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A New Approach to Exploring the Operational Performance of Public Transport Links, the case of Melbourne, Australia

Katerina Pavkova[1], Graham Currie[1], Alexa Delbosc[1], Majid Sarvi[1]

Institute of Transport Studies, Department of Civil Engineering, Monash University, Clayton, Victoria 3800, Australia

Email for correspondence: Katerina.Pavkova@monash.edu

Abstract

Urban congestion in cities is one of the most expensive and fastest growing global problems. Together with increasing world population and urbanisation, it is exacerbating transport performance problems in world cities.

The operational performance of public transport is currently facing challenges due to patronage growth, limited capacity and the impacts of traffic congestion on on-road service reliability. The majority of public transport takes place on road and giving it priority has been seen as a logical next step in service development. However, despite the benefits of public transport priority, studies have shown that it is problematic to effectively determine where priority should be located. Current ways of evaluating urban transport congestion have been found limiting and obsolete. There is an urgent need to find new ways to understand the distribution and preferences for transit priority in order to improve the performance on on-road public transport.

Lorenz Curves, and the associated Gini Coefficient parameter, have been developed in social science as a powerful tool to study income inequality. This research explores if, and how, these metrics can be re-interpreted to help with targeting improvements for on-road public transport and priority mitigations. A new concept is presented where the Lorenz Curve and Gini Coefficient are adopted as a new and original measure of public transport operational performance. The results of preliminary research applied on Melbourne's tram network show that these metrics have the potential to demonstrate the operational performance of road based public transport routes and networks. It identifies the locations of links for targeted attention through approaches like on-road priority. Implications for future research and policy are discussed.

Key words: *urban transport congestion, transport operational performance, public transport priority, priority zones, Lorenz Curve, Gini coefficient*

1. Introduction

As cities across the world are growing (UN, 2014), travel demand and traffic congestion is also increasing (BTRE, 2014). In the case of Melbourne an increased need for travel to and through the city is expected in next 15 years (PTV, 2012). Public transport priority has proven to be an effective strategy to satisfy this need (Currie et al., 2007). However approaches relevant to planning where the priority should be allocated are limited, there is not a simple tool available to help aid decisions on locating priority treatments (NCHRP, 2011). This paper introduces a new concept developed to assess the potential location of public transport priority treatments on transit networks and routes. It uses the Lorenz Curve, an economic measure, to analyse the spatial distribution of the performance of sections of the tram network in Melbourne, Australia.

The paper is structured as follows: firstly a literature review of public transport priority treatments and warrants[1] is presented. This is followed by a discussion of the Lorenz Curve. The proposed methodology is then described. Results are then presented followed by a discussion and conclusions.

2. Literature review

Public transport priority provides preferential treatment of road space allocation or signal timing to improve the operational performance of public transport vehicles (Currie et al., 2007). Typical decision making process concerning priority have two main approaches:

a. Road management perspective (considering the road capacity and congestion of the shared road space).
b. Public transport perspective (considering the public transport demand)

Most published research focusses on road management perspectives (a.).

Jepson and Ferreira (2000) reviewed guidelines for bus priority treatments and identified a range of warrants in the United Kingdom. UK warrants are conditional on the level of road congestion and the volume of busses. At high road congestion levels, lanes were considered justified only when there are very frequent buses. One warrant identifies a minimum criteria for priority at around 30-40 busses per hour (TRB, 1994). Vuchic (1981) states, that a bus lane is justified when the amount of people using public transport equals the number of people using cars in the remaining lanes. This concept can be 'warrantable' in high traffic conditions as long as vehicle capacities and occupancy are high and services very frequent.

Overall these types of warrants are simple to use but have unclear links to actual impacts on passengers in relation to the operational performance of public transport. They are simple to apply but rather simplistic in their construction. In most cases it is unclear why and how warrants of this kind have been determined.

The majority of studies with a public transport perspective (b.) focus on the design of individual measures and their impacts. Very little research explores approaches which help to decide where to allocate public transport priority.

One of the few tools which analysed how and where priority is allocated from public transport perspective is a ranking model developed by consultants Aecom (2006) in Australia. This model is based on route segments and takes into account three factors:

a. Demand;
b. Strategic importance; and
c. Operational factors. e.g.: travel time, level of existing impendence and the intensity of service.

These inputs are then weighted by a degree of importance, but also matched by the service characteristic/ context conditions (i.e. A.M. peak v. off-peak speed and P.M. peak v. off-peak speed). Final results of this model were proven to match intuitive expectations.

A more complex assessment, including economic appraisal, can be found in the work of Currie et al. (2007). A cost benefit analysis of converting a traffic lane into a bus rapid transit lane was presented in a report by NCHRP (2011). An evaluative approach was also reported in the UK (DTLGR, 1997) however it is unclear how often these more complex approaches are used in practice. None of these approaches are feasible for a network-wide evaluation of where priority should be located and all are rather too complicated for more frequent day to day planning assessment. A simple set of measurements, which can be applied by planning authorities in a clear, open and comprehensive manner is needed.

[1] Priority warrant is a guaranteed allocated road space, e.g. bus lane.

However, overall, very few studies or methods consider where to allocate public transport priority from a public transport perspective.

2.1. Lorenz Curve and Gini Coefficient

The Lorenz Curve is a well-established economic tool typically used to describe inequality in the distribution of wealth and income in society. It was devised by an American economist Max Lorenz in 1905.

A Lorenz Curve is a chart displaying the cumulative proportion of a population on the horizontal axis and a cumulative distribution function of the “interest variable” (such as income) on the vertical axis, both quantities are presented as percentages (Ahmad-Kiadaliri et al., 2011). If the cumulative distribution values are perfectly aligned with the cumulative distribution of population, the Lorenz Curve results in a 45 degree straight line that is known as the ‘line of equality’. The area between the Lorenz Curve and the line of equality is a measure of the discrepancy between the income and population distributions (Frees 2014).

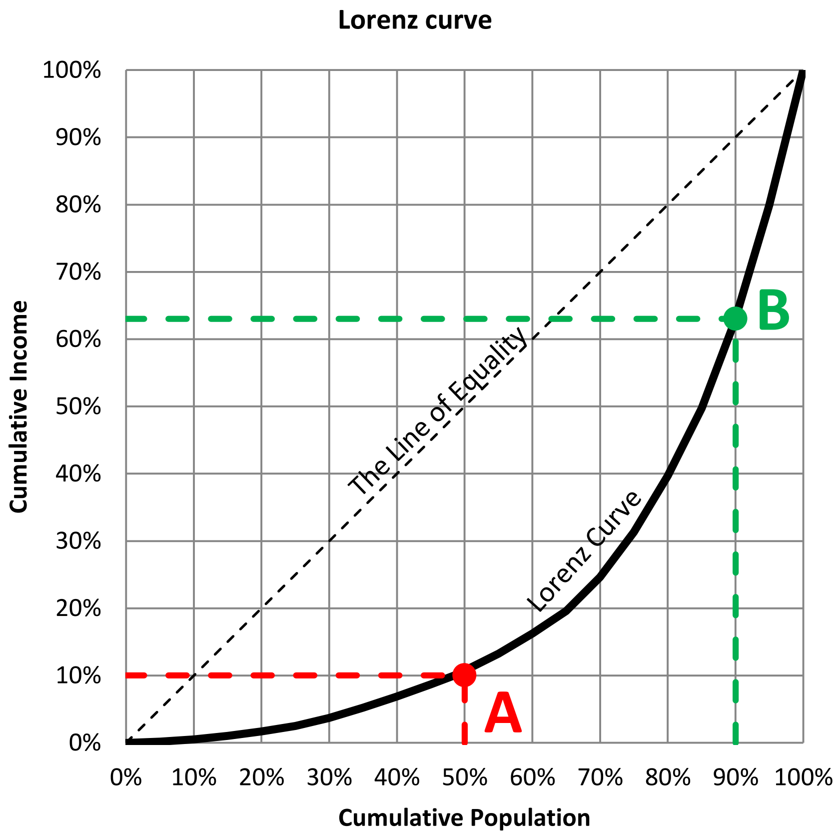


Figure 1: Lorenz Curve

The graph (**Error! Reference source not found.**) shows an example of a Lorenz Curve in comparison to the line of equality. The red and green lines cutting in at the bottom and top of the Lorenz Curve demonstrate selected aspects of the distribution. Line A crosses the Lorenz Curve where 50% of Population earns only 10% of the shared Income. Line B crosses the Lorenz Curve at the point where the last 10% of the Population earns some 38% of Income. By exploring these aspects of the distribution it is possible to better understand how variable the distribution of income is.

The area between the straight line of equality and the Lorenz Curve is also known as Gini Index or Gini Coefficient, developed by Italian statistician Corrado Gini in 1912. (Sen and Foster, 1998, Frees et al., 2014). This is a potentially powerful value since it indicates the variability of inequality (or distribution) as a single number for a large dataset. Values of the Gini Coefficient are between 0 and 1, the higher the Gini Coefficient; the more unequal is the distribution of the studied trend (Frees 2014).

The idea of using the Lorenz Curve and Gini coefficient in other fields outside of economics is not new. A number of applications can be found in the spatial sciences.

Minnich and Chou (1997) and Diaz-Delgado (2001) used the Lorenz Curve and Gini coefficient to evaluate the spatial distribution of large wild fires. They compared the cumulative size of each fire with the percentage of burned areas to determine the influence of the fire size on their spread in the area.

Elvidge et al. (2012) employed the Lorenz Curve principle to the development of a global index describing human settlements and development using satellite data. They compared the cumulative percentage of population on a grid 10 km x 10 km against the cumulative percentage of light patterns, read from a nocturnal satellite image with the same cell size. This unique utilisation showed a strong correlation with a Human Development Index, electrification rates and poverty rates, making this new index based on Lorenz curve an inexpensive and spatially explicit measure of human development.

The Lorenz Curve has recently been applied in the transport discipline. Juan et al. (2008) applied the concept to analyse the fairness of congestion pricing among road users. Similar analyses were done by Gordon and Peters (2011) looking into the impact of toll revenue on road users and by Nahmias-Biran et al. (2014), who measured the equity of transit fares. In all of these cases the Lorenz Curve compared the cumulative percentage of road or transit users with the cumulative percentage of the price (congestion pricing/ toll revenue/ transit fare). Delbosc and Currie (2011) were an exception, measuring the distribution of the provision of public transport rather than the distribution of price.

Most transport oriented studies were utilising the Lorenz curve formula similar to the original income application, when using socio-economic data variables and monetary values. Other spatial studies were more innovative, showing the possibility to analyse two sets of any ordinal, interval or ratio data and visualise their cumulative frequency as a curve (Diaz-Delgado, 2001). To date no applications of the Lorenz Curve have explored the operational performance of transport links.

This paper presents the use of mathematical principle of Lorenz Curve as a new concept to explore the spatial distribution of operational performance of public transport links on Melbourne metropolitan tram network. It explores how this new measure can identify potential locations to target public transport priority treatments.

3. Methodology

3.1. Operational performance analysis based on Lorenz Curve concept

In the example below it is theorised that operational performance can be examined on transit links between stops (Y axis) relative to the ridership that uses these links (X axis). A range of operational performance measures were explored. Link speed (represented by an average speed of a particular link between two stops) and passenger volume (in between the same two stops) were established as measurable parameters of operational performance for this approach. The Lorenz Curve was applied to explore the distribution of a total passenger travel volume occurring on each link (X axis) against the distribution of link speed on each link (Y axis). All values relate to a single link between two stops.

This theoretical approach provides an interpretation of the relative distribution of operational performance, illustrated in Figure 2:

- The line bottom left, point A shows the share of travellers with poorer operational performance (link speed). In this case 50% of travel volume incurs the 10% of slowest average speeds per link.
- The line top right, point B shows the share of total link travel volume which has the best operational performance; in this case 10% of all passengers are experiencing good operational performance representing 38% of fastest link speeds. These travellers have good operational travel performance relative to others.
- It is also hypothesised that this analysis might represent a means of targeting investment in performance optimisation. The theoretical analysis in Figure 2 highlights links with poor performance and high relative passenger volume (bottom left, A). These links might then be isolated visually and targeted for priority treatments.

In addition, the Gini Coefficient can be used to represent the distribution of the operational performance of travel on links using a single numeric measure. This might be adopted as a comparative performance metric to compare different routes and network performance.

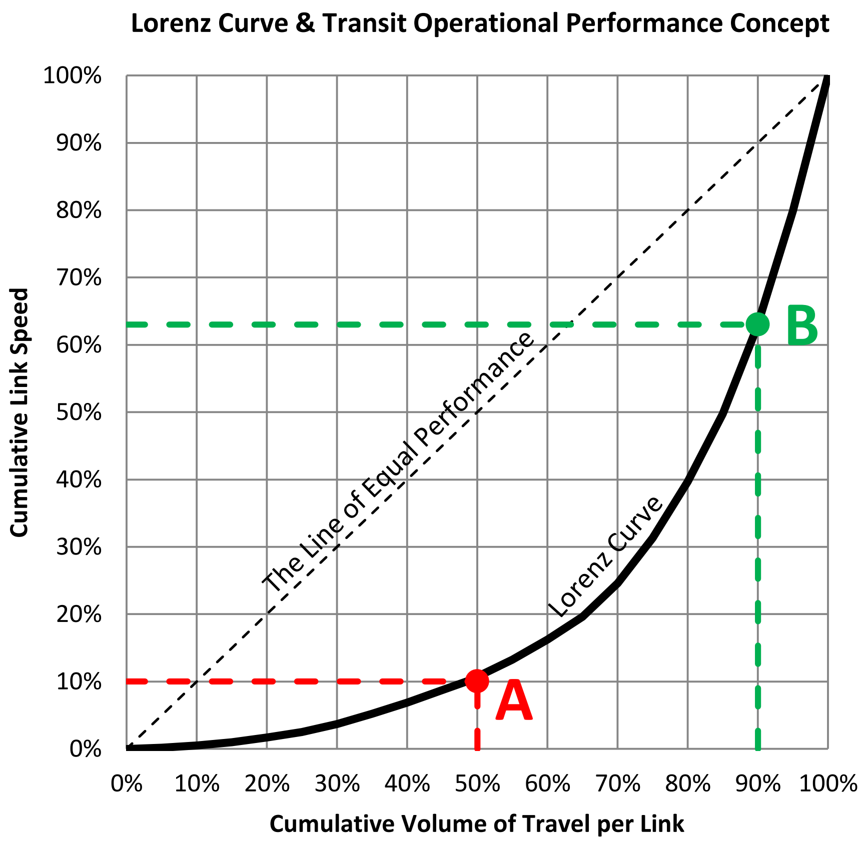


Figure 2. Lorenz Curve as a new transit operational performance concept

This theoretical approach will now be applied in a case study context of tram routes in Melbourne.

3.2. Data description

Melbourne trams were chosen for this the case study application due to availability of appropriate data. Their routes vary in priority provision, which can be clearly distinguished on the road. The routes 19, 55 and 96 were specifically chosen in the Tram Origin Destination Survey 2011 Report by Metlink (2012) to demonstrate the various passenger load profiles in the network. Week day average passenger load information of each link (axis X) was obtained from this report.

Link speed (axis Y) was calculated from scheduled travel time between major stops (links) and their distance dimensions rendered from GIS layer of Melbourne tram network. Scheduled time is available online by Public Transport Victoria (PTV, 2015).

Table 1 describes the selected 3 tram routes:

Table 1: Tram routes main characteristics

Tram Route	Total Volume of Passengers (per average week day)	Length (km)	Min Link Speed (km/h)	Max Link Speed (km/h)	Average Link Speed (km/h)	Segregated Tram right of way provided (%)
19	58,750	12.9	12.2	25.1	17.5	70%
55	46,150	15.9	2.8	31.1	19.9	59%
96	129,550	17.5	4.2	39.8	18.6	73%
Sum	234,450	46.3				

Tram route 19 carries 58,750 passengers per day. Some 70% of the route has segregated rights of way. The link speed is the most consistent along the route, but the average speed is the lowest of the routes analysed (17.5 km/h). Tram route 55 has the lowest daily passenger load (46,150) and the highest average link speed (19.9 km/h). Some 59% of its length has exclusive tram right of way. This is the lowest share of the 3 routes studied. Route 96 is the busiest and longest route studied, also with the highest percentage of segregated tram priority zones (73%). Hence it has the highest average link speeds of the 3 routes studied (39.8 km/h).

The spatial location of the routes and their relative link load passenger volumes are shown on the map in Figure 3 (left). Figure 3 (right) illustrates the average link speeds between major stops and where segregated tram rights of way are provided. These graphics illustrate the spatial distribution of demand and operational performance metrics. In general demand is higher closer to inner CBD sections but this is also generally where operational performance is worse. In general sections with segregated rights of way have better operational performance but there are some exceptions to this rule, notably in inner CBD sections where passenger loadings are also high.

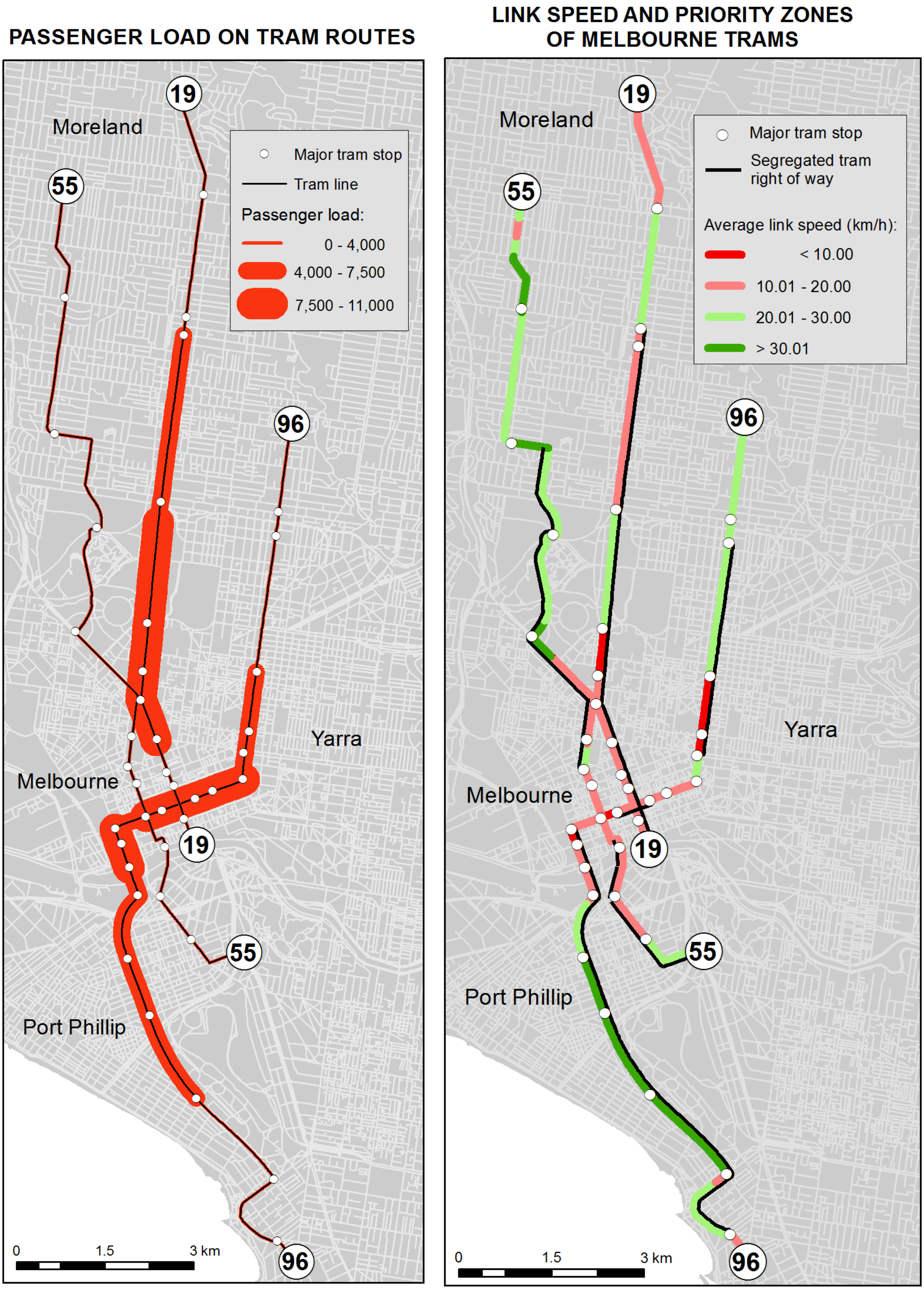


Figure 3. Comparative Map of Passenger Load and Link Speed/Segregated Rights of Way on Tram Routes.

3.3. Operation performance of Melbourne tram links

The proposed Lorenz Curve concept was applied to the Melbourne tram network data described above. Two approaches to the investigation were considered:

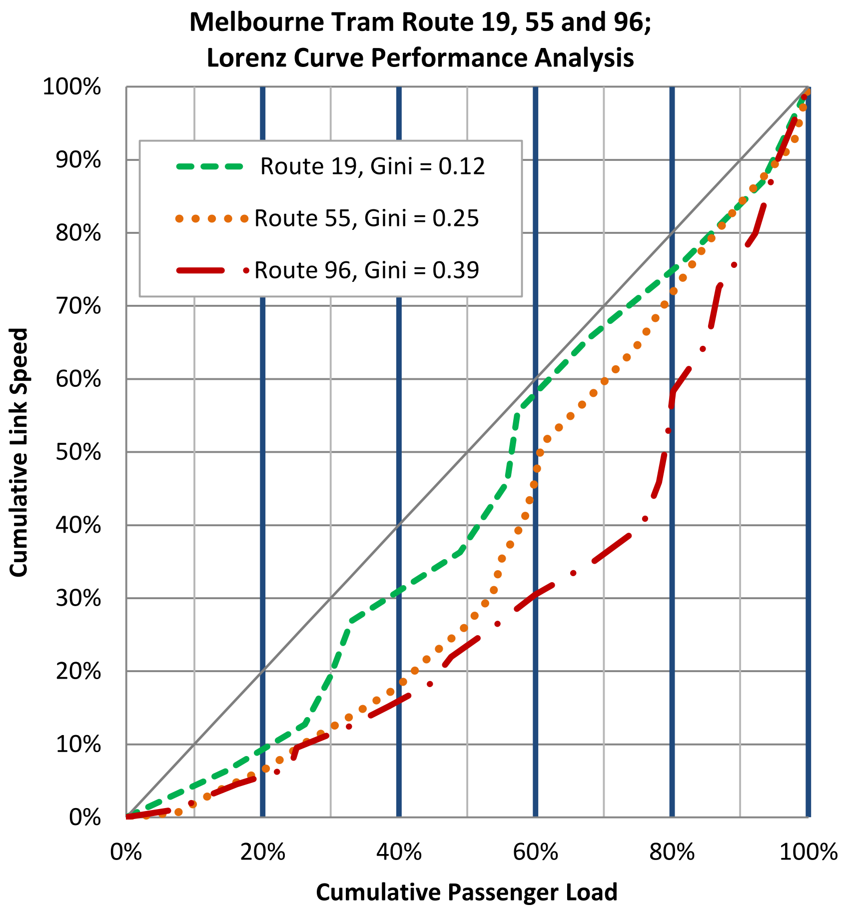
- Route based – on route sections between major stops
- Network based – on the network as a whole comprising the 3 selected tram routes

The aim was to explore the distribution of link operational performance and relative link passenger loading. The hypothesis was that the Lorenz Curve concept might enable a better understanding of the operational performance of transit travel and ridership volumes on links.

4. Results

4.1. Route based analysis

Figure 4 shows the results of the Lorenz Curve analysis of tram routes 19, 55 and 96. Chart on the left shows the cumulative distribution of link speed and link loading plus Gini coefficients computed for each resulting curve. The graph on the right shows the absolute values of link speeds by link for the same data.



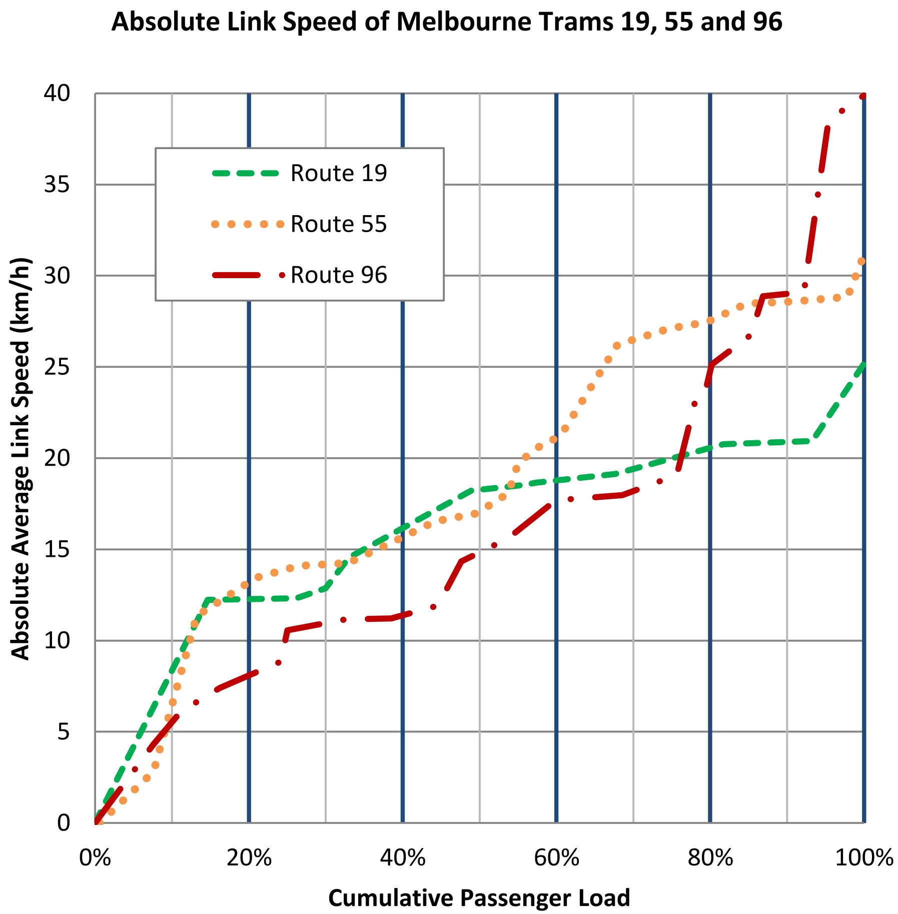


Figure 4. Melbourne tram routes 19, 55 and 96. Lorenz Curve based measurement of relative and absolute Scheduled Link Speed

Results illustrate that:

- There is a significant difference between selected tram routes, both in relative and absolute link speeds and the distribution of passengers using these links.
- These differences are confirmed by varying Gini coefficients (0.12 to 0.25).
- Tram route 96 shows the greatest inequality in average link speed performance by passenger load. The Gini Coefficient of route 96 is 0.39, which verifies an unequal distribution. The absolute values of link speed show the biggest difference. Some 20% of passengers are exposed to the slowest link speeds (less than 8km/h) even slower than for routes 19 and 55. The last 10% of travellers experience the fastest performance available on the route (and the network of the 3 routes as a whole); 30 – 40 km/h.
- Route 19 appears to have the most equal distribution of passenger link load by link speed, (Gini coefficient 0.12). The majority of passengers of route 19 experience similar link speeds between 13km/h and 23 km/h
- Tram route 55 is somewhat unequal (Gini coefficient 0.25), with performance and the distribution of speeds being similar to route 19.

What is interesting about this distribution is that route 96 and 19 have a similar number of sections of tram priority, yet 96 has a far more unequal distribution. Greater inequality for route 96 might partly be explained by higher performance in terms of passenger load and higher absolute average speed for some sections of its route compared to routes 19 and 55. This outcome matches the variation in route general characteristics – high passenger volume, changing throughout the route and a larger range between minimum and maximum link speed. This is also illustrated on the chart showing absolute link speed values. Route 19 has relatively low passenger loads that linearly decrease with the distance from Melbourne CBD, therefore it appears to have a more equal distribution of passenger load and link speed. Similar results were observed for route 55, due to the significantly lower passenger volume.

This analysis only considers the performance of links relative to their respective routes. However this is a somewhat limited analysis as some routes have higher ridership than others. In order to determine where to target priority measures across a network, a network-wide perspective should be considered. The next section undertakes this.

4.2 Network based analysis

A Lorenz Curve based analysis can also consider performance from the network perspective. This approach takes into account the varying loads and speeds across all routes in one single network-wide calculation. Cumulative results then indicate the relative dispersion of operational performance of the whole network. Results of the network-wide analysis are shown in Figure 5. In this analysis both the relative and absolute speeds are presented.

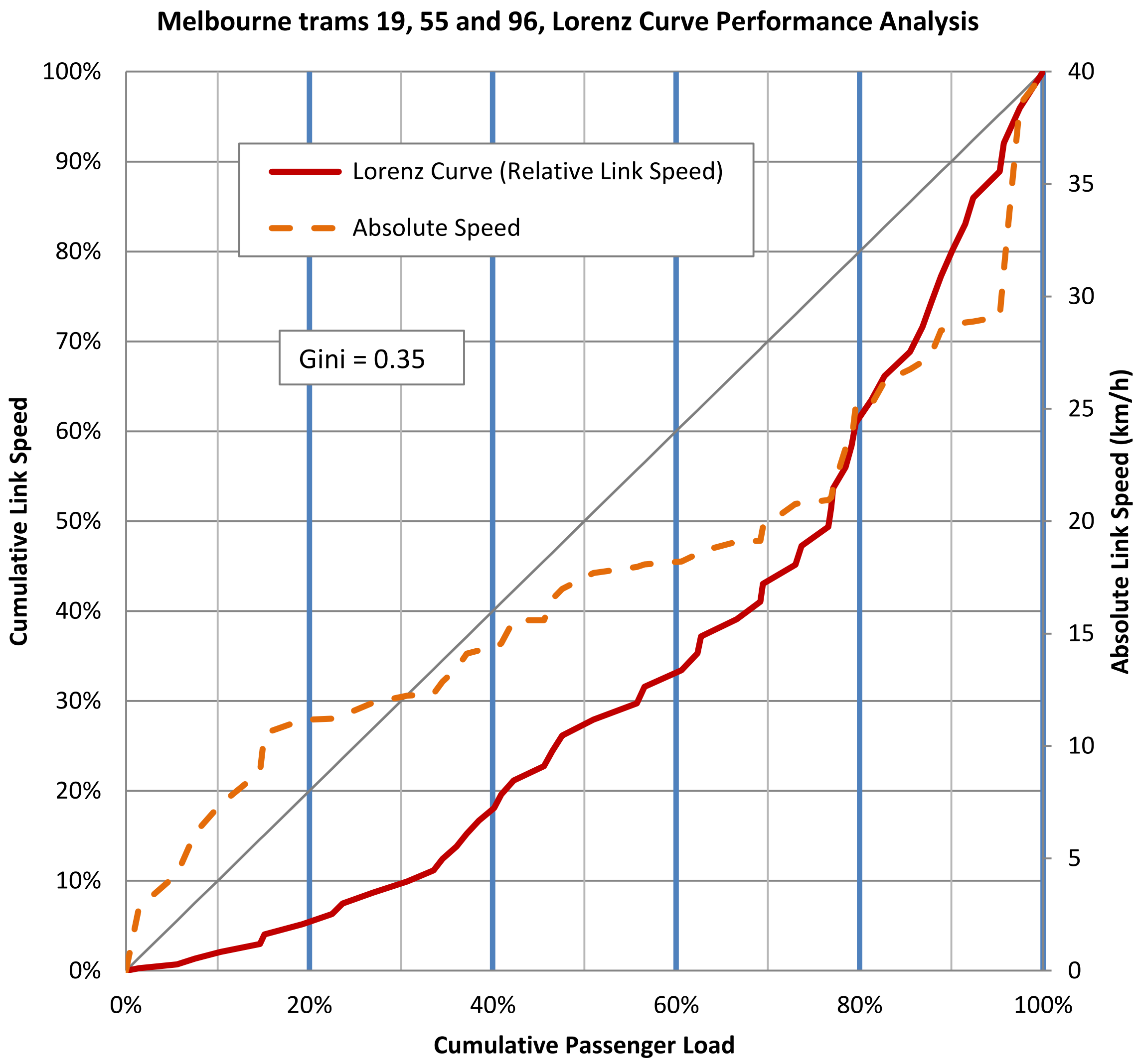


Figure 5: Melbourne trams 19, 55 and 96 network, Lorenz Curve

This indicates that:

- Overall performance of the network is uneven as confirmed by the larger Gini coefficient: 0.35.
- There is a great inequality in performance for the lowest 20% of passengers; these are exposed to the slowest 5% of link speeds (of less than 3 km/h).
- On the other hand last 20% travellers are experiencing almost 40% of fastest relative link speed (more than 24 km/h). The top 5% of passengers experience speeds up to 40km/h.

Figure 6 displays the spatial distribution of the performance quintiles from Figure 5**Error! Reference source not found.**.

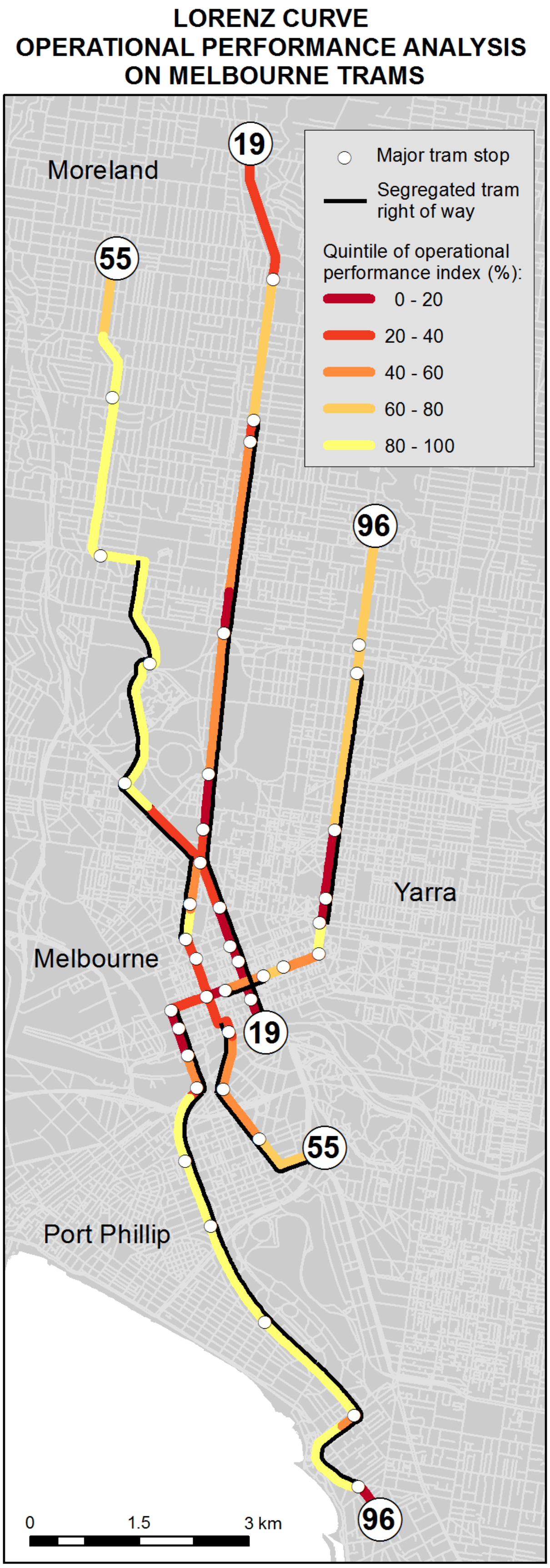


Figure 6. Map of Lorenz Curve analysis on tram operational performance

Figure 6 clearly indicates that sections of the route within and close to CBD are the ones with the poorest performance (shaded dark red) in terms of link speed and travel volume (lowest 20th percentile in Figure 5). Interestingly in each of these cases, tram routes also have a segregated right of way. This implies a well-targeted provision of right of way segregation to locations of poor performance and high ridership volume. It also implies a need for greater application of priority treatments to further improve operational performance at these locations e.g. provision of signal priority or measures to reduce boarding and dwell time.

There is one area on Figure 6 where the lowest quintile of performance is illustrated which do not have right of way segregation; the southern-most section of route 96 (along Acland Street in St Kilda). This is a narrow road section with on-street parking and much pedestrian activity. Interestingly although this route section has no right of way segregation it is well known for tram delays and currently being considered for pedestrianisation. This analysis seems to support this case as a high priority for treatment.

Interestingly Figure 6 also shows that most of the sections where right of way segregation is already implemented are performing at the highest 20th percentile level (shaded light yellow in Figure 6).

Figure 6 also illustrates locations where a segregated right of way is not yet provided but where a ‘second order’ level of need exists; here (shaded dark orange) is the region of the second quintile of performance (20-40) on CBD sections of routes 96 (Burke Street) and route 55 (William Street).

5. Discussion and Conclusions

This paper presents a new approach to understand the operational performance of public transport links relative to passenger load on links. This approach can be used to target priority treatments to improve operational performance based on link speeds and link passenger ridership. A review of previous research and practice established that current methods to establish where priority treatments should be located were either rather simplistic, therefore less effective or too complex and hence difficult to apply in practice. A new way of analysing the operational performance of transit links using Lorenz Curves is presented and applied to 3 tram routes in Melbourne. Analysis demonstrates the results of route based analysis and also a network wide analysis. Of the two, the network based approach is probably the most useful in that it easily identifies specific links with higher passenger volumes but lower operational performance. These are clear targets for preferential priority treatments. The route based analysis is interesting but of less value to targeting preferential treatments. It did however illustrate some interesting patterns in performance between routes.

Overall the findings suggest a promising advanced technique which can highlight links demanding attention, locating parts of the network with lower performance but high passenger volume. The Lorenz curve tool has proven an objective measure in network based analysis, showing the locations in need of improvement, with high volume of passengers experiencing the lowest performance.

There are number of areas for future research suggested by the analysis. The selection of appropriate operational performance measures is one area for further analysis; link speed was adopted in this paper however in theory reliability based measures could also be explored. In the literature review, the Aecom (2006) study explored route performance between peak (congested) and off peak (free flowing) speeds on links. This might be an interesting area for further exploration in the Lorenz curve analysis.

Analysis might also be applied to generate road traffic based analysis which is an area the researchers are exploring next. In addition the Lorenz Curve based analysis, as described could be adapted to forecasting performance and ridership in a ‘futures’ scenario.

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