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Investigating the Transit-Orientation of Existing Urban Development Around Melbourne Trams Compared to Other Public Transport Modes

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Abstract

The travel demands of Melbourne's rapidly growing population cannot continue to be effectively supported by existing transport infrastructure. Transit-oriented development (TOD) is a planning strategy gaining local traction as a means of meeting the increasing demand for transport sustainably. Much literature relates TOD to rail and light rail but less so to bus. An investigation comparing how transit-oriented the existing urban form is around different modes would be a useful baseline to inform and support planning strategies which favour certain modes on the basis of their potential to achieve planning objectives.

This study investigates the extent to which urban development around Melbourne's transit is intrinsically 'transit-oriented', by measuring indicators of TOD for catchment land use of trams, trains and buses, including SmartBus and local bus routes, for a representative sample through inner, middle and outer Melbourne. The hypotheses tested were that the extent of transit-orientation varies with mode, and that tram is associated with sustainable patterns of urban development that is significantly higher quality than other modes, notably bus. Mapping software was used to develop a census profile for each circular catchment. A multi-criteria index, the TOD score, was developed to quantify the transit-orientation of the built environment in terms of walkability (design), land use entropy (diversity) and population density. TOD score was regressed on explanatory variables and the artificial variable of mode, to test the above hypotheses.

Results showed that the TOD Score of tram catchments was higher than that of bus and rail, suggesting that the development around tram nodes is more transit-oriented. However, once proximity to the central business district was incorporated into the analysis, no significant variation was apparent between modes, with the exception of SmartBus, which showed no significant effect on TOD score compared to areas of low transit provision. This result suggests that the close proximity of tram catchments to the CBD is responsible for the high TOD scores achieved. The results identify areas for future research into the potential for bus TOD and the progression of tram TOD strategies.

Keywords: Transit-oriented development, tram, train, SmartBus, local bus, Melbourne, sustainable urban development

1. Introduction

1.1 Context for study

Although private transport by road is the preferred method of travel for Melburnians, with 75 per cent of all work-related trips made in a car (Department of Transport, 2009) an alternative must be sought to cater for Melbourne's estimated population growth by up to 133 per cent by 2061 (ABS, 2013d) An appropriate solution must also seek to mitigate the congestion, air quality and land use ramifications of private motorised vehicle travel (PMVT).

Melbourne's light rail, or tram, network is the most extensive of its kind in the world (Victorian Road Based Pubic Transport Council, 2010). In Melbourne and Australia more broadly, tram-oriented development has been postulated as an enforceable and socially acceptable option for encouraging more sustainable patterns of development in a traditionally low-density society (Woodcock et al., 2013). Such development, a subset of the planning strategy known as Transit-oriented development (TOD), has featured in numerous recent planning documents for Australian cities. These include the *Perth Network Cities Plan* (2014), *Melbourne @ 5 million* (2008), a report jointly commissioned by the City of Melbourne and Department of Transport: *Transforming Australian Cities* (2010), and most recently the Melbourne metropolitan planning strategy, *Plan Melbourne* (2014).

While the connection between TOD and increased public transport use is widely established in literature, less is known about the relative merits of investing in new transport infrastructure for different modes. A baseline which illustrates the similarities and differences in transit-orientation around train, tram and bus stations would act as a useful platform for informing planning strategies, and measuring their effectiveness, as Melbourne embraces TOD strategies.

1.2 Research aims

This study investigates the relationship between mode and TOD in Melbourne, in order to identify whether mode is an important variable to consider when planning TOD. This is achieved firstly by modelling typical characteristics of TOD for circular catchment regions centred on tram, train, local bus and SmartBus stops, and locations without transit provision. Comparison of aggregate TOD scores is then conducted to compare the extent of transit-orientation of development around different modes. A stepwise regression of TOD score on a suite of indicators allows for comparison of modes after accounting for other factors that influence TOD, most notably distance from the central business district (CBD).

1.4 Hypothesis

This study will test the hypothesis that there is a significant observable variation in the degree of transit-orientation of the built environment in catchments of different modes. It will also test the hypothesis that tram infrastructure is the most transit-oriented. Both hypotheses will be tested in relative terms without controls, as well as with explanatory variables of distance, self-selection and transport service provision, included in significance tests.

1.5 Paper structure

The body of literature relating the built environment to transit patterns, and methods of measuring TOD is explored first. Indicators selected for measuring TOD and explanatory variables are described, as well as the approach to modelling catchments. Results are presented firstly in terms of aggregate and component TOD scores by mode. The results of stepwise linear regression of TOD score on an artificial variable for mode and other independent variables are then presented for two cases; firstly with 'no transit' as the baseline, and secondly with tram catchments as the baseline. The results are discussed in the context of existing knowledge about Melbourne's transit network, and implications for future transport planning policy.

2. Literature Review

2.1 Transit-Oriented Development

Transit-oriented development refers to planning strategies that draw on the synergies of land use, transit and policy to bring people closer to destinations, improve environmental quality and improve the utility of public and non-motorised transit modes (Cervero and Kockelman, 1997, Transit Cooperative Research Program, 2004). Successful TOD facilitates low-impact transit that is a competitive alternative to private PMVT, by offering a suite of transport choices. By combining the attributes of both route-bound transit, like trams and trains, and non-motorised modes, the flexibility and speed of PMVT can be achieved through TOD (Renne, 2009). TOD is most commonly associated with heavy rail and light rail, and more recently, with bus rapid transit (BRT) (Organisation for Economic Co-operation and Development (OECD) and European Conference of Ministers of Transport (ECMT), 1994). It is typically characterised by medium to high densities of residents and employees, mixed land-use and design which favours low-impact transport modes over private motorised vehicle transport (Cervero and Kockelman, 1997). A study by McKibbin postulates that the benefit of TOD should be understood less in terms of its impact on increasing public transport mode share and more as a growth policy that facilitates development infill to address increasing demands for accommodation in urban centres (McKibbin, 2011).

While cheaper to maintain and operate than heavy rail transport, trams are much slower than heavy rail, and have a lower passenger capacity. Compared to bus rapid transit, trams are more expensive and less flexible. However, the greater visibility and permanence of light rail, or tram corridors, compared to bus corridors provides incentive for developers to invest in close proximity (Currie 2006). Although a majority of TOD typologies focus on train-oriented development, research has found that bus- and light rail- or tram-oriented development can be equally effective in achieving TOD outcomes (Kamruzzan et al., 2014).

While TOD has been used internationally to achieve planning objectives, it is a relatively new concept in Australia. Tram corridors feature significantly in recent visions for planning that emphasise urban intensification (Transforming Australian Cities, 2010). *Melbourne @ 5 million* also encourages intensification around orbital bus routes, in addition to rail-based activity centres and light rail corridors (Department of Planning and Community Development, 2008)The *Transforming Australian cities* report also identifies priority bus corridors, along with tram routes, as sites with significant potential for intensification. Some inferences about the diversity, density, mode-share and accessibility around transit networks can be deduced from the Victorian Integrated Survey of Travel and Activity (VISTA 07) (Department of Transport, 2009). The possibility that mode is a significant variable to consider when analysing the potential success of TOD strategies is a notable exception to Kamruzzan et al.'s work on defining a TOD typology (2014). However, if tram TOD is to be favoured above other modes, there must be attributes inherent to each mode that differentiates their abilities to support TOD.

2.2 Measuring TOD

TOD is an emerging research field, and as such the key variables understood to reflect TOD are rapidly evolving. The need for context-specific indicators means that a universal set of criteria does not exist for TOD, with 'typologies' regarded as essential for effectively implementing and monitoring the success of TOD in a given location (Kamruzzan et al., 2014, Renne et al., 2005). Studies which seek to evaluate the success of planned TOD provide useful insight into the indicators that can be used as a proxy for the presence of TOD. An early meta-analysis of TOD variables concluded that the three most important variables associated with TOD, all of which were properties of the built environment, included density, diversity and pedestrian-friendly design (Cervero and Kockelman, 1997).

Population density is one of the two most common measures of density in the transit context (Cervero and Kockelman, 1997, Renne et al., 2005). The research into transit corridor intensification conducted for the *Transforming Australian Cities* report found the population density of Melbourne's tram and priority bus corridors to be approximately 30 persons per hectare (p/ha) (2010 p. 8) Separate research found the population density of Melbourne's CBD to be 66 p/ha (AECOM, 2010b). The *Transforming Australian Cities* report sets a 'low density' target of 180 p/ha in its proposal for transit corridor intensification (2010 p. 23). Land use entropy is used by Cervero and Kockelman as a measure of land use mix, or diversity, in their early study which showed correlation between travel demand and the built environment (1997 p. 206). Pedestrian-friendly design is a common interpretation of the third original variable - design. The online Walk Score calculator has been used in planning research and applications to measure the walkability of an address (Tregoning, 2010, Weber and Currie, 2014)

The quantification of the built environment does not suffice to represent TOD. The original '3D's' of TOD – density, diversity and design – have since been expanded to include four more 'D' variables. These are destination accessibility, distance to transit, demand management, and demographics (Ewing and Cervero, 2010). The classification of TOD indicators into 'D' variables is a convenient, but not universal, means of summarising the important variables in TOD. Renne et al. classifies TOD variables into five categories, one of which is 'built environment'. The other four categories are travel behavior, investment, environment; and social indicators (2005).

2.2 Explanatory variables

A study by Litman and Steele (2015) outlines the complexity of the relationships between land use factors and transport ridership patterns. Through an extensive review of literature that examined numerous land-use variables such as regional accessibility, density, car-parking provision, land-use mix, investment in active transport and road design, as well as different planning strategies, the study concludes that impacts on transport ridership are intensely synergistic (2015).

One of the earliest control variables used in studies investigating land use and ridership was the distance between a study site and the regional centre (Newman and Kenworthy, 2006, Transit Cooperative Research Program, 1996). Litman and Steele describe the geographic relationship between mode share and regional accessibility by contrasting mode share in central, suburban and rural locations; noting a 20 to 40 per cent reduction in driving between each band (2015 p. 6). Other service attributes may also have a significant bearing on transit performance. Some intrinsic service attributes include average speed, capital cost and maintenance cost of service delivery, and capacity. Characteristics such as service provision may also influence ridership, while contiguity of catchments makes it difficult to attribute observed catchment characteristics to a particular mode (Cao and Schoner 2014.)

Recently, the confounding impact of self-selection when measuring the success of planning initiatives has been addressed by controlling for socio-demographic factors. Self-selection refers to the tendency for individuals, with a predisposition to using transport, to choose to live in neighbourhoods where they do not have to rely on PMVT, and where they can be close to destinations (Litman and Steele, 2015). Despite its potential to explain part of the success of initiatives aimed at changing ridership patterns, many studies have found statistical support for the influence of the built-environment characteristics on mode choice after accounting for self-selection (Handy et al., 2005). McKibbin employs average weekly personal income as a control for self-selection in his 2011 study into modes and mode share (p. 6).

3. Method

This study aims to measure the extent of transit orientation of catchment development for four transit modes and 'no transit' catchments, in order to compare development transit-orientation between modes. The hypothesis tested is that the extent of transit-orientation of catchment development varies with mode and is most closely associated with tram catchments. Random sampling was used to select study sites. Automated queries were then used to develop a spatial profile, based on Census collection boundaries, using *MapInfo Professional v12.5 (Pitney Bowes*

MapInfo Corporation 2014). Data for each catchment was reduced to a single datum for each indicator using *Excel*. The three original 'D' variables – density, diversity and design - were used to define an overall 'TOD score' to represent the extent to which urban form was transit-oriented. The composite TOD score formed the dependent variable against which other variables were regressed to test for predictive strength.

3.1 Site selection

Study sites comprised station/stop catchments for tram, train, local bus and SmartBus[1]. For each mode, 60 sites were located. In addition, 37 sites located in areas of low/no transit provision were also selected for comparison.

A representative sample of station/stop catchments was selected by a randomised method of site selection but one which ensured a reasonable spread of sites by distance from the CBD, to control for significant distance effects resulting from Melbourne's mono-centrism. A random number-generating website was used to select stop sequence from route termini. The corresponding stop was selected as a site for analysis. Where duplicate stops emerged on different routes (on parallel route sections) they were eliminated and a new study site was found.

Catchments for transit were modelled as a circle of radius 400 metres for trams and buses; and 800 metres for trains, with the transit station at their centre. This method is in keeping with literature-sourced values for walkable distances to transit nodes, including the half-mile standard for access to rail used in the United States (Cervero and Bernick, 1997). *Google Maps* was used to obtain the address of each transit stop. *Geoplaner V2.7* was used to obtain coordinates, in Universal Transverse Mercator coordinate system (UTM), for each transit stop (Nathansen, 2015).

In order to establish a baseline for comparison of modal effects through the stepwise regression technique, "no transit" catchments centred on a point source away from transit stops of any mode were also included in the study. The 'no transit' catchments could not be randomly sampled in the same way as the transit catchments. Instead, the PTV Android application was used to select areas with low transit density. An initial 30 sites were located. 20 more sites were added before the mean, 1st and 3rd quartile distances from the CBD of 'no transit' sites fell beyond one kilometre of the average of the transit sites. This process ensured that a representative spread of catchments was selected for study. Thirteen sites were subsequently removed because they proved to have 'above average' transit accessibility and hence were not fit for our purpose[2].

3.2 Variables

Table 1 summarises the dependent and explanatory variables adopted in this study and also notes the approach to measurement and relevant data sources.

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[1] SmartBus routes are distinguished from other bus routes, termed 'local bus', as per their classification by Public Transport Victoria (PTV). SmartBuses are specifically intended to provide cross-town connections which complement the radial train network (PUBLIC TRANSPORT VICTORIA. 2015. *SmartBus* [Online]. Available: http://ptv.vic.gov.au/projects/buses/smartbus/. [Accessed 15 May 2015 2015].

[2] A basic relationship between distance (D) of transit catchments from the CBD and the Public Transport Accessibility Index was determined through a regression analysis. The relationship, with R^2 = 0.42, was found to be

$$PTAI = 37400 - 10300 \times D$$

Where the actual PTAI for 'no transit' catchments exceeded that derived from the relationship, based on distance from CBD, the site was excluded from study.

Table 1 - Method and source of variables used in analysis of transit-orientation

Variable	Units	Measurement technique	Source
TOD aggregate and component indicators			
TOD score		The TOD score was calculated from three variables, population density (density), land use entropy (diversity); and walkability (design), according to the equation $$TOD\ score = \frac{population\ density}{50} + land\ use\ entropy + \frac{walkability}{100}$$ **Equation 1** Each indicator was calibrated to contribute approximately one third of the final score. Equation 1 illustrates the division factor associated with each variable. By default, diversity was scored out of 1 and required no adjustment. Walk score required division by 100 to give a score out of 1. The division factor for density, the only un-capped variable, was determined to be 50. Ninety per cent of catchments recorded densities lower than 50p/ha and as such this meant that the majority of density scores would be less than one, without significantly reducing the weighting compared to the other two component scores.	
Population density (density) 'PD'	p/ha (place of usual residence)	Density was calculated by combining spatial analysis with population data from the 2011 Census. Shape files with boundaries corresponding to the smallest Census catchment area, Statistical Area Level 1, were imported into *MapInfo*. The seven digit codes corresponding to all regions that fell within a catchment, and the per cent overlap of each with the transit catchment, were determined using the query function. *Excel* was then used to index the statistics corresponding to each SA1 region within a catchment, and to multiply this by the overlap fraction for each, to calculate an overall score for each variable in each catchment.	(ABS, 2013c, ABS, 2013e, ABS, 2013f)
Land use entropy (diversity) 'E'		The 2011 mesh block shape file was used as the basis for inspecting each catchment (ABS 2013a). This file contained information on the dominant land use in each mesh block. The eight land use categories were commercial, education, hospital/medical, industrial, parkland, residential, transport and water. Agricultural and 'other' land uses were not encountered, and thus excluded, given that scoring was relative. A query was used to calculate the area of each land use enclosed in each catchment. The formula then used to calculate a score to indicate the mix of land use was $$Entropy = -\sum_k \frac{P_k ln(P_k}{ln(N)})$$ where k is the land use type, P_k is the proportion of the catchment occupied by land use 'k', and N is the total number of land uses. The formula is an adaptation of the entropy formula used by Cervero and Kockelman in their 1997 study.	(ABS, 2013e)

Variable	Units	Measurement technique	Source
		TOD aggregate and component indicators (cont'd)	
Walkability (design) 'Wk_Sc'		The web platform 'Walk Score', used in planning application to measure walkability, was used to obtain a numerical score for walkability of transit stops (Tregoning, 2010). Walk score is a ranking of 'walkability', or pedestrian- friendly design, on a scale of zero to 100, obtained through an online resource that draws on Geographic Information Systems (GIS) software to generate scores. A 'walk score' was calculated with the transit stop as the origin. The address of each transit node was entered into the calculator tool. Scores were calculated by sourcing spatial data to determine proximity to amenities, in terms of walking time, and then converted into a score out of 100 using an algorithm.	(Walk Score, 2014)
		Explanatory variables	
Mode	1/0	In order to test the hypothesis that mode is correlated to higher TOD scores, an artificial variable to represent the non-numerical characteristic of mode was established. For the 'no transit' baseline in the regression analysis, four artificial variables were created, corresponding to each of the four modes. For each artificial variable, the value '1' was used to signify that a given catchment was of the same type as the artificial variable, while the value '0' would indicate that the catchment was of a different mode. The same logic applied to the 'tram' baseline, with three artificial variables corresponding to train, local bus and SmartBus.	
Distance 'D'	kilometres (km)	The distance of each transit station from a central location in the Melbourne CBD was calculated from UTM coordinates. The regional centre was taken to be the corner of Elizabeth Street and Collins Street.	
Income 'I'	\$/person/week (place of usual residence)	Average income was used to control for self-selection effects of individuals of certain income brackets gravitating to areas of certain transit serviceability. Income was calculated as per the method outlined above for density, with reference to the appropriate census data, which was averaged for each SA1 region using ABS supplied median values to represent each income bracket.	(ABS, 2013b)
PTAI (Public Transport Accessibility)	person trips/45 minutes (am peak)	The accessibility of each destination by public transport modes was calculated using a combination of spatial data and algorithms. An *Excel* tool was used to index the address of the transit node and calculate how many people would be able to access the location by bus, train or tram within 45 minutes (AECOM, 2014). This number formed the score for controlling for catchment overlap effects. Thus a catchment with higher PTAI would be likely to be influenced by modes and services other than that around which the respective catchment is based.	(AECOM, 2010a)
		Independent variable	
Mode share		Public transport mode share (PT mode share) was used for comparison between modes only. Mode share was calculated by finding the fraction of total journeys to work (am peak) recorded in the 2011 Census, made by train, tram or bus as the main mode.	(ABS, 2013a)

Figure 1 - Example of catchment with transit station at centre overlying SA1 shape file in *MapInfo*

Figure 1 provides an example of the shape file overlay used to record SA1 codes and area fractions. The method used was similar to that employed by Guerra et al. when investigating walkable distances to transit (2011).

3.3 Analysis

3.3.1 Aggregate and disaggregate score comparison

The aggregate multi-criteria score, as well as scores for each individual variable including components of the TOD score, was averaged for each mode. The performances of the modes against each variable were compared. Relationships between TOD variables were investigated graphically. For each graph, a line of best fit corresponding to all the transit catchment data points was fitted to the data points. 'No transit' catchment data points were graphed, but excluded from the determination of a relationship between distance and TOD variables.

3.3.2 Regression Analysis

The two hypotheses were tested with respect to explanatory variables by conducting two stepwise regression analyses, using TOD score as the dependent variable. The first stepwise regression tested the hypothesis that transit catchments were correlated to higher TOD scores than catchments without transit, after controlling for distance, income and transport accessibility effects. The second stepwise regression tested the hypothesis that tram catchments were correlated to higher TOD scores than catchments of other modes. In both instances, the dependent variable, TOD score, was initially regressed on all independent variables. One independent variable with significance, 'p', greater than 0.05 was eliminated at a time and the regression repeated until the remaining variables all had p-values less than 0.05.

4. Results

4.1 Modal Average Scores

The overall aggregate TOD score for catchments of each mode type are presented in the first column of Table 1, as the average score for each mode. The modal average for each of the three variables that contribute to TOD score, representing density, diversity and design respectively, are also summarised, as well as four more variables of relevance to TOD, including distance, income, public transport accessibility index and public transport mode share. The ranking of each mode with respect to variables is indicated next to each score in brackets.

Table 2 - Modal average variable scores (rank)

	TOD Score	Disaggregate Scores			Explanatory Variables		
		PD	E	Wk_Sc	D	I	PTAI
Tram	2.13	43.40 (1)	0.40 (2)	86.45 (1)	5.58 (5)	838.62 (1)	3.71E+05 (1)
Train	1.74	26.29 (2)	0.44 (1)	76.52 (2)	14.83 (3)	723.23 (2)	2.51E+05 (2)
Local Bus	1.49	24.93 (4)	0.36 (3)	63.08 (3)	18.67 (1)	645.98 (4)	1.49E+05 (4)
Smart Bus	1.34	21.37 (5)	0.30 (4)	60.48 (4)	16.00 (2)	636.11 (5)	1.69E+05 (3)
No Transit	1.32	26.00 (3)	0.21 (5)	58.86 (5)	13.72 (4)	696.24 (3)	1.29E+05 (5)

The highest aggregate score is for tram catchments, while the lowest is for no-transit catchments. Trains were the second best performing mode, while local bus scored third highest and SmartBus scored lowest. By exploring the component scores, it can be seen that trams achieved the highest scores for density and design, while trains scored highest for diversity. 'No transit' had the lowest average diversity and design scores. SmartBus had the lowest score for density. High scores across all variables appeared to correlate with closer proximity to the CBD. Trams, with an average proximity of 5.83 kilometres from the CBD, scored highest in the categories of average weekly income, public transport access, density, design, public transport rideshare and overall TOD Score. Trains scored highest in the diversity criterion, signifying that the average train catchment shows the most even distribution of land uses. SmartBus returned the lowest scores in the categories of income, diversity, public transport rideshare and TOD Score.

The impact of distance from CBD on TOD score is graphically represented in figures 2 and 3. Figure 2 shows the logarithmic relationship between TOD score and distance. The high coefficient of determination, or R^2 value, of 0.55, for this relationship signifies that the formula is a good fit for the data. In figure 3, nodes in the highest TOD score bracket are observed to be concentrated within the five kilometre radius band.

Figure 2 - Relationship between TOD Score and distance

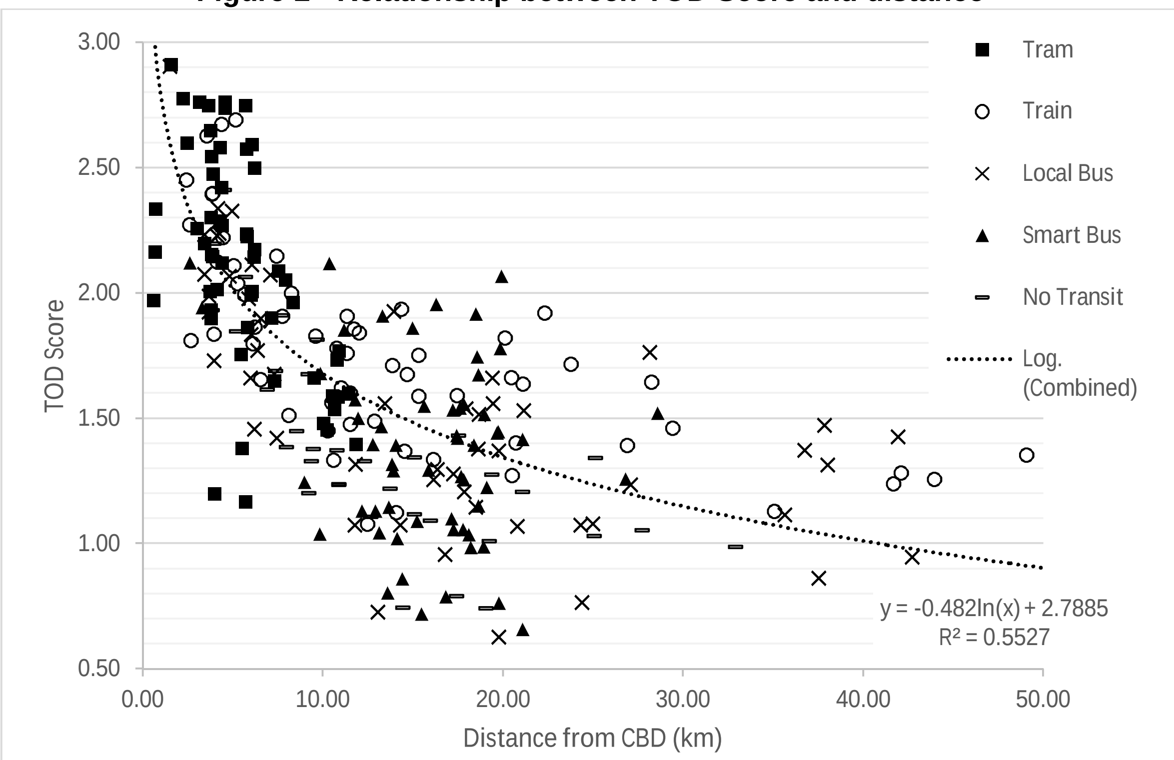
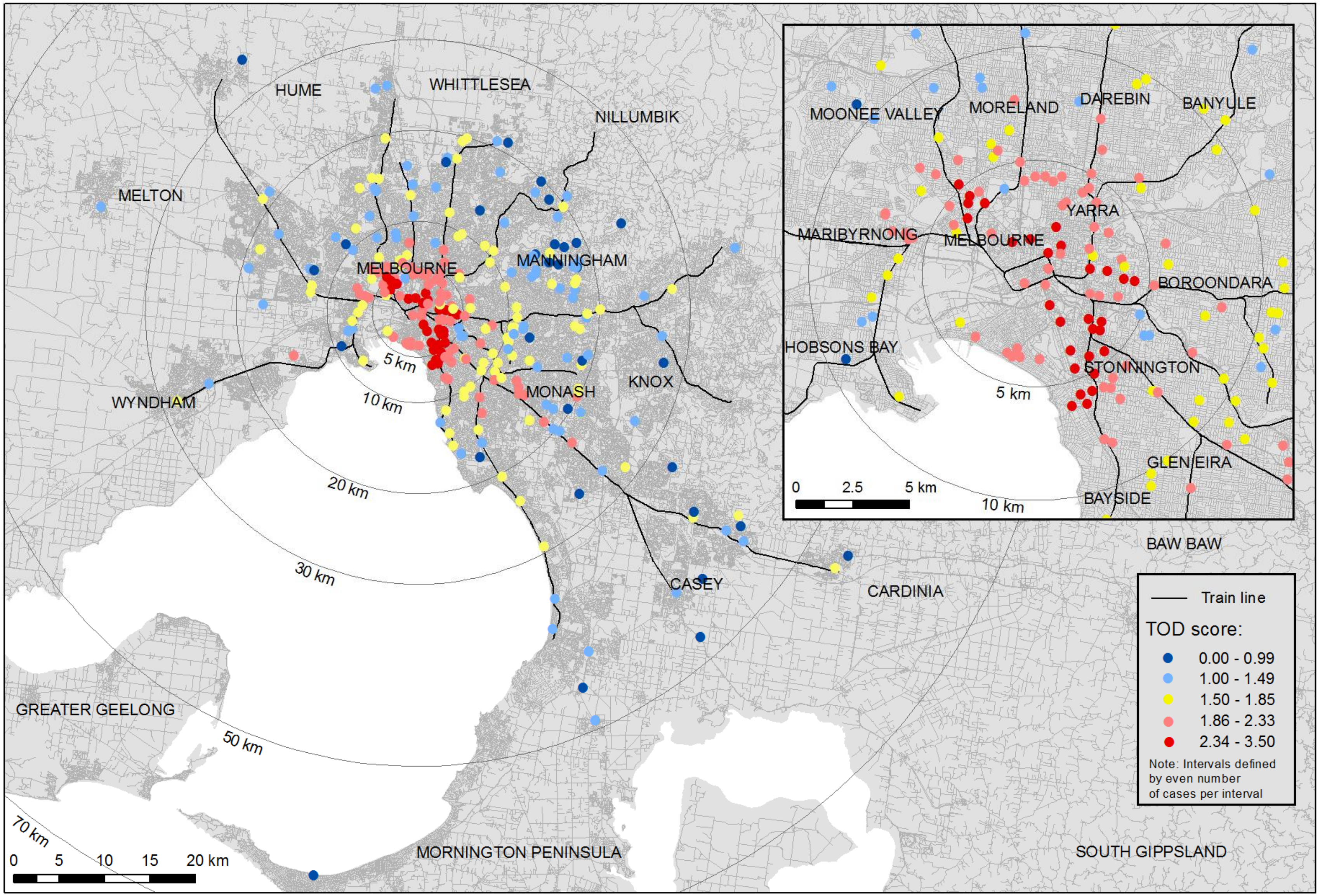


Figure 3 – Geographic spread of TOD score by catchment



The relationship between component variables and distance are illustrated in figures 4 to 6.

Figure 2 - Relationship between walkability (design) and distance

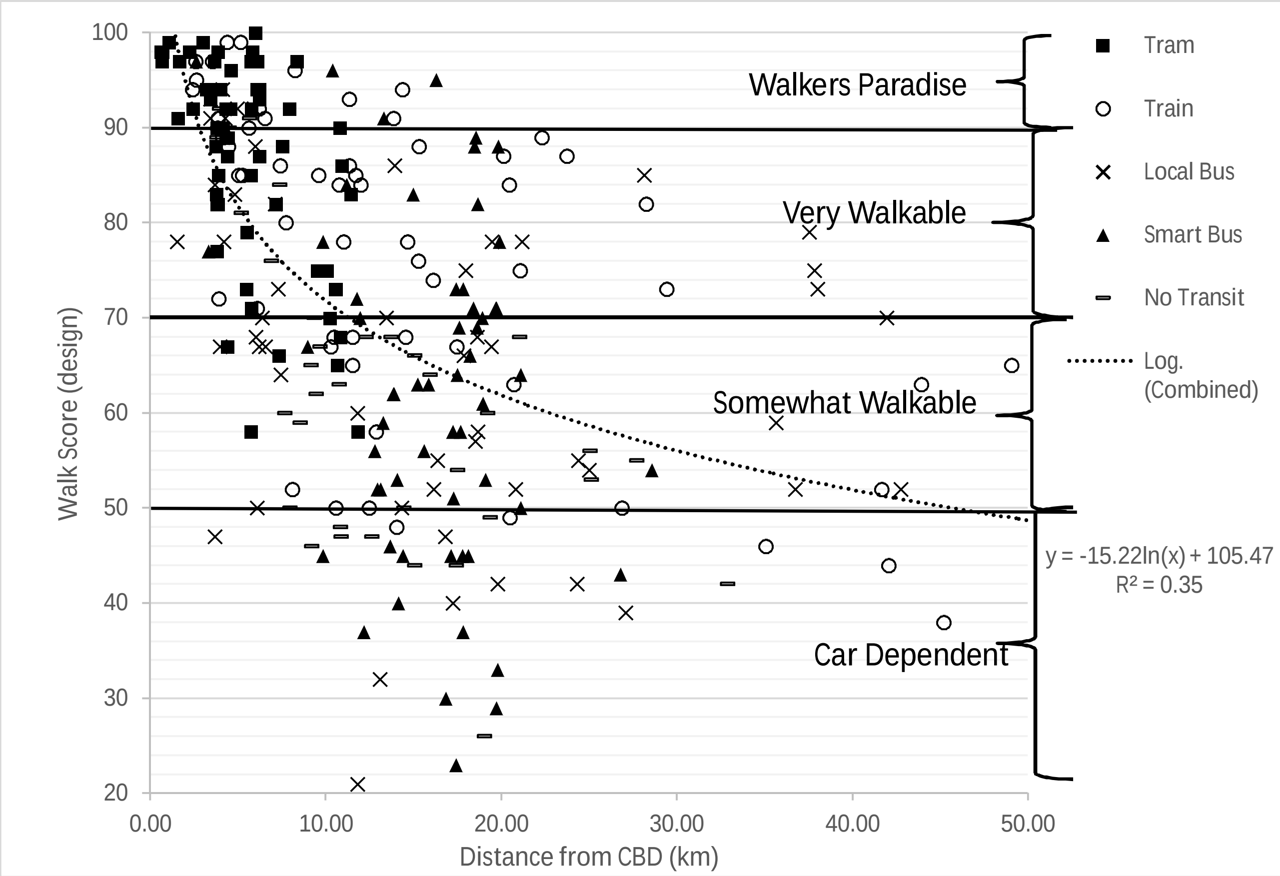


Figure 3 - Relationship between density and distance

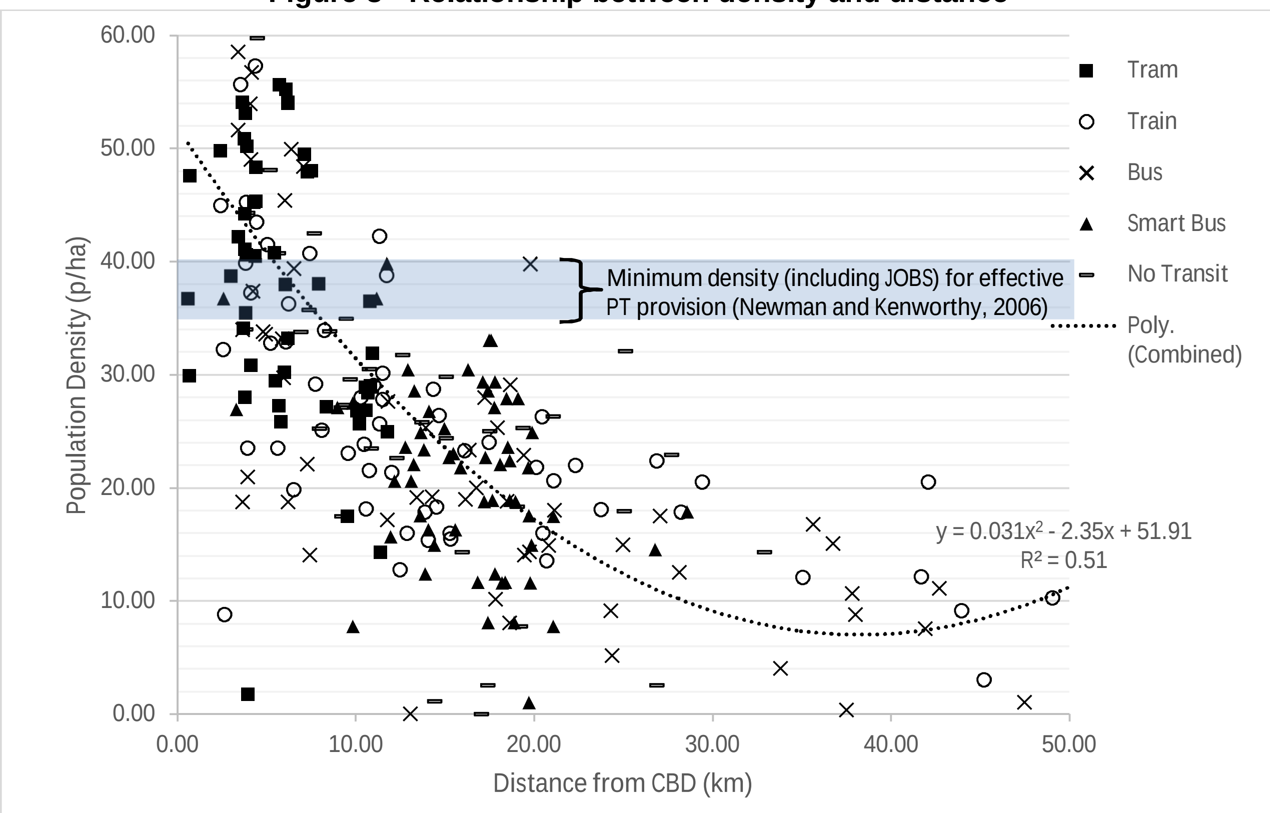
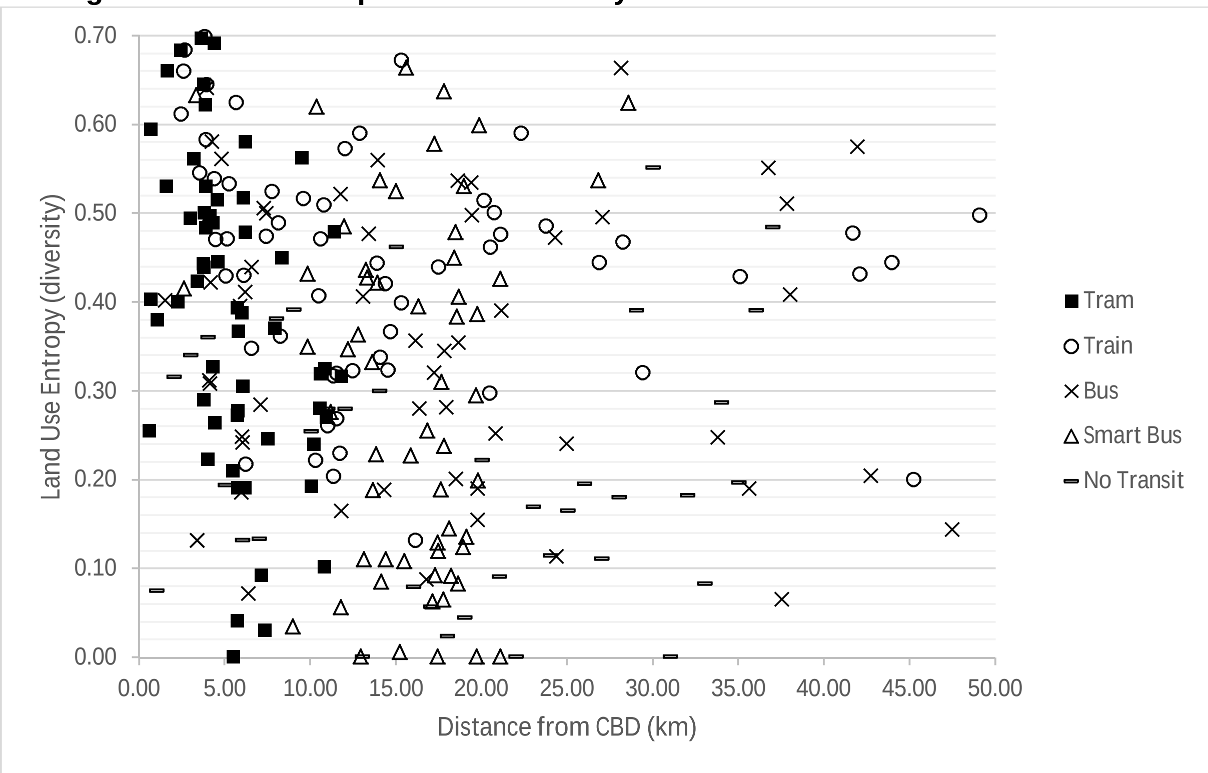


Figure 4 illustrates the relationship between walkability and distance. This best-fit relationship is also logarithmic, with an R^2 of 0.35. It can be seen from the figure that while tram catchments at close proximity to the CBD scored very highly, train catchments are located above the curve signifying above average walkability around train catchments compared to other modes. Similarly, the ‘no transit’ catchments tended to lie below the curve. Figure 5 illustrates the best-fit relationship between density and distance. The best fit relationship here was found to be quadratic. The even dispersion of modes above and below the curve suggests mode bears less of a relationship with density than it does to walkability. Diversity was the only component variable of TOD score that did not show a significant relationship with distance from the CBD. As figure 6 illustrates, the vertical spread of data points showed no link to distance from the CBD.

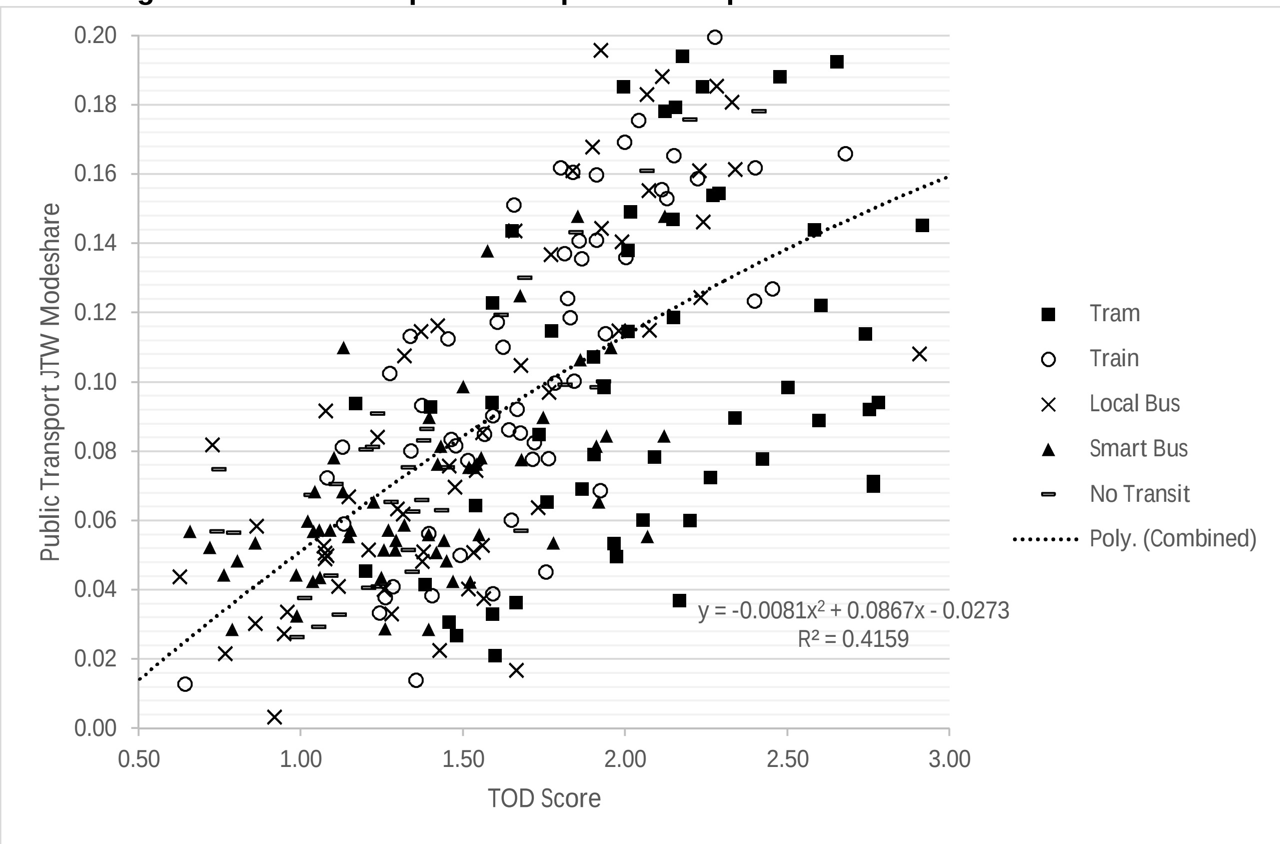
Figure 4 - Relationship between diversity and distance of catchment from CBD



It can be seen that development of train and tram catchments often appeared to have a TOD score above 0.30, while SmartBus and ‘no transit’ tended to feature more significantly in the 0 – 0.30 range. This spread of data is illustrative of the average results for mode, in which trams and trains scored 0.40 and 0.44 respectively, while SmartBuses averaged 0.30 and ‘no transit’ averaged 0.21.

Figure 7 illustrates the relationship between TOD score and public transport mode share (one of the explanatory variables adopted in the analysis). Bus nodes lie equally above and below the curve, whereas tram nodes tend to fall below the average curve. The relationship between TOD score and PT mode share was found to be described by a positive, nonlinear equation. The strength of the link was reasonable with an $R^2$of 0.42.

Figure 5 - Relationship between public transport mode share and TOD score



4.1.1 Regression of TOD score

Regression results are shown in Table 3. The first stepwise regression tested the hypothesis that mode shows a significant relationship with TOD score after considering a number of potential explanatory variables. The null hypothesis would therefore show that no variation is observed between the scores of the different modes compared to scores of the 'no transit' catchments after other variables are considered. The artificial variable for SmartBus was eliminated in the first round of tests due to insignificance. Income was eliminated after the second regression. The five remaining variables showed significance in the third round of regression, with an adjusted R^2 of 0.61. The high value of R^2 implies that the remaining variables act to explain a high proportion of variation of the dependent variable, TOD score. The very low value of significance, f, implies that the null hypothesis can be rejected. The magnitudes of coefficients[3], as well as the R^2 values relating to each regression, are summarized in table 3.

The second stepwise regression tested the hypothesis that tram catchments were associated with urban development that was of higher quality than other modes, defined in terms of its TOD score; after incorporating the influence of self-selection, proximity to the CBD and the provision of public transport services. The null hypothesis tested in this regression analysis was that there is no significant variation in the TOD scores of train, local bus and SmartBus compared to trams, after incorporating other variables. Income was again found to be insignificant. The variables for train and local bus were also found to be insignificant. This result implies that the only significant variation in TOD score between tram catchments and other modes was observed between Tram catchments and SmartBus catchments. Nevertheless, returning a very low significance, the null hypothesis was rejected due to the effects of distance, SmartBus catchments and PTAI on TOD score.

[3] The relative magnitudes of the coefficients for modes may be compared as an indicator of the variation between each mode and the baseline. The magnitudes of the coefficients of distance and PTAI are not comparable as they are measured on differing infinite numerical scales.

Table 3 - Results of stepwise linear regression testing significance of variables in prediction of TOD Score

Baseline Scenario:	1. 'No transit'	2. Tram
R^2	0.621	0.780
Adjusted R^2	0.614	0.609
Significance (f)	5.45E-55	7.79E-48
	Coefficient	
Intercept	1.31	1.56
Tram	0.33	
Train	0.25	insignificant
Local bus	0.22	insignificant
SmartBus	insignificant	-0.27
D	-0.014	-0.014
PTAI	1.54E-06	1.6E-06
Income	insignificant	insignificant

5. Discussion

5.1 Insights on Mode and TOD

Recent Australian planning frameworks that encourage intensification around tram corridors are based on the premise that such sites are 'market friendly' and politically palatable (DPCD 2008; Adams 2010; Woodcock et al. 2013). This premise introduces the idea that the type of transit mode is itself an important variable to consider when implementing new transit infrastructure in the hope of achieving a desired policy outcome. As such this study sought to test the hypothesis that mode was an important variable to consider when planning TOD because different modes are associated with different extents of baseline transit-orientation. The regression analysis which compared four modes to the 'no transit' catchments showed the most significant effect for tram catchments, with a coefficient of 0.33, compared to 0.25 for trains, 0.22 for local buses and no effect for SmartBuses. The results suggest a complex relationship exists between mode, distance and TOD score.

The results of this study confirmed the hypothesis that tram catchments are associated with higher transit oriented development than train, local bus and SmartBus. While the results of the first regression show a relatively higher effect of mode for trams than for the other modes when compared to 'no transit', a second regression reveals that in fact the only significant variation lies between trams and SmartBuses once the impact of distance and service provision is accounted for. This means that the relationship between TOD score and mode does not vary significantly between trams and trains, or trams and local buses.

The superior accessibility and safety of tram corridors, 70 per cent of which operate in mixed, on-road traffic, compared to trains is presented in *Transforming Australian Cities*, as a reason for targeting tram corridor intensification (Transforming Australian Cities, 2010). However, given that both buses and trams operate in such conditions, the logic of favoring tram TOD over bus TOD is not substantiated by the results of this study, which found that bus corridors are not significantly more or less associated with TOD than trams. In addition, tram corridors are considered to be 'market friendly' due to the prominence of their infrastructure compared to buses, a phenomenon that does explain the superior performance of trams over SmartBuses, but is not substantiated relative to local buses. Thus, while results indicate that tram catchments support higher quality urban development compared to low-transit areas, their advantage over buses may be overstated considering the insignificant variation in TOD score once distance is accounted for. Service disruptions, such as level crossings for trains, and shared traffic conditions for trams, are extrinsic factors might influence the relative performance of buses compared to these modes in the Melbourne context.

The poor performance of SmartBus catchments may be explained by their geographic placement, rather than the nature of the service they provide. SmartBus routes were designed to deliver a rapid bus service, bypassing local traffic and supplementing the radial train network (Public Transport Victoria, 2015). Thus SmartBus routes tend to be situated away from other transit, on highways where land uses are more homogenous, and population densities lower. In addition, the purpose of the SmartBus is to service areas of high PMVT volume, namely on significant road corridors that are unattractive and inconvenient to live near. The combination of problems which SmartBus infrastructure is designed to target provides explanation of why it performs poorly compared to the other modes.

5.2 Distance, income and transport accessibility

The result of the graphical analysis of variables demonstrated that a logarithmic relationship between distance and mode goes further in fitting a much higher percentage of the data points to a curve. The R^2 value of 0.552 observable in figure 2 suggests that distance alone explains TOD score to the highest degree of the variables tested. This is supported by the pattern that emerges in the geographic representation of TOD spread. All TOD scores over 1.86 are clustered within five kilometres of the CBD. Despite this evidence for the significance of proximity to the CBD in predicting TOD Score, linear regression revealed mode to maintain its significance after accounting for distance, albeit of lesser significance than proximity to the CBD.

Although recent literature emphasises the significance of self-selection of individuals of higher incomes into areas of high transit provision, both linear regressions found no significant relationship between average income and TOD score. An entropy indicator, such as that used to measure land use mix, may yield different results with respect to self-selection patterns. In addition, there are many possible demographic groups, other than a particular income bracket, that may self-select into areas of high transit provision. These include age, moral values and the possession or not of a driver's license. Such factors were not controlled in this study.

While the Public Transport Accessibility Index was included to control for the impact of contiguous services, it may also have had the effect of masking the significance of those catchments in areas of high transit demand. In areas close to the city, where public transport services are more frequent and dense, the supply of services is often saturated, depriving inner-city dwellers from accessing the abundant services within walking distance. Thus, while controlling for contiguity on one hand, the PTAI index may have diminished the effect most notably of tram catchments which were found to be most concentrated in the inner city.

5.3 TOD and public transport mode share

The purpose of figure 7 is to explore links between the TOD characteristics of existing development and mode share in Melbourne. An increase in PT mode share is a common planning objective of TOD initiatives (Litman and Steele, 2015). The positive, albeit nonlinear relationship identified demonstrates that this is a sound logic. In general Figure 7 suggests that increasing the TOD score of existing catchment development would increase JTW mode share from 6% to 12%. Increasing TOD score from 2 to 3 acts to, on average, increase JTW mode share from 12% to 16%. While there is a vast range of actual scores demonstrated, these findings act to support the targeting of changes in land use to facilitate increased access to and competitiveness of public transport modes. At the higher end of TOD scores (above 2) local buses seem to outperform other modes with higher relative mode shares. In addition, the relationship found for TOD like development around buses, and mode share was found to have the highest coefficient of determination for any of the modes, at R^2 = 0.62 suggesting a stronger link.

In contrast, tram catchments were found to have the poorest fit between TOD score and mode share with R^2 = 0.23. The lower rates of public transport rideshare around trams can be explained by the purpose of tram trips, the saturation of public transport at close proximity to the city, and the prevalence of walking and cycling trips at this proximity. The data used in this study only captures trips made during the morning peak, to access work. Despite close proximity to Melbourne's CBD, 60 per cent of tram trips are for non-work related purposes (VRBPTAC 2010, p. 5). Trams are also regarded as an important link between rail corridors, providing local access to final destinations, but do not constitute the 'main' mode for the purpose of this study (VRBPTAC 2010). Thus, commute mode share is not illustrative of all trips made by trams, which would expectedly influence the PT mode share around tram catchments more than for any other mode. In addition, while public transport service levels at this proximity to the city are high, as outlined above the reality is that during the morning peak, not all potential commuters can access public transport since services become progressively overcrowded as they approach the CBD. Additionally, the prevalence of walking and cycling trips would be expected to be higher at closer distances to the CBD; however this information is not included in the analysis.

5.4 Study design limitations

Public transport ridership is a common measure of success of TOD (Litman and Steele, 2015). This analysis undertook a relatively simplistic regression of PT mode share and development TOD score. A time series analysis might be more revealing however this proved impossible given data limitations (and the time available for the study). As it happens the authors are undertaking further exploration of these issues including an analysis of gentrification rends of land uses adjacent to transit modes.

Determining the relative importance of service attributes, such as speed, reliability, ride quality and perceived permanence, compared to extrinsic properties such as service frequency, service disruptions, and the existing control for distance, would provide further indication of the importance of mode in planning successful TOD. Further study that incorporates capital infrastructure cost would make it possible to determine the extent to which trams or buses show superior achievement of transit-oriented development per unit expenditure. An exploration of time series data would be useful in testing whether the low scores for SmartBus can be attributed to their placement in pre-existing car dependent areas, or whether SmartBus is in fact not delivering land use impacts consistent with BRT theory.

Future study design should consider the target population densities set out in *Transforming Australian Cities*, namely the lower-threshold target for corridor densification of 180 p/ha (2010). The present study does not attempt to compare catchment performance against this target, but does set a division factor (50 p/ha) that represents an increase on the baseline for greater Melbourne which is approximately 17 persons/ha. In addition, future study design should incorporate the updated method for calculating PTAI (Green Building Council of Australia, 2014).

5.5 Conclusions

This study identifies TOD like features of development around different transit modes in Melbourne. A significant relationship is observed between mode and TOD score of this development when TOD score is regressed on mode and key explanatory variables, proving the hypothesis that mode is an important variable to consider in planning TOD like development. Trams, trains and local buses show a positive correlation to the TOD score of their development catchments compared to 'no transit' catchments. SmartBuses show a negative correlation.

Tram catchments achieve the highest TOD scores across a multitude of variables, including the overall TOD score, and the component scores of density and walkability. However, after accounting for the influence of distance on TOD score, no significant variation was observed between TOD around tram catchments compared to TOD around train and local bus catchments. These results imply that the high TOD score observed for tram are related to the close proximity of tram stops to the CBD. This finding supports the logic in pursuing tram TOD over the more expensive train TOD, at distances close to the CBD; however it also highlights the need to consider the potential for successful development using TOD principles around local bus services.

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