibility are limited in several ways. Perhaps the most notable is inconsistency in methods and data, which thwarts comparisons between cities. The purpose of this paper is to develop and present measures of PT accessibility that can be compared between jurisdictions. In doing so, we hope to facilitate knowledge transfer between organisations involved in delivering PT.

Our study seeks to advance the existing literature in three related areas. First, our method is *consistent* and can be used to consistently measure PT accessibility in different cities. Second, the method is *detailed*, in the sense that it is computationally efficient even when working at high levels of spatial detail. Finally, our method is *transparent*, in we use commonly available open data and make our code publicly available. In this spirit, we validate our approach by comparing PT accessibility in Auckland, Brisbane, Perth, and Vancouver.

The following sections of this paper are structured as follows: Section 2 reviews relevant literature; Section 3 specifies the methodology; Section 4 applies the methodology to case study cities; and section 5 concludes.

2. Literature review

During the last decade, a burgeoning body of research has addressed the issue of PT accessibility. Studies have mainly used quantitative spatio-temporal measures accessibility as a proxy for benefits.

Numerous studies suggest PT accessibility as a useful indicator of the socioeconomic opportunities arising from transportation and land use systems (for a review of measures see: A. M. El-Geneidy & Levinson, 2006; Geurs & van Wee, 2004; Handy & Niemeier, 1997). Accessibility is usually calculated for population-based measures, such as total employment.

Notwithstanding its advantages, existing methods for measuring accessibility are limited in several important ways.

First, accessibility analyses have been criticised for using resource-intensive and/or context specific methodologies. Lucas (2006), for example, concludes that 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). Existing studies rely, to differing degrees, on jurisdiction-specific models and/or data. Anderson et al. (2013) and Manaugh & El-Geneidy (2012), for example, use outputs from bespoke transport models, which limits the application of their methodology to other contexts. In our study we seek to address this issue by using open data, exploiting consistency in data structures to facilitate comparisons between projects and jurisdictions.

Second, existing studies often analyse accessibility using relatively coarse spatial units, such as Traffic Analysis Zones, or TAZ. This is problematic because zones are not consistent across cities. Manaugh & El-Geneidy (2012), for example, note their “research is not without limitations. Further research might utilise census micro-data for a more accurate exploration of who lives in certain neighbourhoods” (p. 22). Similarly, SNAMUTS (Curtis *et al.*, no date) measures and compare accessibilities in cities based on census zones which vary in sizes not only inside a city boundary but also between different cities. The issue of spatial detail is one that we also address in this study by converting census zones into homogenous hexagons.

Finally, existing studies often use isochrones to measuring PT accessibility. An isochrone is a polygon showing the area that can be accessed using PT given a certain starting point. Two GIS tools commonly used to compute PT based isochrones. The first is the AddGTFStoNetwork developed by ESRI (Morgan, 2016). Examples of publications using this tool include Fransen et al. (2015) and Widener et al. (2015). The second is Open Trip Planner (OTP) developed in 2009 by TriMet, Oregon's transport agency (TriMet, 2009). Examples of publications using this tool include Boisjoly & El-Geneidy (2016), El-Geneidy & Levinson (2006), and Manaugh & El-Geneidy (2012).

The tool developed as part of this research offers additional capability compared to these two existing tools. In contrast to the ESRI tool, our approach can accommodate a maximum number of trip-legs[1] such as access/egress time, wait-time, number of transfers, or walking between transfers. In contrast to the OTP tool, our approach calculates average wait-time, retaining accuracy while reducing variability and remaining computationally efficient.

Our tool is implemented using an open source Python toolbox, which is suitable for inclusion in a wide range of GIS programs, such as ArcGIS Pro and QGIS.

3. Method

In this section, the case studies and the data used in the analysis is introduced. Then the method to measure accessibility is presented.

3.1. Study area

Our study focuses on Auckland, which is – like most cities – competing to attract people, firms, and capital (Auckland Council, 2012). Auckland’s international competitors include Brisbane, Perth, and Vancouver. We also apply our method to these cities.

Error! Reference source not found. presents summary statistics for each city. One of the issues in a comparative study is the consistency of data. To this end, we only analyse the

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[1] A PT journey in its simplest form, starts with walking to a PT stop, waiting for a PT service, some in-vehicle time, getting off at another PT stop, and finally walking to a destination. In this paper, each part of this journey is called a trip-leg. Trip-legs will be discussed further on section 3.3. Measuring accessibility.

continuous urban areas for each city. This excludes a relatively small number of people living in rural areas and satellite cities. Specifically, we use Open Street Map (OSM) data and an ArcGIS toolbox called Delineate Built-Up Areas to identify built-up areas by delineating densely-clustered arrangements of buildings and streets. Figure 1 shows the map of public transport and urban limits of case study cities by PT mode.

Figure 1: Map of public transport in peer cities showing bus, rail, and ferry routes.

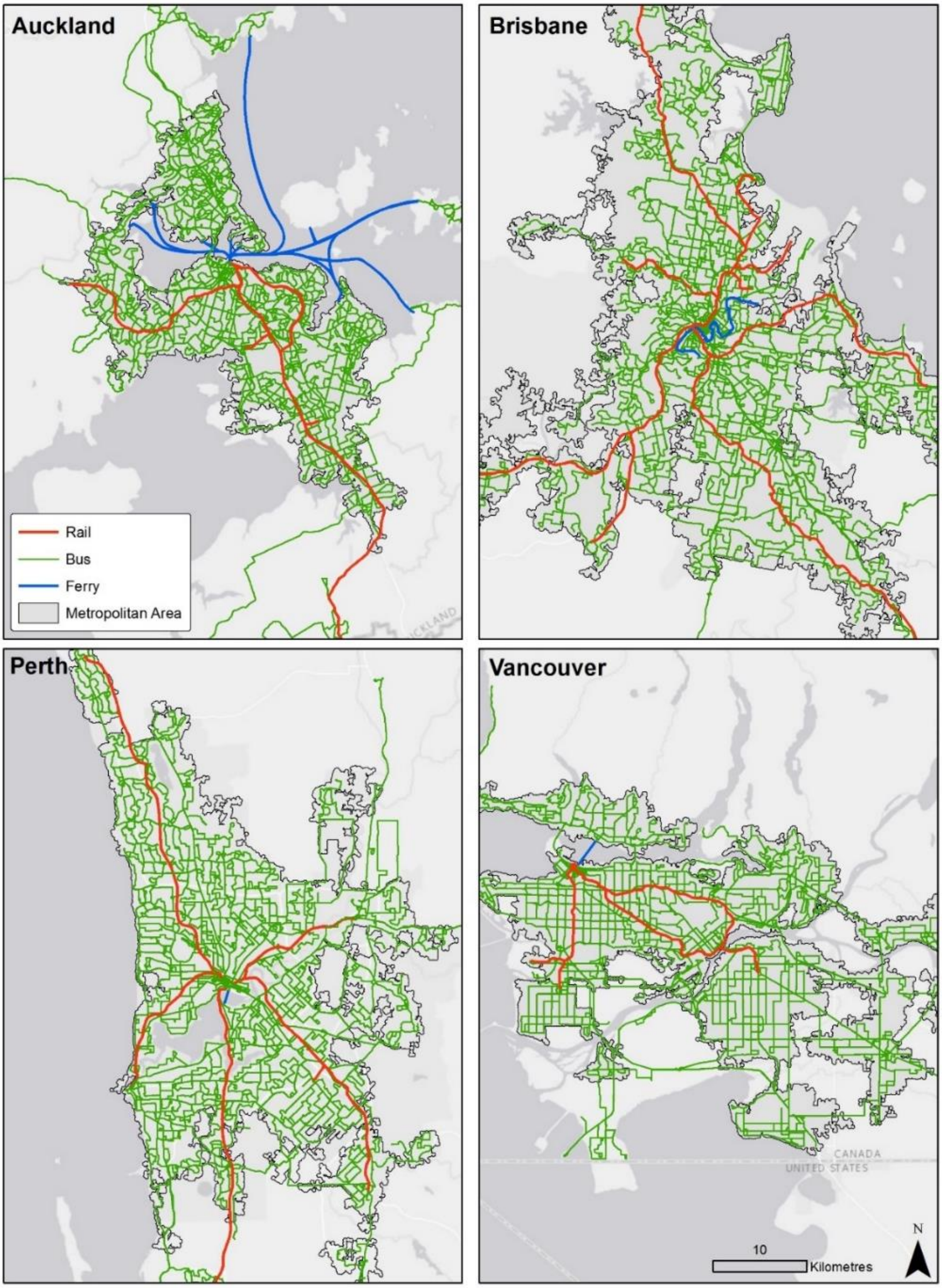


Table 1: Summary PT statistics for case study cities.

City	Land area (km^2)	Population	Population Weighted Density[2]	PT service-km	PT service-hours	PT service-km per km^2 land area	PT service-hours per km^2 land area
Auckland	56,304	1,182,393	30	306,607	8,138	19	0.51
Brisbane / SEQ	153,440	1,824,210	34	1,643,591	12,727	39	0.30
Perth	111,709	1,445,143	24	507,622	9,689	20	0.37
Vancouver	88,977	2,205,365	87	735,413	12,507	41	0.69

We note three high-level features of the urban forms and transport networks of these cities:

First, Auckland has the smallest population and urban footprint of these four cities. Brisbane/SEQ's is twice as large, Vancouver's is 70% larger, and Perth's is 25% larger. As a result, Auckland simply has fewer jobs to reach and smaller average distances to travel to reach them.

Second, despite the fact that all three cities are known for low-density car-oriented development, population-weighted densities vary considerably between them. Vancouver has the highest population-weighted density (87 people per hectare), while Perth has the lowest (24 people per hectare). Auckland is in the middle of the distribution.

Third, different cities offer different levels of PT service per square kilometre of land area. Auckland and Perth have relatively sparse networks, with an average of 19 and 20 PT service kilometres per km^2 of land area, respectively. The three other cities have around twice as much PT service per km^2. This is important, as the quantity and quality of public transport services influences accessibility.

3.2. Data collection

Our analysis makes use of several sources of data on existing transport networks and population and employment locations:

- Open Street Map (OSM) data provides an open database of street networks in the chosen cities. OSM data has been used to model walking network geometry (e.g. street segments, walkways, stairs and their restrictions).
- General PT Feed Specification (GTFS) data is used in this paper to model travel times and distances on public transport networks. A GTFS feed comprises a series of text files, where each file models one particular aspect of the PT system, e.g., stops, routes, trips, and schedules (for full description see Google, 2015). The cities considered in this study (Auckland, Brisbane, Perth, and Vancouver) make their GTFS feeds publicly available. This study uses GTFS data valid for Thursday 11 June 2015.
- Population and employment data has been sourced from national statistics agencies at a highly disaggregated geographic level. For Auckland, we use Census 2013 data from Statistics New Zealand at the meshblock (MB) [3] level for population and employment. In Perth and Brisbane, population data is available at the meshblock

[2] Simple measure of density (i.e. total population / total land area) can significantly underestimate the density of large cities that include both high-density inner-city areas and low-density suburbs. Population-weighted density provides a more meaningful picture of variations between cities. For a further explanation of this measure and a description of how it is computed, see Nunns (2014).

[3] A meshblock is the smallest geographic unit for which Statistics New Zealand collects statistical data. Meshblocks vary in size, from part of a city block to large areas of rural land. Area units are slightly larger – in urban areas they generally cover part of a suburb.

(MB)[4] level and employment data is available at the Destination Zone (DZN)[5] level from the Australia 2011 Census. In Vancouver, 2011 Census population data is available at Dissemination Block (DB) level and employment data from the 2011 National Household Survey is available at Dissemination Area (DA)[6] level.

3.3. Measuring employment

Census data is the main open data available on population and employment. Despite the wide use of census data in accessibility research, this data has some important limitations.

First, measures of employment derived from Census journey-to-work data in Australia and New Zealand exclude people working-from-home and people who did not travel to work on Census day. As such, they represent an undercount relative to other sources of data such as labour force surveys and payroll tax data. This is likely to influence estimates of jobs that can be accessed from any given point. Notwithstanding this limitation, we use Census data because it provides the most detailed geographic information on the location of employment.

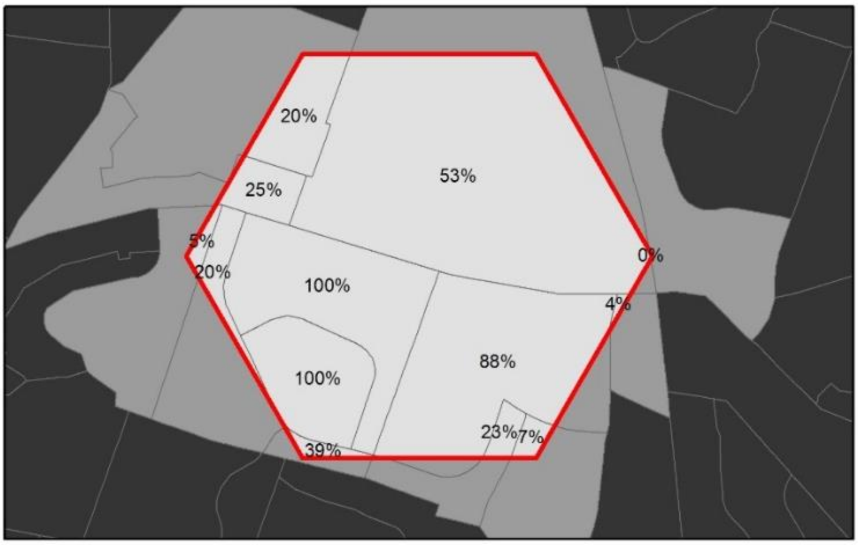
Second, in dense urban areas, a meshblock or dissemination block is approximately equivalent to an urban block, but they tend to become larger in areas with lower population densities[7]. Meshblocks and dissemination blocks are roughly comparable in size between all countries. There is more variation in size among the area units, DZNs, and DAs that we use for employment data, but overall, the accessibility results are sensitive to boundary effects and the size of census zones. In order to make differing levels of spatial aggregation of census data consistent and comparable, the finest grain census data is rescaled into a 0.5 km^2 hexagon mesh (Hex). The rescaling is calculated by the following equation:

$$CV_i = \sum_{j=1}^{n} \left(P_j . CV_j\right)$$

where CV_i is the census variable of hexagon i, n is the number of census areas that intersects hexagon i, P_j is proportion of the census area j that falls into hexagon i, and CV_j is the census variable of the census area j. Figure 2 visualises this calculation.

[4] Mesh blocks are the smallest geographic region in the Australian Statistical Geography Standard (ASGS), and the smallest geographical unit for which Census data are available.
[5] The DZNs were developed by the individual state or territory governments' Transport authorities for the analysis of commuting patterns and the development of transport policy. DZNs are built from Mesh Blocks and aggregate to a subset of the ASGS regions.
[6] Dissemination area is a small area composed of one or more neighbouring dissemination blocks and is the smallest standard geographic area for which all census data are disseminated.
[7] DZNs tend to be larger in areas with lower employment density. Consequently, DZNs tend to be smaller in city centres than in predominantly residential areas.

Figure 2: Graph showing a sample 0.5 km^2 hexagon and the proportion of each intersecting census area inside it.



3.3. Measuring accessibility

In line with the literature, our accessibility analysis takes the cumulative opportunity, or potential, approach and sums the number of essential destinations reachable within certain times by PT (Wachs and Kumagai, 1973; El-Geneidy and Levinson, 2006). This measure is particularly useful in describing how well transportation networks perform in relation to a variety of destinations. This method is limited in two important ways. First, there are downsides to this kind of simple measure, including its sensitivity to boundary effects and the size of TAZs. Second, it disregards accessibility inside TAZs. Here, however, the main interest is in how differences in accessibility between cities are measured.

Cumulative-opportunity accessibility measures are calculated for a specific area (represented by Traffic Analysis Zone, or TAZ) by summing the total number of destinations (jobs, jobs of certain types, schools, medical facilities, etc.) reachable within certain time limit (e.g. 15, 30, 45 minutes) by public PT and automobile. TAZ q is defined to be “accessible” from TAZ p if it is possible to use PT to travel from TAZ p to TAZ q within the specified maximum travel time. Formally, we define accessibility as a binary (0, 1) relationship as follows:

1. For two TAZ 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, maximum number of transfers, maximum walking to/from PT, and maximum walking between transfers denoted by T_{max}, if $t^*(p,q) \leq T_{max}$, then meshblock q is defined to be *accessible* to meshblock p.

Figure 3 illustrates travel time components for a hypothetical 42 minute journey between two TAZs. The time required for a PT journey includes walk (access/egress) time, wait-time, and in-vehicle time. We estimate access/egress time by calculating the distance between TAZ 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.[8] 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 from the GTFS feed.

[8] Several studies (e.g., Bohannon et al., 1996; Dewar, 1992; Knoblauch et al., 2007) report average walk speeds between 4.51 and 5.43 km/h.

Figure 3: Hypothetical 42 minute journey between two meshblocks.

Locations		Origin MB	Bus stop	Bus stop	Train station	Train station	Destination MB	Total time
Walk time		8min		2min Transfer		4min		14min
In transit time	In-vehicle time		10min		13min			23min
	Mean wait time		2min		3min			5min

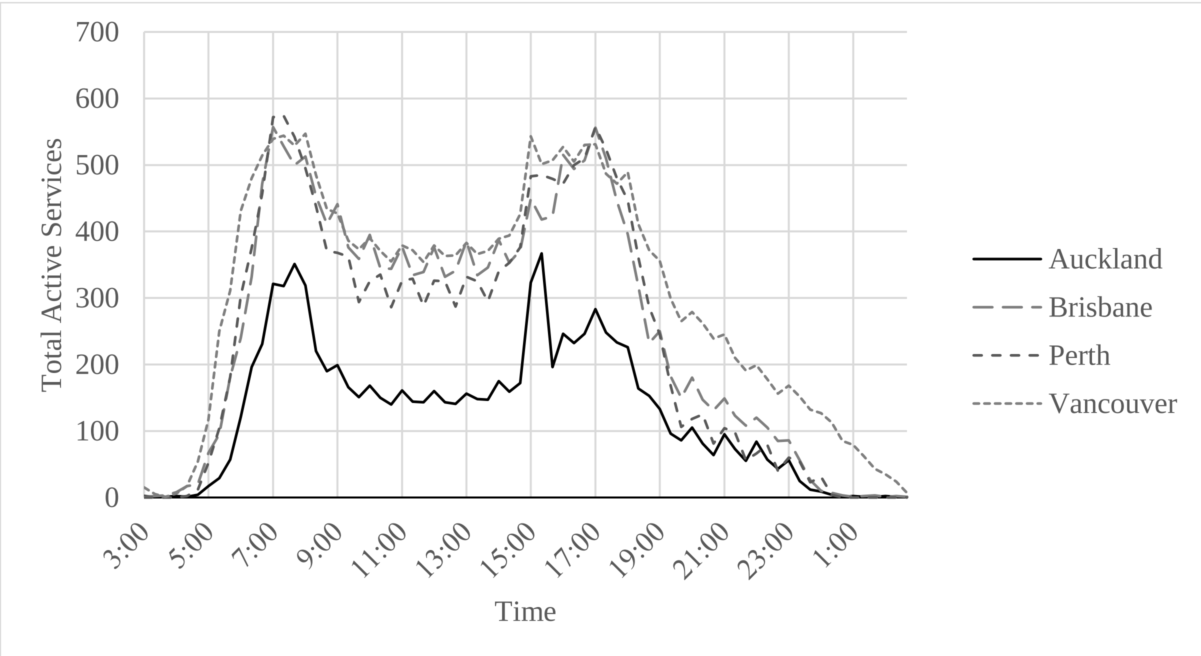
As noted by El-Geneidy et al. (2015), PT accessibility varies over the day. For this reason, we calculate average accessibility for the period 7:00 am to 9:00 am on a typical weekday. In this paper, two TAZs are accessible if the travel time between them is less than 30 minutes (T_{max}). The 30 minutes travel time limit is based on the average PT travel time in Auckland published by Auckland Transport (Greig, 2015, p. 13).

3.4. Morning peak access to jobs as a measure of accessibility

Daily variation in PT services in each network is illustrated in Figure 4. All cities observe broadly similar temporal patterns, albeit on different magnitudes.

We choose to focus on PT based job accessibility in the morning peak from 7 to 9 am. Our focus on accessibility during the morning peak is not to diminish the importance of accessibility at other times, but rather for reasons of computation efficiency. Further research could seek to extend our analysis to accessibility measured across the day.

Figure 4: The number of PT services during a weekday span for case study cities. Despite minor differences, they all show a high utilisation during am peak (7 to 9 am).



3.5. Analysing accessibility

For our analysis, we measure the total number of jobs available to each TAZ by PT. While intra-TAZ commuting is not included in the modelled commute times, we expect these journeys represent a small portion of total commuters.

It is important to note that our focus on PT travel time does not imply that all commuters actually use PT. Instead, we are interested in measuring the accessibility provided by PT to residents based on the locations of their home and work, regardless of their actual selected mode. In this way, we measure the potential benefit that the current system offers to residents.

4. Results

Turning to our results, Figure 6 illustrates access to jobs by PT within 30 minutes of travel time for each of our four cities. Note that all four maps they are on the same scale, allowing for easy comparisons between each city.

Of the four cities we analyse, PT-based job accessibility is highest in Vancouver and lowest in Auckland. **Error! Reference source not found.** further synthesizes our results, by plotting percentage of jobs (vertical axis) accessible to different percentiles of residents (horizontal axis). In Vancouver, 16 percent of the city's population has access to about 19 percent of jobs. This number falls to approximately 10 percent in Perth and Brisbane and only 5 percent in Auckland.

As noted above, we analyse average accessibility to employment in the period from 7 to 9 am using a 30-min travel time window.

Figure 5: Changes in accessibility relative to PT coverage

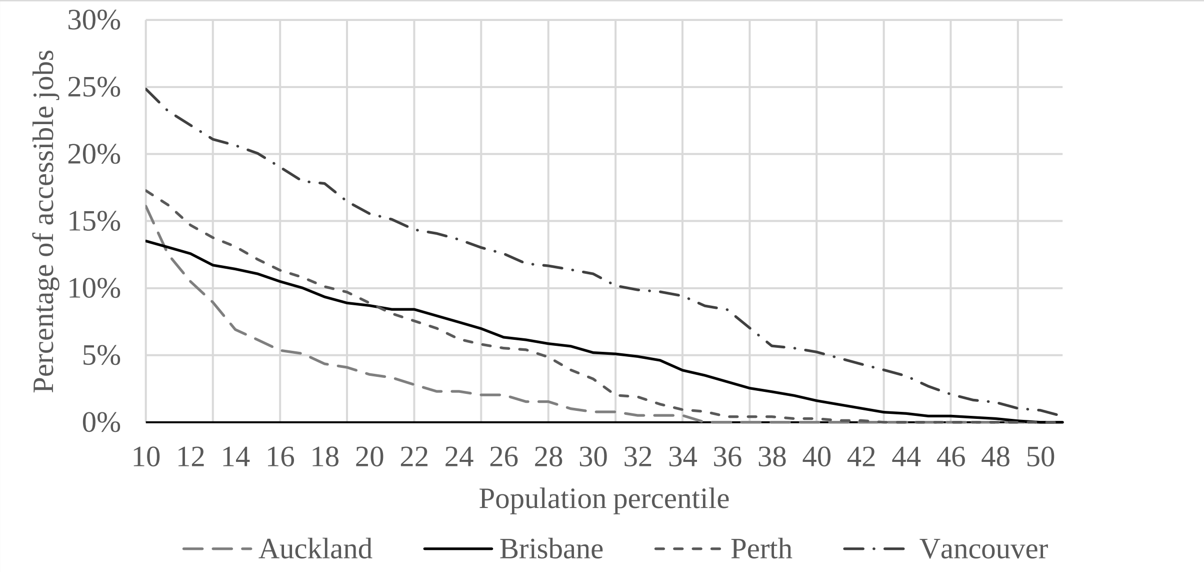
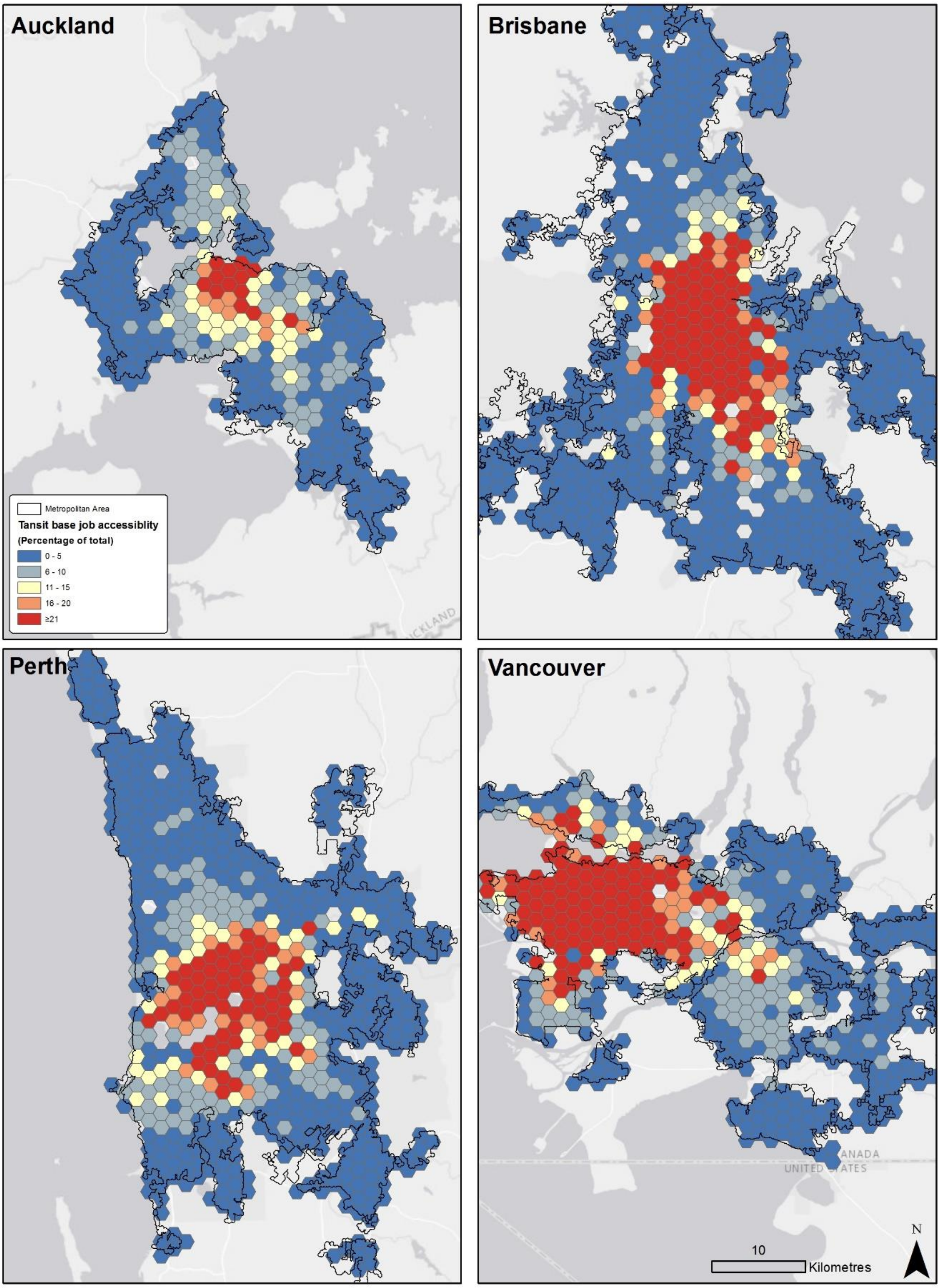


Figure 6: Maps of 30-minute job accessibility in AM peak for case study cities.



5. Discussion

In this study, we develop and apply a methodology for comparing PT accessibility in different jurisdictions. The goal of our study is to enable rapid knowledge transfer on effective transportation planning strategies between jurisdictions.

Our study seeks to advance the existing literature in three related areas. First, our methodology provides a *consistent* measure of PT accessibility in different cities. Consistency is achieved by first identifying the extent of the contiguous urban area and then rescaling underlying spatial units into homogeneous hexagon zones (Hex). Second, our method is *detailed*, in the sense that it is computationally efficient even when working at high levels of spatial detail. For example, our largest case study city, Brisbane, involves 23,854 zones which was analysed in less than four hours by a normal PC. Finally, our method is *transparent*, in we use commonly available open data and make our code publicly available. In this spirit, we validate our approach by comparing PT accessibility in Auckland, Brisbane, Perth, and Vancouver. The resulting method is suitable for modelling a range of PT infrastructure and service investments across projects and between jurisdictions.

Notwithstanding its advantages, our methodology is not without its limitations. The most notable is the aforementioned sensitivity of results to the assumed value for the maximum travel time parameter. An accurate estimate of this parameter is necessary to ensure the reliability of the results. The use of a continuous accessibility function, such as an exponential distance decay function, rather than the binary relationship used in this study, could reduce this sensitivity. Nonetheless, even a sophisticated accessibility function will be sensitive to underlying assumptions, and may even introduce further complications. Careful justification of accessibility measures is, therefore, an integral part of any application.

Another potential limitation is that our methodology abstracts from the demand for PT. We do not consider this to be a fundamental problem for three reasons. First, this issue is common to most accessibility analyses, insofar as they consider *potential* rather than *actual* demand. Second, analysing existing PT demands requires access to ticketing data, with all of the associated confidentiality issues. For these reasons, we consider it reasonable to focus on measures of accessibility, rather than existing demand.

A third limitation is that 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 limitation affects the results depends largely on the proportion of users who access PT using other transport modes, which will be context specific. In theory, it would be possible to replicate our accessibility analysis for a variety of access modes, and then weight results, for example, by mode share.

To finish, we note several directions for further research. One promising avenue would be to incorporate information on the spatial distribution of commutes using 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 maximum travel times that varied by area. Such information could be sourced from census results and/or ticketing data, although the latter is not usually readily available.

Notwithstanding the presence of these limitations, and opportunities for further research, the method developed and applied in this study appears to provide a useful tool for comparing PT accessibility between cities and across projects.

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