ASSESSING CONNECTIVITY EQUITY OF A REGIONAL PUBLIC TRANSPORT NETWORK

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ABSTRACT

It is well understood that travelers from low income households are dependent on public transport. There has been a growing interest to assess equity related to accessibility to various land uses. This study has developed an assessment framework for connectivity equity and applied it to Auckland’s network, which is undergoing a transformation with the government investing in redevelopment to produce an integrated system. Data for the assessment is attained from information available publically and Statistics New Zealand. The connectivity measures of the services are determined for selected suburbs (origins) to Auckland central (destination). These suburbs represent a cross-section of the city and are representative of the population in terms of income, location, and the availability of services. The findings show that suburbs in the income ranges that are “high”, “middle-high” and “middle” have better connectivity. This is partly due to the closer proximity to the destination (i.e. shorter travel times), but also due to a greater level of services available to commuters. Suburbs with poor connectivity were from the “middle-low” and “low” income ranges. Poor bus-bus transfers, a lack of fixed network infrastructure, long journey times, and large headways contributed to poor connectivity for many low income suburbs. The assessment framework can be readily applied to the public transport systems of major cities to enable areas with transport inequity to be identified and brought to the attention of local government; thus enabling connectivity equity to be considered when making regional decisions related to the public transport infrastructure.

Keywords: inequity, connectivity, public transport, service quality
1 INTRODUCTION AND RESEARCH OBJECTIVES

Unequal distribution of transport supply across a region can have an adverse effect on the opportunities available to people with low incomes. There is a strong need for public transport (PT) from those with low incomes. A decline in the number of private vehicles owned can be seen with a reduction in household income (1). Poor accessibility to quality PT services for these individuals can result in low employment participation and long-term cycles of poverty (2). Urban sprawl has been attributed as one of the determinants for inequity in commuting. Lucas et al. (3) conducted a case study in the United Kingdom which evaluated the new services to areas with low income in terms of their increased economic opportunities. Local practitioners indicated that the physical separation of housing from employment activities had a detrimental effect on a number of employees. Ricciardi et al. (1) discussed that in Australia, the high cost of housing means that fringe suburbs of the city are predominantly occupied by low income groups and that there is a lack of PT services to these areas.

A similar issue exists in Auckland, New Zealand. A report by Auckland Council (4), the local government authority, has shown that the increase in population in fringe suburbs is twice that for the central suburbs. Within the metropolis, in the 2013 census, approximately a third of all employed people gave a workplace address in the Auckland region (5). The main employment hub in the Auckland Region is the central business district (CBD). The Ministry of Transport (6) stated that 14% of all commuting destinations are to the CBD. Two universities, The University of Auckland and Auckland University of Technology in conjunction with many private institutes are also located in the CBD. To promote accessibility and growth of the economy, Auckland Transport (AT), the regional transport authority, has proposed significant changes to the network. In 2013, AT produced a statutory document, the Regional Public Transport Plan (RPTP). The plan aims to provide commuters in Auckland with a sustainable transport system in a safe, integrated, responsive and affordable manner. This network redesign has already begun in Auckland, with new interchanges in operation.

The purpose of this study is to develop a framework to assess issues related to horizontal equity in accessibility to various land uses. Auckland’s new PT network is used as the case study. The connectivity measures of the network, using Ceder’s (7) method, is determined and compared to the respective average annual household income of suburbs. The quality of the connectivity between intermodal and intra-modal routes is also investigated. The contribution of this study is the framework that is developed and the procedure that is demonstrated using the case study. Other cities can follow this simple approach to gain an understanding of issues related to equity in accessibility. This will assist local governments to identify areas of needs and facilitate the reduction of equity issues in accessibility. The following section discusses the relevant literature review.

2 LITERATURE REVIEW

2.1 Equity

Equity in transportation can be broadly defined as ‘fairness in access to transport choices’ (8, 9). The concept of equity can be further divided into horizontal, vertical, and spatial equity (10). Vertical equity is defined as ‘the unequal but equitable treatment of unequal’s or the distribution of benefits and costs to groups with differing attributes, such as income (11). Horizontal equity is defined as the ‘equal treatment of equals’ or measuring if parties share benefits and costs equally, and is often assessed using the Gini index (12). Spatial equity is concerned with the distribution of costs and benefits in a space or attaining equity over geographical locations (10, 13).

Kaplan et al. (12) assessed equity in multi-modal PT provisions in the Greater Copenhagen Area, Denmark, using the connectivity method developed by Ceder (7) and the Gini coefficient. They identified three main research areas concerning equity and transport. The first area investigated the links between PT provision, social exclusion, well-being and other factors in relation to the general population and sub-groups such as low income, disabled, and female populations. The second area investigates equity assessment frameworks for the evaluation of transport projects by incorporating it during PT planning and appraisal of modes. Various frameworks have been used to assess the equity of PT systems. Currie and Delbosc (14) provides a single value to assess horizontal equity using Lorenz curves. The study found that PT provision in Melbourne, Australia, was inequitable with 70% of the population sharing 19% of the supply. Welch and Mishra (15) develop their own approach to estimate horizontal equity in the Washington-Baltimore region using a combination of connectivity,
accessibility, and inequality analysis. Their findings showed that equity differs by county due to factors such as the spatial distribution of jobs and transport links. Forth et al. (16) analyzed equity in Toronto, between 1996 and 2006, across three criteria: spatial, temporal, and job type. The methodology used considers the relationship between social disadvantages, job accessibility, and travel time by PT. Their research discovered that the most socially disadvantaged census tracts experience increased accessibility and decreased journey times when compared to the rest of the region over the study period. Casas (17) assessed the spatial equity provided by bus rapid transit in Cali, Colombia by considering accessibility to stops and stations, along with accessibility to activity opportunities. The findings indicate that middle socio-economic strata have the highest accessibility to bus rapid transit in contrast to low and high socioeconomic strata groups which have lower accessibility.

2.2 Accessibility

One of the key measures of accessibility is providing access to different activities/opportunities (18). The other measure is time-based (walking time to stop and journey time). This review focuses on the first definition of accessibility and can also be defined as “the ease with which any land-use activity can be reached from a location using a particular transport system” (19). A conceptual framework by Farrington and Farrington (19) focused on social justice and inclusion; the study reasons that “greater social justice cannot be achieved without greater social inclusion”. It is reasoned that social inclusion can be achieved when the population is able to access activities that reflect societal norms. This implies the provision of an extensive transport network is a potential factor in increasing social inclusion, however it is not guaranteed to increase social inclusion.

Several methodologies have been developed to measure accessibility. A broad review by van Wee et al. (20) found that there were three main areas of accessibility measures: (a) infrastructure-related, (b) activity based and (c) mixed-measures. The infrastructure-related approach considers factors which include speed on a road network, travel times, the length of a road network and congestion. The activity based approach considers activities such as work and leisure. The main emphasis is placed on activities that can be accessed within a specific distance or travel time from a point. With the mixed-measures approach, both the infrastructure-related and activities-related approaches are used in order to give a holistic analysis of accessibility. Four components relating to accessibility have been identified by Geurs and van Wee (21): land-use, transportation, temporal and individual. Factors which define land-use include supply and quality of opportunities at destinations, demand for opportunities at origins and the interrelation between supply and demand. The transportation component focuses on the relative inconvenience of a mode between origins and destinations. The temporal component considers the opportunities available over the course of the day. Lastly, the individual components are linked to the wants, skills and opportunities of an individual. These factors have a direct impact on access to available opportunities and the mode of transport used to access these opportunities. In a more quantitative sense, one of the most famous methods developed to measure accessibility is the gravity model, which was pioneered by Hansen (22) with the aim to model land development. The gravity model is further explained by Meyer and Miller (23). Activity-based measures are found in Dong et al. (24) while Handy and Clifton (25) focused on a utility-based measure. A utility-based measure is founded on the economic theory and takes into account the benefits of a certain activity compared to other alternatives.

2.3 Connectivity

Ceder (26) defines a PT system to be: “An advanced, attractive system that operates reliably and relatively rapidly, with smooth synchronized transfers, part of the door-to-door passenger chain”. Such a system could be described as well-connected, which is a precursor to accessibility. Without connectivity in a network there is little scope for accessibility to opportunities. Ceder (7) proposed that the quality of connectivity of a PT service can be determined by eight quantitative and three qualitative attributes, which are given the notations from $e_1$ to $e_{11}$. Section 3.0 discusses these connectivity notations. Ceder and Perera (27) analyzed a single destination and two origins for each location, London and Auckland. Their study pinpointed the bottlenecks present on both PT networks during major sporting events and suggested that increasing capacity and accessibility of these lines will lead to greater flow. Chowdhury et al. (28) used Google Transit data as a data source and
compared the connectivity measures of three countries’ PT system. The study found that Auckland’s system has poorer connectivity measures both in quantitative and qualitative terms, when compared to London and Paris. Other studies (29, 30) adopted Ceder’s method to assess the connectivity of cities’ network in New Zealand to determine poor PT routes.

3 METHODOLOGY

3.1 Connectivity Framework

Figure 1 shows the framework developed in this study. The framework provides an easy procedure to analyze equity issues related to accessibility by a PT network. Transportation planners and specialists can follow the framework to compare the connectivity measures among suburbs. This will assist in determining areas which require improvements. The first step is to determine the main transport hubs in the interested suburbs. In this study, the CBD was selected as the main destination for employment; however, several destinations can be chosen. The median household income of the suburbs is used to categorize the areas according to income ranges that are sensible for the city. Section 4.1 provides the categories by income ranges used for this study. The second step is to calculate the connectivity measures; more details are given in the successive sections. The final step is to correlate the connectivity measures to the income of the suburbs for determining any inequity associated with accessibility to the selected destination.

<table>
<thead>
<tr>
<th>INPUT</th>
<th>COMPONENT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify the main transport hubs in suburbs as origins ( (O_i) ) and main destinations ( (D_i) ).</td>
<td>Set of income ranges which define low, low-medium, medium, medium-high and high categorises.</td>
<td>Categorise each origin using the median household income by the selected ranges.</td>
</tr>
<tr>
<td>Data of the public transport services from origins ( (O_i) ) to destinations ( (D_i) ).</td>
<td>Set of O-D paths ( (P_{Di}, P_{Oi}) ) ( \forall D_i \in D, O_i \in O )</td>
<td>Define sets of intra-modal and inter-modal paths between selected origins ( (O_i) ) to destinations ( (D_i) ).</td>
</tr>
<tr>
<td>Calculate all trip attributes to determine the quantitative ( (c_{pi}^P) ) and qualitative ( (c_{pi}^L) ) connectivity measures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalized quantitative and qualitative connectivity measures by path</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 1 Assessment of connectivity equity framework
3.2 Connectivity Measures and Assumptions

The measures are grouped into quantitative and qualitative attributes, with a total of 11 attributes as shown in Table 1. The table also provides the weighting attributes (αi) of the measures, which reflect their relative importance (29). Treating these two categories separately allows greater precision in the weighting calibration. The notations and the equations adopted from Ceder (7) are given below. These eleven attributes determine the relative importance of various factors that manipulates travelers’ choice of using PT. It is therefore noted that these eleven attributes may be perceived differently for different individuals and under different situations. The present study will focus on the quantitative connectivity measures and exclude the qualitative measures to determine the operational quality of the PT network in Auckland.

The following list provides a description of how the data was attained for each attribute and states any assumptions. An arc is defined as a service from an origin to a destination. For example, a route with a transfer will be represented by two arcs; one trip from origin to transfer station and another trip from transfer station to destination.

### TABLE 1 Connectivity measures’ notations and weights

<table>
<thead>
<tr>
<th>Quantitative attributes</th>
<th>Weighting attributes (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notation</td>
<td>Measure</td>
</tr>
<tr>
<td>e1</td>
<td>Average walking time</td>
</tr>
<tr>
<td>e2</td>
<td>Variance of walking time</td>
</tr>
<tr>
<td>e3</td>
<td>Average waiting time</td>
</tr>
<tr>
<td>e4</td>
<td>Variance of waiting time</td>
</tr>
<tr>
<td>e5</td>
<td>Average travel time</td>
</tr>
<tr>
<td>e6</td>
<td>Variance of travel time</td>
</tr>
<tr>
<td>e7</td>
<td>Average scheduled headway</td>
</tr>
<tr>
<td>e8</td>
<td>Variance of scheduled headway</td>
</tr>
</tbody>
</table>

(i) Walking time for individual arc (e1 and e2 values)
The value for e1 is assumed to be 13.24 minutes and the value for e2 is assumed to be 6.5min² for all arcs. These values are based on Walton’s (31) research analyzing the walking behavior of 348 people using a survey in New Zealand.

(ii) Waiting time for individual arc (e3 and e4 values)
The average and variance of waiting time is determined from the average and variance of scheduled headway (e7 and e8 values) as shown in Equation 1 and 2.

\[
e_3(\text{min}) = \frac{1}{2} \times \bar{H} \times \left(1 + \frac{Var(H)}{\bar{H}^2}\right)
\]

\[
e_4(\text{min}) = \frac{1}{2} \times Var(\bar{H})
\]

(iii) Travel time for individual arc (e5 and e6 values)
The e5 value is the total journey time for a service from departure at the origin to arrival at the destination. This includes the transfer time, if applicable. The value for e6 is the variance of the journey times for a particular origin.
Scheduled headway for individual arc (e_t and e_l values)

These e_t values are obtained by finding the scheduled headway between all services departing an origin between 7am and 9am on a weekday. The value for e_l is the variance of all headways for an origin.

3.3 Notations And Equations For Connectivity Model Framework

To ease the explicit construction of connectivity measures, a list of notations and formulas followed by the analysis framework are illustrated in this section, excerpting from Ceder (7). For a given time period (e.g. peak hour, average week day):

- \( O = \{O_i\} \) = Set of origins \( O_i \)
- \( D = \{D_o\} \) = Set of destinations \( D_o \)
- \( P_{Dk} = \{P\} \) = Set of inter-route and inter-modal paths to \( D_k \)
- \( P_{Ok} = \{P_i\} \) = Set of inter-route and inter-modal paths from \( O_k \)
- \( M_p = \{m\} \) = Set of transit routes and modes included in path \( p \)
- \( t \) = Index of quantitative attributes
- \( l \) = Index of qualitative attributes
- \( E_t \{e_t^j\} \) = Set of quantitative attributes suitable for connectivity measures
- \( E_l \{e_l^j\} \) = Set of qualitative attributes suitable for connectivity measures
- \( e_{mp}^j \) = The value of attribute \( e_t^j, j = t, l \), related to mode \( m \) on path \( p \)
- \( \alpha_e \) = Weight/coefficient for each attribute \( e_t^j, j = t, l \)
- \( c_p \) = Quantitative and qualitative \((j=t, l)\) connectivity measure of path \( p \)
- \( F_p \) = Average number of passengers using path \( p \)
- \( c_p(i,j) \) = Capacity (flow of passengers) of arc \((i,j)\) between route and mode \( i \) and between route and mode \( j \); each \( i \) can also be an origin \( O_i \) or destination \( D_i \); \((i,j)\) is contained in path \( p \) and is part of a network-flow model.

Equation 3 shows that the connectivity of each path is a summation of the connectivity of arcs (services) from an origin to a destination. A typical path is composed of a succession of riding, walking and waiting times. A higher value of \( c_p \) indicates poor connectivity and a lower value indicates good connectivity.

\[
c_p(i,j) = \sum_{e_t \in E_t} \alpha_e e_{mp}^j , \quad j = t, l
\]  

To allow for comparable connectivity measures, it is necessary to normalize the value of the connectivity attributes, \( e_t^j \), so that the weights \( \alpha_e \) will not be skewed by the differences in scale. Thus, the normalized connectivity attribute is determined by Equation 4.

\[
\left\| e_{mi}^j \right\| = \frac{e_{mi}^j}{\sum_{i=1}^n e_{mi}^j} , \text{ where } e_{mi}^j > 0 \text{ and } n_a = \text{number of arcs}
\]  

4 DETAILS ON THE ORIGINS AND DESTINATION IN AUCKLAND

4.1 Selection of Suburbs (Origins)

The scope of the study is to determine the connectivity of the PT network from the suburbs (origins) to the CBD (destination) in the case study, Auckland region. Auckland metropolis is New Zealand’s largest and most cosmopolitan region with a population of 1.5 million. The morning peak period (7am to 9am) was selected as most commuters travel to the CBD during this time. The central origins were selected based on availability of an interchange or major PT hub and the fringe origins were selected based on PT network availability. Central origins are defined as those with an average off-peak journey time between 30-40 minutes to the CBD and fringe suburbs take an average off-peak journey time of more than 40 minutes. The journey times were determined using Google Maps. The origins
were also selected to provide a variation of geographic locations and income categories. The range for
the income categories was decided using information from Work and Income. This government
agency supports individuals with low incomes. They provide a ‘community services card’ to help with
health care costs for low income earners. For a family of two adults the maximum household income
limit is NZD $49,447 before tax (32). The median income of households in Auckland is $76,500 (4).
Following these guidelines, the categories for the median household income ranges were derived.
Using the 2013 Census data attained from Statistics New Zealand, it was seen that approximately 80%
of the suburbs in the Auckland region have median household incomes between $50,000 and
$110,000. The remaining 20% are in the low and high income categories (33). The income categories
were defined as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Income Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Below NZD $50,000</td>
<td>Low Income</td>
</tr>
<tr>
<td>Category 2</td>
<td>NZD $50,000 to $70,999</td>
<td>Low-Middle Income</td>
</tr>
<tr>
<td>Category 3</td>
<td>Between NZD $71,000 to $90,999</td>
<td>Middle Income</td>
</tr>
<tr>
<td>Category 4</td>
<td>Between NZD $91,000 to $110,999</td>
<td>Middle-High Income</td>
</tr>
<tr>
<td>Category 5</td>
<td>Above NZD $110,000</td>
<td>High Income</td>
</tr>
</tbody>
</table>

Table 2 provides the geographical location, median household income of two adults and the
average number of cars owned by number of adults for the 30 origins selected, 15 central suburbs and
15 fringe suburbs. The stated median household income and average number of cars owned in each
suburb is from the 2013 Census data produced by Statistics New Zealand. The average number of cars
for suburbs Manukau and Massey were not available. As can be seen, the number of cars remains
approximately equal in most of the suburbs with the increasing number of adults in the households.
This emphasizes the reliance larger households have on other modes of transport such as PT to access
places of work, education, or leisure.

4.2 Public Transport Services Between Origins And Destination

The predominant PT modes between the origins and destination are bus and train services. Most
suburbs have access to the train network. All trains start and end at the Britomart Transport Center
located in the CBD. All of the origins apart from Otahuhu have access to bus services which depart
adjacent or from the interchanges. Otahuhu is the only train station with no available bus stations in
close proximity to the train station; the nearest bus station is a 20-minute walk. Otahuhu’s new bus
and train interchange is due to open later in 2016 (34). Grey Lynn, Long Beach/Torbay, Greenhithe,
Northcote, Point Chevalier and Hobsonville, are primarily served by buses to Britomart as there are
no train stations in these suburbs. All other origins have a direct train link to the CBD, or travelers
have the option of taking a bus service to a nearby train station and transferring to a train service.
Albany is served by the Northern Busway which is Auckland’s only Bus Rapid Transit. The Northern
Busway has five interchanges which facilitates intra-modal transfers among feed services and the
main line (30). This offers buses a dedicated lane along the highway enabling faster journey times.

5 RESULTS OF THE CASE STUDY: AUCKLAND

5.1 Overall Connectivity Measures and Average Household Income

Figure 2 provides the relationship between the connectivity measures of the origins selected and the
average annual household income of two adults in the respective suburb. The connectivity measures
for each of the origins were calculated using Equation 5.

\[ C_p = \frac{(C_{bus\ direct} + C_{bus\ transfer} + C_{train\ direct} + C_{bus-train\ transfer})}{Number\ of\ path\ alternatives} \] (5)

The diagram illustrates that, on average, as income decreases, the connectivity measures increase; this
indicates that accessibility to the CBD may not be equitable in terms of income disparity.
### TABLE 2 Details of selected suburbs (origin)

<table>
<thead>
<tr>
<th>Suburb (origin)</th>
<th>Annual household income of two adults (median) NZD; category number</th>
<th>Geographic location</th>
<th>Average number of cars owned by households in units of numbers of adults (&gt;18)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Adults 3 Adults 4 Adults 5 Adults</td>
</tr>
<tr>
<td><strong>Central Suburban Areas</strong></td>
<td></td>
<td></td>
<td>2 Adults 3 Adults 4 Adults 5 Adults</td>
</tr>
<tr>
<td>Otara</td>
<td>38,100; 1</td>
<td>South</td>
<td>1 1 2 2</td>
</tr>
<tr>
<td>Mangere</td>
<td>46,000; 1</td>
<td>South</td>
<td>1 2 2 2.5</td>
</tr>
<tr>
<td>Otahuhu</td>
<td>47,000; 1</td>
<td>South</td>
<td>1 2 2 3</td>
</tr>
<tr>
<td>Manurewa</td>
<td>51,900; 2</td>
<td>South</td>
<td>1 2 2 3</td>
</tr>
<tr>
<td>New Lynn</td>
<td>62,900; 2</td>
<td>West</td>
<td>2 2 2 2</td>
</tr>
<tr>
<td>Glen Innes</td>
<td>65,000; 2</td>
<td>East</td>
<td>2 2 2.5 3</td>
</tr>
<tr>
<td>Papatoetoe</td>
<td>56,200; 2</td>
<td>South</td>
<td>2 2 2.5 3</td>
</tr>
<tr>
<td>Manukau</td>
<td>74,500; 3</td>
<td>South</td>
<td>1 1 Not available</td>
</tr>
<tr>
<td>Panmure</td>
<td>85,900; 3</td>
<td>South-east</td>
<td>2 2 3 2.5</td>
</tr>
<tr>
<td>Onehunga</td>
<td>79,800; 3</td>
<td>South-east</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Penrose</td>
<td>83,100; 3</td>
<td>East</td>
<td>2 2 2.5 3</td>
</tr>
<tr>
<td>Northcote</td>
<td>113,600; 4</td>
<td>North</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Grey Lynn</td>
<td>138,200; 5</td>
<td>West</td>
<td>2 2 2.5 3</td>
</tr>
<tr>
<td>Remuera</td>
<td>142,400; 5</td>
<td>Central-east</td>
<td>2 2 2.5 2.5</td>
</tr>
<tr>
<td>Point Chevalier</td>
<td>123,200; 5</td>
<td>West</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td><strong>Fringe Suburban Areas</strong></td>
<td></td>
<td></td>
<td>2 Adults 3 Adults 4 Adults 5 Adults</td>
</tr>
<tr>
<td>Point England</td>
<td>42,700; 1</td>
<td>East</td>
<td>1 2 2 2</td>
</tr>
<tr>
<td>Clendon</td>
<td>49,200; 1</td>
<td>South</td>
<td>1 2 2 2</td>
</tr>
<tr>
<td>Henderson</td>
<td>57,300; 2</td>
<td>West</td>
<td>1 2 2 2.5</td>
</tr>
<tr>
<td>Glen Eden</td>
<td>68,200; 2</td>
<td>West</td>
<td>2 2 2 3</td>
</tr>
<tr>
<td>Papakura</td>
<td>61,100; 2</td>
<td>South</td>
<td>2 2 2 2</td>
</tr>
<tr>
<td>Clover Park</td>
<td>50,200; 2</td>
<td>South-east</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Albany</td>
<td>86,500; 3</td>
<td>North</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Massey</td>
<td>76,000; 3</td>
<td>West</td>
<td>2 2.5 3 Not available</td>
</tr>
<tr>
<td>Sunnyvale</td>
<td>72,800; 3</td>
<td>West</td>
<td></td>
</tr>
<tr>
<td>Howick</td>
<td>85,500; 3</td>
<td>East</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Pakuranga</td>
<td>75,600; 3</td>
<td>South East</td>
<td>2 2 2 3</td>
</tr>
<tr>
<td>Torbay/Long Beach</td>
<td>88,100; 3</td>
<td>North</td>
<td>2 2 3 3</td>
</tr>
<tr>
<td>Hobsonville</td>
<td>92,200; 4</td>
<td>North-west</td>
<td>2 3 3 3</td>
</tr>
<tr>
<td>Botany</td>
<td>104,800; 4</td>
<td>East</td>
<td>2 2 2.5 3</td>
</tr>
<tr>
<td>Greenhithe</td>
<td>117,900; 5</td>
<td>North</td>
<td>2 3 3 3</td>
</tr>
</tbody>
</table>

Origins within the income categories High, Middle-High and Middle have connectivity measures below 200 indicating good access to the CBD using PT, in comparison to the origins in the Low-Middle and Low income categories which have relatively higher values i.e. poor connectivity. Three origins in the Low-Middle income category (Papakura, Manurewa and Clover Park) and three in the low income category (Clendon, Mangere, and Point England) have significantly greater connectivity measures compared to the other origins. It is to be noted that four of the six origins with poor connectivity are fringe suburbs. Figure 3 provides an in-depth examination of the intermodal and intra-modal routes in these six poor connectivity origins. The connectivity measure for intra-modal transfers for buses is the highest for all origins, with Clover Park (a fringe suburb) having the greatest value.
This indicates that bus-bus transfers contributed to the poor overall connectivity values for the suburbs in Figure 2. The average bus-bus transfer journey time of the six poorest overall connectivity suburbs was 78 minutes. The average headway for bus-bus transfer trips originating in Papakura was
31 minutes (with individual headways ranging from 15 minutes to 50 minutes). The longest individual journey was 113 minutes. For bus-bus transfers from Clover Park, the average headway was 29 minutes with significant variation of individual headways including 0 minutes and 80 minutes. This contributed to a high variance of headway ($e_h$ value of 963) in turn resulting in the highest connectivity value for bus-bus transfers which affects the overall connectivity value for Clover Park. The average bus-bus transfer journey time for Clover Park was 77 minutes, with longest journey time being 99 minutes for an individual trip. Similarly for Manurewa the average headway was 13 minutes with variation of individual headways ranging between 0 minutes and 49 minutes, also contributing to a relatively high $e_h$ value. The average journey time for bus-bus transfer trips from Manurewa was 87 minutes with the longest individual journey time being 105 minutes. This suggests that although Manurewa and Papakura have good direct train connections to the CBD, the poor bus-bus transfer services contributed to the high overall connectivity measures.

5.2 Connectivity Measures for Central and Fringe Suburbs

On average, direct services across all modes from the central suburbs take 49 minutes and 60 minutes from the fringe suburbs to the CBD. As can be seen in Figure 4a, in general, bus direct services have lower connectivity measures (i.e. better connectivity) in comparison to bus-to-bus transfer services. This is due to direct services typically having a higher frequency and shorter journey time than bus transfer services. Northcote, Massey, and Mangere are unique cases where the bus direct services have significantly higher connectivity measures than the bus-bus transfer services. For example, the average headway for Northcote’s direct bus service is 19 minutes with an average journey time of 30 minutes. In comparison the bus-bus transfers have an average headway of 12 minutes and an average journey time of 26 minutes. Similarly for Mangere and Massey the bus-bus transfer services have lower average headways and journey times when compared to the bus direct services. The longer headways and journey times for bus direct services from Northcote, Mangere, and Massey are reflected in the higher connectivity measures compared to the bus-bus transfer services. From Northcote, the bus-bus transfer service is part of the Northern Busway (Bus Rapid Transit), while the better connectivity of the bus-bus transfer services from Mangere and Massey can be attributed to the on-going improvements in the network as Auckland moves towards a more integrated PT system.

Figure 4b shows that direct train links provide lower connectivity values than bus-train transfers. This is expected as a bus-train transfer service will most likely be longer than an equivalent direct train service. Bus-train trips originating from Massey have a high headway of 34 minutes and average journey time of 77 minutes, contributing to the highest connectivity measure. The diagram also illustrates that not all origins benefit from the train network; 14 out of the 30 origins have access to direct train services. Figure 4c shows that direct train services provide excellent connectivity to the CBD when compared to bus services. This is mainly due to the shorter journey times which are less variable and low headways (approximately 10 minutes) during the peak period. Ten of the central suburbs have a direct train connection compared to four of the fringe suburbs. This results in the central suburbs attaining lower connectivity values. The average train journey time for central suburbs is 27 minutes compared to 47 minutes for fringe suburbs. Exceptions exist for New Lynn which has approximately equal direct bus and direct train connectivity measures due to the short journey time and high frequency for both path alternatives. Of interest is Onehunga in which the direct train link has a significantly larger connectivity value compared to the direct bus links. Onehunga’s direct train services have an average headway of 30 minutes, compared to the average headway of 11 minutes for the direct bus services. Train services provide significantly lower connectivity measures than direct bus services in Papakura, Manurewa, and Papatoetoe. This suggests that some suburbs will benefit from rail infrastructure or bus rapid transit to improve their overall connectivity.
(a) Comparison between bus direct and bus transfer connectivity

(b) Comparison between train direct and bus-train transfer connectivity.

*No feasible option for train-train transfers.
The purpose of this study was to develop a framework to assess issues related to horizontal equity in accessibility to various land uses. Auckland’s new PT network is used as the case study. This case study is used as an example and as an explanatory device, to capture the essence of the methodology presented. Data for analysis was attained from public information available for the new network. The connectivity measures of the services available during the morning peak period (7am to 9am) were determined for selected suburbs (origins) to the Auckland CBD (destination). The suburbs chosen represent a cross-section of Auckland and are representative of the population of the city in terms of income, location, and the availability of services. It is evident from the findings that suburbs in the income categories that are “high”, “middle-high” and “middle” have better connectivity. This is partly due to the closer proximity to the CBD which results in a shorter travel time, but also due to a greater level of services available to commuters. For example, Remuera (a high income suburb) has access to a total of 55 routes including direct train, direct bus and bus-bus transfer. This is the greatest level of choice observed for any location selected for the study. Another high income area, Grey Lynn has 26 services which are all bus direct services, resulting in a very low average journey time of 16 minutes. In contrast, Point England (a low income suburb) has a total of 12 services across direct bus, bus-bus transfer, and bus-train transfer services. The six suburban areas with the highest (poorest) connectivity values were from the income category “low-middle” and “low”. Further analysis of the routes has shown that poor bus-bus transfer services contributed to the high values. Four of these six suburbs, which are fringe suburbs, do not have direct train links. Also, the direct bus services available have an average journey time of 69 minutes, which is substantially longer in comparison to other fringe suburbs. Similarly a lack of fixed infrastructure such as rail or bus rapid transit limits the ability of fringe suburbs to obtain PT services with better connectivity.

Although central suburbs have better connectivity on average, there is an extremely high barrier to entry in the form of house prices in these suburbs. The Auckland region is forecasted to reach an average house price of $1 million which is impossible for many, with a house price to income multiple of more than 20 for the lowest income households (35). The higher connectivity of central
suburbs combined with higher house prices may contribute to structural inequity with regards to transport over time. Travelers living in fringe suburbs will likely continue experiencing barriers in living closer to the CBD, a major employment and education hub and thus limited to having access to PT services with poor connectivity. With increasing numbers of people forecast to live in fringe suburbs as Auckland grows, it is important that faster and more accessible services are available to residents in these areas, especially for those commuting to the CBD. Expanding city limits and increasing migration are a common problem for growing cities and may cause equity issues regarding PT access. The assessment framework developed in this study can be readily applied to the PT systems of other major cities to enable areas with transport inequity to be identified and brought to the attention of local government. In doing so the equity of transport access could be considered when making future PT decisions at a regional level and help reduce connectivity inequity within cities, enabling increased social and economic participation from all residents.

7 REFERENCES


