Journal of Transport Geography 19 (2011) 1252–1259

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Using Lorenz curves to assess public transport equity

Alexa Delbosc [a,*], Graham Currie [b,1]

[a] Institute of Transport Studies, Department of Civil Engineering, Building 60, Monash University, Clayton, Victoria 3800, Australia
[b] Chair in Public Transport, Institute of Transport Studies, Department of Civil Engineering, Building 60, Monash University, Clayton, Victoria 3800, Australia

ARTICLE INFO

Keywords:
Equity
Lorenz curve
Public transport

ABSTRACT

Equity has been a major concern of public transport provision and is required by legislation in many countries. Several approaches measure equity in transit supply however none produce a simple system-wide measure of equity performance. A new approach is presented using Lorenz curves to measure the relative supply of transit to the population. Gini coefficients provide a single measure of overall equity using this method. A system-wide assessment of overall transit supply to the population in Melbourne, Australia shows that 70% of the population shares only 19% of the supply (Gini coefficient = .68). When employment is also taken into account, the situation is not much different; 70% of jobs and population share 23% of service (G = .62). In order to gain some understanding of vertical equity, the transit supply was compared between different age, income and vehicle ownership groups. There is some evidence of higher supply for youth and low-income groups in inner Melbourne, and in all parts of Melbourne no-vehicle households lived in areas of higher transit supply. Overall it is unclear how "fair" these distributions are compared to equity in other cities since this is the first time this method has been undertaken. Projects using similar approaches should provide a good basis for establishing comparative equity between cities.

1. Introduction

Equity has been a major concern in public transport since the Montgomery Bus Boycotts by African Americans in the United States in 1955–1956. An assessment of equity issues in transit identified three main concerns arising from past policies: discrimination in public transportation accommodation, secondary impacts such as reductions in transit market share as a result of road building and the cumulative impact of policies such as public housing relocation to areas that provide less access to public transportation (Ward, 2005). The same source provides evidence that in America ethnic and racial minorities and persons living in low-income households may be concentrated away from jobs, goods and services and that transit does not always provide quality access to these facilities.

A range of legislation now requires that Government agencies consider fair treatment of all population groups in the provision of services (see Ward, 2005; American Public Transport Association, 2005). A major problem for public transport authorities concerns the approach to use in measuring and assessing equity impacts of service provision. Different definitions of equity can results in very different priorities for route and service allocation (Litman, 2007).

This paper presents a new approach to assessing the equity of public transit service provision. It uses the Lorenz curve from the field of economics to compare the distribution of public transport supply across population and employment in Melbourne, Australia. It includes a comparison of public transport supply for different social groups in greater need of public transport service.

2. Research context

There are two general categories of transport equity: horizontal equity and vertical equity (Litman, 2007). *Horizontal equity* (fairness or egalitarianism) is concerned with providing equal resources to individuals or groups considered equal in ability. It avoids favouring one individual or group over another and services are provided equally regardless of need or ability. *Vertical equity* (social justice, environmental justice or social inclusion) is concerned with distributing resources between individuals of different abilities and needs. Vertical equity favours groups based on social class or specific needs in order to make up for overall societal inequalities.

These two frameworks reflect two contrasting perspectives in public transport planning. One focus is to efficiently move the largest numbers of people, particularly for commuting to major employment centres and to reduce road congestion (Hay, 1993). This is a horizontal equity framework as its focus is on distributing services to the maximum number of users; it encapsulates the "mass transit" perspective (Betts, 2007). The other focus has been

* Corresponding author. Tel.: +61 3 9905 5568; fax: +61 3 9905 4944.
E-mail addresses: alexa.delbosc@monash.edu (A. Delbosc), graham.currie@monash.edu (G. Currie).
[1] Tel.: +61 3 9905 5574; fax: +61 3 9905 4944.

0966-6923/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jtrangeo.2011.02.008

called the "social transit" perspective (Betts, 2007). Its goal is to provide transit access to those with greatest "need," such as those without private transport or specific demographic groups such as the low-income, youth or ethnic minorities (Murray and Davis, 2001; Ward, 2005; Garrett and Taylor, 1999; Deakin, 2007). This is a vertical equity perspective as it prioritises the needs of specific groups over others. These two perspectives often conflict as prioritising one can come at the expense of the other (Taylor et al., 2009; Sanchez et al., 2007; Litman, 2007).

Another important dimension in equity is the difference between equity of opportunity and equity of outcome (Litman, 2007). There is general agreement that everyone deserves equity of opportunity but there is less agreement over equity of outcome; given the same choice of modes on the same journey, two individuals may make a different mode choice. Most of this paper will be framed in the context of equity of opportunity, measured using various indicators of accessibility and transit supply. Equity of outcome (e.g., revealed mode share) is a discussion for another paper.

The earliest studies examining the quality of transit service have come from studies in the United States (Wachs and Kumagai, 1972; Sherman et al., 1974) which were then applied to rural contexts in the UK (Moseley, 1979; Searle, 1987). They form the basis of what is now termed accessibility planning (Department for Transport, 2006), a framework for identifying spatial maps of service quality. This approach includes some simple but powerful core accessibility indicators such as 'the percentage of pupils of compulsory school age who live within 15–30 min of a primary school by public transport'. Monitoring statistics like this over time enables the assessment of changes in transit equity of opportunity (although not necessarily equity of outcome).

There are a series of methods used to compare the spatial spread of transit service level with the residential distribution of social groups said to be in great social need. Early approaches used the density of service kms as a measure of supply which were compared with census social indicators (Currie and Wallis, 1992). A refinement using a total generalised cost model of public transport and accessibility to a series of trip types was undertaken for Hobart, Tasmania (Currie, 2004).

'PTAL' (Public Transport Accessibility Level) is another approach used to assess equity in transit supply used in the UK since the early 1990s (Wu and Hine, 2003). In this method transit accessibility is measured using an index made up of walking time to the transit stop, reliability of service, number of services within a catchment and average waiting time. This index does not measure whether this supply provides access to a desired range of destinations. Wu and Hine (2003) compare local PTAL index ratings to the spatial distribution of indices of deprivation, an assessment of vertical equity.

Most of the above are examples of vertical equity – the quantity of service provided to disadvantaged social groups. The literature also contains examples of measuring horizontal equity in transit, although they are not usually framed in this context. Reports of this nature generally measure the distribution of transit in relation to either residential or employment distribution. For example Minocha et al. (2008) developed a "Transit Availability Index" made up of frequency, hours of service and service coverage and compared it to a "Transit Employment Accessibility Index" calculated using a gravity model of transit travel times and O-D pairs.

Although past approaches may highlight specific areas of inequality, a limitation of each approach shown is that they do not provide a single value assessing horizontal equity across an entire transit system. Finding a method of doing this is the major aim of this paper. The method also allows a visual representation of gaps in public transport supply relative to population and employment.

3. Methodology

This paper will use Lorenz curves to geographically compare public transport supply in Melbourne to a broad measure of demand (population and employment distribution). The following sections describe the Lorenz curve methodology, the method of calculating public transport supply and the source of population and employment data.

3.1. Lorenz curves

In economics, Lorenz curves are a graphical representation of the cumulative distribution function of wealth across the population (Lorenz, 1905). Fig. 1 is an example of a Lorenz curve of income distribution. The dashed line represents a population of perfectly equitable income distribution; the solid curved line represents an inequitable distribution of wealth (e.g., 70% of the population shares about 25% of the population's income). It is important to note that Lorenz curves do not imply that perfect equity is possible or even desirable.

Lorenz curves can be applied not just to income but to any quantity that can be cumulated across a population. They have been applied in a range of disciplines, from studies of biodiversity to business modelling and even within transport (Fridstrom et al., 2001).

The Lorenz curve is a visual representation of equality whereas the Gini coefficient is a single simple mathematical metric to represent the overall degree of inequality. It is a ratio of the area between the line of equality and the Lorenz curve (marked "A" in Fig. 1) divided by the total area under the line of equality (A + B in Fig. 1) (Gini, 1912). In this way, the distribution of two different Lorenz curves can be mathematically compared.

The mathematical calculation of the Gini coefficient is complex, but can be approximated using the following formula:

$$G_1 = 1 - \sum_{k=1}^{n}(X_k - X_{k-1})(Y_k + Y_{k-1})$$

where X_k is the cumulated proportion of the population variable, for $k = 0, \ldots, n$, with $X_0 = 0$, $X_n = 1$ and Y_k is the cumulated proportion of the public transport service variable, for $k = 0, \ldots, n$, with $Y_0 = 0$, $Y_n = 1$.

3.2. Public transport index

Transit service level was measured using an index that calculated the service level of walk-distance catchments within census tracts. It includes bus, train and tram services distributed across the greater Melbourne area. The calculation of this index is detailed in Currie, (2010) but uses updated service levels taken from June 2010. The calculation uses the following form:

$$SI_{CCD} = \sum_{N}\left(\frac{Area_{Bn}}{Area_{CCD}} * SL_{Bn}\right)$$

where SI_{CCD} is the supply index for the census collection district, CCD is the CCD under analysis, N is the number of walk access buffers to stops/stations in each CCD, Bn = Buffer n for each stop/station in each CCD, $Area_{CCD}$ = square kilometre spatial area of the CCD, SL = Service Level Measure (number of bus/tram/train vehicle arrivals per week).

The following steps were taken:

1. A database of bus and tram stops and train stations was obtained. This included the location of each stop/station plus a listing of rail, bus and tram routes using the stops.

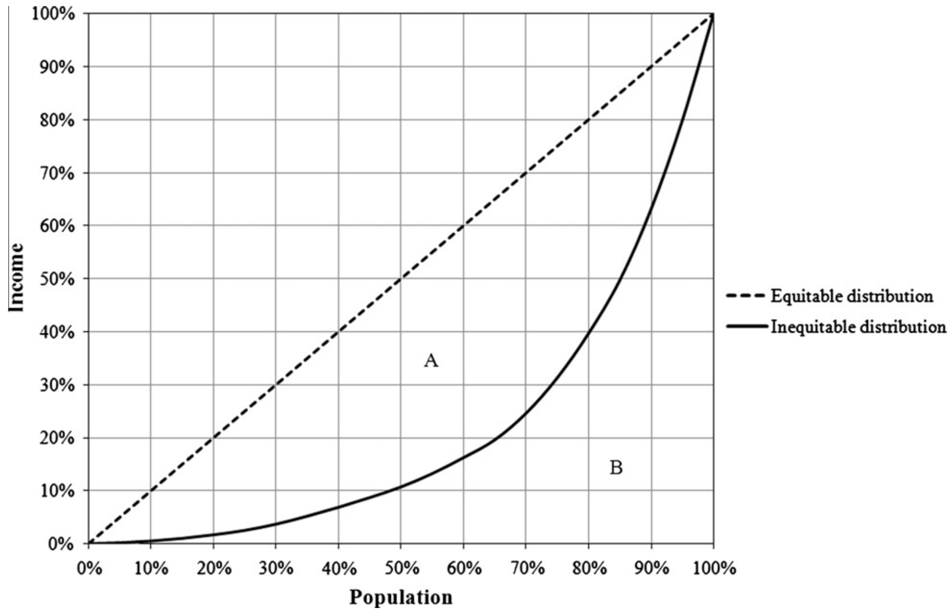


Fig. 1. Example Lorenz curve.

2. This database was integrated with a database of public transport service frequencies in Melbourne. Data was provided by Metlink via the Bus Association of Victoria and was accurate as of June 2010.
3. For each stop/station a measure of service frequency was calculated as the 'total number of service arrivals per week'.
4. Access distance to each stop/station was then measured for each CCD assuming the following thresholds of walk access which are based on typical walk catchments (termed walk 'buffers') for public transport modes. These are the distances that 75% to 80% of people would walk to access a stop (Kittelson and Associates et al., 2003):
   - Access to Bus Stop = 400 m
   - Access to Tram Stop = 400 m
   - Access to Rail Station = 800 m
5. Where two walk buffers within the same route direction were so close as to overlap the buffers were merged together so as not to count the overlap area as "twice" the service (see Fig. 2).

A combined measure of service frequency (vehicle trips per week) and access distance was then computed for each CCD using GIS software and formula 2. Note that service levels are calculated based on the overlap with a stop's walk catchment, not the location of the catchment centroid (transit stop). That is, the actual transit stop does not have to be within a census district in order for its service to contribute to the supply for that district.

Fig. 2 illustrates a simplified example of calculating the index for a collection district where one train station and two bus stops are within walking distance. The two bus stops are part of the same route going in the same direction so their buffer catchments are merged. Notice that one of the bus stops is not physically located within the collection district, but its walk catchment buffer is.

This calculation method is somewhat limited in that it uses service frequency without a measure of access to specific destinations. For example a region centred on a single, high frequency tram line may be assigned the same index value as a region centred on two perpendicular bus lines with half the frequency in each direction. Although this limitation is acknowledged, this simplicity expands its usefulness for practitioners. Anyone with access to a GIS program, service levels and transit stops can calculate this index for their city or local area.

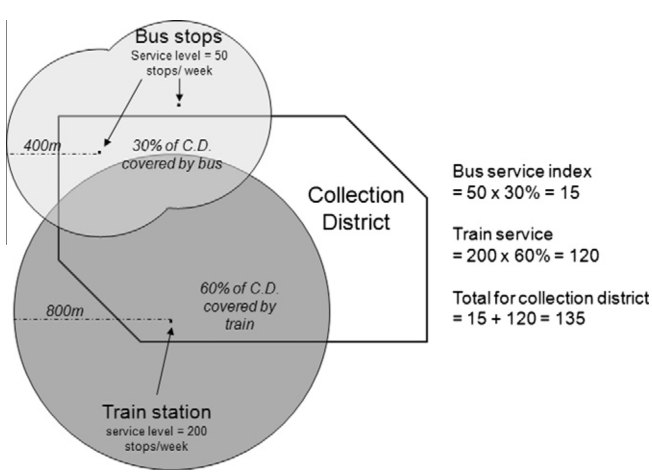


Fig. 2. Simplified example of index calculation.

3.3. Census data

Population and employment were measured at the level of census collection district using the 2006 Australian census (Australian Bureau of Statistics, 2006). Census collection districts are the smallest geographic unit of population available in Australia. This information was used to compare the public transport supply index to the population of Melbourne to evaluate horizontal equity. Demographics from the census were used to evaluate vertical equity.

Fig. 3 displays the residential and employment density in Melbourne as of the 2006 census. Both population and employment are concentrated in the inner and middle suburbs with the balance distributed across a broad fringe at low density.

4. Results

4.1. Horizontal equity across the Melbourne population

In initial analyses, for each census district the transit service level (calculated using Formula 2) was compared to the residential

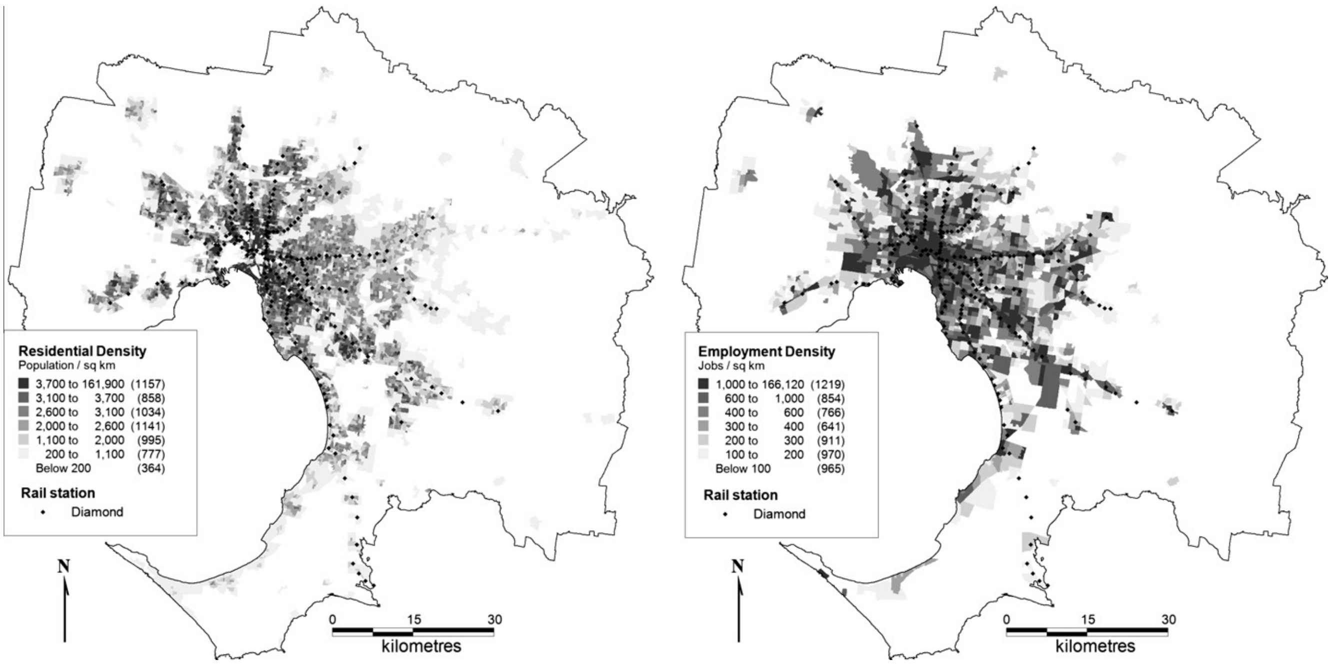


Fig. 3. Residential and employment density in Melbourne.

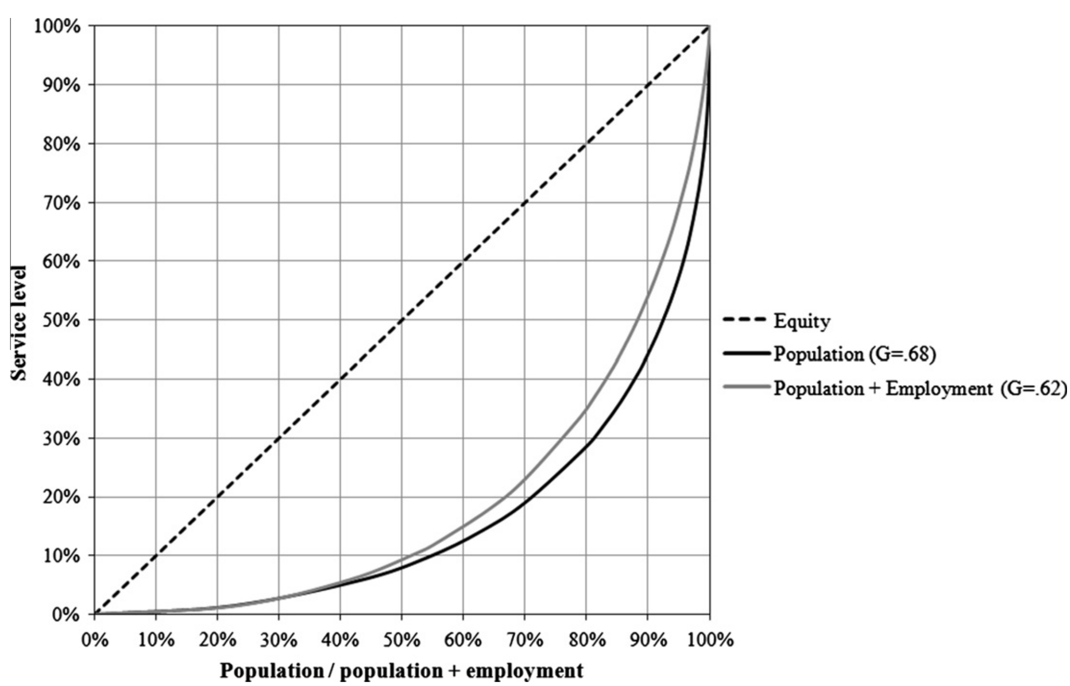


Fig. 4. Lorenz curves of population and employment.

population using Formula 1 to calculate the Gini coefficient. The Gini coefficient for the overall population of Melbourne was .68 (Fig. 4). In practical terms, this means that 70% of Melbourne's population shared only 19% of transit. Conversely, 30% of Melbourne's population share 81% of the transit service.

However the purpose of transit is to service both origins (residential location) and destinations (employment, goods and services). Therefore a second Lorenz curve was calculated comparing service level to a combination of residential and employment density. When employment was included with population, the distribution was slightly more equitable (G = .62), but not by a great deal. Some 70% of combined people and jobs share 23% of transit (Fig. 4). Overall these curves suggest relatively low horizontal equity as the majority of services are available to a small proportion of the population.

4.2. Mapping horizontal equity gaps

The difference between supply and population can be mapped to give an idea of where there are inequities in service. For each census collection district in Melbourne, the proportion of population + employment and the proportion of transit service level was

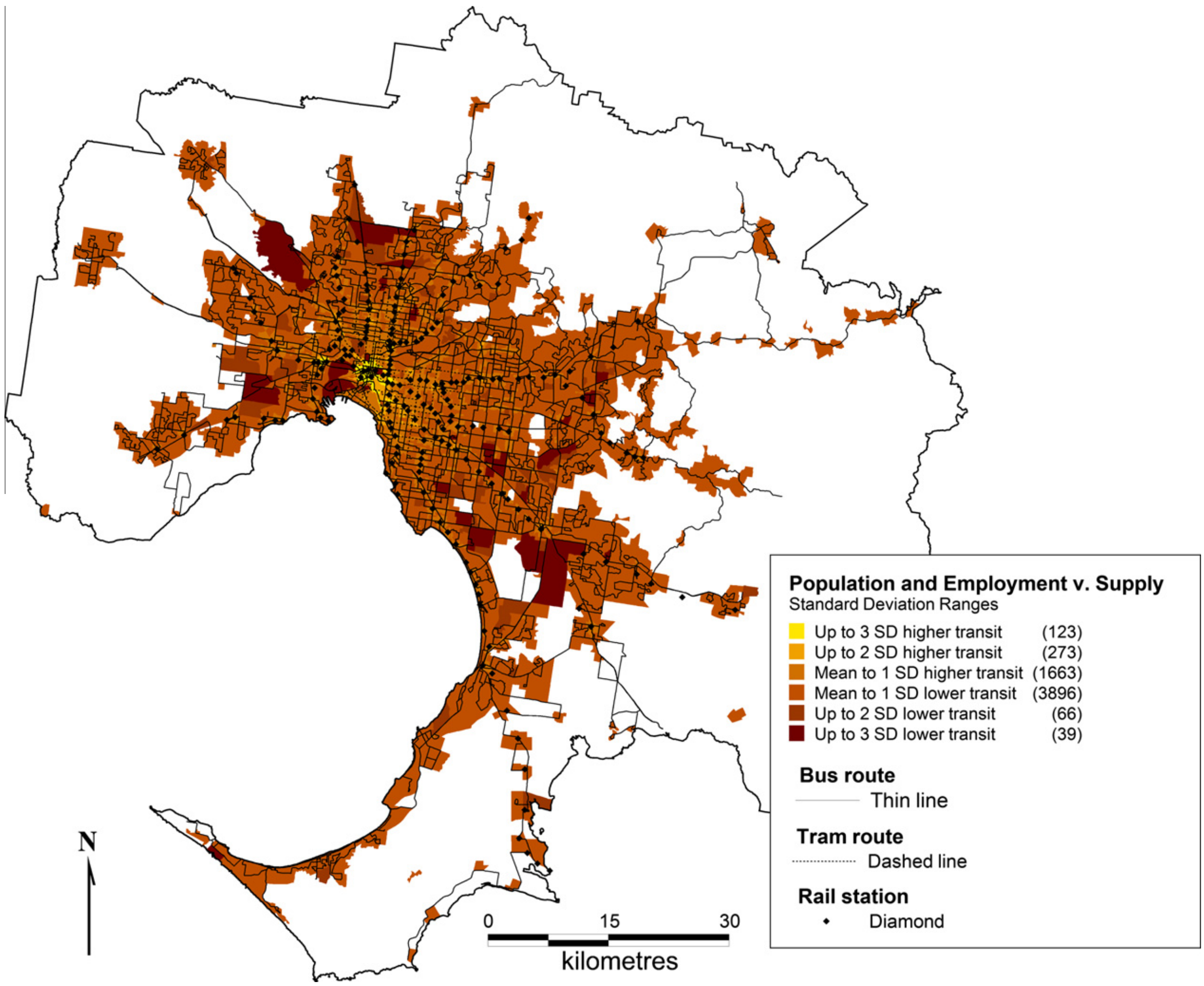


Fig. 5. Difference between population + employment and supply.

calculated as a percentage of the total population or quantum of service index. One was then subtracted from the other to calculate which areas had more transit than people + employment, and vice versa.

Fig. 5 shows this difference data graphically across the greater Melbourne area. For ease of interpretation, only census districts with a population concentration greater than 200 people per square km are shown (the definition of an "urban centre" used by the Australian Bureau of Statistics, (Australian Bureau of Statistics, 2009)).[2] Areas with low residential population but an employment density of over 200 per square km were also included in the map.

The shading ranges represent the difference from the mean in standard deviation ranges. The values in brackets are the number of census districts in each range. Most of Melbourne's census zones (3896) are within one standard deviation lower supply than population. Some 39 census districts are three or more standard deviations below the mean of service to population (darkest regions). There is tendency for these to be on the urban fringe and areas of low density where traditional transit systems may not be viable (see Fig. 3). However some of these gaps are in inner and middle suburbs with relatively high densities.

Fig. 6 is a close-up of Fig. 5 with some of the low-supply "hotspots" identified. Most of the hotspots are industrial or mixed business/industrial zones on the fringe but including the Port of Melbourne. A few major shopping centres in the middle suburbs also appear to be under-supplied. Interestingly, two of the major universities in Melbourne are greatly under-supplied. Some of these areas actually have very high transit supply but the combined population and employment of these zones far outstrips the quantum of transit supply.

Most of the high-supply areas lie in dense inner suburbs and along major rail and tram corridors. However the region of Footscray stands out as a middle-western suburb with some of the highest supply of transit compared to population and employment.

This exercise highlights a methodological shortcoming of the public transport index calculation method. Most of the low-service hotspots identified are located in census tracts that have a larger area than the surrounding tracts. For example the airport is covered by a census tract of over 14 square kilometres even though the immediate airport access would be much smaller than this. Even though the airport is serviced by a high-frequency bus, the 400 m catchment of the bus stop only covers a small proportion of the total area of the census tract. Unfortunately these are the smallest geographic units of measurement available in Australia.

4.3. Vertical equity for specific population groups

The principle of vertical equity suggests that certain vulnerable groups should be provided with a higher quality or quantity of service than other groups. Vertical equity was evaluated using

[2] Note that this was only for ease of graphical interpretation; Gini coefficients were calculated using all collection districts in Melbourne regardless of density.

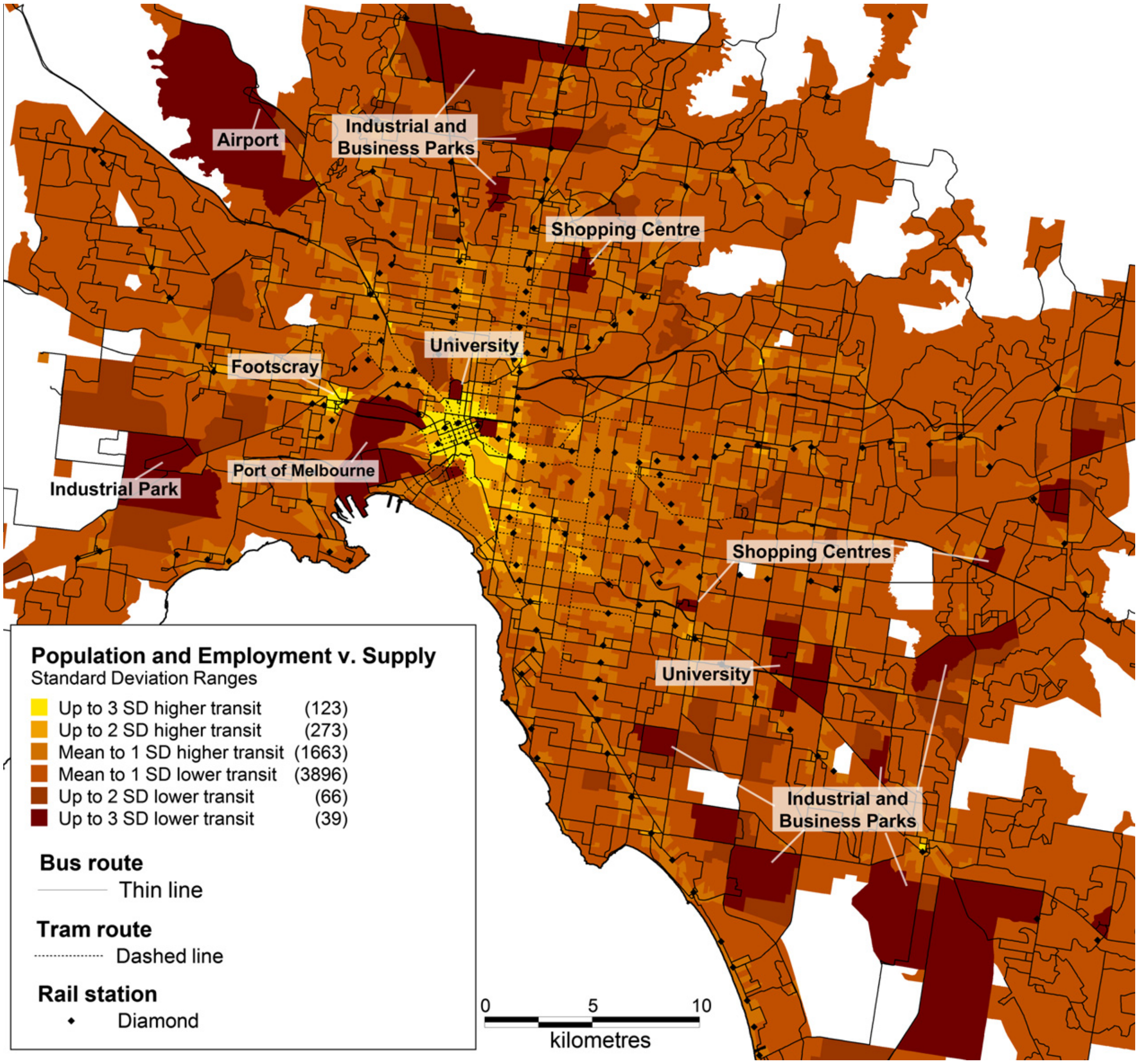


Fig. 6. Close-up of supply gaps in Melbourne.

census data across a range of age groups, income groups and car ownership categories. Age groups included children (under 15 years old), youths (15–24), adults (25–64) and the aged (65+). Personal income (per week, in Australian dollars) was used as only "family" (not "household") income was available. Motor vehicles per household were classified into zero, one, two, and three or more vehicles. These characteristics are associated with high transport needs (Currie and Wallis, 1992; Travers Morgan, 1992; Currie, 2004).

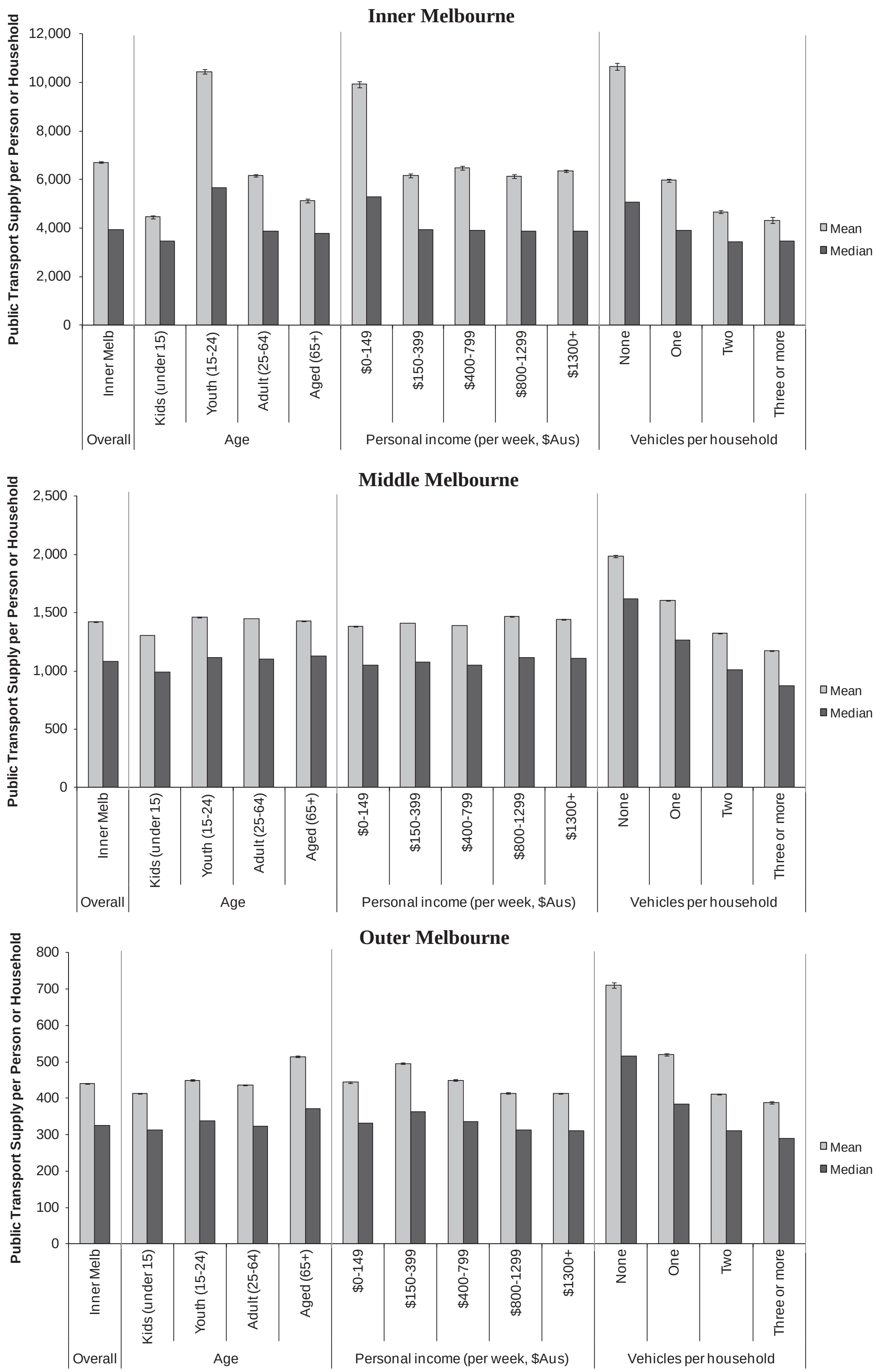
As demonstrated in Figs. 5 and 6, public transport supply is highly skewed toward inner areas. For this reason vertical equity was compared for three different regions of Melbourne: inner, middle and outer areas.

The degree of vertical equity varies slightly between regions of Melbourne, as shown in Fig. 7. In inner areas, youth and low-income groups live in areas with far greater public transport supply than the other age groups however older people have a transit supply closer to the overall average. This suggests some vertical equity "advantage" for low-income and youth in inner areas. In middle Melbourne, on the other hand, transit supply is almost identical across age and income groups, although it is lower for children. In outer Melbourne it is the aged and the second-lowest income group who have a higher transit supply and therefore, a degree of vertical equity "advantage". There is a degree of skew in the difference between the average and the median transit supply score in these regions indicating vertical equity outcomes will vary within the regions (see Fig. 7).

Across all three regions, no-vehicle households have very high relative transit supply which drops off abruptly as the number of household vehicles increases. It appears that no-vehicle households are locating themselves in areas of higher-quality public transport and/or households close to quality public transport are more likely to sell their cars.

5. Summary and conclusion

A number of approaches to measuring the spatial supply of transit have been developed. The advantage of the method proposed in this paper is its relative simplicity to measure and the ability of the Gini coefficient to provide a single value of overall system equity. A Lorenz curve approach is presented comparing



Note: Error bars show 5% confidence intervals of the mean. Income is in Australian dollars per week.

Fig. 7. Vertical equity of public transport supply.

overall transit supply to population and shows that 70% of the population of Melbourne shares only 19% of the supply (Gini coefficient = .68). When employment is also taken into account, the situation is not much different; 70% of jobs and population share 23% of service (Gini = .62).

It is unclear how "fair" these distributions are compared to equity in other cities since this is the first time this method has been applied to transit access in this way. Although perfect horizontal equity is not attainable (or even desirable), it seems rather inequitable for 77% of transit to be concentrated to only 30% of people and employment in a city. In future it would be interesting to track this Gini coefficient over time or compare Melbourne's Gini coefficient to other cities. All that would be needed to compare is basic GIS software, population and employment at a relatively fine geographic level, a database of all transit stops in a city and the number of services per week at each stop.

Mapping the difference between transit and population + employment reveals some of the ''hot spots'' around a city where population and employment far outstrips supply. ''Hot spots'' such as these must be examined within a local context. Some of these gaps are in fringe locations with very low density where traditional transit systems may not be financially viable; however governments may step in to ensure a basic minimum level of service, as they have in Melbourne (Loader and Stanley, 2009). As another example in Australia most university students do not live on campus and in Melbourne 33% of trips to a university campus are made by transit,[3] suggesting that the hot spots at major universities deserve greater scrutiny. However in other cities, a university campus may be so self-contained that walking and biking may be a more appropriate solution than transit. Furthermore hot spots around major shopping centres should be addressed in the context that ''big box'' shopping is difficult to conduct without a car, taxi or delivery service.

There is some evidence of vertical equity advantages for specific groups in parts of Melbourne. In inner Melbourne youth and the lowest income groups have much higher transit supply than other groups and in outer Melbourne older people have a slightly higher supply. However in middle Melbourne there is little difference in supply across these groups. In all three areas of Melbourne, households with no cars are located in places with much higher supply than households with one, two, or more vehicles.

Together these tools can provide a simple yet easy to apply measure of macro-level transit equity across a geographic region.

Acknowledgements

The authors would like to thank Prof Cameron Gordon of the University of Canberra and Professor Jonathan Peters, City University of New York, College of Staten Island for suggesting Lorenz Curves as a means of measuring equity in transport. Any omissions or errors are the responsibility of the authors.

References

American Public Transport Association, 2005. Safe, Accountable, Flexible, Efficient Equity Act, A Legacy for Users: A Guide to Transit-Related Provisions. <http://www.apta.com/gap/policyresearch/generalpolicy/Documents/safetea_lu_guide.pdf>.

Australian Bureau of Statistics, 2006. Census of Population and Housing.

Australian Bureau of Statistics, 2009. Australian Standard Geographical Classification (ASGC).

Betts, J., 2007. Transport and social disadvantage in Victoria: a government perspective. In: Currie, G., Stanley, J., Stanley, J. (Eds.), No Way to Go: Transport and Social Disadvantage in Australian Communities. Monash University Press.

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, 137–146.

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

Currie, G., Wallis, I., 1992. Determining priorities for passenger transport funding: the needs assessment approach. Australasian Transport Research Forum. Canberra.

Deakin, E., 2007. Equity and Environmental Justice in Sustainable Transportation: Toward a Research Agenda. University of California Transportation Centre, Berkeley.

Department for Transport, 2006. Guidance on Accessibility Planning in Local Transport Plans. <http://www.dft.gov.uk/pgr/regional/ltp/accessibility/guidance/gap/> (accessed 02.06.09).

Fridstrom, L., Minken, H., Vold, A., 2001. The income distribution effect of road pricing: a modelling case study. European Transport Conference, Cambridge, UK.

Garrett, M., Taylor, B., 1999. Reconsidering social equity in public transit. Berkeley Planning Journal 13, 6–27.

Gini, C.W., 1912. Variability and Mutability, Contribution to the Study of Statistical Distributions and Relations. Studi Economico-Giuricici della R. Universita de Cagliari.

Hay, A., 1993. Equity and welfare in the geography of public transport provision. Journal of Transport Geography 1, 95–101.

Kittelson & Associates, KFH Group, Parsons Brinkerhoff Quade and Douglas Inc., & JHunter-Zaworski, K., 2003. Transit Capacity and Quality of Service Manual, second ed. Transit Cooperative Research Program TCRP, Washington, DC.

Litman, T., 2007. Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transportation Planning. Victoria Transport Policy Institute.

Loader, C., Stanley, J., 2009. Growing bus patronage and addressing transport disadvantage – the Melbourne experience. Transport Policy 16, 106–114.

Lorenz, M.O., 1905. Methods of measuring the concentration of wealth. Publications of the American Statistical Association 9, 209–219.

Minocha, I., Sriraj, P.S., Metaxatos, P., Thakuriah, V., 2008. Analysis of transit quality of service and employment accessibility for the greater Chicago, Illinois, region. Transportation Research Record 2042, 20–29.

Moseley, M.J., 1979. Accessibility: the Rural Challenge. Methuen & Co., London.

Murray, A.T., Davis, R., 2001. Equity in regional service provision. Journal of Regional Science 41, 577–600.

Sanchez, T., Upton, A., Jones, P., Lucas, K., 2007. Integrating urban service delivery research for distributional analysis and transport equity. Transportation Research Board 86th Annual Meeting.

Searle, G., 1987. Value for money from rural public transport subsidies: a summary of the Lewes approach. In: Glaister, S. (Ed.), Transport Subsidy Policy Journals. Department of Transport, UK.

Sherman, L., Barber, B., Kondo, W., 1974. Method for evaluating metropolitan accessibility. Transportation Research Record 499, 70–82.

Taylor, J., Barnard, M., Neil, H., Creegan, C., 2009. The Travel Choices and Needs of Low Income Households: The Role of the Car. National Centre for Social Research.

The Urban Transport Institute, 2008. Victorian Integrated Survey of Travel & Activity 2007–2008: Survey Procedures and Documentation. The Victorian Department of Transport.

Travers Morgan, 1992. Strategies to Overcome Transport Disadvantage. Department of the Prime Minister and Cabinet, Canberra.

Wachs, M., Kumagai, T.C., 1972. Physical accessibility as a social indicator. School of Architecture and Urban Planning. University of California.

Ward, B., 2005. Case studies in environmental justice and public transit title VI reporting. Transit Cooperative Research Program Project TCRP J-06. Tampa Florida: National Centre for Transit Research. University of Southern Florida.

Wu, B., Hine, J., 2003. A PTAL approach to measuring changes in bus service accessibility. Transport Policy 10 (4), 307–320.

[3] Authors' analysis of weighted data from The Urban Transport Institute, 2008. Victorian integrated survey of travel & activity 2007–2008: Survey procedures and documentation. The Victorian Department of Transport.