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Are network planning guidelines based on equal access equitable?

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ABSTRACT:	Public transport network planning principles include simplicity, legibility, frequency and spatial coverage. These principles are normally translated into a series of "Guidelines" setting out the specific standards for network design within a jurisdiction. In practice such guidelines usually concentrate on creating a bus network or on the role of buses within a multimodal network as rail-based routes are regarded as fixed in location and separate planning processes are typically used to design rail frequencies and stopping patterns. The outcome of the network planning gives rise to trade-offs between the economic and institutional environments and is conditioned by historical legacy. Bus routes often continue because historically this is where they operated. This paper offers a case study based on Sydney, Australia where the network planning guidelines still place emphasis on equality of spatial coverage despite moving towards a more 'integrated' approach to network planning. This paper identifies that guidelines focusing on equal spatial coverage may inadvertently promote inequity through not taking account of the difficulties (and therefore higher cost) of serving challenging topographical areas. This paper therefore examines the equity impacts of the implementation of service planning guidelines based on equal spatial coverage using Sydney as a case study. Criteria relating to equity will be established which are then measured using bus supply data, journey to work and socio-economic data. The conclusions of the paper are a contribution to network planning implementation with many cities both in Australia and elsewhere implementing similar guidelines to Sydney.

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Introduction

Traditional network or service planning guidelines (SPGs) emphasise the importance of providing a minimum level of service across the network, this is often expressed in terms of ensuring that a particular percentage of the population lives within a certain distance of a bus service offering a minimum level of service. For instance the Sydney, New South Wales (NSW), Australia guidelines, before 2006, were that 95 percent of households were to be within 400 metres of a public transport route. The contrasting approach, which has been labelled 'integrated' network planning in Sydney [1], places emphasis on providing service to areas of greatest need and greatest patronage potential.

Given limited budgets, guidelines that emphasise geographical coverage must lead to networks that do not place as much emphasis on directing services to areas of most need (e.g. those people who lack access to a private car or those people who would most benefit from supporting access to jobs, education and services) or areas where demand might be highest [2, 3].

Modern SPGs appear to be introducing more flexibility than their predecessors by placing less emphasis on the requirements for spreading service levels across the service area and more emphasis on providing services designed to attract patronage from the private car. By way of example, the guidelines for Sydney have evolved over the last 11 years towards an integrated model. The guidelines were relaxed in 2006 such that '90 percent of households should be within 400 metres (as the crow flies)' of a public transport route during the daytime. The latest guidelines [1] have, on the one hand, strengthened this so that service should now be provided such that 90 percent of households are within 400 metres of a public transport stop during the day but, on the other hand, has placed less importance on achieving this goal. However, the question remains as to what impact these guidelines actually have on the provision of service across the network and whether or not they lead to an equitable distribution of resources.

Using the case study of Sydney this paper uses the PTAL methodology [4] to assess the extent to which the guidelines are creating a network that simply spreads service levels across the urban area or provides higher services to areas of either greatest need or greatest demand. The paper is structured as follows, Section 2 discusses the modern and traditional approaches to service planning guidelines and discusses how transport equity can be measured and assessed. Section 3 summarises the PTAL methodology for measuring the level of supply of public transport services, discusses how to measure the socio-demographic need for public transport and the patronage potential of an area. Section 3 also introduces the methodology used in this paper to compare service levels against the measures of need and potential patronage for public transport. Section 4 looks at the results of the modelling exercise in terms of a number of maps of supply, need and patronage potential and in a number of regression models linking the three factors. Section 5 discusses what lessons can be learnt from the analysis of this paper and the implications for policy.

Literature Review

Service Planning Guidelines

Network or service planning guidelines (SPGs) exist in most urban areas where governments have responsibilities for, at a minimum, the subsidy of public transport services [5-10]. In Sydney the SPGs are provided in this guidelines [11] which replaced the previous guidelines that were contained in [12].

Under the Strategic-Tactical-Operational (STO) framework [13, 14], Service planning guidelines (SPGs) are created at the tactical level to provide instructions to public transport network and route planners on how to implement the overarching strategy of the transport authority. Typically, this overall strategy will be to either match services to demand or to match services to needs or some combination of the two. The two types of networks are discussed in more detail in Nielsen, et al. [2] and form the basis of the patronage network versus coverage network distinction used by practitioners such as Walker [3]. In all cases, guidelines will also target value for money in terms of not providing subsidised service above that required to meet the other goals.

No matter what objectives the SPGs aim to achieve, all must account for the drivers of patronage: Fares, availability of alternatives and service attributes of both the public transport mode and alternatives. In the examples of SPGs cited above, fares policy is outside the remit of the network planners who are then only concerned with service attributes. The public transport service attributes that are within the control of the planners have been grouped by Daniels and Mulley [15] into four categories: Coverage, frequency (see Abrantes and Wardman [16] for a discussion of the importance of this attribute), legibility (see Wardman 2001 [17] and Paulley et al. [18]) and directness (see Jansson [19] and Ljungber [20]).

Fixed budgets forming a cap on subsidies require trade-offs between the four categories of service attributes in planning networks. A network of frequent and direct routes creates legibility and supports patronage growth but at the expense of network coverage (see Nielsen, et al. [2]). As direct routes tend to require more walking, a network plan with the objective of providing a safety net of service for those without access to a private car will tend to favour higher coverage at the expense of frequency and directness.

Equity

Equity as a concept has been more often associated with social justice and fairness and discussed from a philosophical perspective. In the transport sector, it is recognised that transport policy gives rise to winners and losers [21, 22] but the discussion of equity from a formal economic perspective (in terms of vertical and horizontal equity) is lacking in the literature. There are some notable exceptions, for example, Peters and Kramer [23] or Welch [24] but these are used for the evaluation of particular policies, for example public transport subsidies [23] and public transport and

affordable housing [24]. The spatial nature of transport provision has only been considered by one recent paper [25, 26].

In policy frameworks it is perhaps the norm to consider first the efficiency outcomes of policy and then to consider if adjustments need to be made to meet equity concerns. In the transport domain, the way in which the spatial dimension is often ignored means that policy might inadvertently introduce inequity through a lack of attention to this dimension. Discussions of equity normally distinguish between horizontal and vertical equity. Horizontal equity requires the equal treatment of like persons, e.g. the user pays approach provides horizontal equity in relation to outcomes by charging of the same bus fare to all users for the same consumption of service. Vertical equity requires fairness in the distribution of wealth amongst different income groups and is often the motivation behind the implementation of new transport infrastructure, although the cost benefit evaluation procedure, being based on the Kaldor-Hicks criterion [27], does not require that equity considerations are central to the decision (even if there are significant equity implications). How to address this problem has been the concern of transport policy for some time and is well articulated in Thomopoulos et al [28]. In terms of public transport access, vertical equity is often assumed by the simple statement of giving equal opportunity to access but this simple definition ignores the spatial component.

The definitions of horizontal and vertical equity above suggest that determining horizontal equity is intrinsically easier than evaluating the degree of vertical equity when the spatial dimension is taken into account. Accessibility studies, such as accessibility planning in the UK, have become widespread as a way of measuring vertical equity, especially for the contribution that public transport, or transport more generally, can make for the transport disadvantaged [29] but there is scepticism as to how successful approaches up to now have been in providing solutions [30]. The evidence that exists suggests that more of a multidimensional approach needs to be taken to the question of equity and this is the motivation of this paper.

This paper is concerned with an analysis of the 'fairness' in the implementation of the network planning guidelines, using Sydney as a case-study. As detailed above, the network planning guidelines aim to offer public transport which emphasise equal spatial access to citizens. Also, guidelines for Sydney are similar to those implemented in many of the big cities around the world. However, the difference for Sydney is that the intent to have an equal spatial distribution of public transport might have different equity impacts to other cities because of the unique topographical conditions of Sydney and the distribution of the population with different socio-demographics. In all cities that promote equal spatial access for public transport, it is possible that unfairness is introduced through inadequate consideration being given to this spatial dimension.

This paper addresses the equity issue in a number of different ways. First, by considering whether there is a mismatch between demand and supply using maps of demand drivers and

accessibility of supply. This is not straightforward since a single measure of supply which characterises the accessibility of public transport supply needs to take account of its location in space and its service quality: this paper uses the Public Transport Accessibility Level (PTAL), originally developed by the London Borough of Hammersmith and Fulham and later adopted by Transport for London as their standard measurement of accessibility. This measurement recognises the multidimensional nature of transport supply focussed at the bus stop level. For this paper we have calculated the level of public transport supply at the meshblock level which is a finer level of geographical detail than Delbosc and Currie [31] who used the Census Collection District. Our method is capable of providing a better estimate of accessibility.

Second, building on the discussion on mismatch the paper presents a more formal modelling approach to this question to allow the simultaneous recognition of a number of variables, including those relating to spatial difference, to identify specific spatial areas where the network planning paradigm of equal spatial access might give rise to equity concerns.

Methodology and Data

This section describes the method and data used to investigate the three research questions identified in the previous section. This section starts by discussing the level of aggregation of the data and the definition and calculation of the PTAL, this is followed by the methodology for the descriptive analysis, the methodology underpinning the modelling and the descriptive statistics for the data.

PTAL as a measure of supply and the level of aggregation

The spatial identification of supply is undertaken by a Public Transport Accessibility Level (PTAL) analysis undertaken for the Sydney Urban Centre (UC). The evidence for potential drivers of demand is taken from various Census variables at the SA1 geography, the smallest level available. SA1s average a population of 400 persons with a range of 200 to 800 [32] and a UC is defined [33] as a "cluster of contiguous SA1s with an aggregate population exceeding 1,000 persons contained within the SA1s that are of 'urban character'". Urban character here relates to specific population density requirements. Some of the comparisons in this paper require the PTALs to be aggregated up to the SA1 level.

Public Transport Accessibility Level (PTAL) is a measure of the accessibility of a point of interest (POI) to the public transport network [4]. The PTAL methodology defines accessibility in terms of the time taken to walk to a public transport access point (i.e. bus stop or railway station), the average waiting time for a public transport service at that access point and the reliability of the mode. All access points within a certain walking distance of the POI (or meshblock for the purposes of this paper) are included in the calculation but only the nearest access point for each route is included.

The Total Access Time (TAT) from a POI to a particular access point is calculated as the sum of walking time, average waiting time and the mode reliability penalty. This is converted to an

Equivalent Doorstop Frequency (EDF) using the formula EDF = 30/TAT. The sum of the EDFs for each route give the PTAL for that point. Public transport access at a particular point can then be categorised according to the value of the PTAL index and is classified as being very poor, poor, moderate, good, very good or excellent.

Within NSW the walk speed is assumed to be 4 km/h with maximum walk distances of 400m for bus and 800m for rail, ferry and light rail. Reliability penalties in NSW are set to a penalty of 30 seconds for Transitway and Metrobus routes, rail and light rail, 157 seconds for other bus routes and 88 seconds for ferry.

The PTAL methodology can be criticised for applying the same weighting to walking time, waiting time and unexpected waiting time when users display different valuations of time for these activities. Furthermore, the methodology ignores differences in the numbers and qualities of the destinations serviced by the available routes, differences in the built environment (e.g. availability of footpaths), differences in access modes (cycling or driving rather than walking) and assumes that all people share the same walking speed, ability or willingness to walk to public transport access points. However since being developed in Greater London, the methodology has been applied to other cities both by researchers (e.g. Wu and Hine [34] for Belfast, Northern Ireland and Kamruzzaman et al. [35] for Brisbane, Australia) and by network planners [7].

Descriptive analysis using maps

For the descriptive part of this paper maps of supply are compared with maps of the potential drivers of demand so as to look at the outcome of applying the service planning guidelines in terms of equal service access for the most vulnerable members of the community – the aged, households with low income and the indigenous population. This is the beginning of the horizontal equity investigation in which access to supply, based on equal service access, ought not discriminate between different sectors of the population.

Methodology for Modelling

Ordinary least squares (OLS) regression was employed with public transport supply (PTAL) as the dependent variable explained in terms of demand drivers and need drivers as independent variables. The demand drivers include population density, employment density, elevation, number of jobs within 30 minutes by public transport and by car and distance to inland water, the harbour, beach and coast measured from the centroid of the SA1 polygon The need drivers include variables measuring the percentage of the population of lower income, of older age or indigenous plus Socio-Economic Indexes for Areas (SEIFA) all calculated at the SA1 level and taken from the 2011 census. Disability and unemployment rates were considered but found not to be significant in the models. Descriptive statistics for all variables are presented in Table 1.

Table 1: Descriptive analysis of the variables

Variable	Obs	Mean	Std. Dev.	Min	Max
PTAL at peak hours	9093	35.93	40.34	0.34	555.36
PTAL at off-peak hours	9065	28.69	37.66	0.34	513.61
Population density	9154	43.54	48.44	0.00	1677.18
Employment density	9154	18.31	91.76	0.01	2955.72
Maximum elevation	9154	74.09	54.50	0.00	489.00
Distance to inland water by public transport	9154	77.65	25.47	2.60	153.48
Distance to beach by public transport	9154	50.76	27.69	0.20	118.86
% Low-income population	9154	21%	6%	0%	73%
% Indigenous population	9154	1%	2%	0%	93%
% Population aged over 75	9154	6%	6%	0%	89%
SEIFA	9154	1029	107	456	1234

The distribution of PTAL values are skewed toward zero so a logarithm transformation of PTAL data was used to provide compliance with OLS assumptions. Separate models for the peak hour (7-8 am) and off-peak hour (10-11 am) were estimated with the best models selected using adjusted R2. Some highly correlated variables were not used to avoid multicollinearity.

Results

The evidence for the question as to whether there is a mismatch between supply and demand is addressed descriptively in Section 4.1 where maps of public transport accessibility or supply, as described by PTALs, are compared with potential drivers of demand.

Spatial matching of Supply and Demand

Figure 1 shows two maps. These maps are indicative of public transport accessibility or supply, as determined by the PTAL for a peak hour period on the top and an off-peak hour period on the bottom. The blue areas are low or very poor accessibility whereas the red areas are high or very good accessibility to public transport. Comparing these two maps with each other shows the anticipated reduction in accessibility in the off-peak period as a reduction in areas of red colour.

To look at the interaction of supply and demand, further maps are provided as Figures 2 to 4. These maps show areas with a higher or lower PTAL (as measure of supply), percentage of older people, low income people or indigenous people (all measures of potential demand). For each variable, the median level for all Sydney is used to distinguish areas of higher or lower values. The maps indicate high demand, high supply areas (green areas); high supply, low demand areas (red areas); low supply, high demand areas (blue areas) and low supply, low demand areas (grey areas). Each map is provided for the peak and off-peak periods. If there was no spatial mismatch, the maps

would be predominantly green or grey. It is clear that there is substantial variation between the maps for each of the populations considered.

Figure 2 concerns income and the blue areas are of most concern. These are concentrated in the west and at the periphery of Sydney and are areas where there is low supply but high percentages of low income population. Low income people in this area may well be constrained for economic inclusion through access to public transport for journey to work purposes. There are also considerable areas of red which suggest a greater provision in terms of supply than might be warranted in terms of serving a low income population which is the population most likely to be disadvantaged. However there are also considerable areas of green which shows a good match between supply and the potential demand from the low income population. The pattern is similar for both peak and off-peak maps with the proportion of blue areas being greater in the off-peak period.

Figure 3 has the same basic layout as Figure 2 but here the population of interest is older people, defined as aged 75 or more. This map shows significant areas of blue on both the peak and the off-peak maps. Of these, the off-peak map is the more concerning since older people are more likely to travel in this period, being unconstrained by the need to attend a workplace. Also, as compared to Figure 2, there are considerably less areas of green where the demand and supply might be considered in balance and red areas where there is good supply but a low percentage of older people.

Figure 4 concerns the indigenous population. The indigenous population is more likely to be of lower income, more often unemployed and with higher risk of social exclusion. It might be expected that these maps would show similarities with Figures 2 and 3. However, there is much more of a clear spatial mismatch here between the supply and areas of high indigenous population, particularly in the western parts of the metropolitan area. This mismatch is observed in both the peak and off-peak periods. However, these maps need to be treated with some caution since these maps relate to a small absolute number of people.

These figures show only some of the potential drivers of demand. However, these groups are typically thought of as disadvantaged so it is clear that there are causes for concern for horizontal equity. If all population groups had the same treatment through the network planning guidelines that have delivered the supply or accessibility to public transport, then we should see similar spatial matches or mismatches between all these maps.

However, this descriptive approach has only allowed for one variable at a time to be considered and the determination of supply, as with demand, is multi-dimensional. For this reason, a modelling approach is taken next to link the accessibility to public transport service to a number of quantitative factors simultaneously.
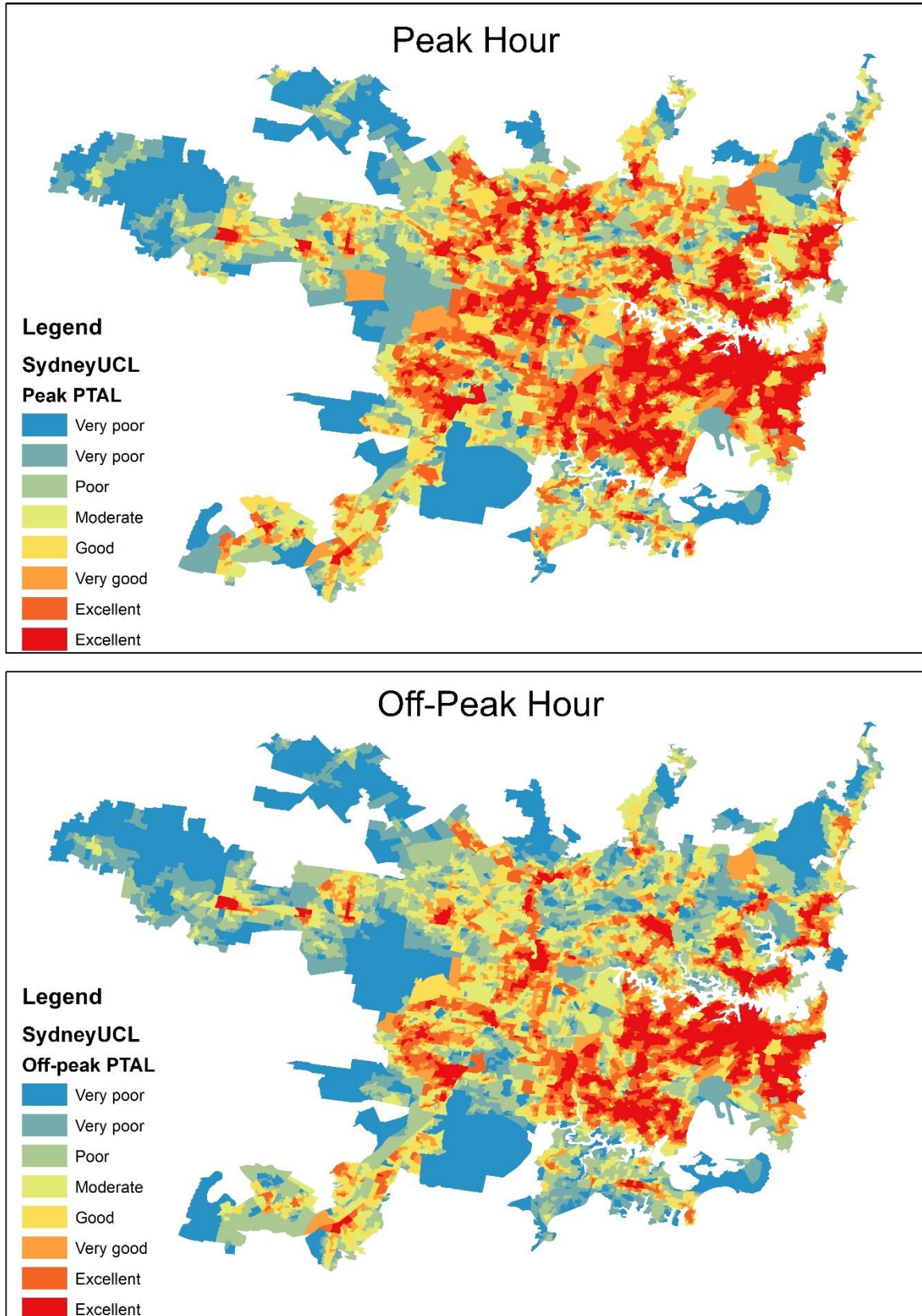
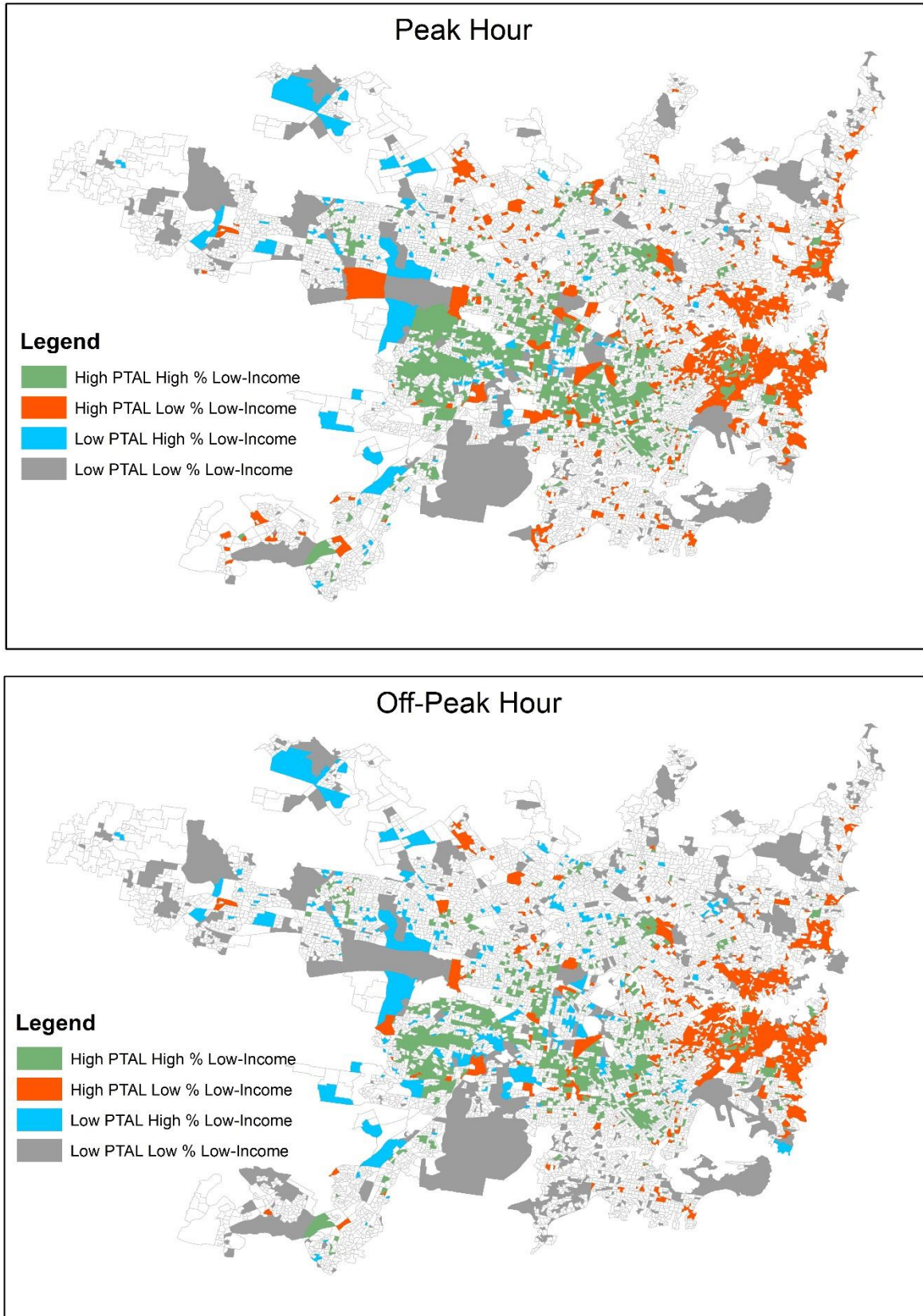*Figure 1: Peak and off-peak patterns of supply, based on PTALs.*

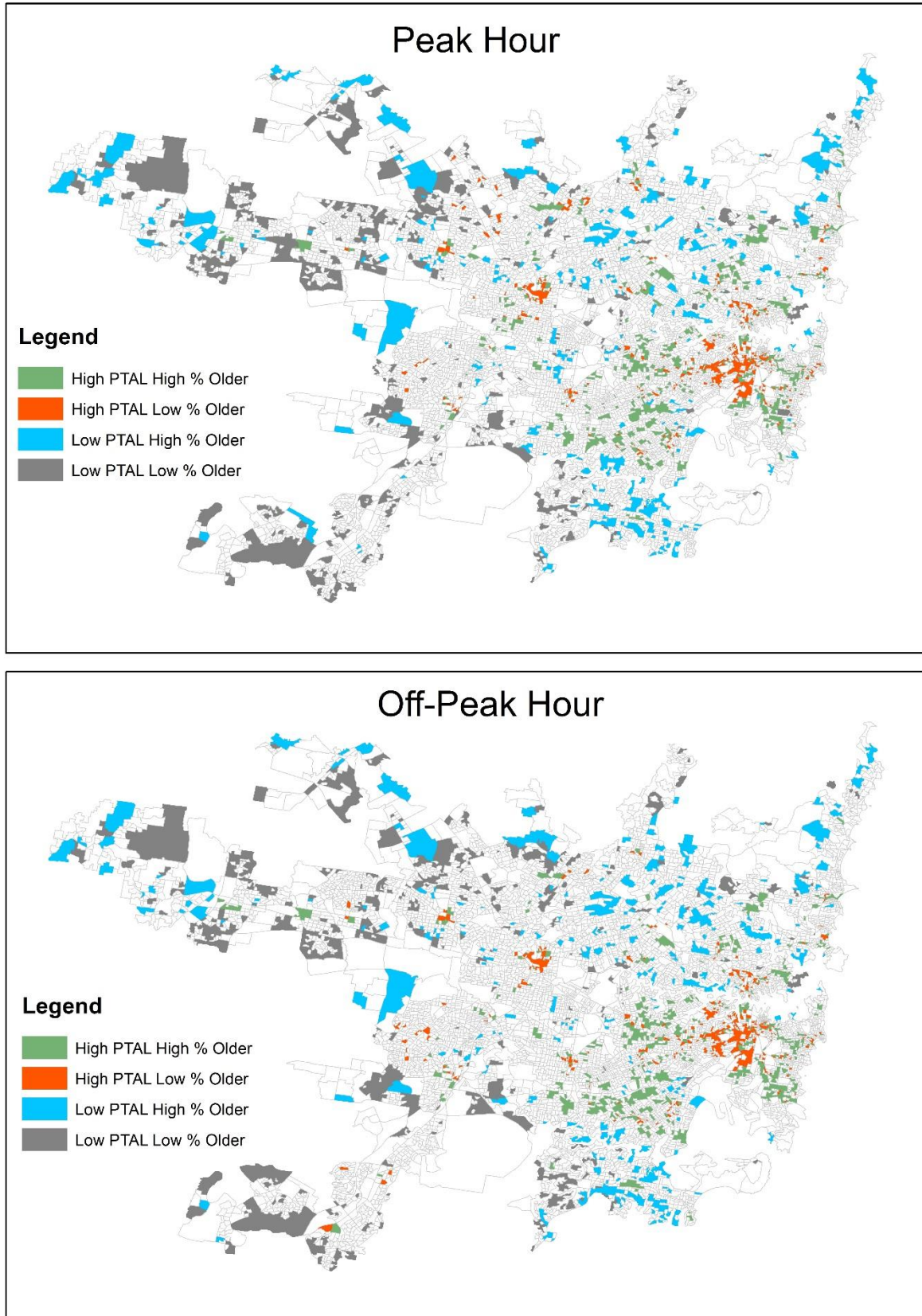*Figure 2: Mismatch between public transport supply/accessibility and lower income.*

Figure 3: Mismatch between public transport supply/accessibility and the older population.
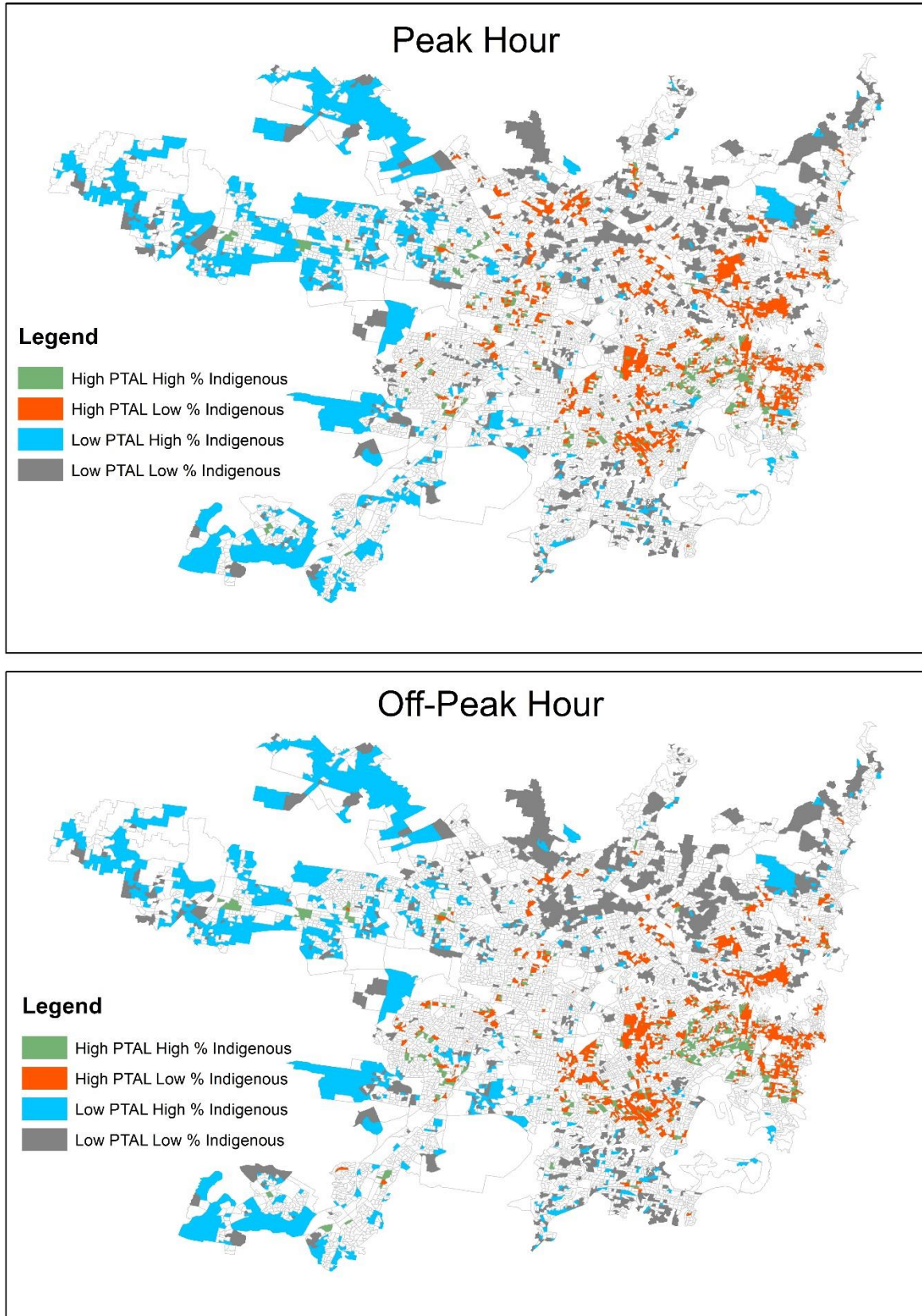
Figure 4: Mismatch between public transport supply/accessibility and the indigenous population.

Modelling Results

The model results for peak-hour and off-peak public transport supply (PTAL) are summarised in Table 2 with all independent variables significantly different from zero. Because of potential multicollinearity, variables were entered into each model in two steps. The first step included a composite measure of need drivers using the SEIFA index, while in the second step the more detailed measures of need drivers were included. Both the peak and off-peak models explained about 37 percent of the variance in the PTALs.

As expected, population density and employment density are the two strong demand drivers of public transport supply. Elevation was negatively associated with the PTAL, indicating that public transport supply decreased at areas with increased elevation, typically areas further from the coast. Interestingly, in the peak-hour model, the SEIFA was positively associated with PTAL, suggesting, everything else being held constant, socio-advantaged areas have better public transport supply. However, this relationship is reversed in the off-peak hour model. Both distance to inland water and distance to beach is negatively associated with the PTAL, indicating that public transport supply is better at areas close to inland water and beaches. Finally, the three variables measuring the need drivers, the percentage of indigenous population, percentage of low-income population, and percentage of older population, were all negatively associated with PTAL, indicating that the public transport supply is lower than expected for these demand drivers suggesting that supply is lower where public transport is most needed for both the peak and the off-peak hour.

Table 2: Model results.

Models for the peak hour with PTAL as the dependent variable				
	Coef.	P>t	Coef.	P>t
Population density	0.0060	0.000	0.0039	0.000
Employment density	0.0015	0.000	0.0014	0.000
Maximum elevation	-0.0034	0.000	-0.0024	0.000
SEIFA	0.0002	0.031	-0.0020	0.000
Distance to inland water by public transport			-0.0089	0.000
Distance to beach by public transport			-0.0096	0.000
Percentage of indigenous population			-3.9800	0.000
Percentage of low-income population			-1.0515	0.000
Percentage of older population			-0.3677	0.007
constant	2.9655	0.000	6.6917	0.000
Number of obs	9093		9093	
R-squared	0.2360		0.3650	
Adj R-squared	0.2350		0.3640	
Model for the off-peak hour with PTAL as the dependent variable				
	Coef.	P>t	Coef.	P>t
Population density	0.0071	0.000	0.0049	0.000
Employment density	0.0017	0.000	0.0015	0.000
Maximum elevation	-0.0045	0.000	-0.0032	0.000
SEIFA	-0.0006	0.000	-0.0029	0.000
Distance to inland water by public transport			-0.0076	0.000
Distance to beach by public transport			-0.0111	0.000
Percentage of indigenous population			-4.0433	0.000
Percentage of low-income population			-1.2319	0.000
Percentage of older population			-0.3479	0.028
constant	3.4363	0.000	7.3294	0.000
Number of obs	9065		9065	
R-squared	0.2710		0.3730	
Adj R-squared	0.2710		0.3720	

As the model is a semi-log functional form, the estimated coefficients may be interpreted as percentage change to the dependent variable. Table 2 shows that a change in the percentage of population has a very significant effect on the PTAL for both the peak and off-peak models (over 300

per cent and 400 percent respectively). However, whilst these percentages are big, a 1 per cent increase in the indigenous population would represent a doubling of the indigenous population (see Table 1). This does not mean that it is unimportant but that the impact of change of the independent variable needs to be understood in the context of the means of the variables.

Figure 5 shows the residual distribution of the peak hour model. This shows where the model is over and underestimating the match between supply, measured by PTAL, and the combined effect of all independent variables. The blue/green areas show where the level of supply is lower than might be expected from the model, whereas the orange/red is the opposite – where the level of supply is higher than might be expected from the model. This shows clearly greater lower supply at the periphery of the map but also clear red areas following the strategic corridors where the network planning has deliberately built up frequency.
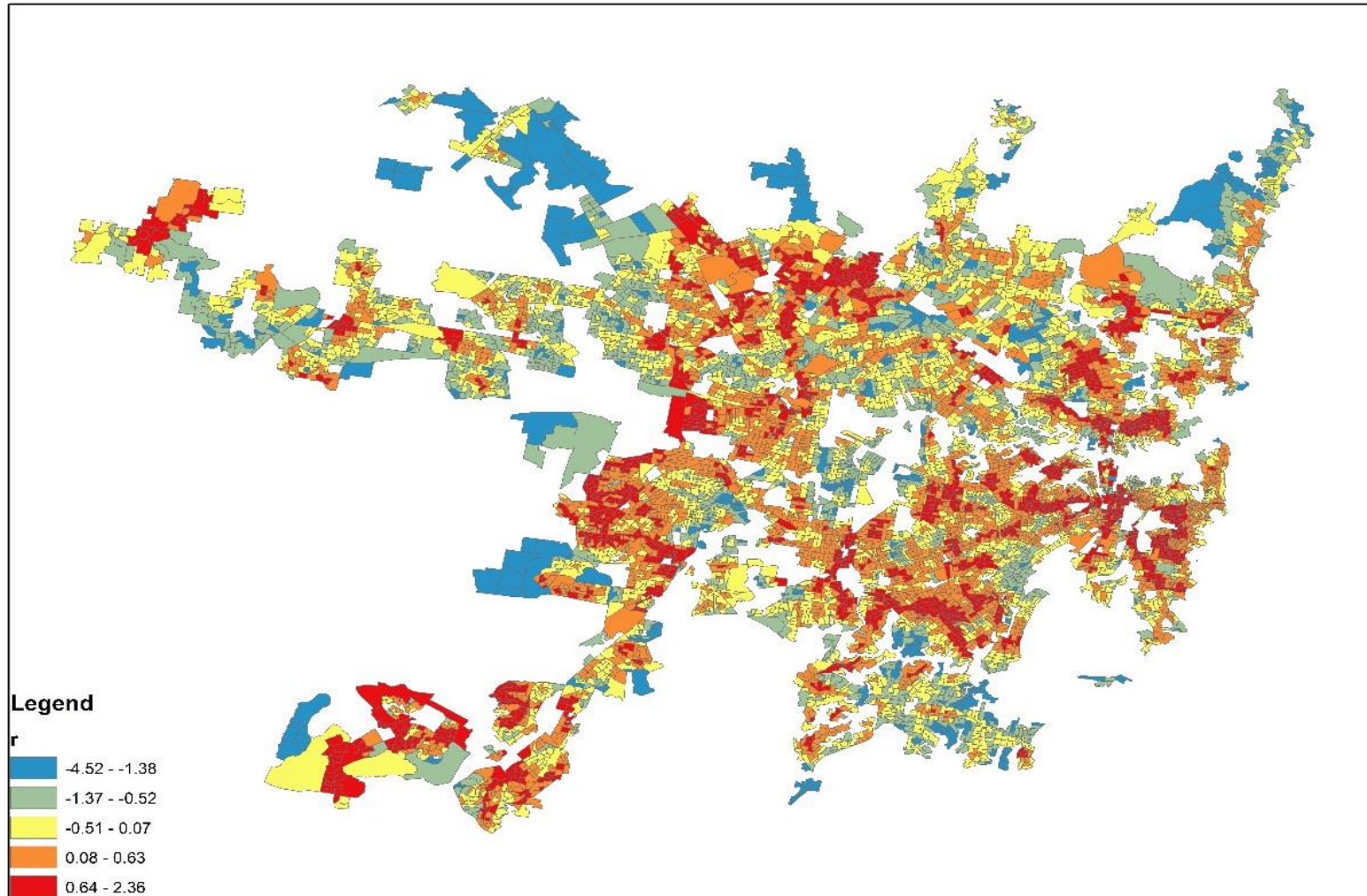
Figure 5: Residual distribution of peak-hour model

Conclusions

This paper examines the equity impacts of the implementation of service planning guidelines based on equal spatial coverage using Sydney as a case study. Modern planning guidelines appear to be introducing more flexibility than their predecessors in that whilst there is a preponderance of expectation that there should be equal coverage of service provision for citizens, this is increasingly tempered by the need to take account of demand.

This therefore appears to recognise the way in which equal coverage is not necessarily equitable. However, in the case of Sydney, the modelling shows that the relaxation of the equal coverage mantra appears to be relatively small with emphasis towards demand in the peak and emphasis towards coverage in the off-peak. This is consistent with Ho and Mulley (2014) which identified the contribution of new services in the Sydney network to linking regional centres and 'arms' of the radial heavy rail network. In the future, when the network proposed in Sydney's Bus Future plan (NSW Government 2013) is introduced, there may well be more emphasis placed on allowing patronage to drive the supply of services.

PTALs, as a measure of supply, have been shown to be consistent and effective. Whilst there is some criticism in the literature as to their use, their simplicity has allowed a good comparison to be made in the case study of Sydney. In the future, because PTAL is an internationally recognised measure, this study could be extended to compare Sydney with other global cities.

In terms of results, a comparison of PTALs with measures of low-income, indigenous and older populations showed some mis-match. However, the maps of this paper are univariate in measurement and, as the modelling shows and experience notes, network planning is more complicated than this. The modelling results, even using a simple framework, shows that the commuter is doing well in Sydney, as a result of the more integrated planning framework. This suggests a movement towards more vertical equity is possible.

Disadvantaged people are more likely to be captured passengers on public transport. Although income for the state is progressively raised, the equity analysis here suggests that greater public transport subsidies are going to areas of higher socio-economic means than areas of greater need. The evidence from Sydney suggests that network planning guidelines that attempt to spread public transport provision across an urban area have a tendency to undersupply both areas of concentrated need and areas of concentrated demand.

In the future, some better variable definitions e.g. replacing elevation by slope might inform more about the impact of topography on supply and also separate out the issues of being close to the coast from changes in elevation. Looking at more than one peak and off-peak hour period might also reveal variation not observed by only comparing two one hour periods. Including patronage data at the mesh block level, which is becoming available through the Opal smart card, would allow realised demand to be modelled and this could take account of the simultaneity of demand and supply.

The paper is also limited by a lack of consideration of the linkages between the funding of public transport services and the role of this in determining supply. For example, there are areas where there is a high service for a relatively affluent population but there is also a high take up of these services such that the farebox revenue would be considerably higher than average for the metropolitan area.

These conclusions are a contribution to network planning implementation with many cities both in Australia and elsewhere implementing similar guidelines to Sydney.

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