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A clustering method for measuring accessibility and equity in public transportation service: Case study of Melbourne

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ABSTRACT

This paper proposes a Modified Cumulative Accessibility (MCA) measure incorporating actual travel demand information (Origin-Destination trip patterns) to improve the accuracy of the measure as a reliable proxy for equity evaluation and amelioration in accessing Public Transportation (PT) services. The travel demand information is reflected into the MCA measure by evaluating and clustering PT and Private Vehicle Transportation (PVT) trip diaries. Both vertical and horizontal equities are measured for the network's Transportation Analysis Zones (TAZs). To redress the inequities, a priority list of operational recommendations for each TAZ is identified. The proposed method is tested with the Greater Melbourne area datasets and the TAZs with the highest inequity along with prescribed operational recommendations are identified. In terms of equitable distribution of public transportation service, a major observation from the case study model was that the outer suburban areas located in the eastern side of the the Melbourne metropolitan area are relatively underserved as compared to the inner and western suburbs.

1. Introduction

Urban sprawl and population growth can give rise to transportation inefficiencies and traffic congestion. Improving accessibility and mobility by Public Transportation (PT) services have the potential to shift a portion of Private Vehicle Transportation (PVT) trips to PT and reduce traffic congestion (Vuchic, 1981; Zhang et al. 2019; Yang, 2019). Moreover, from a social perspective, PT can fill the existing mobility gaps especially for carless and mobility-impaired populations (Kompil et al., 2019). Accordingly, PT services not only should meet the travel demand capacity requirements, but they should also provide equitable accessibility to job opportunities particularly for the low-income and disadvantaged people.

This research aims to improve the precision of the location-based accessibility measures, particularly the Cumulative Accessibility (CA) measure by incorporating travel demand information. Various transportation and land use factors are known to affect PT network accessibility, including: service coverage, travel times, fare, convenience, safety and security (on the service side), distribution of job opportunities in the network, type of available jobs and demand, and competition over existing job opportunities (on the land use side) (Yang, 2019; Yang et al., 2019). Travel time, service coverage, and fare factors are the most common transportation and land use factors studied by the literature (Geurs and Van Wee, 2004; El-Geneidy et al. 2016b).

Although incorporation of some of the factors such as fare and service travel time into the accessibility measure can increase its precision, it is not enough particularly when the measure is used to identify Transportation Analysis Zones (TAZs) treated unfairly in benefiting from PT services. For instance, a competitive PT service from a certain residential zone to a particular activity center with employment opportunities may not necessarily mean reasonable PT accessibility, unless the exiting employment opportunities and other qualitative factors of PT services such as safety, security, and convenience match the types and needs of the zone residents.

Exploring trip diaries and identifying mobility patterns in the PVT and PT modes can demonstrate how jobs and PT services match the types and needs of the zone residents.

In this research, we propose an accessibility measure called Modified Cumulative Accessibility (MCA) that incorporates a demand distribution factor as a proxy of a majority of the influential factors on the accessibility value. The demand distribution factor is prepared by clustering and evaluating historical trips in the PVT and PT modes. Trip clustering

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helps to divide a graph into different subgraphs, where the vertices of a subgraph have a high degree of inter-connection and relatively low connection with vertices of other subgraphs (Akbarzadeh et al., 2018). As another motivation for this research, a majority of the insights in the literature on PT accessibility evaluation are descriptive. They either evaluate accessibility in the TAZ level or network level. In addition to the descriptive insights, this study provides a priority list of operational recommendations towards improving PT accessibility of each TAZ treated unfairly (i.e. called in this paper "Underserved TAZ"). The provided priority lists of the operational recommendations can assist local authorities to efficiently allocate budget to future development projects towards equity rectification.

This paper contributes to the literature in the following ways:

- Modifying the traditional CA measures by incorporating actual demand information and travel patterns into the estimated accessibility measure;
- Extracting the travel demand patterns by investigating the matrix of trips records on the PVT and PT modes and clustering the network zones;
- Proposing a method to develop a priority list of operational recommendations to rectify service inequity for access to jobs (or other opportunities in the network).

These contributions are clarified in Section 2 by presenting a comprehensive conceptual framework of the problem features and reviewing the literature in light of this framework.

The rest of the paper is organized as follows. A review on relevant literature is reported in Section 2. In section 3, our developed method is presented. Section 4 is specified for introducing the investigated real case study. Results and insights of applying method on a real case study are reported in Section 5, and the paper is concluded in Section 6.

2. Literature review

The section presents a comprehensive review of the literature on equity evaluation in PT systems. A classification of key features in equity evaluation for PT systems is presented by Fig. A1, and the literature is is summarized in Table A1 based on this classification.

The literature on equity evaluation in PT systems are categorized into six classes namely: "Equity Type", "Equity Assessment", "Accessibility Components and Variables", "Accessibility Measures", "Method of Counting Disadvantaged People", and "Research Findings".

2.1. Equity type

equity in general is defined as fair (not necessarily equal) distribution of benefits among people. Three major types of equity can be defined:

- Horizontal (H): distribution of benefits among individuals equally
- Vertical with regards to income and social class (VS): distribution of benefits among individuals with considerations of socio-economic characteristics
- Vertical with regards to mobility need and ability (VM): distribution of benefits among individuals according to their mobility needs and physical abilities

Much attention has been drawn recently to measuring accessibility to PT services with consideration of vertical equities (with regards to income and social class, Mayaud et al., 2019; Nazari Adli et al., 2019). The underlying argument in this category is that disadvantaged individuals should take priority in PT benefits in comparison to others. On the other hand, there are arguments supporting the idea that publicly funded utilities, including PT services, should be equally distributed between people regardless of their socio-economic characteristics or possible disabilities (e.g. Lee and Miller, 2019; Ben-Elia and Benenson, 2019); hence, the horizontal equity measures. Meanwhile, another group of researchers investigate both horizontal and vertical equities (e.g. Chaloux et al., 2019; Song et al., 2018). This study also investigates both to see how PT benefits are evaluated through these equity distribution definitions.

2.2. Equity assessment

equity assessment can be done by comparative approaches or statistical approaches (e.g. Gini coefficient). The comparative approaches aim to highlight the gaps between demand and supply in the network zones and identifying zones that display the largest gaps (i.e. inequity). A majority of the literature, nearly 80%, has assessed equity by this simple gap identification method (e.g. Sharav et al., 2019; Kelobonyea et al., 2019). Moreover, some measures such as index of PT needs gap (Currie, 2004) or ratio of supply over demand (Golub and Martnes, 2014) has been proposed to facilitate the process of gaps identification in comparative approaches. However, in statistical approaches, the degree of equity (or inequity) in whole PT system is concerned; hence, the degree has measured through different indices such as Gini index, Variance index, Theil entropy index, and Spearman Correlation index (Chen et al., 2019; Cao et al., 2018). In this research, we assess equity by adopting a comparative approach.

2.3. Accessibility components and variables

Accessibility has four major components as follows: (1) land-use, (2) transportation, (3) temporal, and (4) individual (Geurs and Van Wee, 2004). For land-use component, investigating diverse job opportunities rather than a single job (e.g. Qi et al., 2019; Mayaud et al., 2019; Grisé et al., 2019), demand features (e.g. Pucci et al., 2019; Lee and Miller, 2019), quality and/or quantity of job opportunities (e.g. Oviedo et al., 2019; Slovic et al., 2019), and competition over job opportunities (Mayaud et al., 2019) are predominant attributes in the reviewed literature. Although competition over jobs in measuring PT accessibility was only studied by Mayaud et al. (2019), several method for incorporating competition effects into measuring accessibility for different transportation modes have been proposed including completion factors or balancing factors (Williams, 1978; Knox, 1978; Van Wee et al., 2001; Moreno-Monroy et al., 2018).

Moreover, land-use investigation can be done in a micro level, where the distributions of jobs and demands are investigated within TAZ levels (Farber et al., 2016, Järv et al., 2018, Lee and Miller, 2019, Nazari Adli et al., 2019).

Travel time, including waiting, walking, and in-vehicle time (e.g. Legrain et al., 2016), service regularity/frequency (e.g. Chen et al., 2018; Currie., 2010), service reliability (Eboli and Mazzulla., 2011; Cheng et al., 2017), service connectivity (Cheng et al., 2017; Welch, 2013; Mortazavi and Akbarzadeh, 2017), fare (Bocarejo and Oviedo, 2012; Eboli and Mazzulla, 2011; Bureau and Glachant, 2011; Kaplan et al., 2014a; Serulle and Cirillo, 2016; El-Geneidy et al. 2016b), accident risks and on-board safety (Cheng et al., 2017) are some attributes that constitute the transportation component of PT accessibility measures. Temporal features are related to either time-dependency of service characteristics (e.g. travel time, fare, or quality) (e.g. Järv et al., 2018; Serulle and Cirillo,. 2016; Farber et al., 2016; Mullyey, C et al., 2017) or time-dependency of job opportunities (e.g. availability of jobs at different time of a day) (e.g. Fransen et al., 2015;Ben-Elia and Benenson, 2019; Lee and Miller, 2019).

The individual component of PT accessibility measures is meant to reflect users' needs, abilities, and preferences. Trip-based and population-based categorizations facilitate the process of investigating users' needs and abilities, respectively. Karou and Hull (2014) and Pucci et al. (2019) investigate users' needs by measuring accessibility to jobs for various trip purposes. Grisé et al. (2019) cover users' abilities by measuring accessibility to jobs by PT services for people with and

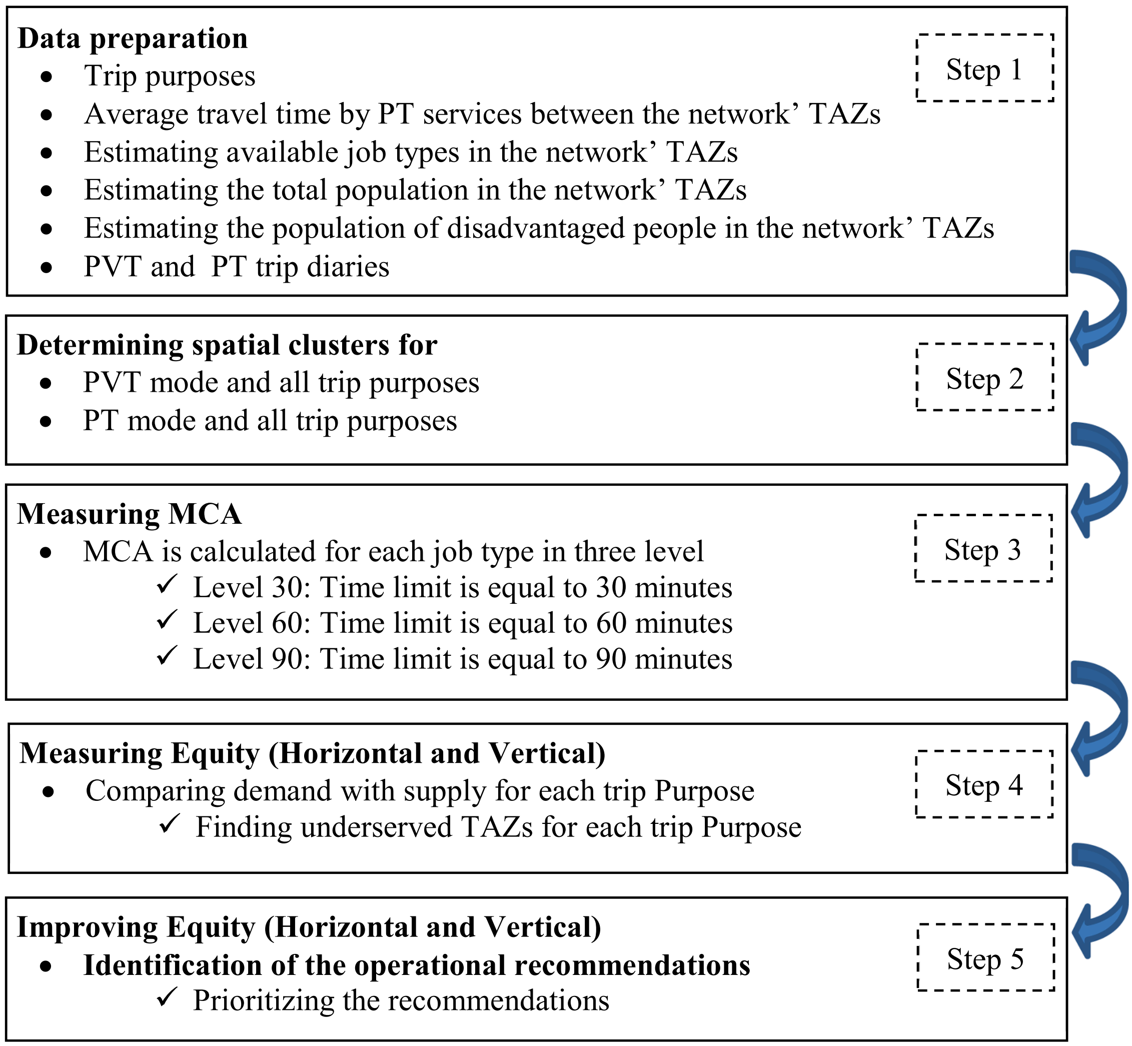

Fig. 1. The framework of the research method.

without a physical disability. Mayaud et al. (2019) measure accessibility to healthcare facilities for two vulnerable groups of people (i.e. youth and senior people).

Also, users' preferences can be quantified and reflected into accessibility measures using utility-based measures built on stated-preference choice models (Nassir et al., 2016), or other techniques such as exploring mobility patterns (Farber et al., 2016), or based on customer satisfaction surveys (Chaloux et al., 2019). This research contributes to the literature by addressing users' preferences into the CA measure by a demand distribution factor. The demand distribution factor is prepared according to the results of clustering network TAZs by historical trip patterns in PT and PVT modes.

2.4. Accessibility measures

Geurs and Van Wee (2004) present an insightful classification for existing accessibility measures: infrastructure-based measures, location-based measures, person-based measures, and utility-based measures. Our review on the literature shows that recently, a new category has added to the classification integrating infrastructure-based and location-based measures (Chen et al., 2018; Ben-Elia and Benenson, 2019; Chaloux et al., 2019; Pucci et al., 2019). Hence, in this study, we update the classification by an additional category called "Mixed Infrastructure- and Location-Based Measures".

Infrastructure-based measures emphasize on transportation components such as speed, travel cost, and congestion regardless of land-use features such as the location and quantity or quality of job opportunities. These measures can be defined based on the coverage of PT stations on population or jobs (Murray and Davis, 2001), PT travel time or speed (e.g. Järv et al., 2018; Qi et al.,2019; and Sharav et al., 2019), both coverage of PT stations and PT frequency (called "supply index") (e.g. Currie, 2004; Currie, 2010; Ruiz et al., 2017), or PT network connectivity (e.g. Welch and Mishra, 2013; Welch, 2013; Farber et al., 2017). Moreover, some studies measure the accessibility of PT services based on customers' point of view by evaluating their satisfaction of PT services (Eboli and Mazzulla, 2011) or difficulties in using the PT services (Kaplan et al., 2014a).

The location-based accessibility measures simultaneously regard to land-use and transportation components. Moreover, they can cover temporal and individual components. Location-based accessibility measures have been frequently applied in the literature (i.e. more than half of the literature has used these measures), where cumulative and gravity measures are the most common accessibility measures in this category. The cumulative measure counts the number of opportunities that can be accessed within a given threshold time, where usually in PT literature the threshold is set in congruous with trip purposes (Karou and Hull, 2014), where for working trips the PT accessibility measures in different levels by setting the threshold values from 10 to 90 minutes (Fransen et al. 2015; Lucas et al. 2016; El-Geneidy et al. 2016b). In contrast to the cumulative measure, the gravity measures incorporate a distance-decay function, where the PT accessibility decreases by increasing the travel distance, cost, or time between TAZs (e.g. Sun et al., 2018; Nazari Adli et al., 2019).

The category of the "Mixed Infrastructure- and Location-Based Accessibility Measures" includes four papers (Chen et al., 2018; Ben-Elia and Benenson, 2019; Chaloux et al., 2019; Pucci et al., 2019). Chen et al. (2018) integrate PT network's connectivity with the CA measure. Ben-Elia and Benenson (2019) incorporate coverage of PT stations into the CA measure. Chaloux et al. (2019) develop a gravity accessibility measure by customer satisfaction of PT services. Also, Pucci et al. (2019) is an example of combining mobility indices with the gravity accessibility measures.

Although person-based and utility-based measures have the potential to incorporate user details, the literature shows low interest in using these measures. Accordingly, only Serulle and Cirillo (2016) and Lee and Miller (2019) use utility-based and person-based measures, respectively.

This research contributes to the literature by integrating a demand distribution factor into the CA measure. The demand distribution factor is prepared based on OD matrix of trip diaries. Hence, the proposed measure called MCA belongs to the category of "Mixed Infrastructure- and Location-Based Accessibility Measures".

One potential shortcoming of conventional CA measures is neglecting actual travel demand distributions in measuring accessibility. In the proposed MCA model, the actual travel patterns are taken into account, and this allows the model to evaluate the access to opportunities that matter to the residents, and match more effectively with their preferences and abilities.

2.5. Method of counting disadvantaged people

Some socio-economic groups of people, referred to in the literature as disadvantaged or vulnerable people, may highly depend on PT services to fulfill their household mobility needs. Various social indices have been used to estimate the total number of disadvantaged households at TAZ level. These indices are based on population of low-income people, women, elderly, students, immigrants, people with physical disabilities or/and other classes of community. Accordingly, many of the reviewed papers (i.e. 25 out of 54 papers in the literature) count disadvantaged population based on population in one of the above-mentioned classes (e.g. Pucci et al., 2019; Karner, 2018; Hu, 2017), where most of them used the population of low-income people. Other research works count the population of disadvantaged people based on populations of multiple classes weighted equally or unequally. The equal weighting approach is more common in comparison to the unequal weighting. Deboosere and El-Geneidy (2018), Chaloux et al. (2019), Grisé et al. (2019) are examples of equally weighting approach, while Currie (2004), Currie (2010), Jiao and Dillivan (2013), Ruiz et al. (2017), and Qi et al. (2019) applied the unequally weighting approach in PT accessibility evaluation. Although weighting logics vary across different studies, some indices such as population of low-income people, women, carless, and elderly generally received more weights in the majority of reviewed literature. In this research, without losing generality, we count the population of disadvantaged people based the population of low-income people.

2.6. Research findings

A majority of the presented insights by the literature are descriptive. Accordingly, they can describe the level of equity at the whole network (e.g. Song et al,. 2018; Ben-Elia and Benenson, 2019), at the TAZ level (e.g. Pucci et al., 2019; Mayaud et al., 2019), or both of them (e.g. Cao et al., 2018; Chen et al., 2018; Deboosere and El-Geneidy, 2018). However, this research contributes to the literature by embedding a prescriptive analysis into the proposed method to recommend efficient solutions to redress inequities in PT services. Also, the recommendations are sorted in the order of effectiveness and efficiency in a priority list.

3. Method

In this section, we present a four-step method for measuring and redressing inequities in distribution of PT benefits among network's TAZs. To measure the inequities, we compare demand with supply in the TAZs. The supply is measured by the proposed MCA measure that incorporates travel demand information. The travel demand information is reflected into the MCA measure by evaluating and clustering PT and PVT trip diaries. To redress the inequities, we propose a priority list of operational recommendations for each TAZ to improve its accessibility level to job opportunities. Fig. 1 demonstrates the framework of the proposed method.

Steps are explained in detail as follow:

Step 1 (Data preparation): This step is dedicated to preparation of necessary input data that are five datasets as follow:

- ü ***Trip Purpose:*** Service inequities are measured based on trip purpose. Therefore, trip clusters are classified by trip purpose.
- ü ***Average Travel Time by PT services***[1]***:*** The average travel time by PT between TAZs by trip purpose is calculated during the rush hour of each trip purpose. For instance, morning rush hour for business trips and evening rush hour for social and recreation trips.
- ü ***Estimating available job types in the network' TAZs***[2]***:*** The count of opportunities for each trip purpose is estimated in the TAZs.
- ü ***Estimating total population and the population of disadvantaged people in the network' TAZs:*** Total population is necessary to measure horizontal equity while the population of disadvantaged people is used to measure vertical equity.
- ü ***PVT and PT trip diaries:*** Collected data through household travel surveys or via mobility sensors within intelligent transportation systems can provide the information.

Step 2 (Determining spatial clusters): In this step, we need to identify spatial clusters of trips in PT and PVT modes. There are different algorithms to detect clusters of a network. In this research, we use the approach proposed by Blondel et al. (2008). The algorithm is based on modularity optimization and comprised of an initial phase and two iterative phases (Phases 1 and 2). In this algorithm, the quality of clusters is determined by the so-called modularity concept. The modularity (Q) of a cluster is a scalar value between -1 and 1 that compares the density of intra-cluster and inter-cluster connections. In a weighted network, this index is defined as the following equation:

[1] There are several ways followed by previous studies to obtain PVT and PT travel time including Urban.Access (i.e. an ArcGIS extension), the statistics of AVL devices installed on PT vehicles, some parsers developed to extract trip information from Goggle Map or TripGo.In this study we extract PT travel time by using Google Maps API and writing some parsers in Python.

[2] It could be done by various surrogate measures. For instance, the business/shopping jobs can be counted by multiplying the area of business/shopping facilities and number of attracted employees/visitors per one area unit of the facility

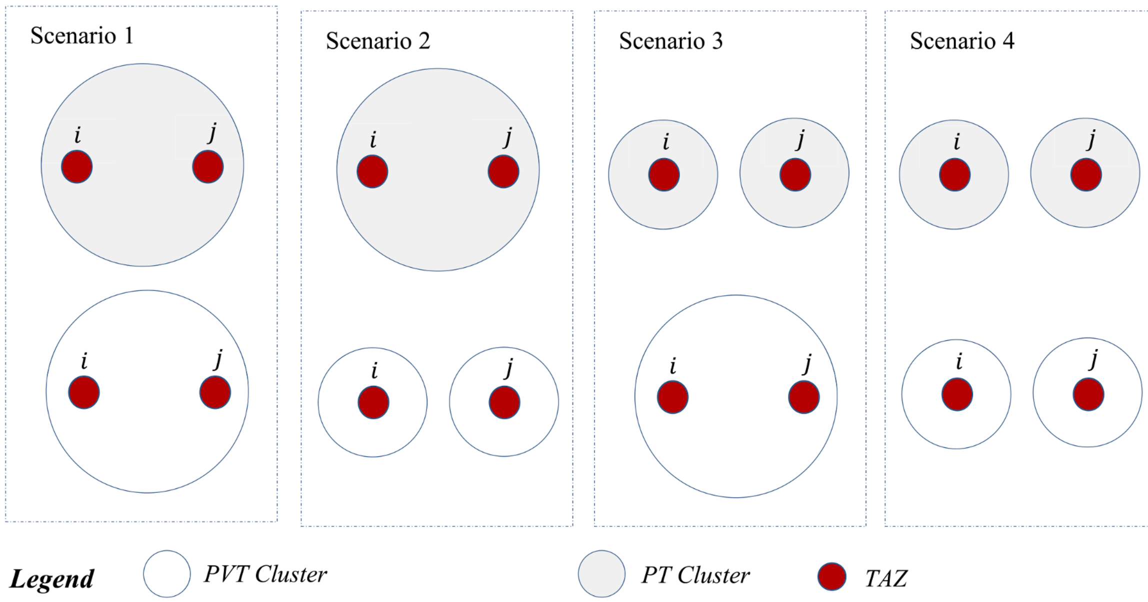

Fig. 2. Possible scenarios for position a pair of TAZs (*i* and *j*) in clusters of PT and PVT modes.

Table 1.
Potential accessibilities with their priorities.

ID	$f(t_{ij}^{p})^{1(30\ minutes)}$	$f(t_{ij}^{p})^{2(60\ minutes)}$	$f(t_{ij}^{p})^{3(90\ minutes)}$	Are *i* and *j* in one cluster of		Priority Class	Useful for Accessibility Level
				PT Mode	PVT Mode		
1	0	0	0	Yes	Yes	1	All
2	0	0	1	Yes	Yes	1	30 and 60
3	0	0	0	Yes	No	2	All
4	0	0	0	No	Yes	2	All
5	0	0	1	Yes	No	3	30 and 60
6	0	0	1	No	Yes	3	All
7	0	1	1	Yes	Yes	3	30
8	0	1	1	Yes	No	4	30
9	0	1	1	No	Yes	4	All

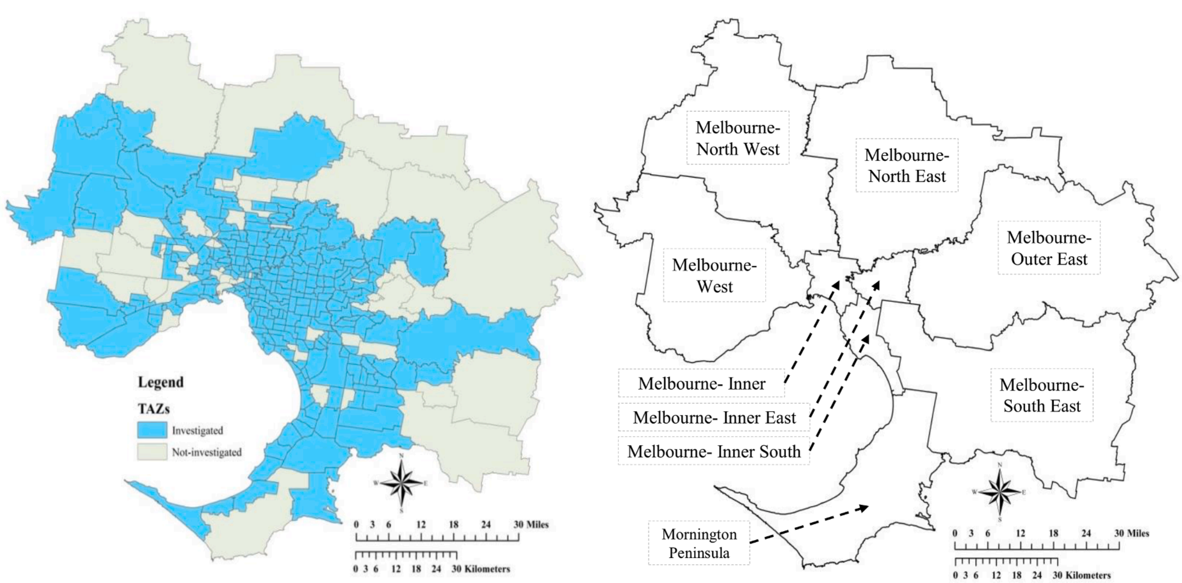

Fig. 3.. The maps of investigated TAZs and SA4s in the Greater Melbourne.

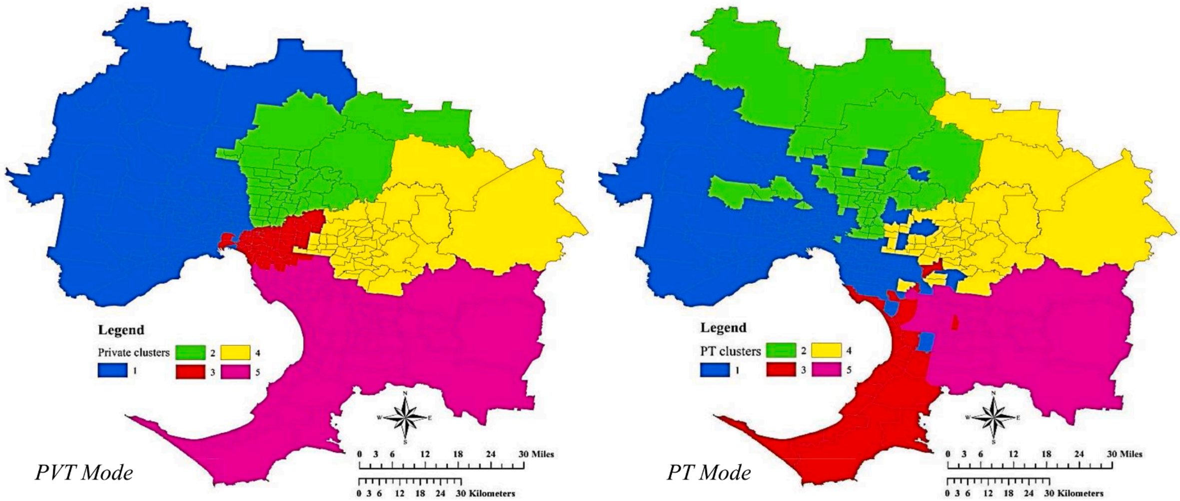

Fig. 4. The clusters in PVT and PT modes.

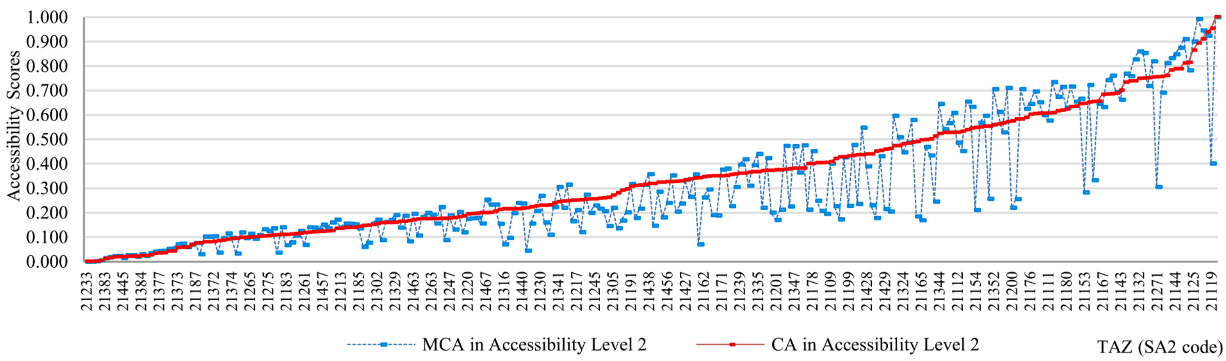

Fig. 5. CA and MCA scores in the accessibility level 60.

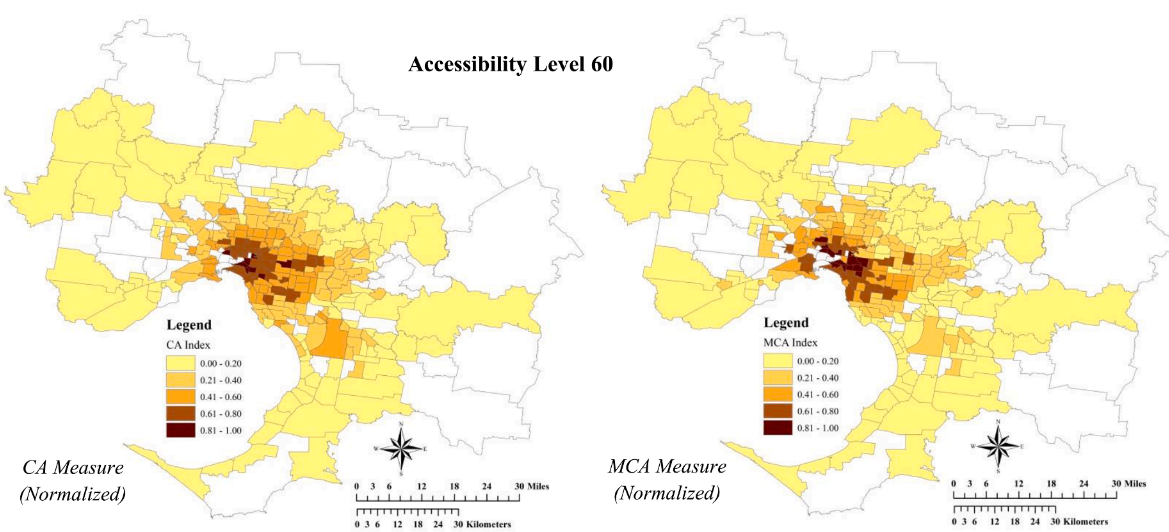

Fig. 6. CA and MCA comparison in the accessibility level 60.

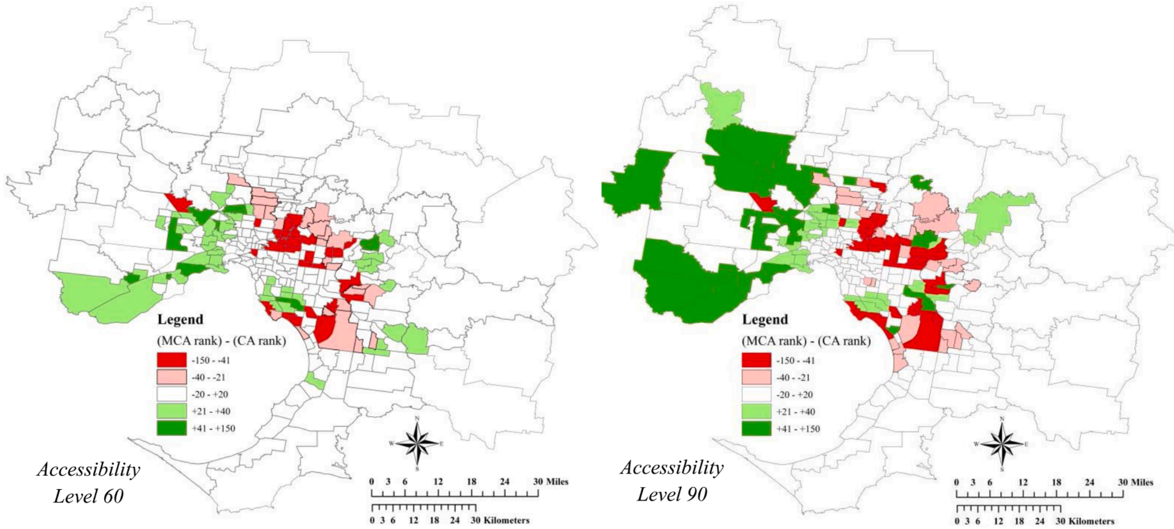

Fig. 7. The TAZs with considerable gaps between MCA and CA indices.

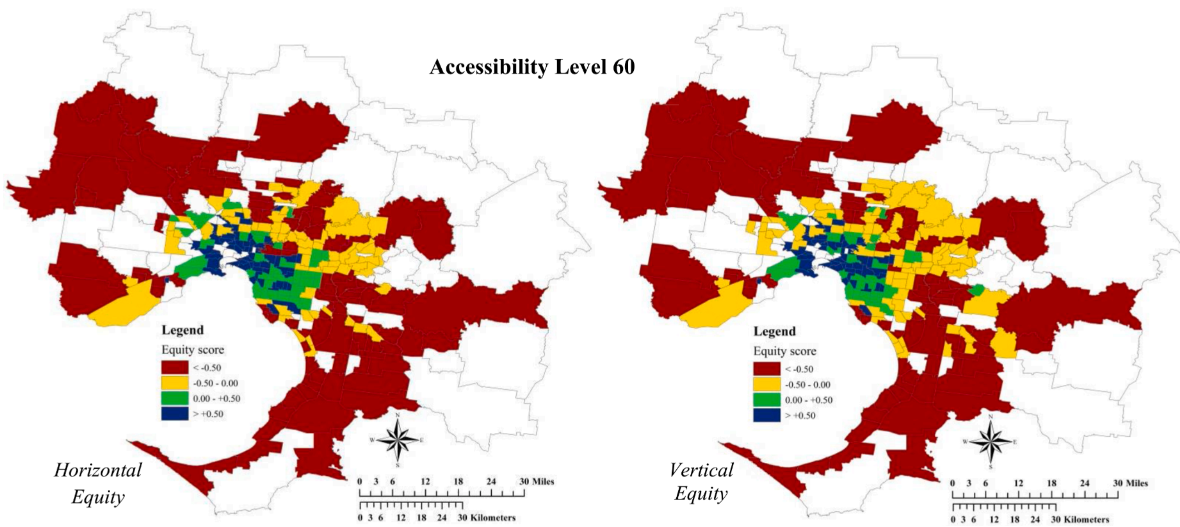

Fig. 8. The horizontal and vertical equity scores for the network's TAZs in the accessibility level 60.

$$Q = \frac{1}{2m}\sum_{i,j}\left[A_{ij} - \frac{K_i K_j}{2m}\right]\beta_{ij} \tag{1}$$

Where:

A_{ij} :weight of the edge between the vertex i and vertex j (i.e. total recorded trips)

K_i: the sum of weights of the edges attached to vertex i ($K_i = \sum_j A_{ij}$)C_i: the cluster that includes vertex $i\beta_{ij}$: a binary variable which equals one if i and j are in a same cluster; and zero otherwise.

m: the total weight of all edges in the network ($m = \frac{1}{2}\sum_{ij} A_{ij}$)

Initial phase: Initially the algorithm considers each vertex as a cluster. Hence, there are as many clusters as the total vertices.

Phase 1: In the first phase, the algorithm selects an arbitrary vertex (i), separates it from its cluster and inserts it into a neighboring cluster (j), and then computes difference between modularity index of target cluster with that of original cluster (ΔQ). It repeats this process for all vertices adjacent to vertex i, and ultimately adds the vertex i to the neighboring cluster with maximum positive ΔQ. The algorithm repeats this process for all vertices in the network and continues until ΔQ cannot be improved any further. The change in the modularity index (ΔQ) is calculated by Eq. (2) as follow:

$$\Delta Q = \left[\frac{\sum_{in} + K_{i,in}}{2m} - \left(\frac{\sum_{tot} + K_i}{2m}\right)^2\right] - \left[\frac{\sum_{in}}{2m} - \left(\frac{\sum_{tot}}{2m}\right)^2 - \left(\frac{K_i}{2m}\right)^2\right] \tag{2}$$

Where:

$\sum_{in}$: Total weights of all edges inside the cluster C

$K_{i,in}$: Total weights of all edges connecting vertex i to other vertices of

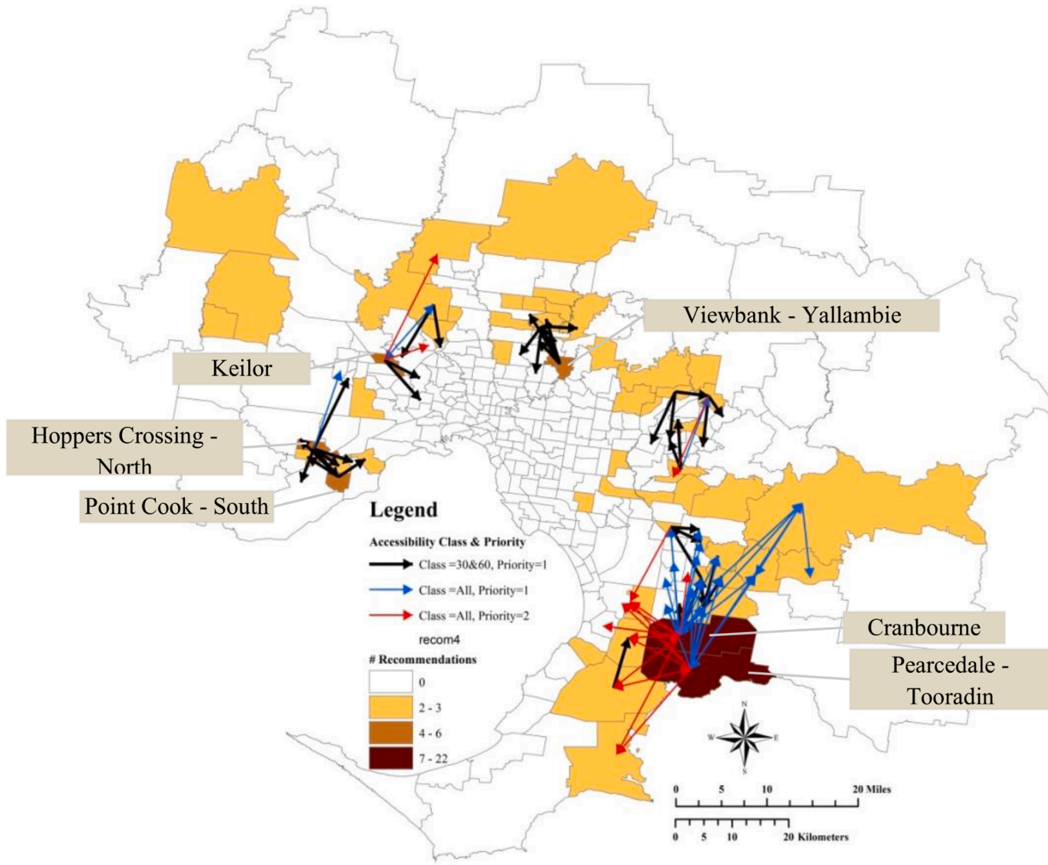

Fig. 9. The operational recommendations for underserved TAZs.

cluster C

$\sum_{tot}$: Total weights of all edges incident to the vertices of the cluster C

Phase 2: In the second phase, each cluster is considered as a new vertex. The weights of the edges between the new vertices are given by the sum of the weights of the edges between vertices in the corresponding two clusters. With this transformation, the modularity concept reapplies to this new network. This phase of the algorithm continues until ΔQ cannot be further improved. This marks the end of algorithm's first iteration and the start of a new iteration back to Phase 1. These iterations continue until modularity index cannot be improved any further.

Step 3 (Measuring MCA): The MCA measure is a developed form of the CA measure that considers travel demand distribution patterns in the network. The PVT and PT trip diaries are used as proxies to capture the patterns of travel in the network. To incorporate this information, (i) total PT trips between network's TAZs are evaluated and (ii) the TAZs are clustered based on PT and PVT trips separately.

Fig. 2 is an illustrative example of the output of Step 2; it demonstrates different scenarios assumed for a pair of TAZs in the clusters of PT and PVT modes. In contrast to the CA measure, the MCA measure accumulates the opportunities adjusted by weights that are estimated according to observed travel patterns in the network. This means that the proposed MCA only takes into accounts accessible opportunity counts from each residential TAZ, if there is evidence that such opportunities are actually desired and accessed by the TAZ residents.

Mathematically, the CA computes by Eqs. (3) and (4), but for calculating the proposed MCA, Eqs. (4), (5), and (6) are also used.

$$CA_i^{l,p} = \sum_{j \in N} S_j^p f\left(t_{ij}^p\right)^l \ \forall\ i \in N,\ l \in L,\ p \in P \tag{3}$$

$$f\left(t_{ij}^p\right)^l = \begin{cases} 1 \ if \ t_{ij}^p \leq t_{threshold}^l \\ . \\ 0 \ if \ t_{ij}^p \geq t_{threshold}^l \end{cases} \ \forall\ l \in L,\ p \in P \tag{4}$$

$$w_{ij}^p = \begin{cases} (5.1): \ 1.00 \ \delta_{ij} = 1, \ \forall\ \delta_{ij}^{'} \in \{0,1\}, \ h_{ij} \geq 0 \\ (5.2): \ 1.00 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 1, \ P_i^{75} \leq h_{ij} \\ (5.3): \ 0.75 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 1, \ P_i^{50} \leq h_{ij} < \ P_i^{75} \\ (5.4): \ 0.50 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 1, \ P_i^{25} \leq h_{ij} < \ P_i^{50} \\ (5.5): \ 0.25 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 1, \ h_{ij} < \ P_i^{25} \\ (5.6): \ 0.75 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 0, \ P_i^{75} \leq h_{ij} \\ (5.7): \ 0.50 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 0, \ P_i^{50} \leq h_{ij} < \ P_i^{75} \\ (5.8): \ 0.25 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 0, \ P_i^{25} \leq h_{ij} < \ P_i^{50} \\ (5.9): \ 0.00 \ \delta_{ij} = 0, \ \delta_{ij}^{'} = 0, \ h_{ij} < \ P_i^{25} \end{cases} \tag{5}$$

$$MCA_i^{l,p} = \sum_{j \in N} S_j^p f\left(t_{ij}^p\right)^l w_{ij}^p \ \forall\ i \in N,\ l \in L,\ p \in P \tag{6}$$

Where:

i, j: Index of network's TAZs, $i,j \in N$$l$: Index of levels considered for time threshold, $l \in L$$p$: Index of trip purposes, $p \in P$$N$: Set of network's TAZs

L: Set of levels considered for time threshold (L = {30, 60, and 90 minutes })

P: Set of trip purposes

h_{ij}: Total PT trips done from TAZ i to TAZ $j$$S_j^p$: The amount of jobs in

TAZ j for trip purpose pt_{ij}^{p}: Travel time from TAZ i to TAZ j for trip purpose $pt_{threshold}^{l}$: Time threshold's value for level l (for $l = 30$, 60, and 90, $t_{threshold}^{l}$ is 30, 60, and 90 minutes, respectively[3])

$f(t_{ij}^{p})^{l}$: A binary input parameter that is equal to one if travelling by PT service from TAZ i to TAZ j for trip purpose p takes a time less than corresponding time threshold for accessibility level l; and zero otherwise.

$CA_{i}^{l,p}$: The value of CA measure for TAZ i, trip purpose p and level of time threshold $lMCA_{i}^{l,p}$: The value of MCA for TAZ i, trip purpose p and level of time threshold $l\delta_{ij}$: A binary parameter which is equal to one if TAZ i and TAZ j are in a same PT cluster; and zero otherwise.

$\delta_{ij}^{'}$: A binary parameter which is equal to one if TAZ i and TAZ j are in a same PVT cluster; and zero otherwise.

P_{i}^{25}, P_{i}^{50}, P_{i}^{75}: The 25th, 50th, and 75th percentiles of the number of PT trips on the set of connections that start from TAZ i and end to the network's TAZs

Eq. (6) represents the MCA measure. The MCA measure has one term more than the CA measure that is w_{ij}^{p}. In fact, w_{ij}^{p} is the assigned weight for accumulating accessibility from TAZ i to TAZ j for trip purpose p. The value of w_{ij}^{p} depends on the positions of TAZ i and TAZ j among PVT and PT clusters, $\delta_{ij}^{'}$and δ_{ij}, respectively, as well as the position of the total PT trips made from TAZ i to TAZ j within the 25th, 50th, and 75th percentiles of the number of PT trips on the set of connections that start from i and end to the network's TAZs, i.e. P_{i}^{25}, P_{i}^{50}, and P_{i}^{75}. Eq. (5) is comprised of nine conditions that are explained in the following. According to Condition (5.1), if TAZs i and j belong to a same PT cluster, regardless of other conditions, the value of w_{ij}^{p} is equal to one. Therefore, Condition (5.1) represents Scenarios 1 and 2 in Fig. 2. Other conditions, (5-2 to 5-9), represent Scenarios 3 and 4. In both Scenarios 3 and 4, TAZ i and TAZ j do not belong to a same PT cluster, but in Scenario 3, they belong to a same PVT cluster while in Scenario 4, they do not belong to a same PVT cluster.

Accordingly, we assign greater weights for cases belonging to Scenarios 3 than those belonging to Scenario 4 because of two reasons. First, the size of PVT trips database is usually bigger than PT trips database due to the PVT transportation mode is usually the predominant mode of transportation. Therefore, we expect the clusters in PVT transportation mode to have more accuracy than the clusters in PT mode. Hence, to mitigate the impact of clustering errors, we assign bigger weights to cases in Scenario 3 than Scenario 4. Second, existence of TAZs i and j in a same cluster of PVT mode means that there is a good matching between a majority of people's preferences in TAZ i and the jobs in TAZ j. Hence, reasonably an efficient PT service between TAZs i and j can bring more accessibility to jobs for cases in Scenario 3 than Scenario 4.

To reasonably define the weights, the position of number of PT trips from TAZ i to TAZ j (h_{ij}) among the number of PT trips from TAZ i to other network's TAZs is investigated. For instance, when h_{ij} is between P_{i}^{25} and P_{i}^{50}, if the positions of TAZ i and TAZ j among PT and PVT clusters are like Scenario 3/4, w_{ij}^{p} is equal to 0.75/0.5 which is the upper/lower bound of the percentile range. Accordingly, the weights for Conditions (5-2 to 5-9) are defined.

Step 4 (Measuring Equity): The objective of this step is to find the underserved TAZs in each trip purpose and each accessibility level. Three different accessibility levels are considered by setting the time threshold on 30, 60, and 90 minutes. We consider these different levels to identify inequities in accessibility to PT services under multiple accessibility levels and prescribe some customized recommendations to redress the inequities for the underserved TAZs under each accessibility level. To find the underserved TAZs in each trip purpose and each accessibility level, first, we compute the ratio of $MCA_{i}^{l,p}$ to total population of people or population of low-income people (D_i) for each TAZ (e.g. i) by Eq. (7). If D_i represents the total population in i, then $R_i^{l,p}$ indicates the horizontal equity, while if $D_i$represents the population of low-income people in i, then $R_i^{l,p}$ indicates the vertical equity.

$$R_{i}^{l,p} = \frac{MCA_{i}^{l,p}}{D_i} \; \forall \; i \in N, \; l \in L, \; p \in P \tag{7}$$

Then, by making a descending sort list of $R_{i}^{l,p}|\forall \; i \in N$ for each trip purpose and accessibility level, the TAZs ranked at the bottom of the list with a distinct gap with others will be selected as the underserved TAZs in the relevant trip purpose and accessibility level.

Step 5 (Improving equity): The purpose of this step is to improve the equity for the underserved TAZs by adopting relevant strategies to the status of each TAZ, where the strategies are ranked. For this purpose, we identify and prioritize some operational recommendations for improving the accessibility to jobs by PT services for the underserved TAZs. The operational recommendations for a TAZ are in the form of some connections from the TAZ to others. Accordingly, as the first step, we categorize the entire PT connections between TAZs into three groups as follows: (1) connections that start from and end in a TAZ located in inner regions, (2) connections that start from and end in a TAZ in outer regions, and (3) connections that start from a TAZ in inner/outer regions and end in a TAZ in outer/inner regions.

Second, we calculate PT speed for all the connections based on the PT distance and travel time of the connections. Then, in each category, the connections having a PT speed less than the 25th percentile of PT speeds in the category are selected for the further investigations. These connections are those that have an inefficient PT service in comparison to their similar connections. Finally, to nominate some of the selected connection for accessibility improvement and prioritize them, the values of the following binary parameters are evaluated: $f(t_{ij}^{p})^{1(30\ minutes)}$, $f(t_{ij}^{p})^{2(60\ minutes)}$, $f(t_{ij}^{p})^{3(90\ minutes)}$, are TAZs i and j in a same cluster of PT clusters?, and are TAZs i and j in a same cluster of PVT clusters?

Systematically, according to different possible values for these five binary parameters, 2^5 combination outcomes can be assumed for a connection in each trip purpose. However, as Table 1 shows, we only accept 9 of the connections as the operational recommendations, and categorize them into four different priority classes so that classes 1 and 4 have the highest and lowest priorities, respectively. Table A2, in Appendix A, shows the other 23 combination outcomes along with our reasons for rejecting them as an operational recommendation towards improving accessibility and equity.

Moreover, as the last column of Table 1 shows, we determine for which accessibility levels (i.e. 30, 60, or 90 minutes) the actions are suitable. For instance, combination outcome 9 is suitable for all accessibility levels because although TAZs i and j are not in a same cluster of PT clusters, they are in a same cluster of PVT clusters. It means there could be a possibility to shift the PVT trips to PT by improving the accessibility if the accessibility level is not in a perfect level. Hence, as the combination outcome 9 shows, the accessibility can be improved more because the current travel time is between 30 to 60 minutes and it could be reduced to less than 30 minutes. Therefore, if TAZs i and j place in a same PT cluster by reducing travel time to an

[3] These are the most common thresholds investigated by the literature for the case studies in size of the Greater Melbourne.

amount less than 30 minutes, then the MCA for all the accessibility levels will have a value more than zero. For another example, the combination output 8 is only suitable for improving accessibility in level 30 because both TAZs are in a same cluster of PT and the travel time from TAZ i to TAZ j is between 30 to 60 minutes $(f(t_{ij}^{p})^{2} = f(t_{ij}^{p})^{3} = 1)$. As a result, because the MCA had a positive value for levels 60 and 90, in advance, the accessibility in level 30 has a potential improvement.

In the following, we explain how the accepted connections as the operational recommendations towards improving accessibility and equity are prioritized. Moreover, some extra justifications around nominating only the ninth case as the suitable connections are provided.

Priority Class 1: The cases with $ID = 1$ or 2 are put in this class because although there is a weak accessibility from TAZ i to TAZ j, the TAZs are in one cluster in both PVT and PT modes. When a pair of TAZs are in a same cluster of PT's clusters even with lack of any appropriate accessibility by PT service (i.e. PT travel time is bigger than 90 minutes), it implies that there is a strong need to travel by PT services between the TAZs. Hence, improving accessibility by PT services between the TAZs will result in shifting the trips done by PVT to PT system.

Priority Class 2: This class has also two members, the cases with $ID = 3$ or 4. Also, accessibility by PT services from TAZ i to TAZ j is so weak in this class. However, because the TAZs are in a same cluster in one of the transportation modes, there is an optimistic possibility to increase the contribution of PT mode by improving the accessibility by PT services between the TAZs in the future.

Priority Class 3: This class is similar to Class 2 but the level of accessibility is better in comparison to previous class. However, still improving accessibility can contribute to increasing the contribution of PT system in servicing to the travel demand between the pair of the TAZs.

Priority Class 4: In this class, accessibility is good (i.e. PT travel time is between 30 to 60 minutes between the pair of the TAZs) but improving accessibility by PT services is still possible by reducing the PT travel time to less than 30 minutes.

Accordingly, the two last columns of Table 1, titled "priority class" and "useful for accessibility level", will help us to understand in which accessibility level and with what priority class the actions are suitable for improving equity in accessibility to jobs by PT service. For instance, if TAZ l is a underserved TAZ in accessibility level 60 and trip purpose p, the case IDs 7 or 8 are not suitable because they only improve accessibility in level 30.

4. Case study and data preparation

The proposed method is tested on the Greater Melbourne region, Victoria, Australia. The Greater Melbourne, also known as metropolitan Melbourne, is the capital region of Victoria state, has an area just fewer than 10000 km^2 and homes to nearly 5 million people from more than 200 countries, according to the the estimated population for 2019 (Metropolitan Melbourne, 2019). PT system in Melbourne includes train, bus, and tram services. The Melbourne has the world's largest tram network, with 250 km of double track, more than 2200 tram stations, 500 trams, and 1200 drivers (Yarra Tram, 2018). Also, the Melbourne's PT network consists of 300 bus routes and 16 train lines mainly connect suburban regions to central areas (Yarra Tram, 2018). More than 600 million passenger trips are taken on Victoria's PT network each year that accounts for nearly 16% of total trips in this state (Public Transport Victoria, 2019). According to the nine directions designed for the Melbourne 2030 vision, Melbourne should be a fair city, where the social infrastructures are equitable distributed between people, with high accessible PT transport connections (Policies 6.2, 8.2, and 8.3) (Melbourne 2030, 2019). Hence, this study is motivated to test the method on Melbourne case study.

The Australian Bureau of Statistics (ABS) uses a hierarchical structure for publishing statistics (Australia bureau of Statistics, 2016). Accordingly, the structure is comprised of Mesh Blocks (MBs), Statistical Areas Level 1 (SA1s), SA2s, SA3s, SA4s, and State and Territory (S/T). The number of SA1s, SA2s, SA3s, and SA4s in the Greater Melbourne region are 10289, 309, 40, and 9, respectively. Accordingly, we define our network's TAZs based on the SA2s. We apply the method on Greater Melbourne region to find the inequities in accessibility to jobs by PT services for the working trip purpose. Other trip purposes would be studied in the future research. Hence, five sets of data on the level of SA2s are necessary. These data are as follow: (1) the mobility patterns by PVT and PT between SA2s, (2) PVT and PT travel time between SA2s during the rush hour for working trips in Greater Melbourne, (3) the number of available job opportunities in SA2s, (4) the total population in SA2s, and (5) the population of low-income people in SA2s. In the following, we explain how the required data is prepared:

Mobility patterns: The mobility patterns in PVT and PT modes are extracted from the Victorian Integrated Survey of Travel and Activity (VISTA) dataset 2016 which is an ongoing survey of household travel activity. The targeted dataset includes nearly 130 thousand trips over the five years. From the 130 thousand trips, we only use the trips taken on weekdays with a working purpose. Accordingly, we found nearly 16k and 4ktrips for PVT and PT modes and applied the clustering method on them.
TAZ centroids: for every TAZ, a representative centroid point is identified. This centroid point is calculated by considering the residential population of all SA1 zones within the TAZ. In other words, this centroid is an approximate center of mass (population) of the TAZ.
Travel time: Travel time extraction from Google Maps has been frequently used in the literature (e.g. Chaloux et al., 2019; Qi et al. 2019). Hence, in this study, PVT and PT travel time are between the TAZ centroids resulted by running a set of developed parsers coded in Python, for extracting trip information from Google Maps. The parsers connect to Google Maps API (i.e. Distance Matrix API service) and provide travel time for an OD matrix including waiting, access and egress time (Distance Matrix API, 2021). The date and time for extracting the data are set on 17 February 2020, 8:30 AM (Melbourne time) representing the morning rush hour for working trips on weekdays (Australia bureau of Statistics, 2016).
Job opportunity The number of available job opportunities in the TAZs is extracted from the Australia bureau of Statistics database (Australia bureau of Statistics, 2016).
Population: The total population in SA2s along with the population of low-income people is extracted from the 2016 Census data (Australia bureau of Statistics, 2016). Low income people are those earn less than 650 AUD per week (Community profile, 2016).

It should be noted that in the process of data preparation, we found that the number of generated trips from 59 TAZs (according to the VISTA dataset), which are mostly some large TAZs, are insufficient. Accordingly, due to missing data and limited spatial resolutions our proposed model is not able to accurately measure accessibility in these zones. This is identified as a caveat in this paper and we identified a potential direction of research to address this in the future, if high resolution data is available. Therefore, we avoid investigating accessibility and equity for such TAZs. Hence, 250 TAZs are nominated for further investigations. Fig. 3 shows the investigated and not-investigated TAZs as well as the map of SA4s in the Greater Melbourne.

5. Results and discussion

This section is organized in four subsections. In Sections 5.1, the results of applying the clustering method on PVT and PT trips are presented. Section 5.2 presents a comparison between CA and MCA measures in various accessibility levels. In Section 5.3, horizontal and vertical equities (i.e. H and VS) are calculated for the network's TAZs in different accessibility levels and the underserved TAZs for further investigations are introduced. The operational recommendations as well as their priorities towards improving the equity for some of the underserved TAZs in various accessibility levels are presented in Section 5.4.

To apply the clustering method presented in Step 2, Gephi software is used. Gephi is an open-source network analysis and visualization software package written in Java on the NetBeans platform. The heuristic clustering method proposed by Blondel et al. (2008) is embedded into the software, where researchers can simply apply it on their cases. Other steps of the proposed method are coded in MATLAB software (Version 2013) on a system with the following specifications: Intel(R) Core(TM) i7 CPU @2.13 GHz and 6 GB of RAM with Windows 7 (64 bit). To analyze and visualize the results, Microsoft Excel and ArcGIS Pro are used.

5.1. Clustering results

The proposed clustering method is applied on PVT and PT trips done for the working purposes in weekdays which had 16 and 4 thousand records in VISTA database. Accordingly, Fig. 4 illustrates the clusters in PVT and PT modes.

As Fig. 4 shows, both PVT and PT modes have five clusters which are relatively similar. Moreover, interestingly the clusters are nearly similar to the configuration of SA4s in the Greater Melbourne, presented by Fig. 3. However, some clusters include more than one SA4s. Furthermore, the clusters of PVT mode are more spatially homogeneous than the clusters of PT mode and the inner parts of Greater Melbourne selected as a unique cluster.

5.2. CA & MCA comparison

In this section, the values of CA and MCA measures are computed for the investigated network's TAZs and then are normalized with Min-max normalization method because it guarantees that all features have an exact same scale (e.g. between zero to one). The Min-max normalization method cannot handle outliers properly. However, our investigation showed that there are no outliers in values of CA and MCA measures for various accessibility levels. In this regard, Fig. 5 indicate the scores of MCA and CA in accessibility level 60 (i.e. less than 60 minutes) for TAZs. The figure shows that there are significant differences between these measures, particularly for TAZs with large CA scores. For instance, there are some TAZs with a CA score bigger than 0.75 but a MCA score lower than 0.40. However, the MCA and CA scores are close to each other, where CA score is small (i.e. less than 0.20). To see the differences between MCA and CA scores on the Melbourne map, Fig. 6 is prepared. Also, the visual comparisons between MCA and CA for accessibility levels 30 and 90 are presented by Fig. B1 in Appendix B.

Fig. B1, in Appendix B, shows the normalized values of CA and MCA are considerably similar to each other in accessibility level 30 (i.e. when only jobs in a range of 30 minutes are considered accessible). This observation means that for the case of Melbourne and evaluation of accessibility in the level 30, CA and MCA can be used interchangeably. However, as Figs. 5, 6, and B1 show some significant differences between the normalized values of CA and MCA for some TAZs are observed in accessibility levels 60 and 90. Accordingly, we ranked the normalized values of CA and MCA in each accessibility level from lowest to highest and found the TAZs that their ranks considerably increased or decreased (i.e. The TAZ's rank based on MCA index is 20 or 40 times bigger or lower than that of CA index). Fig. 7 demonstrates the TAZs with better and worse ranks in the list based on MCA measure than that of CA measure. Red/Green TAZs show the TAZs with worse/better ranks in MCA than CA.

Fig. 7 shows that an effective accessibility to jobs by PT services is lacked in the east side of inner regions in the Greater Melbourne. In fact, although they have appropriate CA index, the MCA index is not adequate for them. It means that if the demand information is ignored in measuring the accessibility, we will underestimate the accessibility problems of the TAZs identified by red in Fig. 7. Moreover, the west side of the inner regions benefits of a PT services that are well-matched with their mobility needs. Therefore, it means if the accessibility is measured by the CA measure, we will overestimate the accessibility problems of the TAZs identified with green in Fig. 7. Accordingly, we highly recommend practitioners to measure accessibility by the MCA measure rather than the CA measure. Particularly, for the Greater Melbourne case study, measuring accessibility by CA causes to underestimate/overestimate accessibility problems for the TAZs located at the east/west side of the inner regions.

5.3. Equity evaluation

The purpose of this section is to identify the underserved TAZs in each accessibility level based on a vertical and horizontal evaluation of equity. Hence, we calculate the values of $R_i^{l,p}$ $(\forall i, l,\ p = work)$ based on the total population to measure horizontal equity and the total low-income population to measure vertical equity in each TAZ. Moreover, we normalize the values of $R_i^{l,p}$ $(\forall i, l,\ p = work)$ in each equity type (i.e. horizontal and vertical) by Z-score normalization method. We use Z-score rather than Min-max because there were some outliers in the distributions of $R_i^{l,p}$. In this regard, Fig. 8 shows the normalized score of $R_i^{l,p}$ for working trips, accessibility level 60, and the total network's TAZs. Moreover, both horizontal and vertical equities in the accessibility levels 30 and 90 are depicted by Fig. B2, in Appendix B.

As Figs. 8 and B2 show, the TAZs located in and around inner parts of Greater Melbourne have a positive equity score (i.e. they have better condition than normal condition) while the inequities almost are for the TAZs far from the city center (i.e. outer TAZs). Moreover, Fig. 8 demonstrates that no significant discrepancy between the horizontal and vertical equity scores is existed in the outer TAZs. In fact, most of the discrepancies are summarized to the TAZs in and around inner parts of Greater Melbourne that have a positive equity score (i.e. the layers indicated by Green or Blue). Both vertical and horizontal equities are mainly satisfied for the TAZs located in the inner parts of Greater Melbourne. Therefore, we highly recommend the decision makers, who seek either horizontal or vertical equity, that improve accessibility for the TAZs far from the city center because they are treated unfairly in accessibility to jobs by PT services.

By increasing the level of accessibility (e.g. from 60 to 90) the contribution of outer TAZs, particularly those located on west side of the Greater Melbourne, with positive or small negative equity score has been enhancing. It means the people living in the west side of Greater Melbourne benefits from PT service more than the people living in the east side of Greater Melbourne. Therefore, the decision makers should focus on improving the accessibility for the TAZs located in the east side of Greater Melbourne to rectify equity.

5.4. Equity amelioration

The equity evaluation in previous section resulted in many underserved TAZs, with a negative equity scores less than -0.50. Therefore, the operational recommendations towards improving their accessibility values are identified for the underserved TAZs. Accordingly, we found 109, 31, 237, and 113 recommendations with the priorities of 1, 2, 3, and 4, respectively. For brevity, we only present the recommendations with priority 1 or 2 for the TAZs having at least three recommendations (i.e. 28 underserved TAZs). Fig. 9 shows the number of recommendations for the underserved TAZs, as well as the prescribed connections, customized for different accessibility levels and having different priorities, to improve equity for the underserved TAZs.

As the figure indicates, some TAZs such as Cranbourne South (with 22 proposed recommendations) and Pearcedale-Tooradin (with 13 proposed recommendations) have the largest operational recommendations with the highest priorities. It means that the residents living in these zones are significantly underserved by PT service while the improvement is possible by only improving their accessibilities to their neighboring zones. As an example the operational recommendations for five TAZs including Cranbourne South and Pearcedale-Tooradin with their priorities are illustrated by Fig. 9. The total recommendations for the underserved TAZs as form of some connections are presented by Table B1. It should be noted that the TAZs are represented by their SA2 names.

6. Conclusion

In this research, a method for identification and amelioration the inequities in accessibility to the jobs by PT services is presented, where the process of identifying inequities is by a proposed MCA measure. In contrast to the CA measure, the MCA measure takes into account travel demand information in both PVT and PT modes for various trip purposes. The travel demand information is incorporated into the MCA measure using a weighting factor resulted from evaluating and clustering PVT and PT trip diaries. By comparing the total population and the low-income population of each TAZ with its MCA index, the underserved TAZs based on horizontal and vertical equity are found. To ameliorate the equity for each identified underserved TAZ, a set of prioritized operational recommendations towards improving its MCA index is proposed. To prescribe the operational recommendations, the proposed method takes into account the PVT and PT clusters of the TAZs, PT speed, travel time, and distance between TAZs. Furthermore, the operational recommendations are customized for various accessibility levels (i.e. accessibility to jobs by PT services having a travel time less than 30, 60, and 90 minutes). The actions can highly assist local authorities to productively and fairly allocate budget to future development projects.

The proposed method is tested for Melbourne case study. The results are evaluated to (1) clarify the differences between the MCA and CA measures, identify underserved TAZs in Melbourne based on horizontal and vertical equity evaluation, and propose the sets of the prioritized operational recommendations for the underserved TAZs. According to the evaluations, several observations and insights are resulted. A summary of the insights is as follows:

- The CA and MCA measures can be used interchangeably if accessibility is counted only for trips take a time less than 30 minutes.
- Measuring accessibility by the CA measure causes to underestimate/overestimate accessibility problems for the TAZs located at the east/west side of the inner parts of Greater Melbourne.
- Both vertical and horizontal equities are mainly satisfied for the TAZs located in the inner parts of Greater Melbourne. The inequities are related to the TAZs far from the city center.
- The people living in the west side of Greater Melbourne benefits from PT service more than the people living in the east side of Greater Melbourne.

This research opens a new door for equitably redesigning PT networks by considering the effective lists of actions and other specifications such as budget limitation. Hence, the research can be developed in the future by solving a PT network design towards addressing the operational recommendations by various strategies such as integrating bike and PT networks, making some changes in the configuration of PT lines and stations, and proposing some development plans for train or other rail rapid transit networks. As another limitation, we had to exclude 59 SA2s from the Melbourne case study because of their high area, low population and stated trips in VISTA dataset. Future researches should divide these regions into smaller parts based on disaggregated spatial levels (e.g. SA1s) and incorporate sufficient high resolution data data that can be collected from various digital payment services (e.g. PT smart card data) as a revealed preferences data for running clustering method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Fig. A1,
Table A1, A2

Appendix B

figure B1, B2
Table B1

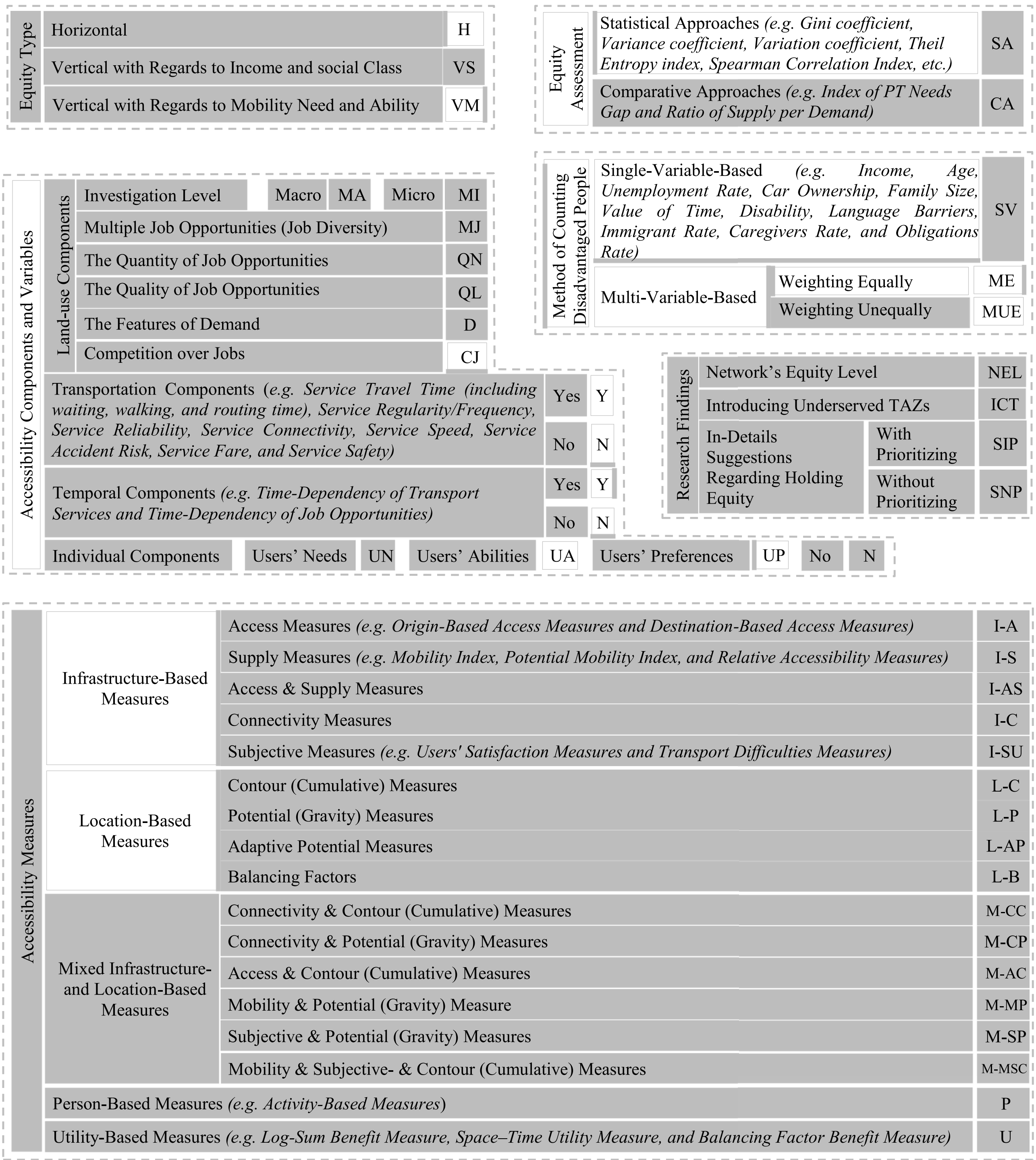

Fig. A1. A framework of features involved in evaluation of equity in PT service.

Table A1
Review of studies done in equity evaluation of PT services.

Reference	Equity Type	Equity Assessment	Accessibility Measures	Accessibility Components Land-use	Transport	Temporal	Individual	Method of Counting Disadvantaged People	Research Findings
Murray and Davis 2001	VS	CA	I-A	MA	Y	N	N	ME	ICT
Currie 2004	VS	CA	I-AS	MA & D	Y	N	N	MUE	ICT
Currie 2010	VS	CA	I-AS	MA	Y	N	N	MUE	ICT
Delbosc and Currie 2011	H & VS	SA	I-AS	MA	Y	N	N	ME	ICT & NEL
Eboli and Mazzulla 2011	H	CA	I-SU	MA	Y	N	N	-	-
Bureau and Glachant 2011	H & VS	CA	I-S	MA	Y	N	N	SV	ICT
Bocarejo and Oviedo 2012	VS	CA	L-P	MA	Y	N	N	SV	ICT
Jiao and Dillivan 2013	VS	CA	I-C	MA	Y	N	N	MUE	ICT
Welch and Mishra 2013	H	SA	I-C	MA	Y	N	N	-	ICT & NEL
Welch 2013	H & VS	SA	I-C	MA	Y	N	N	SV	ICT & NEL
Foth et al. 2013	VS	CA	L-C	MA	Y	N	N	ME	-
Kaplan et al. 2014a	H	CA	I-SU	MA	Y	N	N	-	-
Golub and Martnes 2014	VM	CA	L-C	MA & MJ	Y	N	N	SV	ICT
Karou and Hull 2014	H	CA	L-C	MA & MJ	Y	N	UN	-	ICT
Kaplan et al. 2014b	VS	SA	L-P	MA & MJ	Y	N	N	SV	ICT & NEL
Fransen et al. 2015	VS	CA	L-C	MA & MJ	Y	Y	N	ME	ICT
Ricciardi et al. 2015	H & VS	CA & SA	I-AS	MA	Y	N	N	SV	ICT & NEL
Legrain et al. 2016	VS	CA	L-P	MA	Y	Y	N	SV	ICT
Serulle and Cirillo 2016	VS	CA	U	MA	Y	Y	N	SV	-
El-Geneidy et al. 2016a	VS	CA	L-C	MA	Y	N	N	ME	ICT
Farber et al. 2016	VS	CA	I-S	MI	Y	Y	UP	SV	-
Lucas et al. 2016	H	SA	L-C	MA	Y	N	N	-	NEL
Xia et al. 2016	H & VS	SA	I-AS	MA & D	Y	N	N	ME	ICT & NEL
El-Geneidy et al. 2016b	VS	CA	L-C	MA	Y	Y	N	ME	ICT
Ruiz et al. 2017	H & VS	SA	I-AS	MA	Y	N	N	MUE	ICT & NEL
Hu 2017	VS	CA	L-P	MA	Y	N	N	SV	-
Mortazavi and Akbarzadeh. 2017	VS	SA	I-C	MA	Y	N	N	SV	ICT & NEL
Farber et al. 2017	H	CA	I-C	MA	Y	Y	N	-	ICT
Mulley, C et al. 2017	H & VS	CA	I-AS	MA	Y	Y	N	SV	ICT
Zhou et al. 2018	VS	SA	L-P	MA	Y	N	N	SV	NEL
Guzman and Oveido 2018	VS	CA	L-P	MA	Y	N	N	SV	ICT
Sun et al. 2018	VS	CA	L-P	MA	Y	N	N	SV	ICT
Song et al. 2018	H & VS	SA	I-AS	MA	Y	N	N	SV	NEL
Karner 2018	VS	CA	L-P	MA	Y	N	N	SV	ICT
Garcia et al. 2018	VM	CA	L-P	MA	Y	N	N	-	ICT
Järv et al. 2018	H	CA & SA	I-S	MI	Y	Y	N	-	ICT & NEL
Cao et al. 2018	VS	SA	I-AS	MA	Y	N	N	ME	ICT & NEL
Chen et al. 2018	VS	CA & SA	M-CC	MA	Y	N	N	SV	ICT & NEL
Deboosere and El-Geneidy 2018	VS	CA & SA	L-C	MA	Y	N	N	ME	ICT & NEL
Guzman et al. 2018	VS	CA	L-C	MA	Y	N	N	SV	ICT
Hernandez 2018	H	CA	L-C	MA & MJ	Y	N	N	-	ICT
Ben-Elia and Benenson 2019	H	SA	M-AC	MA	Y	Y	UP	-	NEL
Oviedo et al. 2019	VS	CA	L-P	MA	Y	N	N	SV	ICT
Slovic et al., 2019	VS	CA	L-C	MA	Y	N	N	SV	ICT
Chaloux et al. 2019	H & VS	CA	M-SP	MA	Y	N	UP	ME	ICT
Kelobonyea et al. 2019	VM	CA	L-C	MA & MJ	Y	N	N	-	ICT
Grisé et al. 2019	VS & VM	CA	L-C	MA & MJ	Y	N	UA	ME	ICT
Lee and Miller 2019	H	CA	P	MI & D	Y	Y	UP	-	ICT
Mayaud et al. 2019	VS	CA	L-C	MA & MJ & CJ	Y	N	UA	SV	ICT
Nazari Adli et al. 2019	VS	CA & SA	L-P	MI	Y	N	N	SV	ICT & NEL
Pucci et al. 2019	VS	CA	M-MP	MA & D	Y	N	UN	SV	ICT
Qi et al. 2019	VS	CA	I-S	MA & MJ	Y	N	UP	MUE	ICT
Sharav et al. 2019	VM	CA	I-S	MA	Y	N	N	-	ICT
Chen et al. 2019	VS	CA	L-C	MA	Y	N	N	SV	ICT & NEL
Tahmasbi et al. 2019	H & VS	SA	L-P	MA	Y	N	N	SV	ICT & NEL
Current Research	VM & VS	CA	M-MSC*	MA & MJ & CJ	Y	N	UN & UP	ME	SIP*

* Contributions:

Table A2
Rejected combination outcomes for counting as a potential accessibility.

ID	$CA_i^{1,p}$	$CA_i^{2,p}$	$CA_i^{3,p}$	Are *i* and *j* in one cluster of		The Reason of excluding from set of potential accessibilities
				PT mode	PVT mode	
10	0	0	0	No	No	Lack of any trip potential in both transportation modes
11	0	0	1	No	No	Lack of any trip potential in both transportation modes even with existence accessibility to PT services less than 45 minutes
12	0	1	0	No	No	It is impossible that $CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
13	1	0	0	No	No	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = CA_i^{3,p} = 0$
14	0	1	0	No	Yes	It is impossible that $CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
15	1	0	0	No	Yes	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = CA_i^{3,p} = 0$
16	0	1	0	Yes	No	It is impossible that $CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
17	1	0	0	Yes	No	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = CA_i^{3,p} = 0$
18	1	1	0	No	No	It is impossible that $CA_i^{1,p} = CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
19	1	0	1	No	No	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = 0$
20	0	1	1	No	No	Lack of any trip potential in both transportation modes even with existence accessibility to PT services less than 30 minutes
21	0	1	0	Yes	Yes	It is impossible that $CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
22	1	0	0	Yes	Yes	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = CA_i^{3,p} = 0$
23	1	0	1	No	Yes	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = 0$
24	1	1	0	No	Yes	It is impossible that $CA_i^{1,p} = CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
25	1	0	1	Yes	No	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = 0$
26	1	1	0	Yes	No	It is impossible that $CA_i^{1,p} = CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
27	1	1	1	No	No	Lack of any trip potential in both transportation means modes with existence accessibility to PT services less than 15 minutes
28	1	1	1	Yes	No	No more improvement in accessibility is possible. Also, no potential of shifting trips from PVT to PT mode is existed
29	1	1	1	No	Yes	No more improvement in accessibility is possible.
30	1	1	0	Yes	Yes	It is impossible that $CA_i^{1,p} = CA_i^{2,p} = 1$ but $CA_i^{3,p} = 0$
31	1	0	1	Yes	Yes	It is impossible that $CA_i^{1,p} = 1$ but $CA_i^{2,p} = 0$
32	1	1	1	Yes	Yes	No more improvement in accessibility is possible.

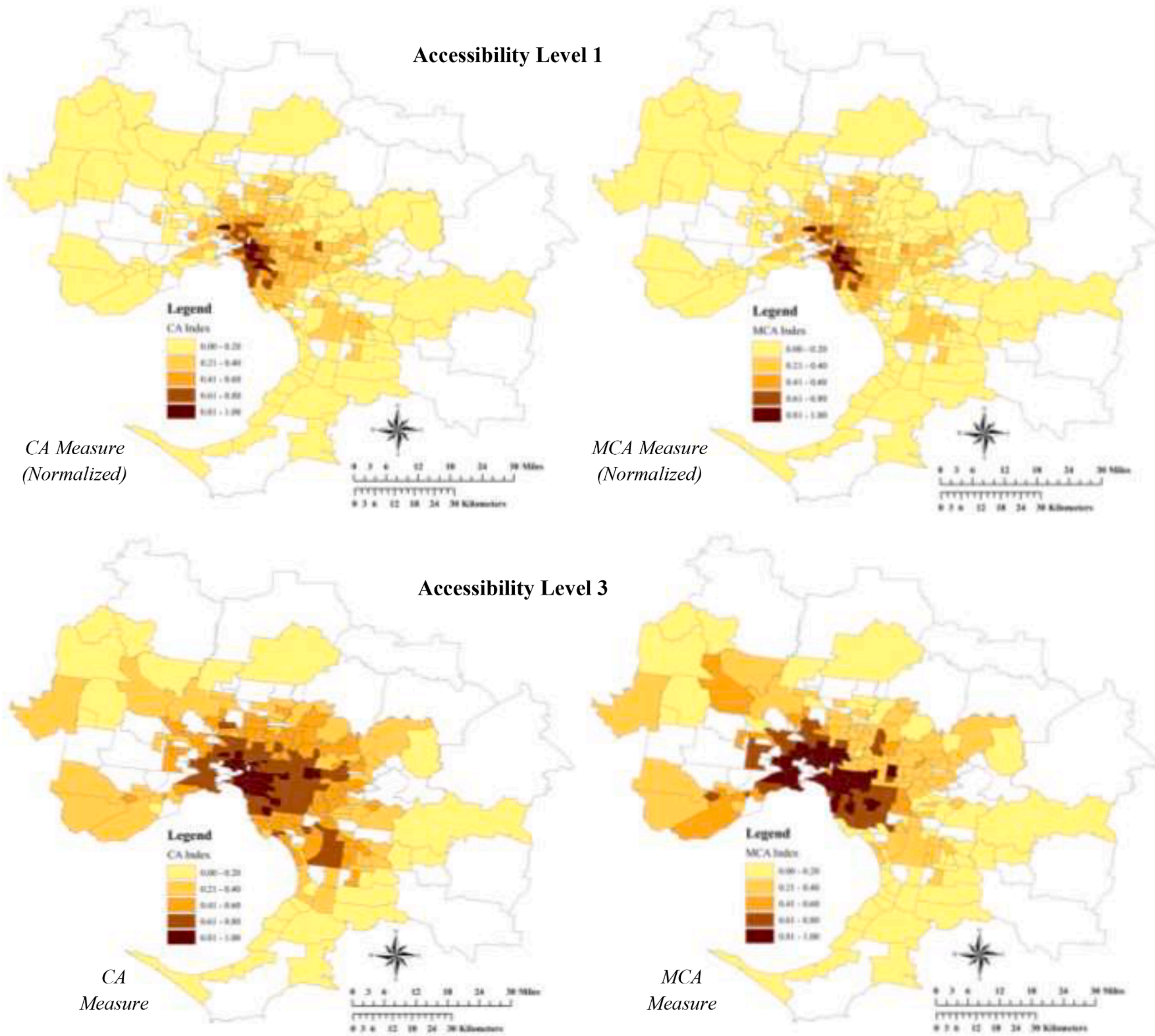

Fig. B1. CA and MCA comparison in the accessibility levels 30 and 90.

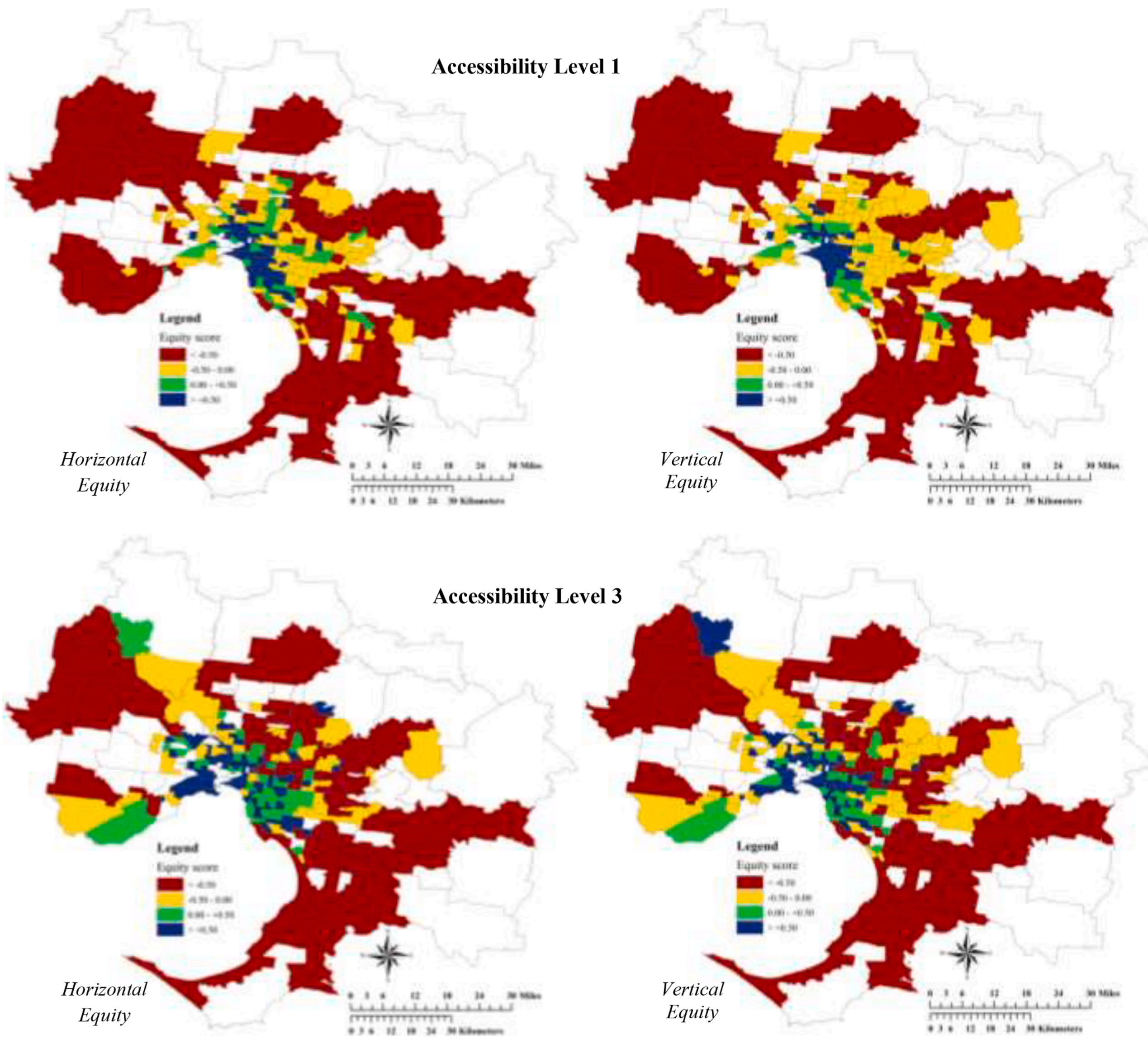

Fig. B2. The horizontal and vertical equity scores for the network's TAZs in the accessibility levels 30 and 90.

Table B1
The total operational recommendations with priorities 1 or 2 for the underserved TAZs.

Underserved TAZ ID	The TAZs should be connected better to the underserved TAZ
Beaconsfield - Officer	Emerald - Cockatoo, Pearcedale - Tooradin
Berwick - North	Cranbourne East, Endeavour Hills - South
Berwick - South	Cranbourne East, Cranbourne South, Emerald - Cockatoo
Cranbourne East	Berwick - North, Berwick - South, Narre Warren South (East)
Cranbourne South	Beaconsfield - Officer, Berwick - North, Berwick - South, Carrum Downs, Cranbourne, Cranbourne East, Cranbourne North, Cranbourne West, Emerald - Cockatoo, Endeavour Hills - South, Frankston North, Hampton Park - Lynbrook, Hastings - Somers, Langwarrin, Lynbrook - Lyndhurst, Narre Warren - North East, Narre Warren - South West, Narre Warren North, Narre Warren South (East), Narre Warren South (West), Skye - Sandhurst, Somerville
Croydon Hills - Warranwood	Bayswater, Mooroolbark, Wantirna
Deer Park - Derrimut	Keilor Downs, Laverton
Emerald - Cockatoo	Beaconsfield - Officer, Pakenham - North, Pearcedale - Tooradin
Endeavour Hills - South	Narre Warren - North East, Narre Warren North, Skye - Sandhurst
Epping - West	Fawkner, Hadfield
Ferntree Gully (South)	Bayswater, Croydon South, Mooroolbark
Gisborne	Melton, Melton West
Greenvale - Bulla	Gowanbrae, Keilor, Keilor Downs
Hastings - Somers	Cranbourne South, Pearcedale - Tooradin
Hoppers Crossing - North	Burnside, Caroline Springs, Point Cook - North, Point Cook - South, Seabrook, Werribee - South
Keilor Downs	Braybrook, Greenvale - Bulla, Keilor East, Mickleham - Yuroke, Tullamarine
Mickleham - Yuroke	Keilor Downs, Taylors Lakes
Mill Park - South	Heidelberg West, Plenty - Yarrambat, Reservoir - East
Mooroolbark	Montrose, Rowville - North, The Basin
Narre Warren - North East	Endeavour Hills - North, Endeavour Hills - South
Narre Warren South (East)	Cranbourne East, Cranbourne South, Endeavour Hills - South
Pearcedale - Tooradin	Beaconsfield - Officer, Berwick - North, Berwick - South, Carrum Downs, Cranbourne East, Cranbourne North, Cranbourne West, Emerald - Cockatoo, Hastings - Somers, Langwarrin, Narre Warren South (East), Skye - Sandhurst, Somerville
Point Cook - North	Sunshine West, Tarneit
Point Cook - South	Altona Meadows, Hoppers Crossing - North, Hoppers Crossing - South, Tarneit
Skye - Sandhurst	Cranbourne South, Endeavour Hills - South
Somerville	Cranbourne South, Langwarrin, Pearcedale - Tooradin
Viewbank - Yallambie	Bundoora - North, Bundoora - West, Epping - South, Mill Park - North, Mill Park - South
Warrandyte - Wonga Park	Croydon - East, Croydon South

References

Akbarzadeh, M., Mohri, S. S., & Yazdian, E. (2018). Designing bike networks using the concept of network clusters. *Applied Network Science, 3*(1), 1–21.

Australia bureau of Statistics, 2016, available at < https://www.abs.gov.au/ >accecced on 20 October 2020.

Ben-Elia, E., & Benenson, I. (2019). A spatially-explicit method for analyzing the equity of transit commuters' accessibility. *Transportation Research Part A: Policy and Practice, 120*(1), 31–42.

Blondel, V. D., Guillaume, J. L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory And Experiment, 2008*(10), 10008.

Bocarejo, S., J.P., & Oviedo, H., D.R. (2012). Transport accessibility and social inequities: A tool for identification of mobility needs and evaluation of transport investments. *Journal of Transport Geography, 24*(1), 142–154.

Bureau, B., & Glachant, M. (2011). Distributional effects of public transport policies in the Paris Region. *Transport Policy, 18*(5), 745–754.

Cao, X., Chen, H., Liang, F., & Wang, W. (2018). Measurement and spatial differentiation characteristics of transit equity: A case study of Guangzhou, China. *Sustainability (Switzerland)., 10*(4).

Chaloux, N., Boisjoly, G., Grisé, E., El-Geneidy, A., & Levinson, D. (2019). I only get some satisfaction: Introducing satisfaction into measures of accessibility. *Transportation Research Part F: Traffic Psychology and Behaviour, 62*(1), 833–843.

Chen, Y., Bouferguene, A., Li, H. X., Liu, H., Shen, Y., & Al-Hussein, M. (2018). Spatial gaps in urban public transport supply and demand from the perspective of sustainability. *Journal of Cleaner Production, 195*(1), 1237–1248.

Chen, Y., Bouferguene, A., Shen, Y., & Al-Hussein, M. (2019). Assessing accessibility-based service effectiveness (ABSEV) and social equity for urban bus transit: A sustainability perspective. *Sustainable Cities and Society, 44*(1), 499–510.

Cheng, L., Chen, X., Lam, W. H., Yang, S., & Wang, P. (2017). Improving travel quality of low-income commuters in China: Demand-side perspective. *Transportation Research Record, 2605*(1), 99–108.

Community profile, 2016a, Greater Melbourne household income, available at < https://profile.id.com.au/australia/household-income?WebID=260 >accessed on 20 October 2020.

Kompil, M., Jacobs-Crisioni, C., Dijkstra, L., & Lavalle, C. (2019). Mapping accessibility to generic services in Europe: A market-potential based approach. *Sustainable Cities and Society, 47*(1), Article 101372.

Currie, G. (2004). Gap analysis of public transport needs: measuring spatial distribution of public transport needs and identifying gaps in the quality of public transport provision. *Transportation Research Record, 1895*(1), 137–146.

Currie, G. (2010). Quantifying spatial gaps in public transport supply based on social needs. *Journal of Transport Geography, 18*(1), 31–41.

Deboosere, R., & El-Geneidy, A. (2018). Evaluating equity and accessibility to jobs by public transport across Canada. *Journal of Transport Geography, 73*(1), 54–63.

Delbosc, A., & Currie, G. (2011). Using Lorenz curves to assess public transport equity. *Journal of Transport Geography, 19*(6), 1252–1259.

Eboli, L., & Mazzulla, G. (2011). A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view. *Transport Policy, 18*(1), 172–181.

El-Geneidy, A., Buliung, R., Diab, E., van Lierop, D., Langlois, M., & Legrain, A. (2016a). Non-stop equity: Assessing daily intersections between transit accessibility and social disparity across the Greater Toronto and Hamilton Area (GTHA). *Environment and Planning B: Planning and Design, 43*(3), 540–560.

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016b). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice, 91*(1), 302–316.

Farber, S., & Fu, L. (2017). Dynamic public transit accessibility using travel time cubes: Comparing the effects of infrastructure (dis) investments over time. *Computers, Environment and Urban Systems., 62*(1), 30–40.

Farber, S., Ritter, B., & Fu, L. (2016). Space–time mismatch between transit service and observed travel patterns in the Wasatch Front, Utah: A social equity perspective. *Travel Behaviour and Society, 4*(1), 40–48.

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006. *Journal of Transport Geography, 29*(1), 1–10.

Fransen, K., Neutens, T., Farber, S., De Maeyer, P., Deruyter, G., & Witlox, F. (2015). Identifying public transport gaps using time-dependent accessibility levels. *Journal of Transport Geography, 48*(1), 176–187.

Garcia, C. S. H. F., Macário, M. R. M. R., Menezes, E. D. A. G., & Loureiro, C. F. G (2018). Strategic assessment of Lisbon's accessibility and mobility problems from an equity perspective. *Networks and Spatial Economics, 18*(2), 415–439.

Geurs, K. T., & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport geography, 12*(2), 127–140.

Golub, A., & Martens, K. (2014). Using principles of justice to assess the modal equity of regional transportation plans. *Journal of Transport Geography, 41*(1), 10–20.

Grisé, E., Boisjoly, G., Maguire, M., & El-Geneidy, A. (2019). Elevating access: Comparing accessibility to jobs by public transport for individuals with and without a physical disability. *Transportation Research Part A: Policy and Practice, 125*(1), 280–293.
Guzman, L. A., & Oviedo, D. (2018). Accessibility, affordability and equity: Assessing 'pro-poor' public transport subsidies in Bogotá. *Transport Policy, 68*(1), 37–51.
Guzman, L. A., Oviedo, D., & Cardona, R. (2018). Accessibility changes: Analysis of the integrated public transport system of Bogotá. *Sustainability (Switzerland), 10*(11).
Hernandez, D. (2018). Uneven mobilities, uneven opportunities: Social distribution of public transport accessibility to jobs and education in Montevideo. *Journal of Transport Geography, 67*(1), 119–125.
Hu, L. (2017). Job accessibility and employment outcomes: Which income groups benefit the most? *Transportation, 44*(6), 1421–1443.
Järv, O., Tenkanen, H., Salonen, M., Ahas, R., & Toivonen, T. (2018). Dynamic cities: Location-based accessibility modelling as a function of time. *Applied Geography, 95*(1), 101–110.
Jiao, J., & Dillivan, M. (2013). Transit deserts: The gap between demand and supply. *Journal of Public Transportation, 16*(3), p2.
Kaplan, S., de Abreu e Silva, J., & Di Ciommo, F. (2014a). The relationship between young people[U+05F3]s transit use and their perceptions of equity concepts in transit service provision. *Transport Policy, 36*(1), 79–87.
Kaplan, S., Popoks, D., Prato, C. G., & Ceder, A. A (2014b). Using connectivity for measuring equity in transit provision. *Journal of Transport Geography, 37*(1), 82–92.
Karner, A. (2018). Assessing public transit service equity using route-level accessibility measures and public data. *Journal of Transport Geography, 67*(1), 24–32.
Karou, S., & Hull, A. (2014). Accessibility modelling: Predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK. *Journal of Transport Geography., 35*(1), 1–11.
Kelobonye, K., McCarney, G., Xia, J. C., Swapan, M. S. H., Mao, F., & Zhou, H. (2019). Relative accessibility analysis for key land uses: A spatial equity perspective. *Journal of Transport Geography, 75*(1), 82–93.
Knox, P. L. (1978). The intraurban ecology of primary medical care: Patterns of accessibility and their policy implications. *Environment and planning A, 10*(4), 415–435.
Lee, J., & Miller, H. J. (2019). Analyzing collective accessibility using average space-time prisms. *Transportation Research Part D: Transport and Environment, 69*(1), 250–264.
Legrain, A., Buliung, R., & El-Geneidy, A. M. (2016). Travelling fair: Targeting equitable transit by understanding job location, sectorial concentration, and transit use among low-wage workers. *Journal of Transport Geography, 53*(1), 1–11.
Lucas, K., Van Wee, B., & Maat, K. (2016). A method to evaluate equitable accessibility: Combining ethical theories and accessibility-based approaches. *Transportation, 43*(3), 473–490.
Mayaud, J. R., Tran, M., Pereira, R. H. M., & Nuttall, R. (2019). Future access to essential services in a growing smart city: The case of Surrey, British Columbia. *Computers, Environment and Urban Systems., 73*(1), 1–15.
Metropolitan Melbourne, 2019, Explore the different areas of Melbourne and discover what makes this one of the world's most liveable cities, available at < https://liveinmelbourne.vic.gov.au/discover/melbourne-victoria/metropolitan-melbourne >accessed on 15 June 2021.
Melbourne 2030, 2019, Melbourne 2030 in summary, available at < https://www.planning.vic.gov.au/_data/assets/pdf_file/0018/100692/In-Summary.pdf >accessed on 15 June 2021.
Moreno-Monroy, A. I., Lovelace, R., & Ramos, F. R. (2018). Public transport and school location impacts on educational inequalities: Insights from São Paulo. *Journal of Transport geography, 67*(1), 110–118.
Mortazavi, S. A. H., & Akbarzadeh, M. (2017). A framework for measuring the spatial equity in the distribution of public transportation benefits. *Journal of Public Transportation, 20*(1), p3.
Mulley, C., Ma, L., Clifton, G., & Tanner, M. (2017). *Are Network Planning Guidelines Based On Equal Access Equitable? Transportation Research Record, 2651* pp. 1–11). SAGE Publications Ltd.
Murray, A. T., & Davis, R. (2001). Equity in regional service provision. *Journal of Regional Science, 41*(4), 577–600.
Nassir, N., Hickman, M., Malekzadeh, A., & Irannezhad, E. (2016). A utility-based travel impedance measure for public transit network accessibility. *Transportation Research Part A: Policy and Practice, 88*(1), 26–39.
Nazari Adli, S., Chowdhury, S., & Shiftan, Y. (2019). Justice in public transport systems: A comparative study of Auckland, Brisbane, Perth and Vancouver. *Cities, 90*(1), 88–99.
Oviedo, D., Scholl, L., Innao, M., & Pedraza, L. (2019). Do bus rapid transit systems improve accessibility to job opportunities for the poor? The case of Lima, Peru. *Sustainability (Switzerland)., 11*(10).
Public Transport Victoria, 2019, Annual report, available at < https://www.ptv.vic.gov.au/footer/data-and-reporting/annual-report/ >accessed on 15 June 2021.
Pucci, P., Vecchio, G., Bocchimuzzi, L., & Lanza, G. (2019). Inequalities in job-related accessibility: Testing an evaluative approach and its policy relevance in Buenos Aires. *Applied Geography, 107*(1), 1–11.
Qi, Z., Lim, S., & Hossein Rashidi, T. (2019). Assessment of transport equity to Central Business District (CBD) in Sydney, Australia. *Transportation Letters*.
Ricciardi, A. M., Xia, J. C., & Currie, G. (2015). Exploring public transport equity between separate disadvantaged cohorts: A case study in Perth, Australia. *Journal of Transport Geography., 43*(1), 111–122.
Ruiz, M., Segui-Pons, J. M., & Mateu-Lladó, J. (2017). Improving Bus Service Levels and social equity through bus frequency modelling. *Journal of Transport Geography, 58*(1), 220–233.
Serulle, N. U., & Cirillo, C. (2016). Transportation needs of low income population: a policy analysis for the Washington DC metropolitan region. *Public Transport, 8*(1), 103–123.
Sharav, N., Givoni, M., & Shiftan, Y. (2019). What transit service does the periphery need? A case study of Israel's rural country. *Transportation Research Part A: Policy and Practice, 125*(1), 320–333.
Slovic, A. D., Tomasiello, D. B., Giannotti, M., Andrade, M. D. F., & Nardocci, A. C (2019). The long road to achieving equity: Job accessibility restrictions and overlapping inequalities in the city of São Paulo. *Journal of Transport Geography, 78*(1), 181–193.
Song, Y., Kim, H., Lee, K., & Ahn, K. (2018). Subway network expansion and transit equity: A case study of Gwangju metropolitan area. *South Korea. Transport Policy., 72*(1), 148–158.
Sun, C., Cheng, J., Lin, A., & Peng, M. (2018). Gated university campus and its implications for socio-spatial inequality: Evidence from students' accessibility to local public transport. *Habitat International, 80*(1), 11–27.
Tahmasbi, B., Mansourianfar, M. H., Haghshenas, H., & Kim, I. (2019). Multimodal accessibility-based equity assessment of urban public facilities distribution. *Sustainable Cities and Society, 49*(1), Article 101633.
Van Wee, B., Hagoort, M., & Annema, J. A. (2001). Accessibility measures with competition. *Journal of Transport geography, 9*(3), 199–208.
Vuchic, V.R. 1981. Urban public transportation; systems and technology.
Welch, T. F. (2013). Equity in transport: The distribution of transit access and connectivity among affordable housing units. *Transport Policy, 30*(1), 283–293.
Welch, T. F., & Mishra, S. (2013). A measure of equity for public transit connectivity. *Journal of Transport Geography, 33*(1), 29–41.
Williams, H.L. (1978). Accessibility, spatial interaction and the spatial benefit analysis of land use-transportation plans. Spatial interaction theory and planning models.
Xia, J. C., Nesbitt, J., Daley, R., Najnin, A., Litman, T., & Tiwari, S. P. (2016). A multi-dimensional view of transport-related social exclusion: A comparative study of Greater Perth and Sydney. *Transportation Research Part A: Policy and Practice, 94*(1), 205–221.
Yang, L. (2019). Evaluating the urban land use plan with transit accessibility. *Sustainable cities and society, 45*(1), 474–485.
Yang, L., Chau, K. W., & Chu, X. (2019). Accessibility-based premiums and proximity-induced discounts stemming from bus rapid transit in China: Empirical evidence and policy implications. *Sustainable Cities and Society, 48*(1), Article 101561.
Zhang, A., Xia, C., Chu, J., Lin, J., Li, W., & Wu, J. (2019). Portraying urban landscape: A quantitative analysis system applied in fifteen metropolises in China. *Sustainable Cities and Society, 46*(1), Article 101396.
Yarra Tram, 2018, Facts & figures, available at < https://yarratrams.com.au/facts-figures >accessed on 15 June 2021.
Zhou, Q., Dai, D., Wang, Y., & Fan, J. (2018). Decade-long changes in disparity and distribution of transit opportunity in Shenzhen China: A transportation equity perspective. *Journal of Advanced Transportation, 2018*.