Can an Aggregated Transport Mode Choice Model, for London Buses, be used to assist Policy Making and Intervention?

Demonstration of using spatially aggregated transport data with population characteristics, to direct intervention and policy change to London Wards, where bus mode share is lower or higher than normal.

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Table of Contents

Table of Tables

Table of Figures

Chapter 1 Introduction

In 2016, an average of ~£6.2m journeys took place on the Transport for London (TFL) bus network every day (Transport for London, 2016). Operating, maintaining and enhancing this network costs ~£3bn per annum (Transport for London, 2017a). This paper develops a statistical model of bus mode share across London. The model is then used to help target interventions and policy making by identifying wards where bus mode share departs significantly from the model.

Six 'under-performing' areas are identified, where bus mode share is significantly lower than expected by the model. Further consideration of these areas is recommended, for example for the implementation of infrastructure, operational or policy intervention.

22 'over-performing' areas are identified, where bus mode share is significantly higher than expected by the model. Further consideration of these areas is recommended, for example to identify additional factors of bus travel choice not included in the model.

In addition, this paper demonstrates the combination of household data with transport data to model mode choice. This is achieved by developing an aggregate model, with mode choice considered at London Ward level.

Chapter 2 Literature Review

2.1 Influencing factors for transport mode share

Transport mode choice models are typically based on a utility theory framework where agents are assumed to be maximising the utility gained from journeys and minimising the disutility from the journey (R Buehler, 2010). As such an individual's choice of travel mode is driven by availability of different choices, by the attractiveness of these options and by the individual's attributes such as demographic and socio-economic.

Socio economic attributes such as deprivation and income are commonly identified as primary drivers of mode choice (N Paulley et al., 2004), where higher income enables car ownership and therefore less public transport use.

However, in the case of developed countries such as the UK, where the cost of car ownership and travel is less likely to be limiting, it is more appropriate to also consider demographic variables (Lipps and Kunert, 2005), such as age or household size.

Furthermore, London's extensive metropolitan area with its multitude of public transport options and relatively high road congestion means that availability and performance of public transport is a key driver of mode choice (Schmöcker et al., 2008).

This paper therefore considers a variety of factors linked to transport 'Connectivity' and 'Performance'. Where 'Connectivity' is the availability of different public transport modes and 'Performance' indicative of the disutility of using these modes, such as journey speed. Demographic, socio-economic and geographic attributes such as population density are commonly referred to as 'Population Attributes' by this paper.

2.2 Existing Methodologies

Transport mode choice models are predominantly dis-aggregate, i.e. they consider individuals mode choice based on individual characteristics, typically obtained by survey (Train, 1978). Analysis also often incorporates some form of population segmentation using clustering (Damant-Sirois, G and El-Geneidy, 2015) to explain varying travel behaviour.

This paper demonstrates the use of transport variables, such as bus speeds, that are not easily attributed to individuals (Parkin et al., 2008). This paper therefore uses an aggregate model, with attributes considered at the ward level, rather than individual. Complex interactions and segmentation are avoided in order to ease interpretation and therefore implementation of the results.

Chapter 3 Research Questions

By identifying areas with 'over-performing' and 'under-performing' bus mode share - this paper primarily asks whether a statistical model can assist TFL with policy making and intervention.

In addition, this paper verifies the significance of all variables considered (at the five percent level). The general hypothesis below is used, where β_i is the coefficient for exogenous variable Xi, in a generalised linear predictor:

Null hypothesis: H_0^i: $\beta_i = 0$

Alternative hypothesis: H_1^i: $\beta_i \neq 0$

Linear predictor: $\mu = \alpha + \boldsymbol{\beta X}$

Chapter 4 Summary of data

4.1 Bus Mode Share

Bus Mode share is extracted from the 2015 London Travel Demand Survey (LTDS). The LTDS provides household data on mode choice, which is aggregated to London Ward level using address, then combined over five years (2011 to 2015), to achieve a minimum sample size of 80. LTDS household weightings are used to make the data representative of the population. City of London is treated as a single ward.

Table 4-1: Bus Mode Share Summary

	Bus Mode Share
Mean	0.145
Standard Dev.	0.0725
Minimum	0.00243
Median	0.134
Maximum	0.429

Table 4-1 and Figure 4-1 show the variation of bus mode share by London Ward. The lowest mode share (of close to zero) occurs in the Outer London Borough of Hillingdon. The highest mode share (of over 40%) occurs in the Inner London Borough of Hackney.

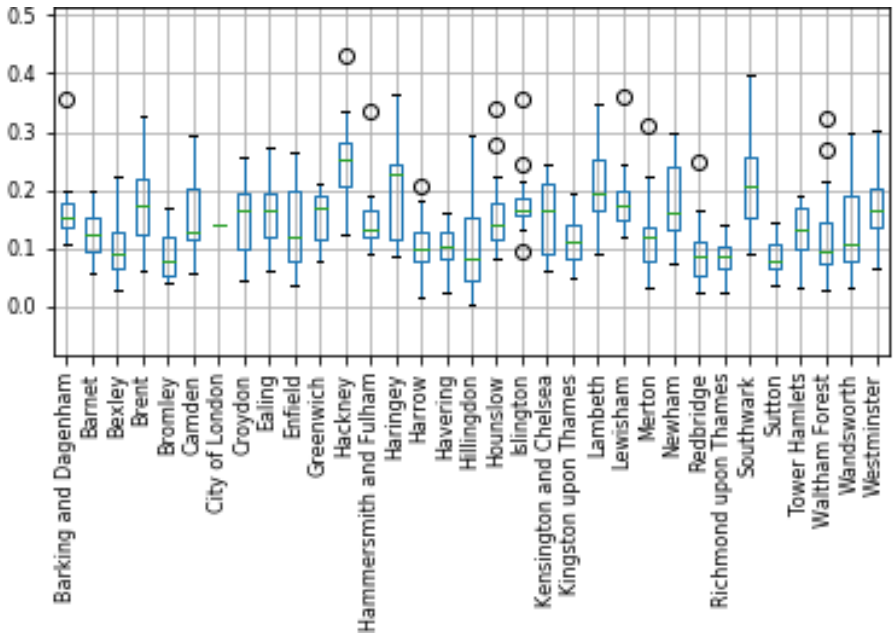


Figure 4-1: Bus Mode Share by London Borough

4.2 Exogenous variables

Exogenous modelling variables are listed in Appendix B and investigated in detail in Appendix G. Data is split into three domains: (i) Connectivity, (ii) Performance and (iii) Population.

4.3 Connectivity

TFL's 2015 Public Transport Accessibility Level (PTAL) (Transport for London, 2015) is used as an indicator of ease of availability of bus, underground, rail and tram travel. The Accessibility Index (AI) score is the sum of these modal scores. Higher scores denote better connectivity - typically closer, faster and more regular services by the given mode.

PTAL scores are provided by TFL on a 100m square grid. Scores are aggregated to ward level using grid centroids. Scores are averaged, with zero scores included. Figure 4-2 suggests a positive relationship between bus PTAL score and bus mode share.

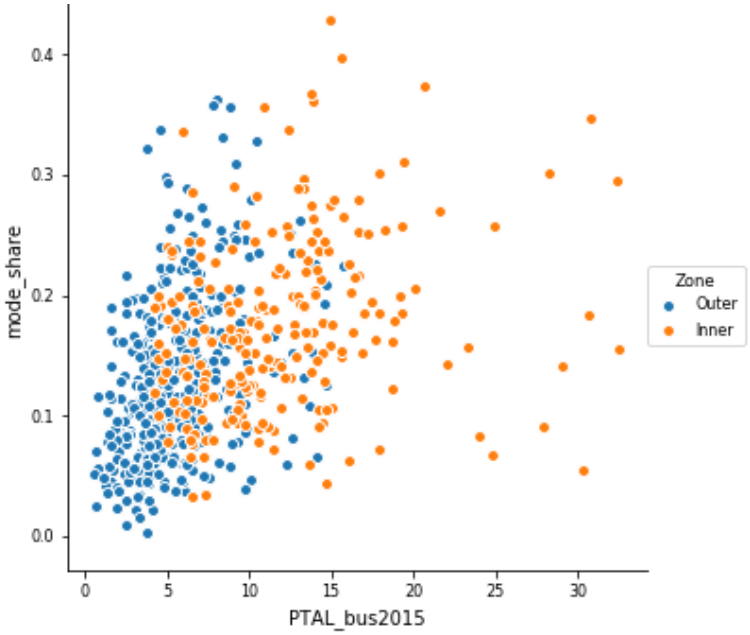


Figure 4-2: Bus Mode Share vs Bus PTAL

4.4 Performance

Bus performance data has been supplied by TFL. All bus performance data is aggregated from bus network level to ward level. Per bus km averages are used.

Average (i) all-day, (ii) morning and (iii) inter-peak bus speeds (weekday) (2016/17) and speed changes (2014/15 to 2016/17) are considered. Welsh Harp Ward is removed as an outlier, due to extreme change in bus speed.

Average weekday boarding (start of passenger bus journeys) is incorporated as an indicator of crowding. Two ratios of bus boarding and alighting are also calculated for this analysis:

I. The ratio of weekend to weekday boarding (all-day average)
II. the ratio of alighting to boarding (average weekday morning period)

These ratios indicate travel behaviour in the area and so could be considered 'Population' attributes. Figure 4-3 suggests a positive relationship between high boarding at weekends (compared to weekdays) and high bus mode share.

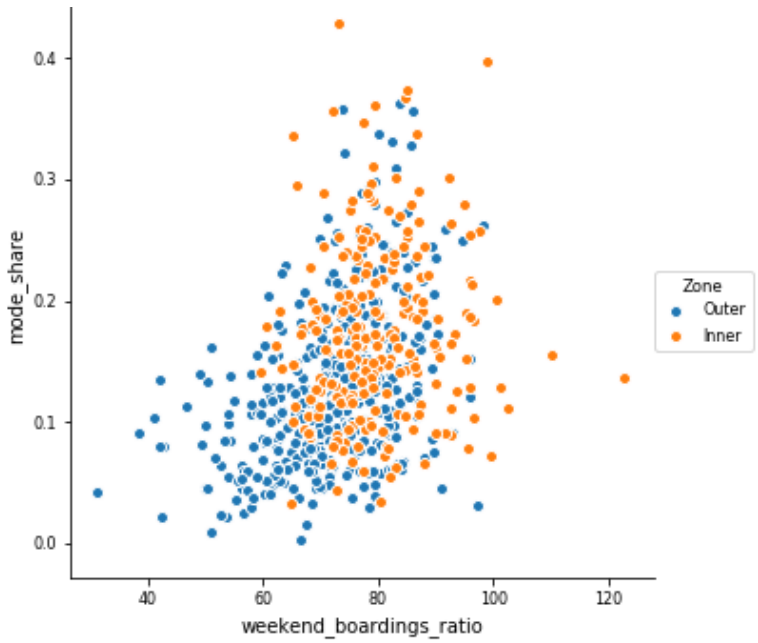


Figure 4-3: Bus Mode Share vs Weekend-Weekday Boarding Ratio (all-day av., %)

Note that a higher boarding ratio signifies more weekend boarding compared to weekday boarding.

4.5 Population data

Geographic, demographic and socio-economic data is extracted from the 2014 'Ward Profiles and Atlas' in the London Date Store (GLA, 2014). Minor changes are made to normalise some attributes by ward population or ward area as appropriate.

4.6 Data Overview

Figure 4-4 shows a heat chart summarising the variation of ward variables by borough and by Inner/Outer London. Note that variables have been standardised using min-max methodology.

Better Connectivity is observed in Inner London Boroughs, particularly City of London. Conversely, we see that Performance, measured by bus speed and bus speed change is worse in these boroughs. Population indicators are as expected. For example, denser populations are in Inner London Boroughs and greater car ownership in Outer London Boroughs.

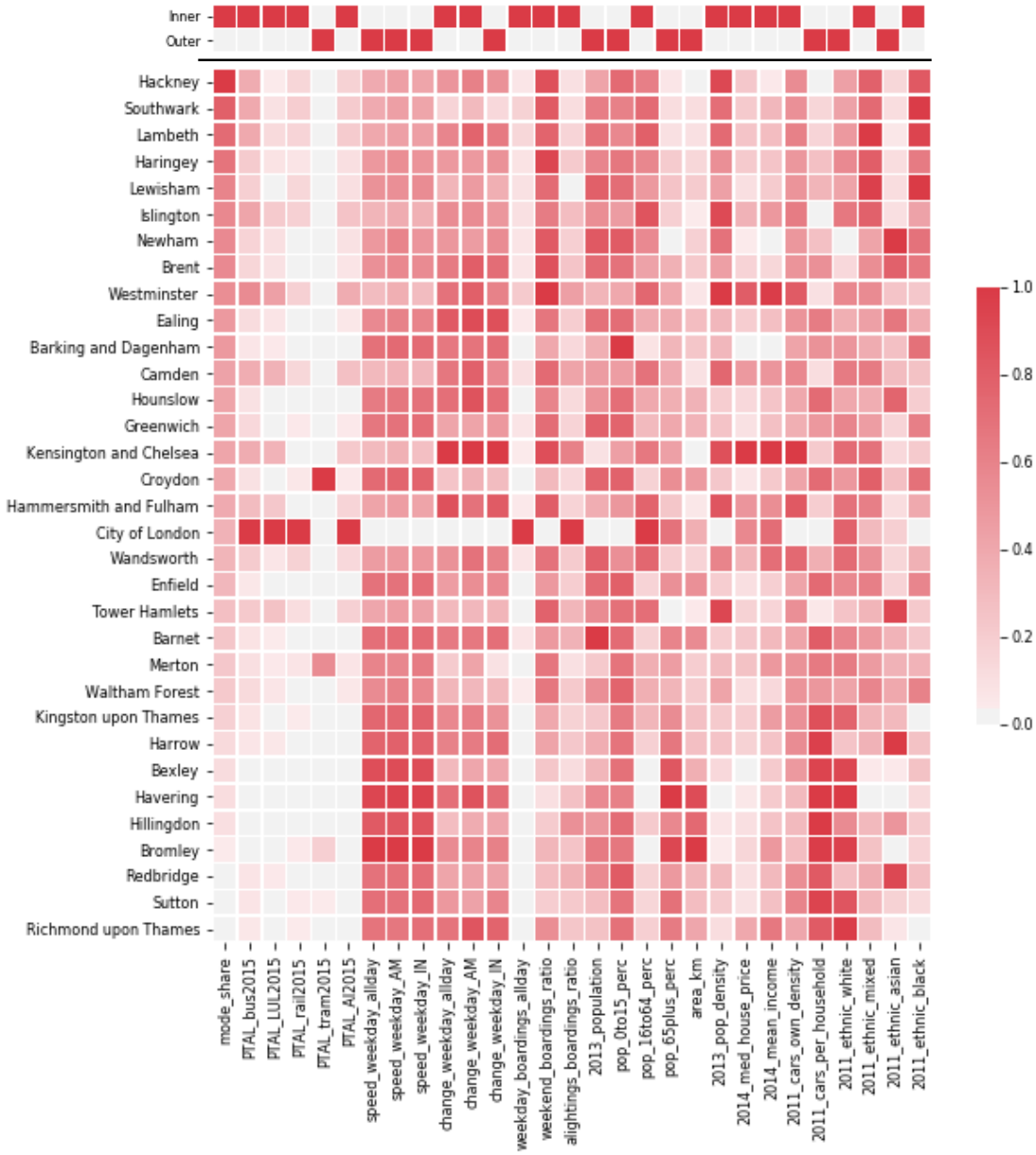


Figure 4-4:Borough Level Min-Max Data Summary

Chapter 5 Methodology

5.1 Regression Methodology

Bus mode share is a Binomial variable bounded between 0% and 100%. This can usefully be thought of as the probability of an individual in a given ward travelling by bus.

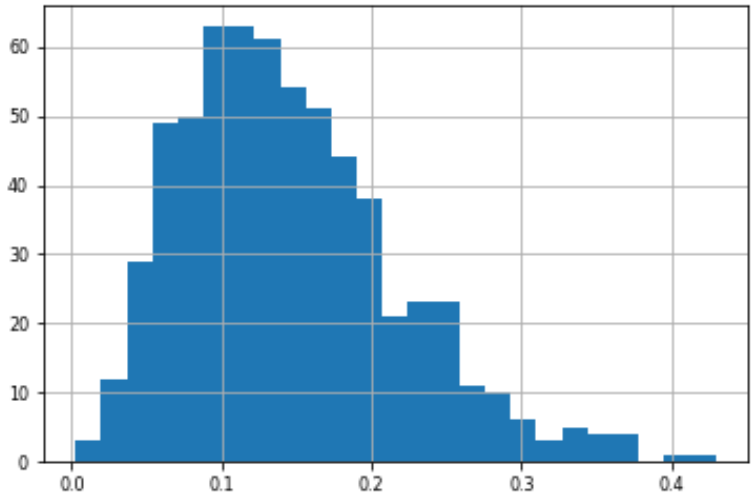


Figure 5-1: Bus Mode Share Histogram

The primary model used by this paper is a Generalised Linear Model (GLM) with logistic (Logit) link function. This is a similar approach to Owen and Levinson, 2015.

Linear predictor: $$\mu = \alpha + \boldsymbol{\beta X}$$

Logistic link function (Logit): $$ln\left(\frac{pn}{n-pn}\right) = \alpha + \boldsymbol{\beta X}$$

Where p is the probability of an individual in a given ward choosing to travel by bus (analogous to the predicted mode share of buses), n the number of instances (analogous to the ward population), α and $\boldsymbol{\beta}$ coefficients of the GLM and $\boldsymbol{X}$ the selected exogenous variables for each model.

Regression using Ordinary Least Squares (OLS) methodology is inappropriate for modelling this distribution as many of the observations are close to the distribution lower bound (Figure 5-1) (G Rodriguez, 2017). However, OLS Regression is used as a simple verification of the Binomial models and to assist model selection using the R^2 parameter.

5.2 Model Optimisation

A number of models with varying number of exogenous variables are considered. No variable interaction or non-linear interactions are considered (other than the Logit link function) in order to assist easier interpretation and therefore implementation of results.

Model variable selections are made using the general hypothesis in Chapter 3. Variable selection is further made with consideration of the correlation matrix (Appendix C) (to reduce co-correlation) and with sense checking. Overall model performances are compared using Pearson Chi^2. Although some consideration is made using R^2 from the OLS method.

5.3 Outlier Selection

Two methodologies are used to identify significant outliers from the model:

I. Actual data is > 10% deviation from modelled
II. Actual data is > 2 Pearson Residual Deviations (PRDs) from modelled

Chapter 6 Results

6.1 Single Variable Models

Single exogenous variable models are checked for each variable. Appendix D details the results. Proportion of population of black ethnicity is found to be the best performing.

6.2 Domain Models

Three domain models are developed by grouping the Connectivity, Performance and Population variables. Results from these models are in Appendix E. The Population model is best performing, followed by Performance and then Connectivity.

6.3 Full Models

Eight models are developed with varying number of exogenous variables. Results are in Appendix F. Final model selection is based on the parameter summary in Figure 6-1. A 15-variable model is selected (Model 4) based on the following observations:

I. Model 4 is the simplest model available prior to a drop of model quality
II. Model 4 has a relatively low and consistent number of outliers identified

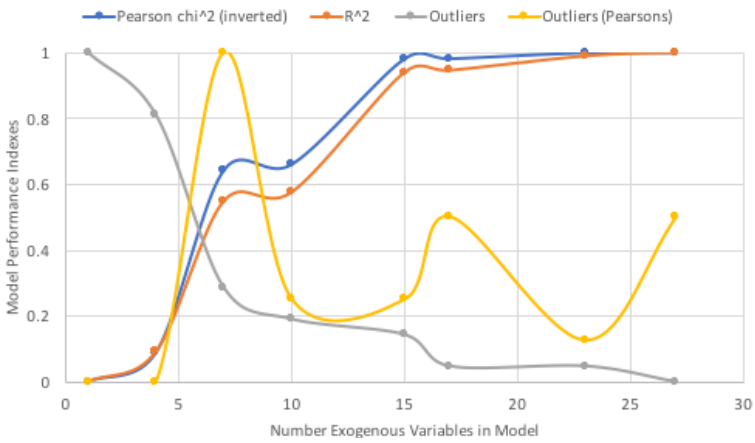


Figure 6-1: Model Selection Parameters.

Figure 6-2 shows fitted results from Model 4 against actual bus mode shares. There are no obvious patterns in the distribution of outliers, in-fact Figure 6-3 suggests a normal distribution of errors from the model.

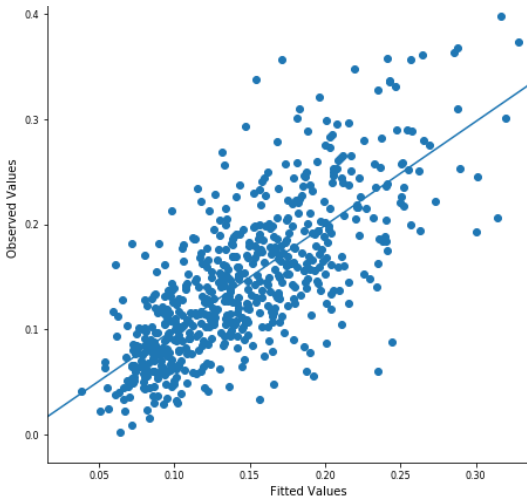


Figure 6-2: Model 4 - Fitted Versus Actual Ward Bus Mode Share

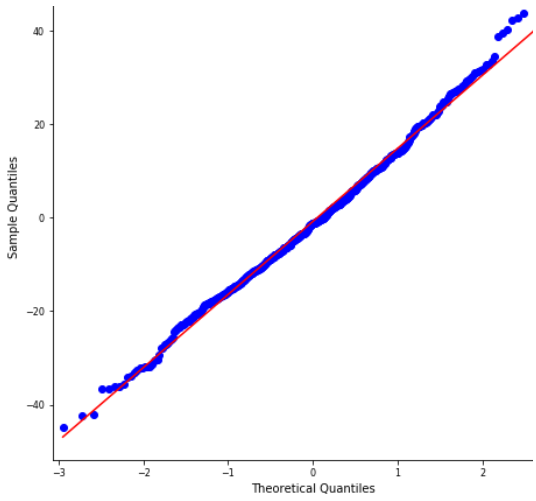


Figure 6-3: Model 4 - QQ - Plot

6.4 Model 4 Outliers

Identification of Model 4 outliers (using the PRD methodology) is shown in Figure 6-4. Figure 6-5 shows a min-max summary of variables for the over-performing and under-performing outliers. Outliers can be seen to occur in areas with higher population density and high levels of non-white ethnicities. A full list of the outliers is shown in Appendix A.

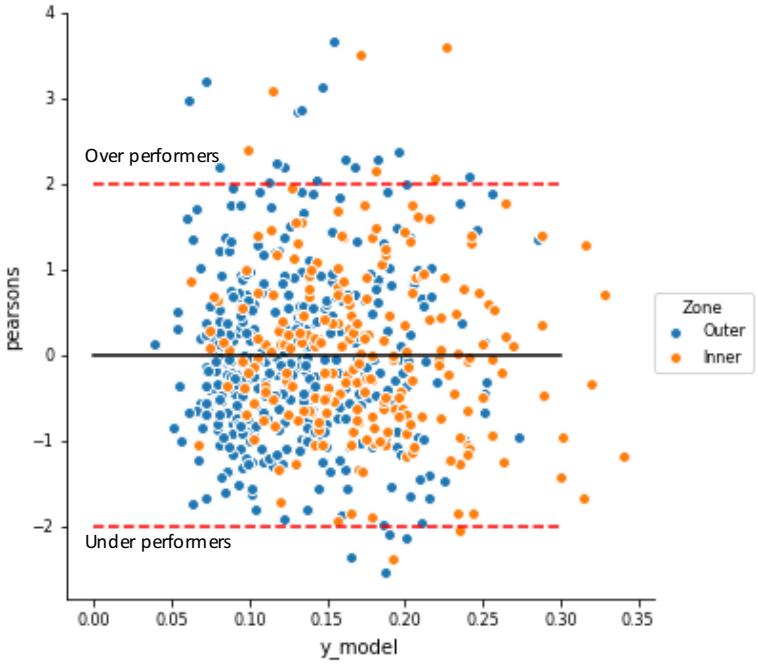


Figure 6-4: Model 4 - Standard Deviations (PRDs) of Actual vs Fitted Mode Share

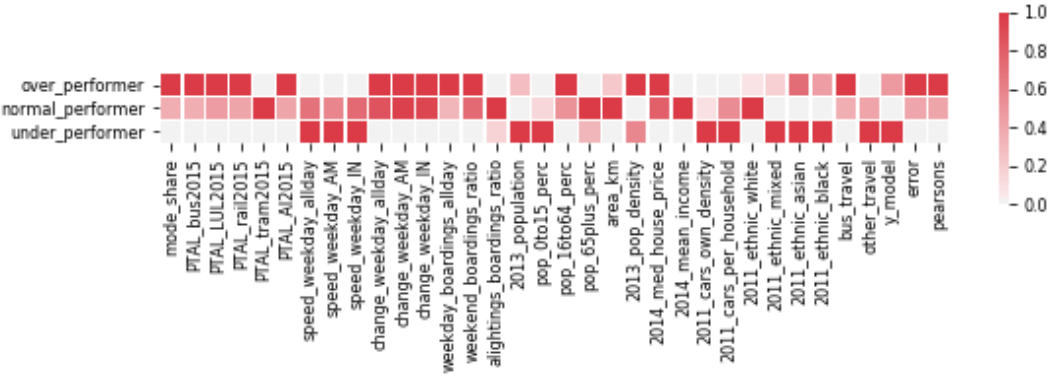


Figure 6-5: Model 4 – Outlier Min-Max Summary

Chapter 7 Conclusion and Discussion

The primary research question – whether a statistical model can assist TFL with policy making and intervention is confirmed. The methodology demonstrates the identification of 28 outlier wards. These wards are recommended for more detailed investigation by TfL, both to improve the model (therefore developing a better understanding of bus mode share) and to direct implementation of infrastructure, operational or policy change.

The model developed is aggregated to ward level in order to incorporate transport data such as Connectivity and Performance variables. This aggregation causes a trade-off between the incorporation of new data and the loss of individual dis-aggregate information.

When building the bus mode share models, population characteristics such as demographics and socio-economic status are found to provide more information than the transport Connectivity and Performance characteristics. This calls into question the usefulness of the aggregation methodology, however this would likely be improved by the inclusion of more data available through aggregation, such as land use and performance of other transport modes.

A more effective methodology for future analysis might be to aggregate by journey. This would allow inclusion of dis-aggregate traveller information as well as data linked to the journey by origin, route and destination.

Word count: 1777 (excluding figures, tables & appendices)

Appendix A. Outlier Results

			Mode Share			
Ward Name	Borough	Zone	Actual	Model	Error	Deviations
Over Performers						
Cranford	Hounslow	Outer	0.34	0.15	0.18	3.67
Hoxton West	Hackney	Inner	0.43	0.23	0.20	3.59
Hillrise	Islington	Inner	0.36	0.17	0.19	3.50
Northfield	Ealing	Outer	0.18	0.07	0.11	3.20
Barnhill	Hillingdon	Outer	0.29	0.15	0.15	3.12
West Hill	Wandsworth	Inner	0.23	0.12	0.12	3.08
Emerson Park	Havering	Outer	0.16	0.06	0.10	2.98
Northolt Mandeville	Ealing	Outer	0.26	0.13	0.12	2.87
Valley	Waltham Forest	Outer	0.27	0.13	0.14	2.84
Campden	Kensington and Chelsea	Inner	0.21	0.10	0.11	2.40
Higham Hill	Waltham Forest	Outer	0.32	0.20	0.13	2.38
Stratford and New Town	Newham	Outer	0.25	0.16	0.09	2.29
Figge's Marsh	Merton	Outer	0.31	0.18	0.13	2.27
Lesnes Abbey	Bexley	Outer	0.22	0.12	0.10	2.23
Hounslow West	Hounslow	Outer	0.28	0.17	0.11	2.20
Palmers Green	Enfield	Outer	0.21	0.12	0.09	2.19
Chessington South	Kingston upon Thames	Outer	0.17	0.08	0.09	2.19
St. James's	Westminster	Inner	0.30	0.18	0.12	2.14
Gascoigne	Barking and Dagenham	Outer	0.36	0.24	0.12	2.09
Bishop's	Lambeth	Inner	0.35	0.22	0.13	2.06
Lady Margaret	Ealing	Outer	0.24	0.14	0.09	2.04
West Finchley	Barnet	Outer	0.19	0.11	0.08	2.01
Under Performers						
Norland	Kensington and Chelsea	Inner	0.06	0.24	-0.18	-2.05
Forest	Waltham Forest	Outer	0.08	0.19	-0.11	-2.09
Royal Docks	Newham	Outer	0.09	0.20	-0.11	-2.13
William Morris	Waltham Forest	Outer	0.05	0.17	-0.12	-2.36
Bloomsbury	Camden	Inner	0.06	0.19	-0.14	-2.38
Valentines	Redbridge	Outer	0.06	0.19	-0.13	-2.54

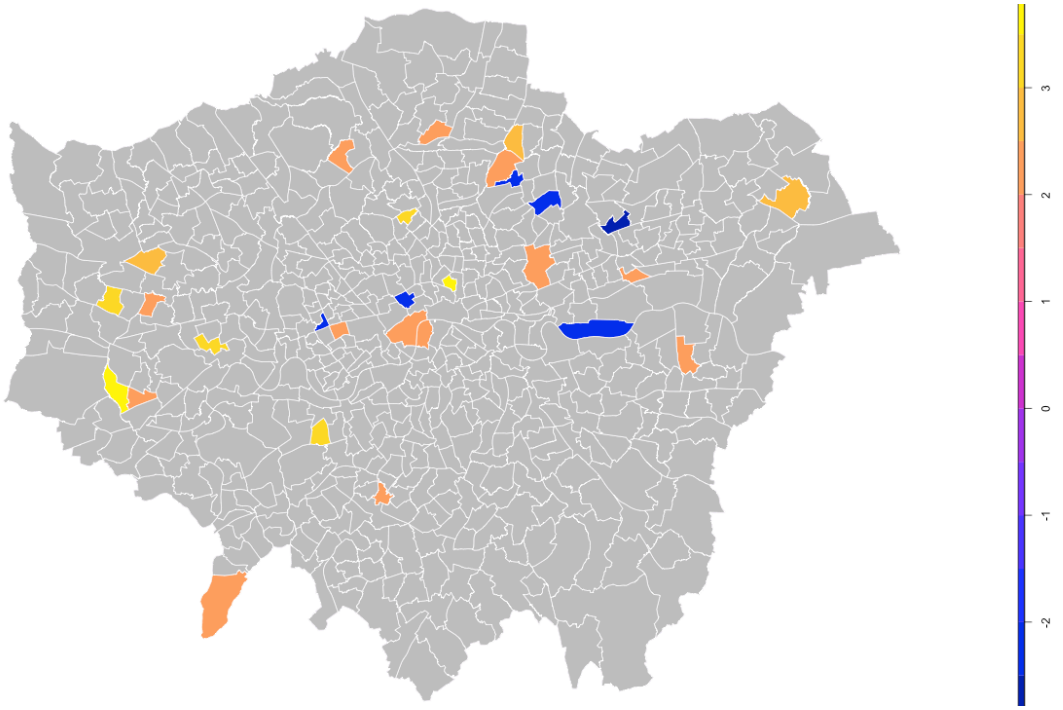


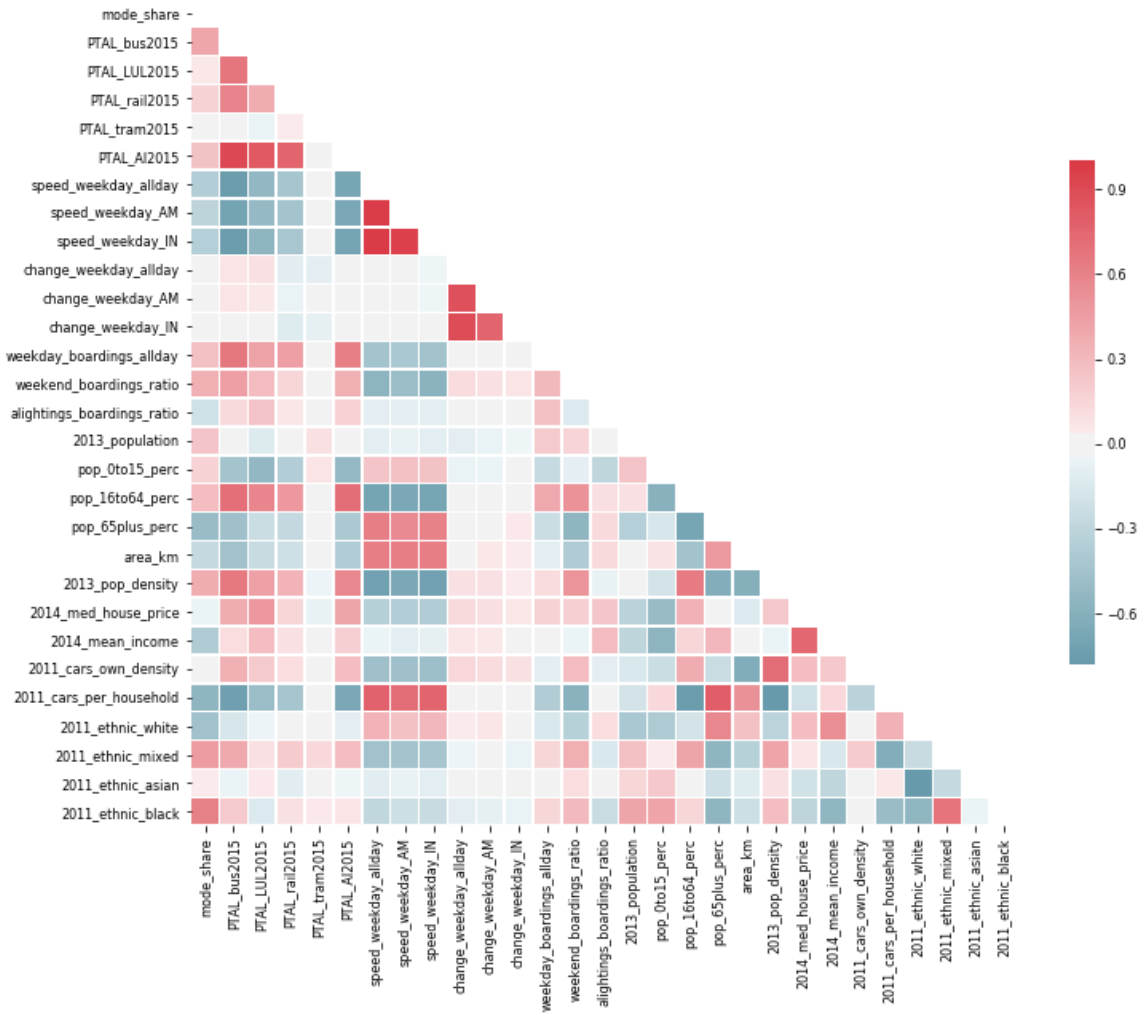
Figure 7-1: Model 4 – Outlier PRD Map

Appendix B. Data List and Sources

Table 7-1: Exogenous Variable Summary

	Variable	Source
Connectivity	PTAL_bus2015	TFL
	PTAL_LUL2015	TFL
	PTAL_rail2015	TFL
	PTAL_tram2015	TFL
	PTAL_AI2015	TFL
Performance	speed_weekday_allday	TFL
	speed_weekday_AM	TFL
	speed_weekday_IN	TFL
	change_weekday_allday	TFL
	change_weekday_AM	TFL
	change_weekday_IN	TFL
	weekday_boardings_allday	TFL
	weekend_boardings_ratio	TFL
	alightings_boardings_ratio	TFL
Population	2013_population	London Data Store
	pop_0to15_perc	London Data Store
	pop_16to64_perc	London Data Store
	pop_65plus_perc	London Data Store
	area_km	London Data Store
	2013_pop_density	London Data Store
	2014_med_house_price	London Data Store
	2014_mean_income	London Data Store
	2011_cars_own_density	London Data Store
	2011_cars_per_household	London Data Store
	2011_ethnic_white	London Data Store
	2011_ethnic_mixed	London Data Store
	2011_ethnic_asian	London Data Store
	2011_ethnic_black	London Data Store

Appendix C. Correlation Matrix



Appendix D. Single Variable Model Results

		BINOMIAL - GLM					OLS				
		β	P>|t|	[0.025	0.975]	chi2	β	P>|t|	[0.025	0.975]	R^2
Connectivity	PTAL_bus2015	0.0419	***	0.042	0.042	21.9	0.0058	***	0.005	0.007	0.165
	PTAL_LUL2015	0.007	***	0.007	0.007	26	0.009	***	0	0.002	0.003
	PTAL_rail2015	0.021	***	0.021	0.021	25.3	0.0031	***	0.002	0.004	0.03
	PTAL_tram2015	0.0565	***	0.052	0.061	26.1	0.007		-0.007	0.021	0.001
	PTAL_AI2015	0.0118	***	0.012	0.012	24.3	0.0016	***	0.001	0.002	0.069
Performance	speed_weekday_allday	-0.062	***	-0.063	-0.061	22.5	-0.0072	***	-0.009	-0.006	0.133
	speed_weekday_AM	-0.0582	***	-0.059	-0.058	23.5	-0.0067	***	-0.008	-0.005	0.094
	speed_weekday_IN	-0.0559	***	-0.056	-0.055	22.7	-0.0066	***	-0.008	-0.005	0.124
	change_weekday_allday	0.0303	***	0.027	0.034	26.1	0.039		-0.006	0.014	0.001
	change_weekday_AM	0.032	***	0.029	0.035	26.1	0.004		-0.006	0.014	0.001
	change_weekday_IN	0.0177	***	0.014	0.021	26.1	0.0018		0.025	0.975	0
	weekday_boardings_allday	1.72E-07	***	1.70E-07	1.74E-07	24.4	2.60E-07	***	1.87E-07	3.33E-07	0.072
	weekend_boardings_ratio	0.0199	***	0.02	0.02	22.6	0.0024	***	0.002	0.003	0.132
	alightings_boardings_ratio	-0.0024	***	-0.002	-0.002	25	-0.0003	***	0	0	0.042
Population	2013_population	5.19E-05	***	5.12E-05	5.26E-05	25.3	6.60E-06	***	4.62E-06	8.77E-06	0.06
	pop_0to15_perc	0.0286	***	0.028	0.029	25.5	0.034	***	0.002	0.005	0.03
	pop_16to64_perc	0.0308	***	0.03	0.031	24	0.0041	***	0.003	0.005	0.083
	pop_65plus_perc	-0.0729	***	-0.08	-0.079	18.7	-0.0089	***	-0.01	-0.008	0.256
	area_km	-0.0905	***	-0.092	-0.089	23.7	-0.0076	***	0.01	-0.005	0.072
	2013_pop_density	4.25E-05	***	4.21E-05	4.29E-05	22.5	5.59E-06	***	4.53E-06	6.65E-06	0.146
	2014_med_house_price	-2.21E-07	***	-2.30E-07	-2.12E-07	26	-1.85E-08		-4.00E-08	3.09E-09	0.005
	2014_mean_income	-1.79E-05	***	-1.80E-05	-1.77E-05	23.3	1.75E-06	***	-2.09E-06	-1.41E-06	0.141
	2011_cars_own_density	1.15E-05	***	9.23E-06	1.38E-05	26.1	1.98E-06		-4.57E-06	8.53E-06	0.001
	2011_cars_per_household	-1.0358	***	-1.042	-1.03	17.8	-0.1221	***	-0.137	0.108	0.304
	2011_ethnic_white	-0.0136	***	-0.014	-0.014	20.7	-0.0018	***	-0.002	-0.002	0.205
	2011_ethnic_mixed	0.167	***	0.166	0.168	20.6	0.022	***	0.019	0.025	0.223
	2011_ethnic_asian	0.0018	***	0.002	0.002	26.1	0.0002		0	0.001	0.002
	2011_ethnic_black	0.0327	***	0.032	0.033	17.3	0.0047	***	0.004	0.005	0.374

*** < 5% significance test ** <10% significance test *<20% significance test

Appendix E. Domain Model Results

		Connectivity Model			Performance Model			Population Model		
		BINOMIAL - GLM		OLS	BINOMIAL - GLM		OLS	BINOMIAL - GLM		OLS
		β	P>|t|	β	β	P>|t|	β	β	P>|t|	β
Connectivity	PTAL_bus2015	0.0757	***	0.0107						
	PTAL_LUL2015	-0.0428	***	-0.0062						
	PTAL_rail2015	-0.0156	***	-0.0021						
	PTAL_tram2015	0.0262	***	0.0032						
	PTAL_AI2015	Removed due to not providing additional information								
Performance	speed_weekday_allday				-0.4259	***	-0.0506			
	speed_weekday_AM				0.1773	***	0.0218			
	speed_weekday_IN				0.2131	***	0.0251			
	change_weekday_allday				0.1667	***	0.0178			
	change_weekday_AM				-0.0211	***	-0.0026			
	change_weekday_IN				-0.1212	***	-0.013			
	weekday_boardings_allday				1.28E-06	***	1.83E-07			
	weekend_boardings_ratio				0.005	***	0.0006			
	alightings_boardings_ratio				-0.003	***	-0.0003			
Population	2013_population	Removed due to statistical insignificance								
	pop_0to15_perc							1.10E-03	***	4.75E-05
	pop_16to64_perc	Removed due to not providing additional information								
	pop_65plus_perc							0.0098	***	0.0015
	area_km							-0.0211	***	-0.0021
	2013_pop_density							-1.41E-06	***	1.84E-06
	2014_med_house_price							4.66E-07	***	4.17E-08
	2014_mean_income							-1.14E-05	***	-9.01E-07
	2011_cars_own_density							-4.38E-05	***	-1.26E-05
	2011_cars_per_household							-0.5599	***	-0.0455
	2011_ethnic_white							-0.0154	***	-0.002
	2011_ethnic_mixed	Removed due to statistical insignificance								
	2011_ethnic_asian							-0.0122	***	-0.0017
	2011_ethnic_black							0.0033	***	0.001
Model	Pearson chi^2	**19.7**			**18.3**			**13.1**		
	R^2			**0.26**			**0.288**			**0.495**
	Adj R^2			**0.255**			**0.277**			**0.486**

*** < 5% significance test

Appendix F. Full Model Results

		MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8
		β	β	β	β	β	β	β	β
Connectivity	PTAL_bus2015	0.0369	0.0361	0.0377	0.0368				
	PTAL_LUL2015	-0.0272	-0.0267	-0.0269	-0.027	-0.0065	-0.0092		
	PTAL_rail2015	-0.0083	-0.0078	-0.0077	-0.0074	0.0015			
	PTAL_tram2015	0.0424	0.0354						
	PTAL_AI2015								
Performance	speed_weekday_allday	-0.0863	-0.0796						
	speed_weekday_AM	0.0304	0.0312	0.003	0.0151				
	speed_weekday_IN	0.069	0.0624	0.0133					
	change_weekday_allday	0.061	0.0593						
	change_weekday_AM	0.0365	0.035	0.0495	0.0398	0.0714	0.0648	0.0845	
	change_weekday_IN	-0.0471	-0.0439	-0.0108					
	weekday_boardings_allday	-5.88E-08							
	weekend_boardings_ratio	7.00E-04	0.0008	0.0007	0.0003	0.0021	0.0009		
	alightings_boardings_ratio	-0.0015	-0.0015	-0.0015	-0.0015	-0.0012	-0.0012	-0.0008	
Population	2013_population	2.77E-06							
	pop_0to15_perc	5.38E-02							
	pop_16to64_perc	5.52E-02							
	pop_65plus_perc	6.84E-02	0.0134	0.0127	0.0122				
	area_km	-2.03E-02	-0.02						
	2013_pop_density	-8.36E-06	-6.46E-06	-1.78E-05	-1.81E-05	-1.25E-05			
	2014_med_house_price	5.05E-07	4.85E-07	4.84E-07	4.77E-07				
	2014_mean_income	-9.64E-06	-9.38E-06	-1.02E-05	-1.02E-05	-5.34E-06			
	2011_cars_own_density	-6.73E-05	-7.75E-05						
	2011_cars_per_household	-0.69	-0.6668	-0.8335	-0.8162	-0.9423	-0.8007		
	2011_ethnic_white	-0.0177	-0.0171	-0.0173	-0.0176				
	2011_ethnic_mixed	-0.0178							
	2011_ethnic_asian	-0.0129	-0.0119	-0.011	-0.0116	0.0038	0.0052	0.0045	
	2011_ethnic_black	-0.003	-0.0038	-0.0035	-0.004	0.0151	0.0201	0.033	0.0327
Model	Variables	27	23	17	15	10	7	4	1
	Model Pearson chi^2	11.7	11.7	11.8	11.8	13.6	13.7	16.8	17.3
	Model R^2	0.558	0.556	0.548	0.547	0.48	0.475	0.391	0.374
	Outliers (>10%)	29	30	30	32	33	35	46	50
	Outliers (>2 Standard Devs.)	30	27	30	28	28	34	26	26

Appendix G. Data Investigation

7.1 Connectivity Data

PTAL Codes:

AI: Accessibility Index, **LUL**: London Underground Lines, **bus**: London buses, **rail**: Rail Services, **tram**: London Tram.

Table 7-2: Bus Mode Share Summary

	PTAL_bus2015	PTAL_LUL2015	PTAL_rail2015	PTAL_tram2015	PTAL_AI2015
Mean	7.830	2.684	2.483	0.065	13.063
Standard Dev.	5.070	4.745	4.063	0.401	11.670
Minimum	0.617	0.000	0.000	0.000	0.617
Median	6.513	0.561	1.130	0.000	9.355
Maximum	32.423	31.874	37.239	4.668	91.315

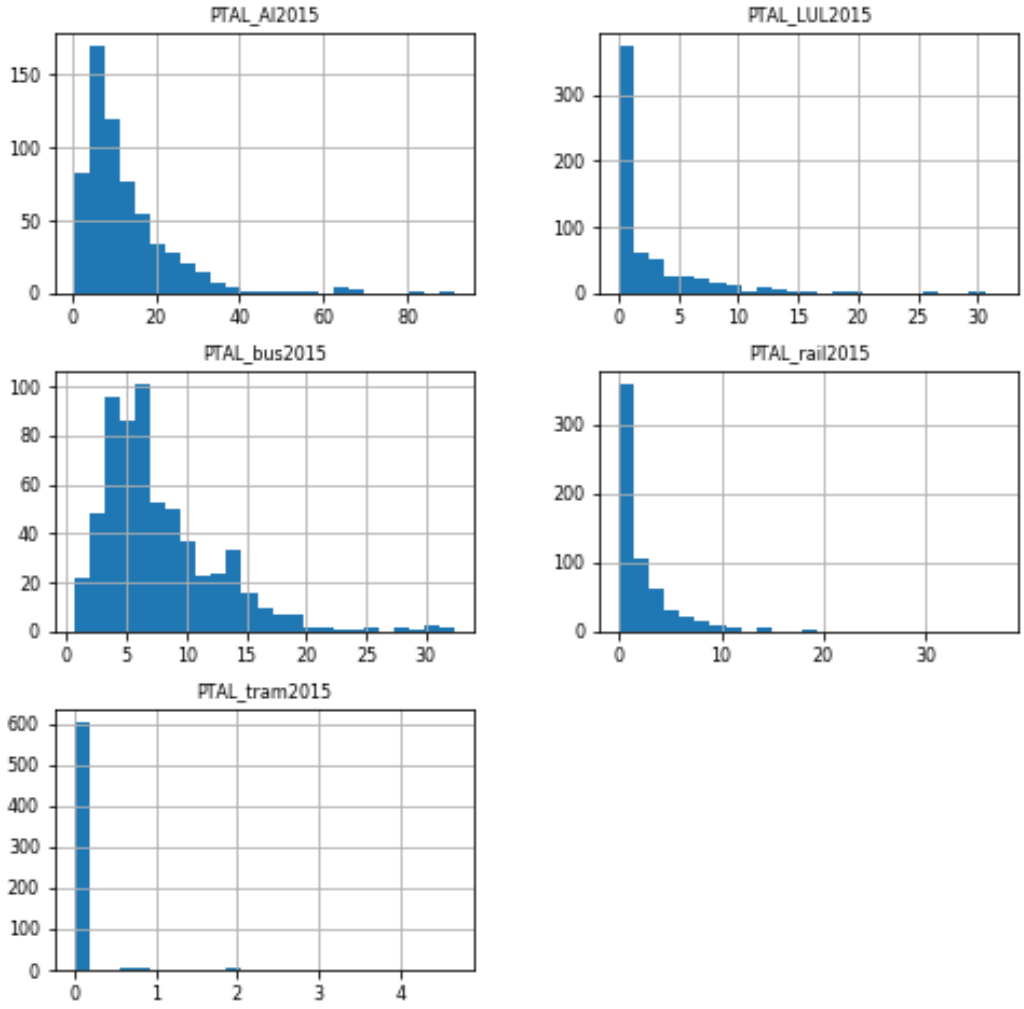


Figure 7-2: PTAL distribution

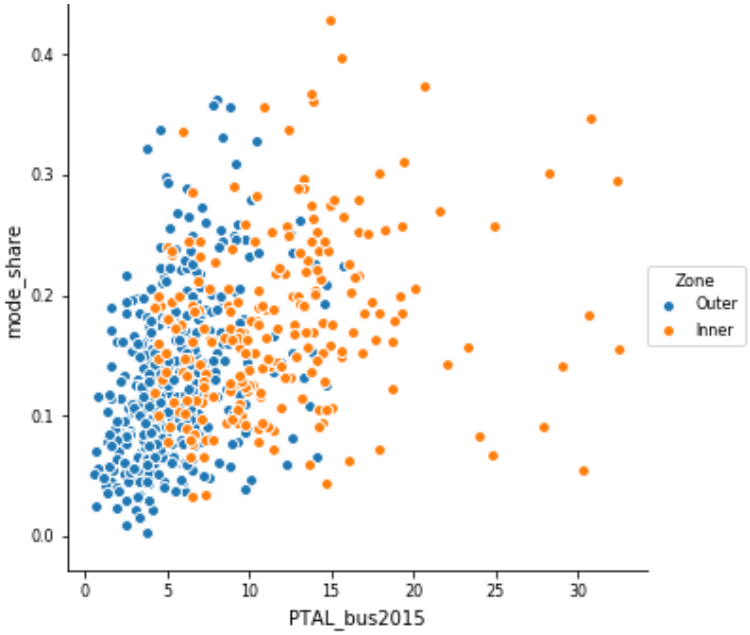


Figure 7-3: Bus Mode Share vs Bus PTAL

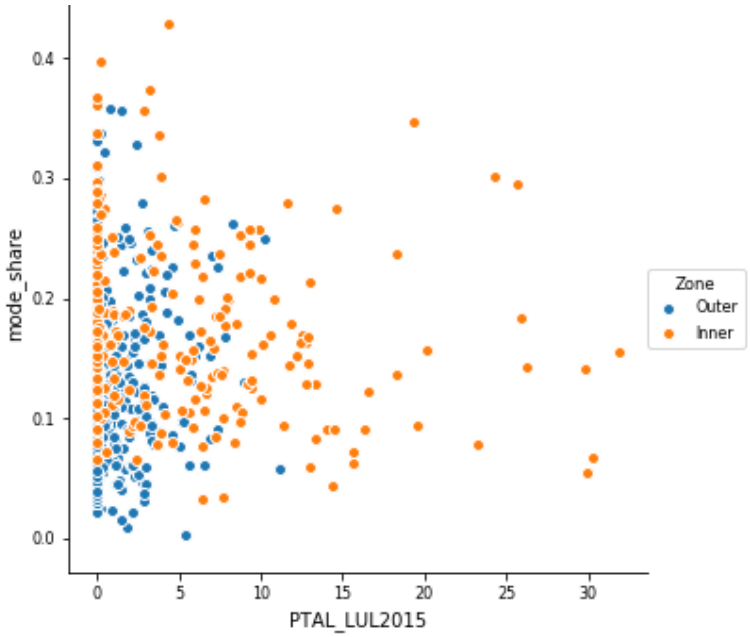


Figure 7-4: Bus Mode Share vs LUL PTAL

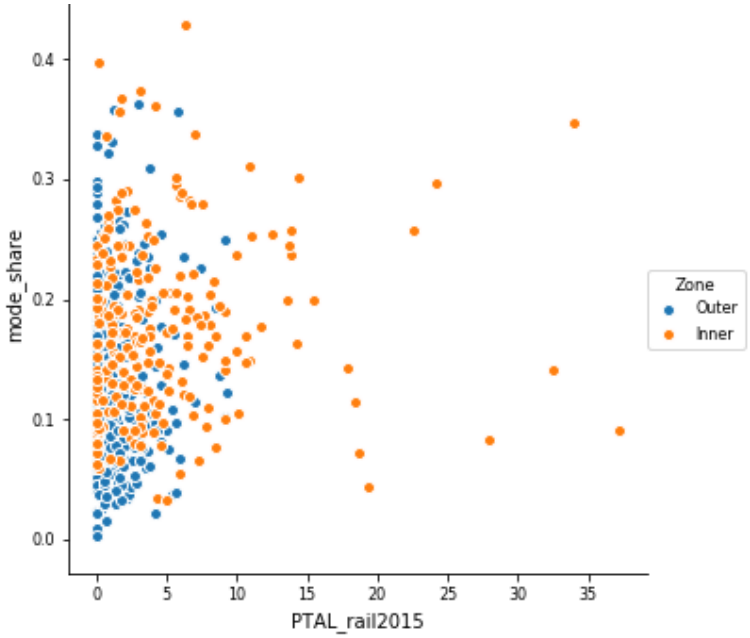


Figure 7-5: Bus Mode Share vs Rail PTAL

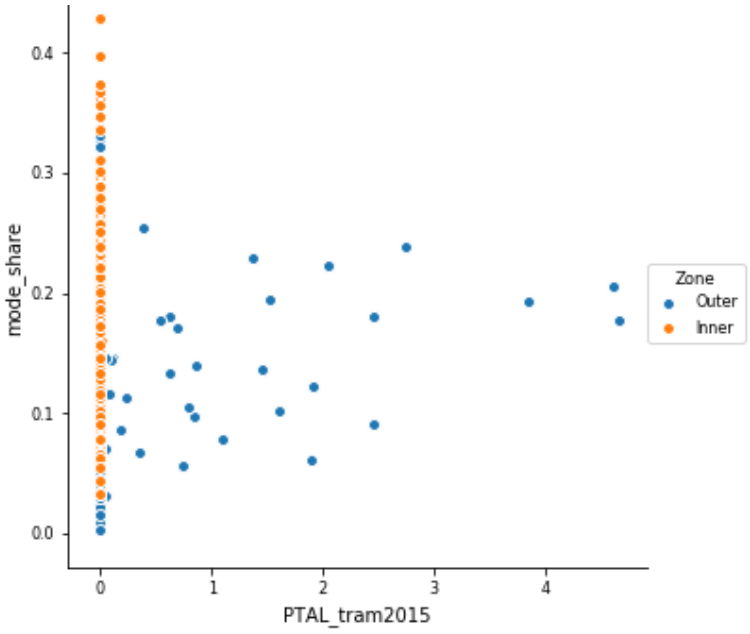


Figure 7-6: Bus Mode Share vs Tram PTAL

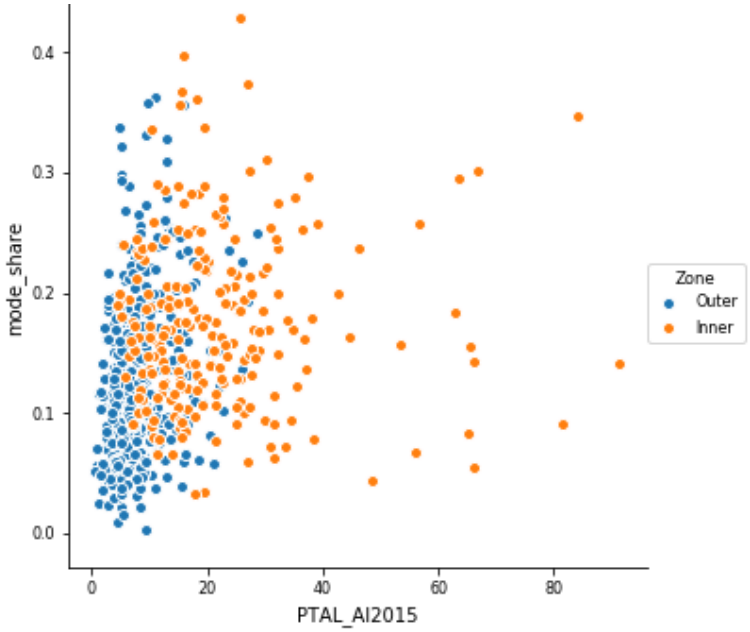


Figure 7-7: Bus Mode Share vs Accessibility Index PTAL

7.2 Performance data

7.2.1 Bus Speeds

Bus Period Codes:	
AM: Morning period 07:00 to 09:00	**IN**: Inter-peak period 10:00 to 16:00

Table 7-3: Average Bus Speeds Summary

	Speed_weekday_all-day	Speed_weekday_AM	Speed_weekday_IN
Mean	18.661	17.407	17.993
Standard Dev.	3.673	3.309	3.895
Minimum	10.124	7.612	8.363
Median	18.315	17.084	17.656
Maximum	36.708	35.001	36.470

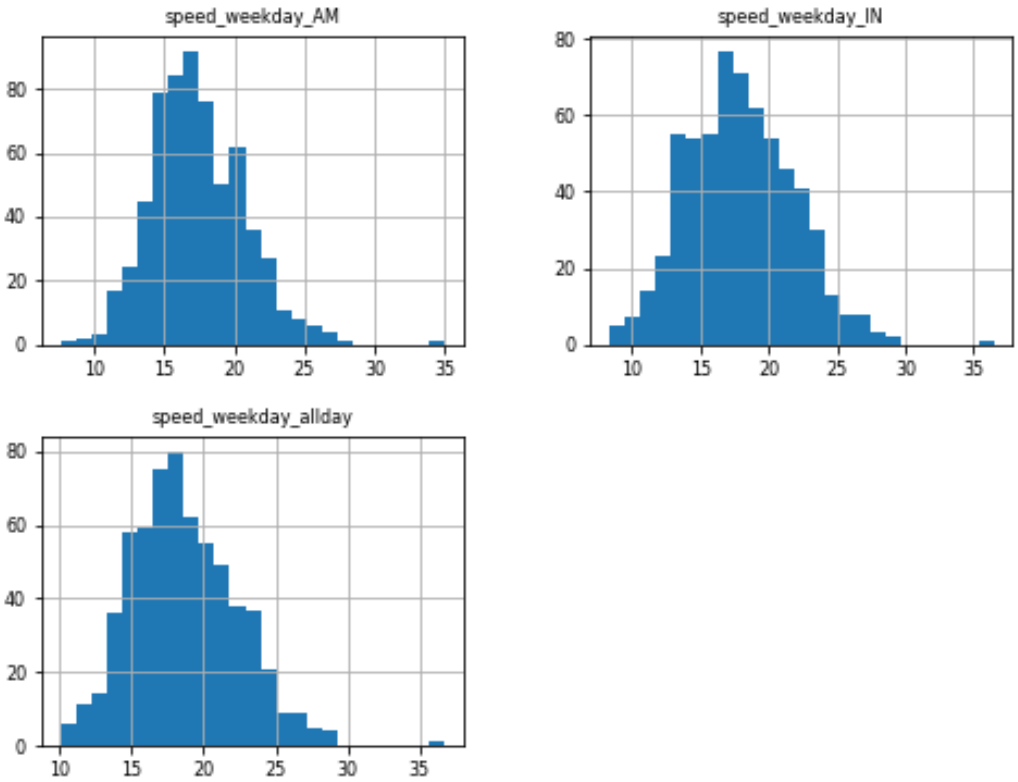


Figure 7-8: Average Bus Speeds Distributions

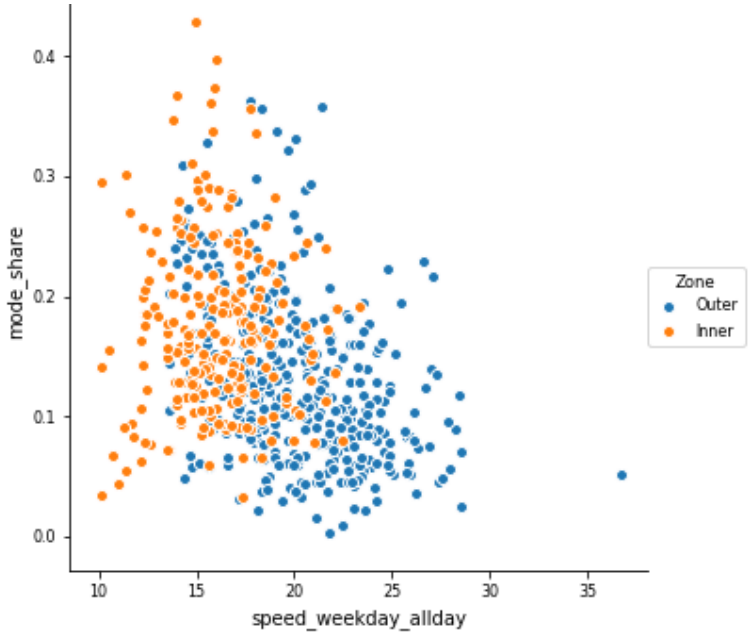


Figure 7-9: Bus Mode Share vs Bus Speed (all-day average)

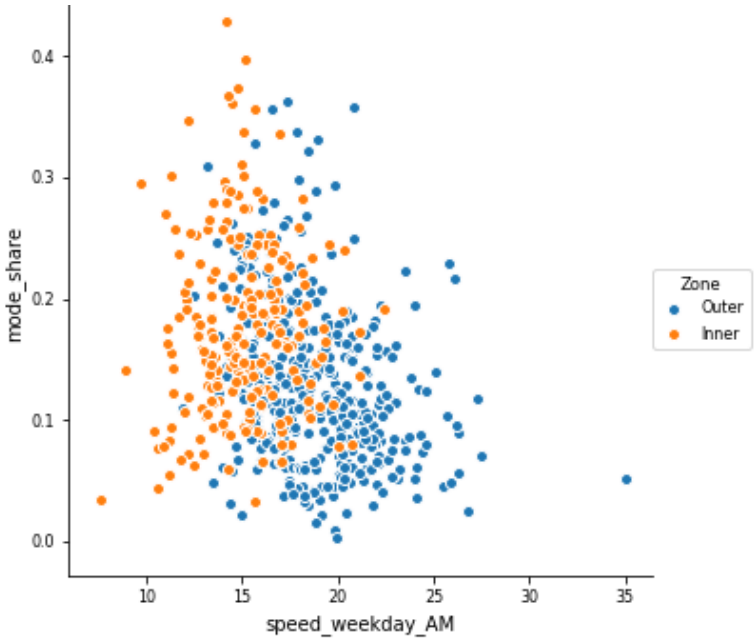


Figure 7-10: Bus Mode Share vs Bus Speed (morning average)

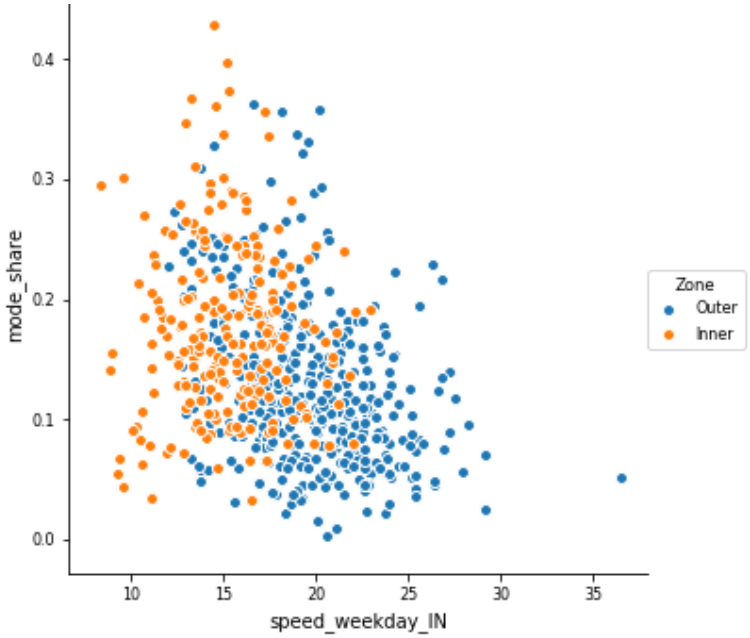


Figure 7-11: Bus Mode Share vs Bus Speed (inter-peak average)

7.2.2 Bus Speed Change

Bus speed change from 2014/15 to 2016/17 is considered for the all-day, morning and inter-peak periods.

Table 7-4: Average Bus Speed Change Summary

	Change_weekday_all-day	Change_weekday_AM	Change_weekday_IN
Mean	-0.521	-0.547	-0.532
Standard Dev.	0.547	0.596	0.591
Minimum	-2.791	-3.008	-3.046
Median	-0.522	-0.543	-0.537
Maximum	3.294	2.791	2.907

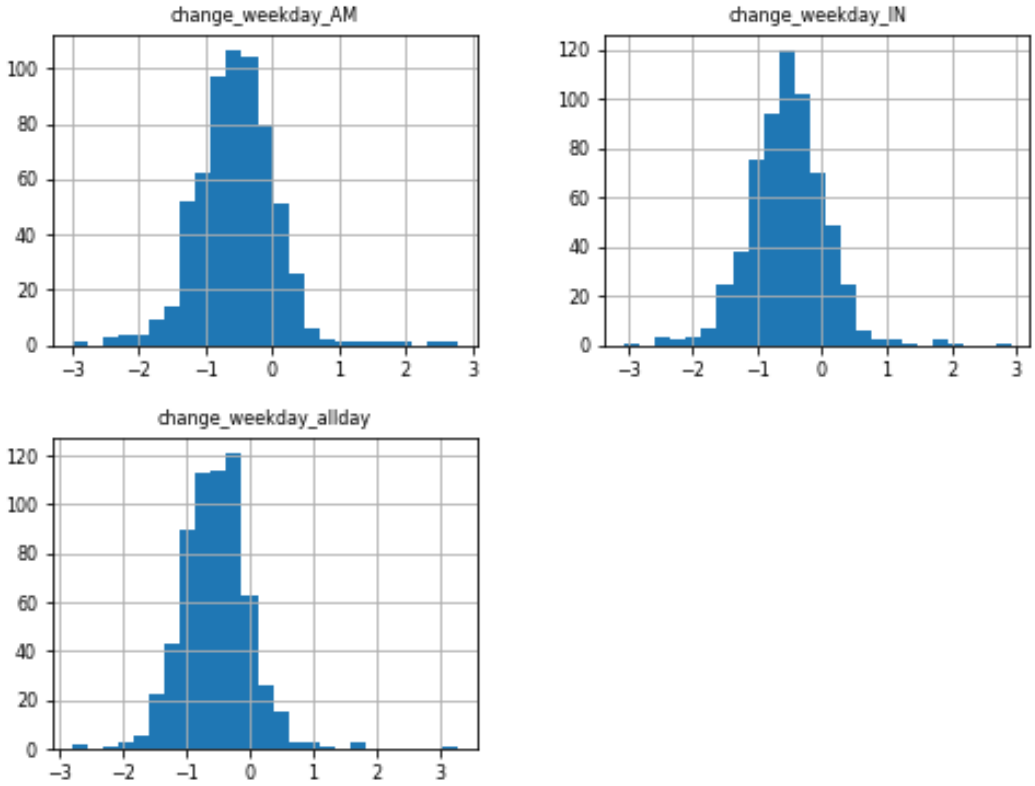


Figure 7-12: Average Bus Speed Change Distributions

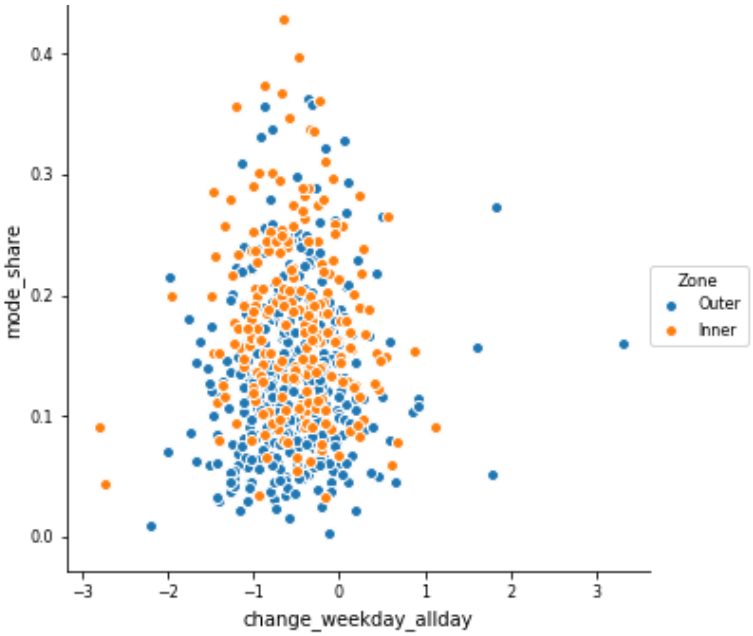


Figure 7-13: Bus Mode Share vs Bus Speed Change (all-day average)

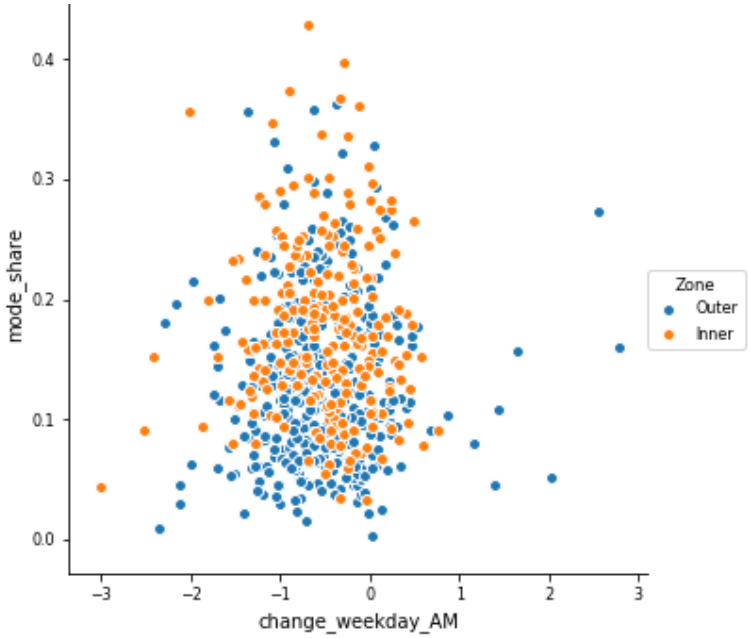


Figure 7-14: Bus Mode Share vs Bus Speed Change (morning average)

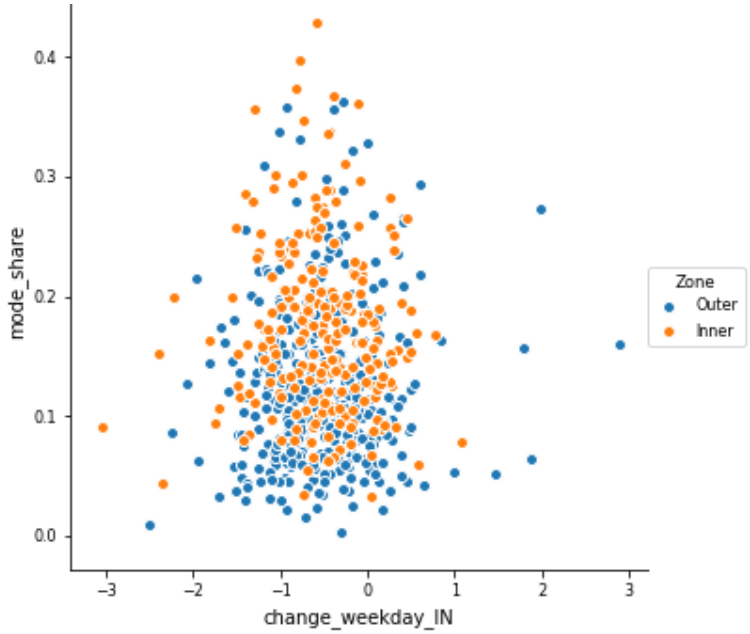


Figure 7-15: Bus Mode Share vs Bus Speed Change (inter-peak average)

7.2.3 Bus Boarding and Alighting

Table 7-5: Bus Boarding and Alighting Summary

	weekday_boardings_allday	weekend_boardings_ratio	alightings_boardings_ratio
Mean	52443.835	74.616	102.053
Standard Dev.	74679.653	10.812	54.765
Minimum	1016.418	31.209	12.735

Median	29349.201	75.186	92.940
Maximum	805654.050	122.559	511.055

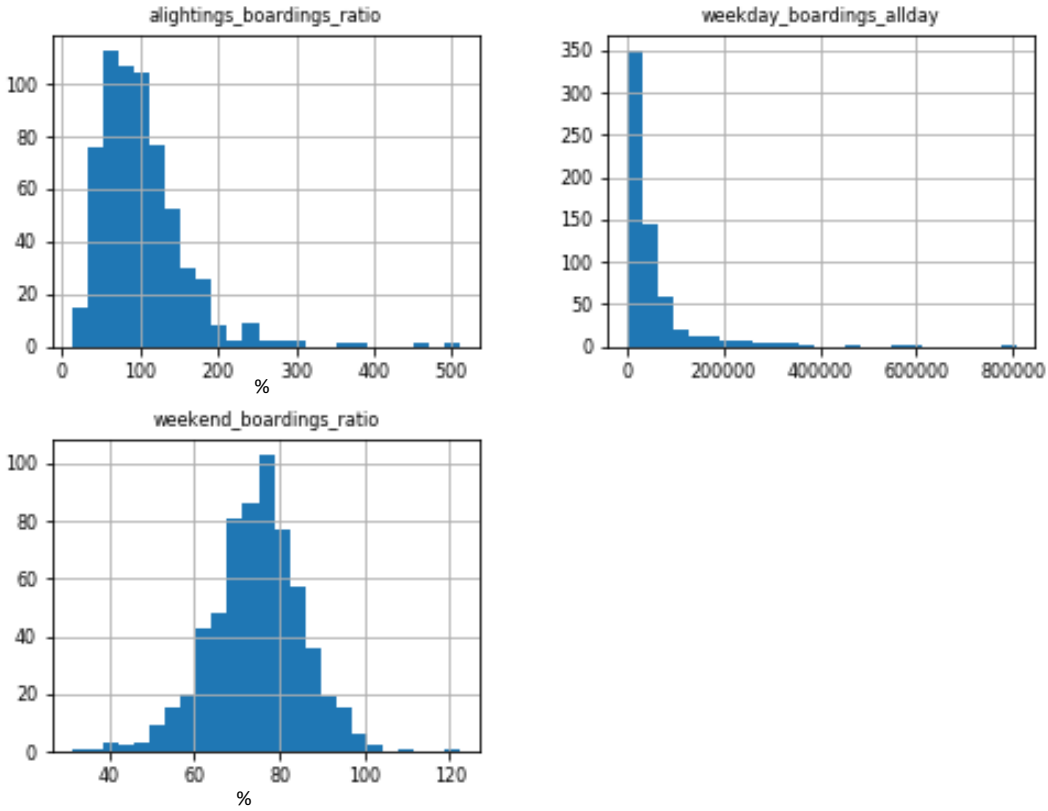


Figure 7-16: Bus Boarding and Alighting Distributions

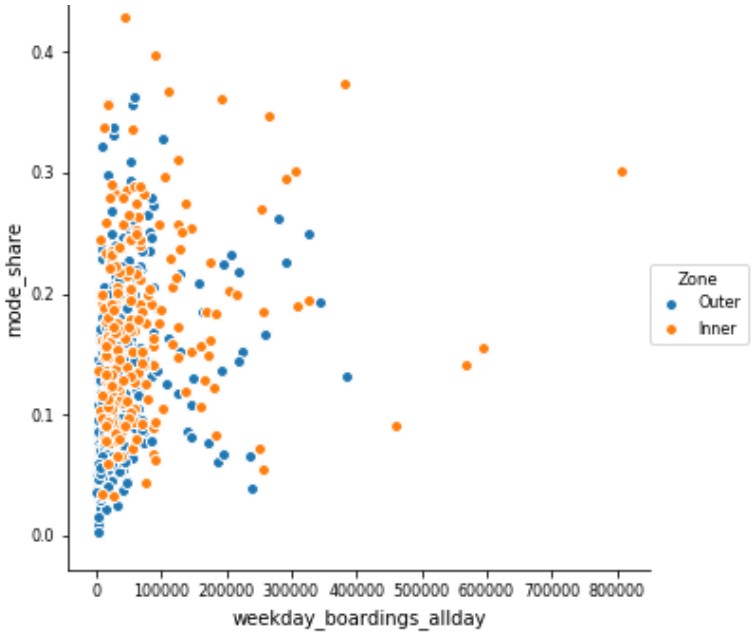


Figure 7-17: Bus Mode Share vs Boarding (all-day average)

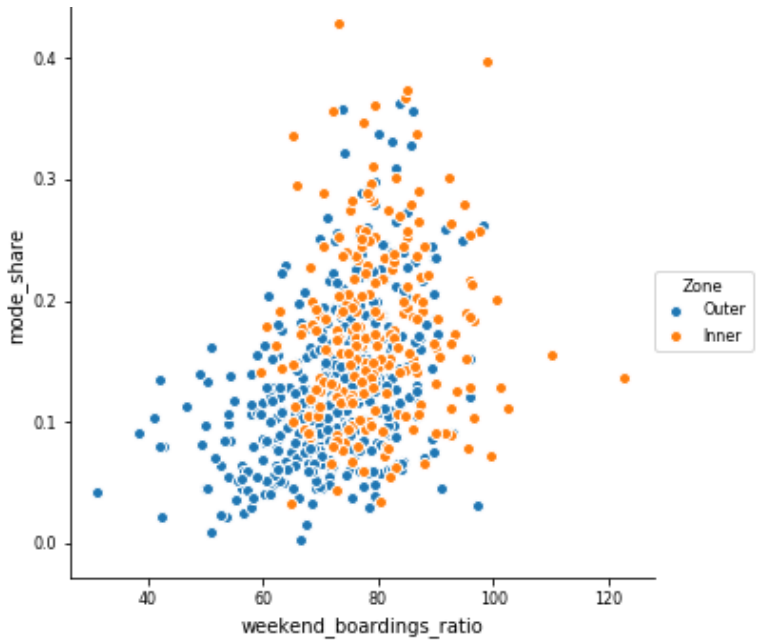


Figure 7-18: Bus Mode Share vs Weekend-Weekday Boarding Ratio (all-day av., %)

Note that higher ratios signify more weekend boarding compared to weekday boarding.

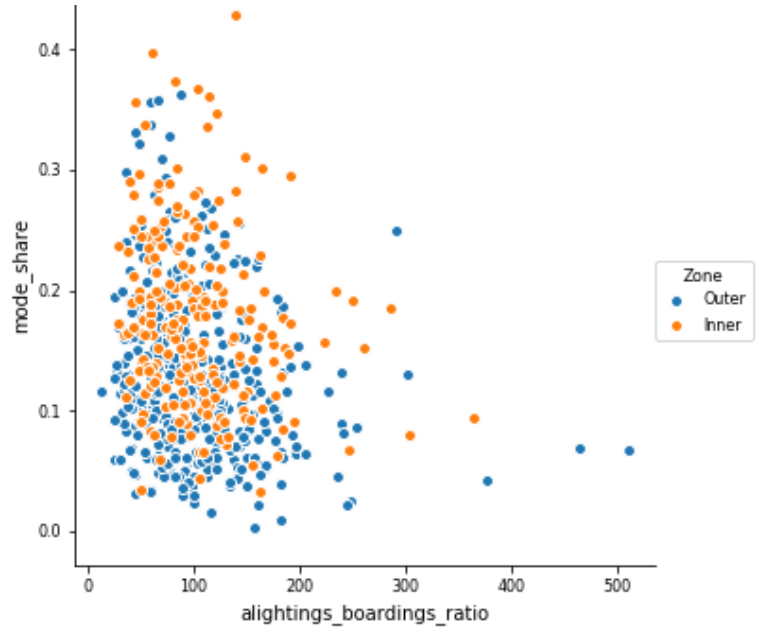


Figure 7-19: Bus Mode Share vs Alighting-Boarding Ratio (am av., %)

Note that higher ratios signify higher morning arrivals compared to departures (by bus).

7.3 Population data

7.3.1 Ward Attributes

2013 ward population, area and then population density are considered.

Table 7-6: Ward Attribute Summary

	2013_population	Area_km	2013_pop_density
Mean	13396.30	2.50	8405.85
Standard Dev.	2655.72	2.56	4949.24
Minimum	5249.00	0.35	180.75
Median	13254.00	1.84	7155.53
Maximum	22393.00	29.04	26985.02

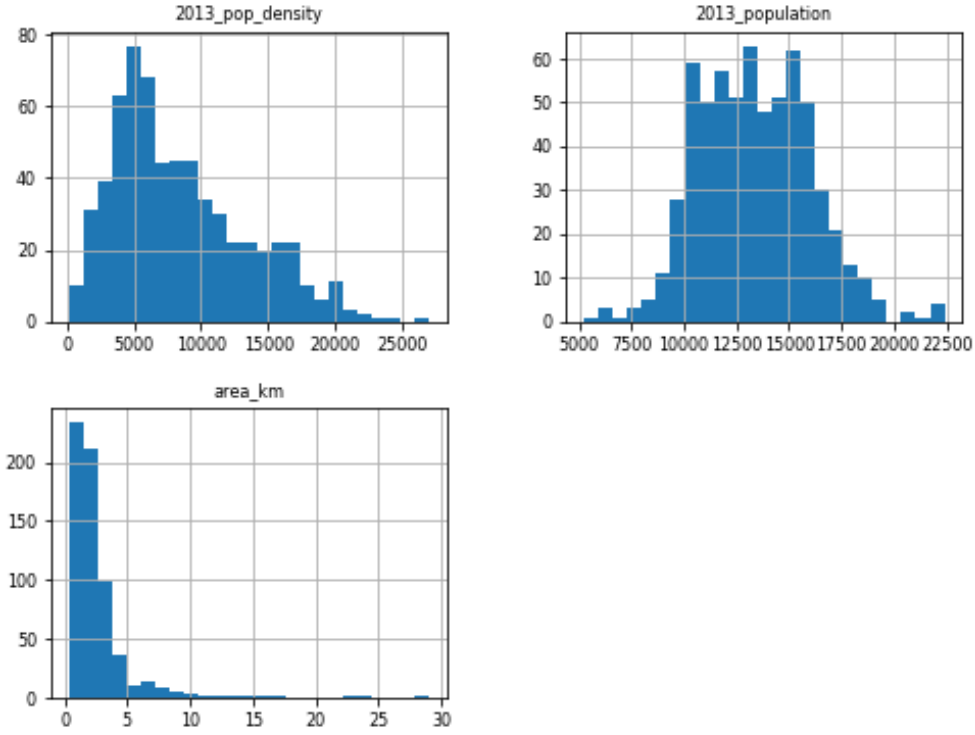


Figure 7-20: Ward Attribute Distributions

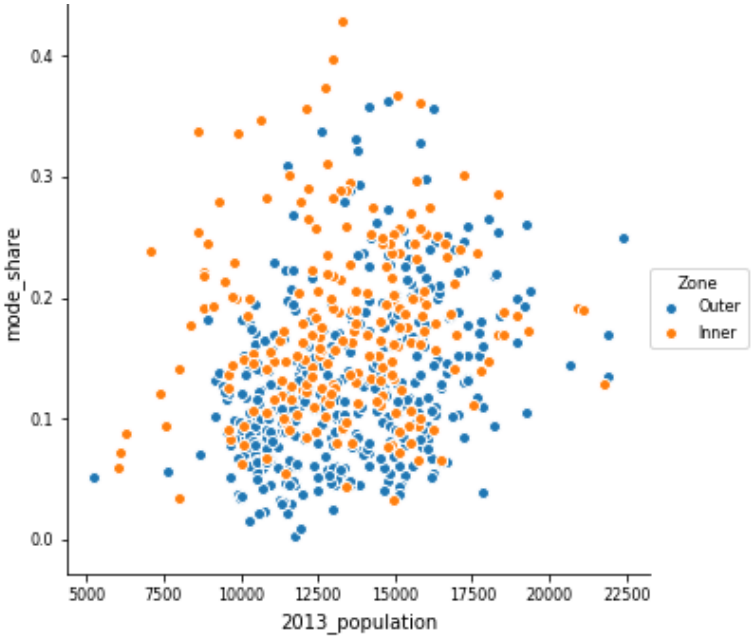


Figure 7-21: Bus Mode Share vs 2013 Population

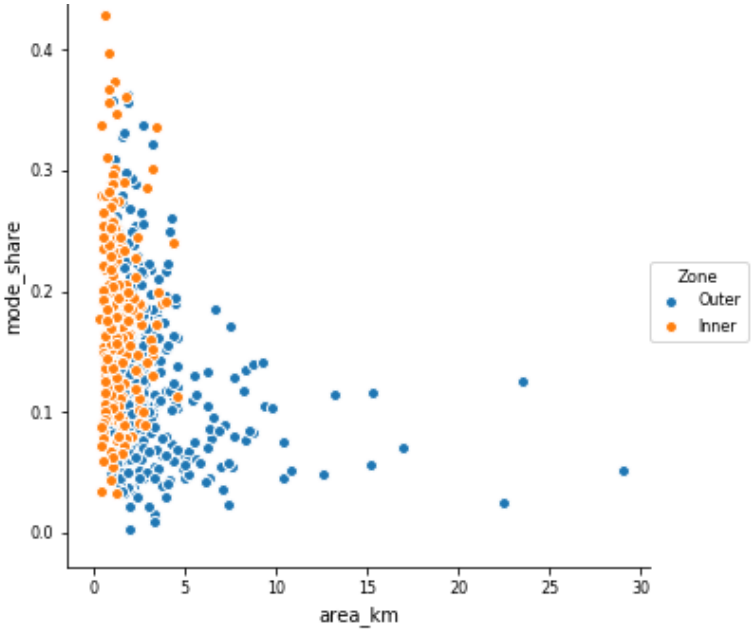


Figure 7-22: Bus Mode Share vs Ward Area (km^2)

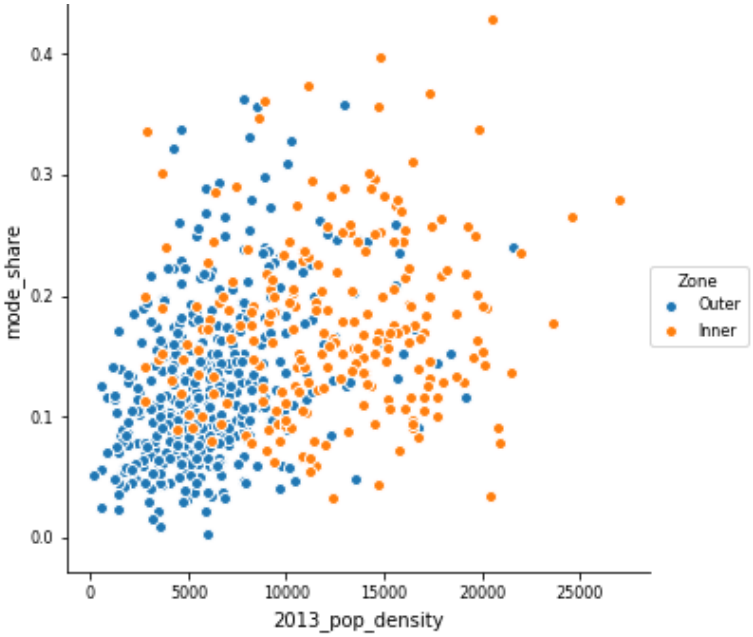


Figure 7-23: Bus Mode Share vs 2013 Ward Population Density (pop/km^2)

7.3.2 Ward Demographic Attributes

2011 Age groups and ethnicities are considered as 2011 proportions (%) of total ward population.

Table 7-7: Ward Demographics Summary

	pop_0to15	pop_16to64	pop_65+	ethnic_white	ethnic_mixed	ethnic_asian
Mean	19.65	68.69	11.65	59.44	4.72	17.44
Standard Dev.	3.68	5.05	4.13	18.73	1.55	14.90
Minimum	6.87	58.10	4.03	5.69	1.25	1.22
Median	19.60	67.94	10.88	62.06	4.60	11.86
Maximum	31.67	83.69	24.70	94.29	9.62	75.33

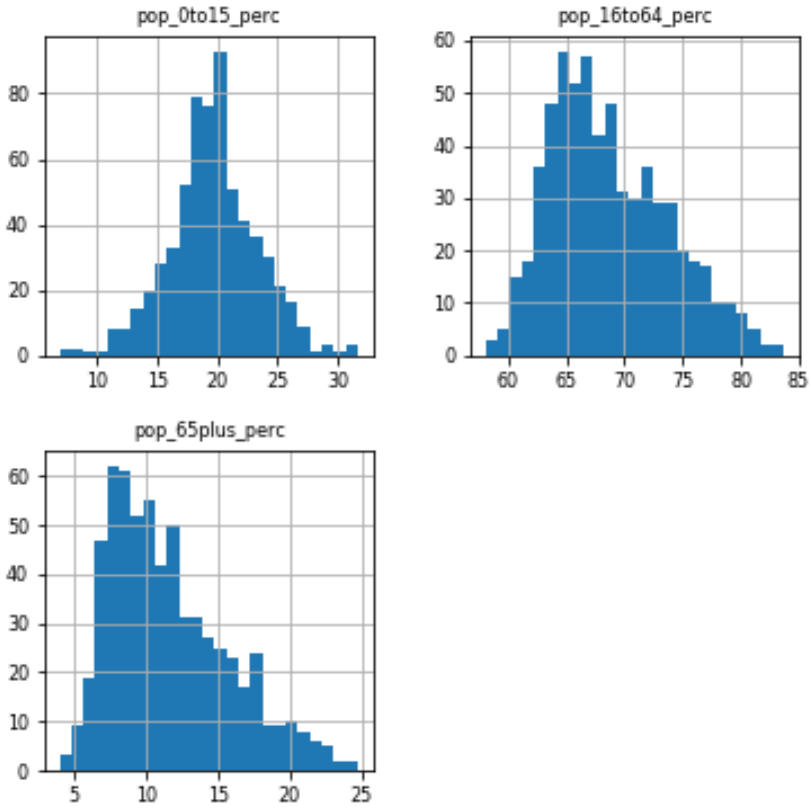


Figure 7-24: Ward Age Distributions

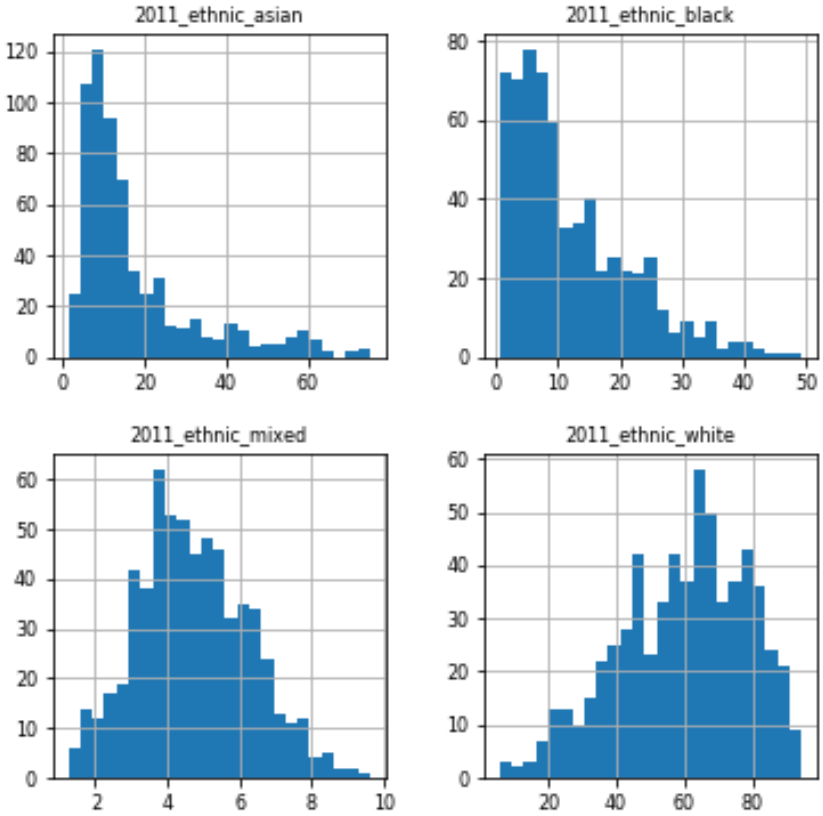


Figure 7-25: Ward Ethnicity Distributions

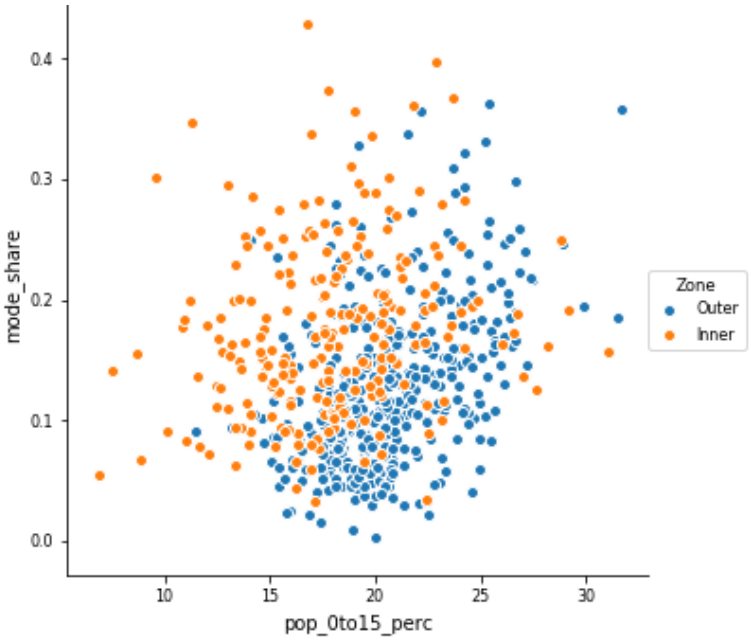


Figure 7-26: Bus Mode Share vs Proportion of Pop. Under 16 (%)

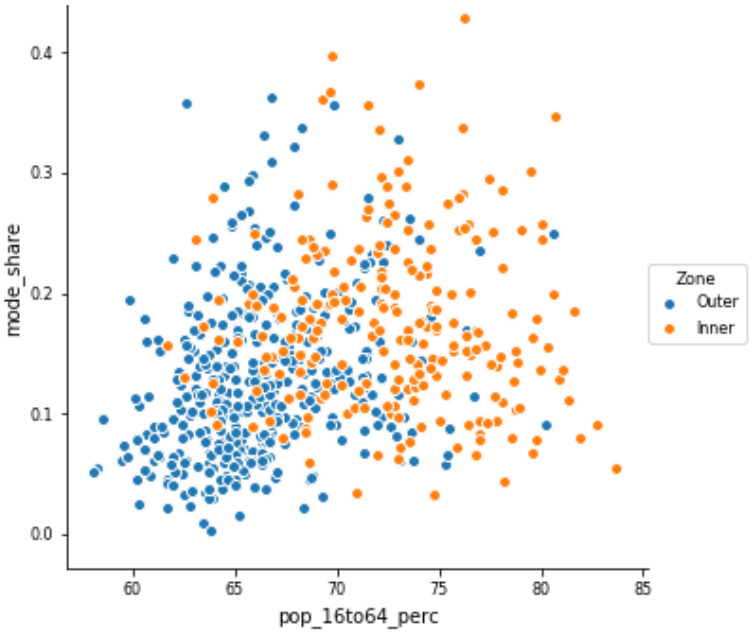


Figure 7-27: Bus Mode Share vs Proportion of Pop. 16-64 (%)

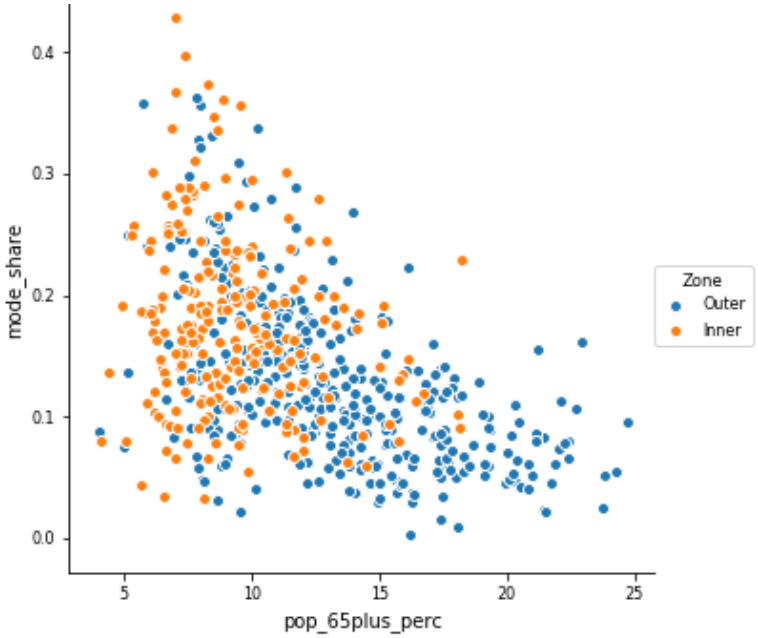


Figure 7-28: Bus Mode Share vs Proportion of Pop. Over 64 (%)

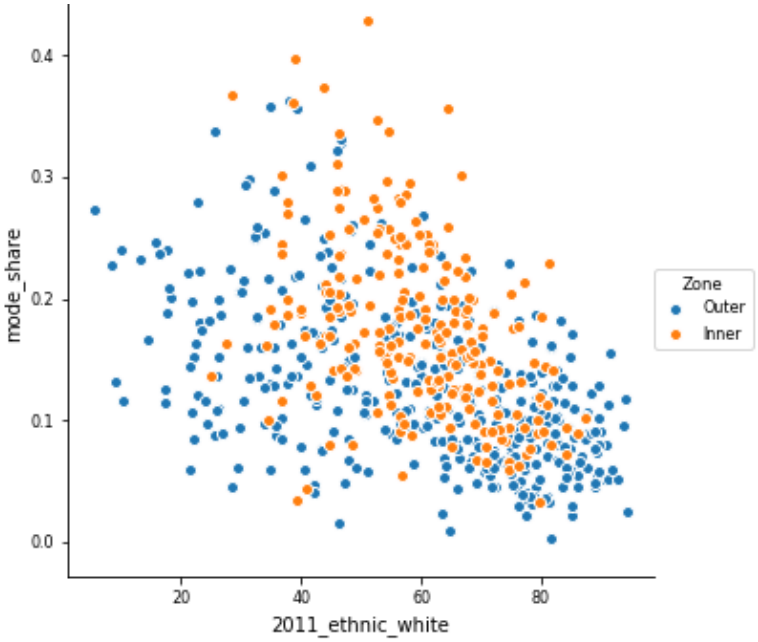


Figure 7-29: Bus Mode Share vs Proportion of Pop. Ethnicity Group White (%)

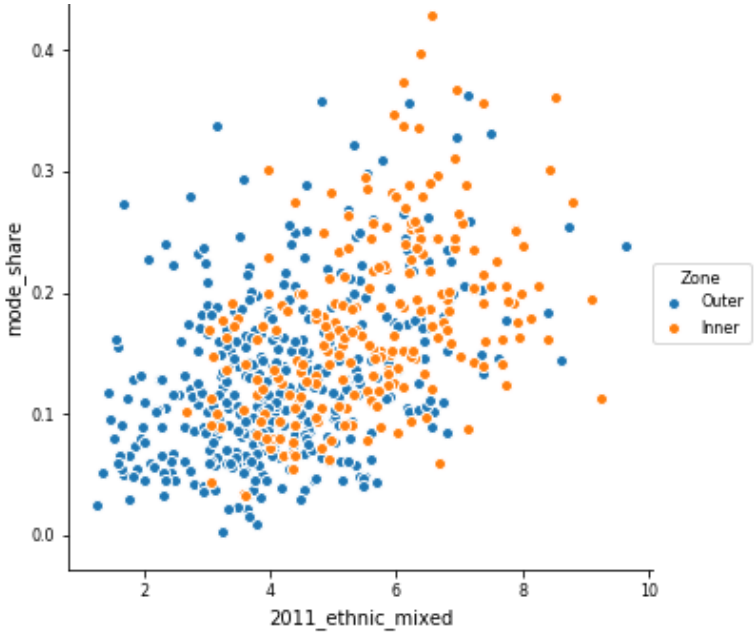


Figure 7-30: Bus Mode Share vs 2011 Proportion of Pop. Ethnicity Group Mixed (%)

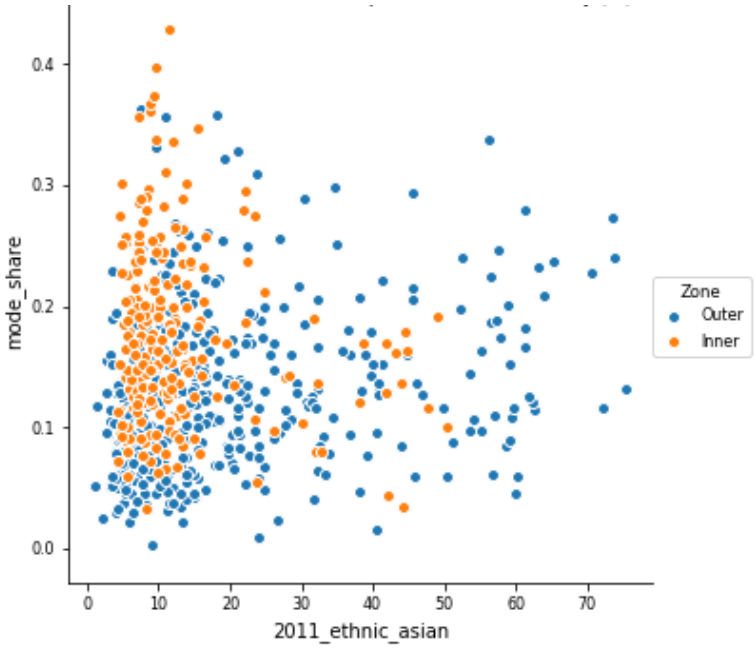


Figure 7-31: Bus Mode Share vs Proportion of Pop. Ethnicity Group Asian (%)

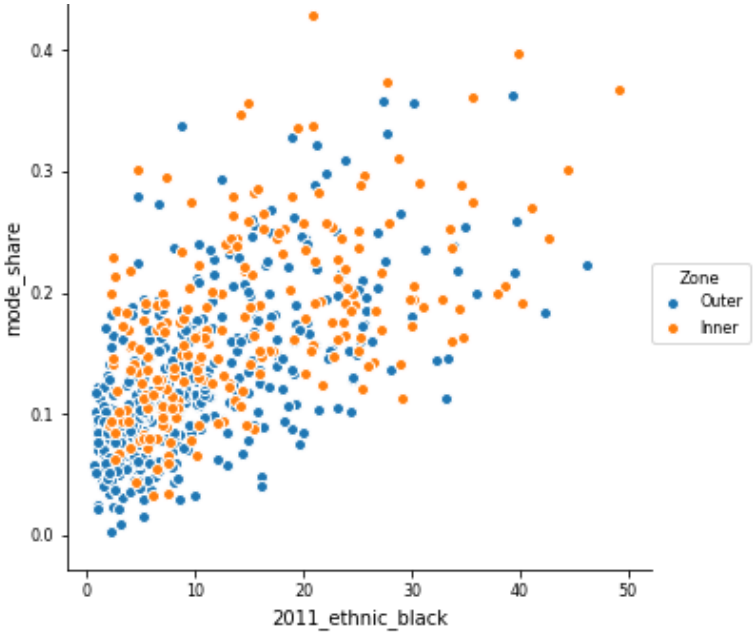


Figure 7-32: Bus Mode Share vs Proportion of Pop. Ethnicity Group Black (%)

7.3.3 Ward Socio-Economic Attributes

2014 median house prices and mean income by ward are considered. 2011 car ownership is considered as both cars per km^2 and cars per household.

Table 7-8: Ward Socio-Economic Attributes Summary

	Median_house_price	Mean_income	cars_own_density	cars_per_household
Mean	433020	45632	2256	0.84
Standard Dev.	263587	15563	867	0.33
Minimum	173000	19272	122	0.23
Median	363500	41734	2291	0.82
Maximum	3500000	143815	5553	1.71

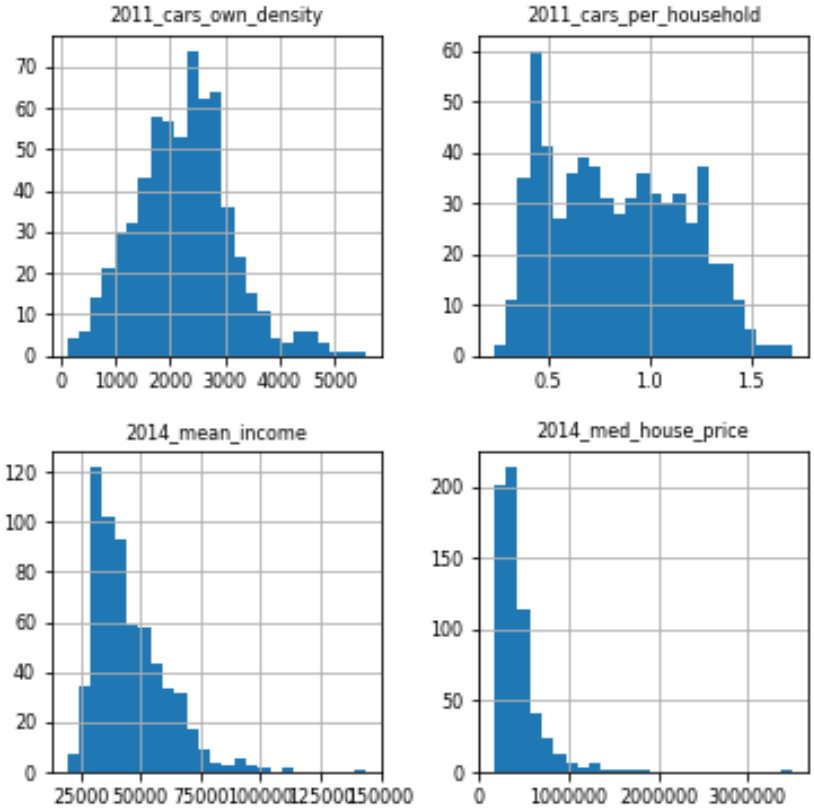


Figure 7-33: Ward Socio-Economic Attribute Distributions

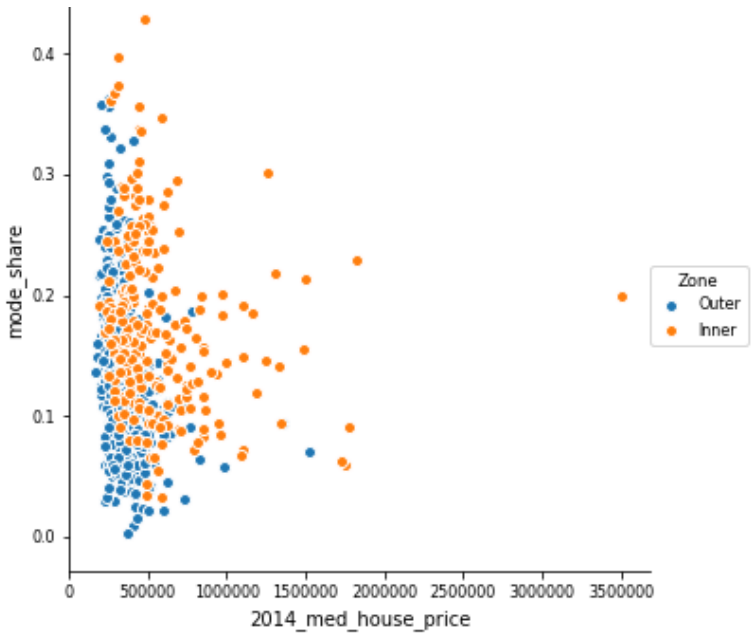


Figure 7-34: Bus Mode Share vs 2014 Median House Price

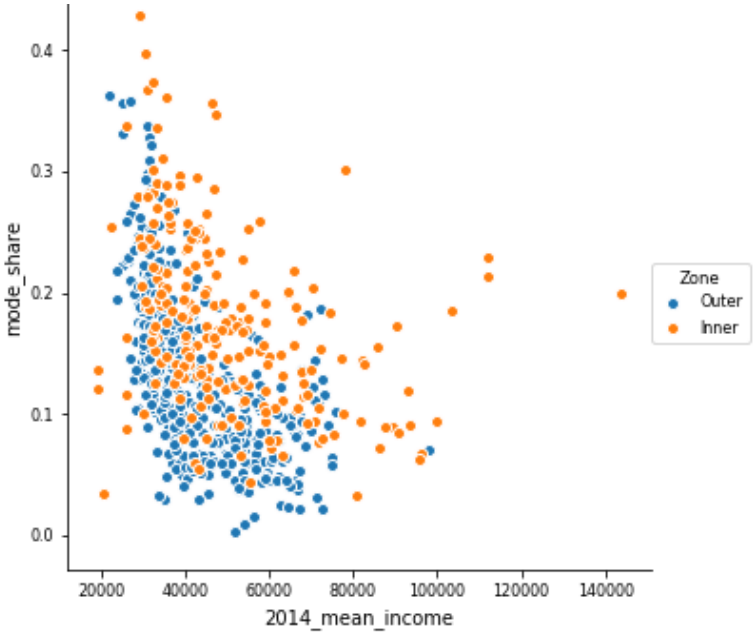


Figure 7-35: Bus Mode Share vs Ward Mean Income

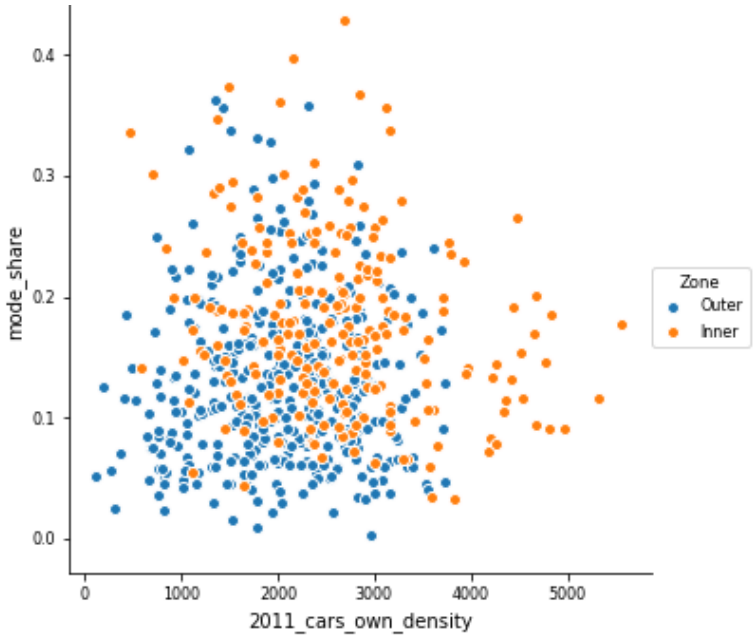


Figure 7-36: Bus Mode Share vs 2011 Car Ownership per km^2

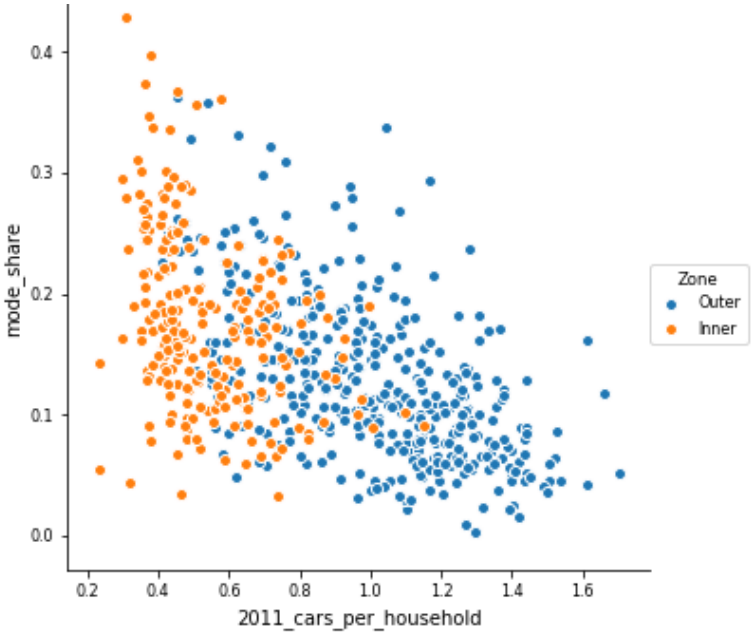
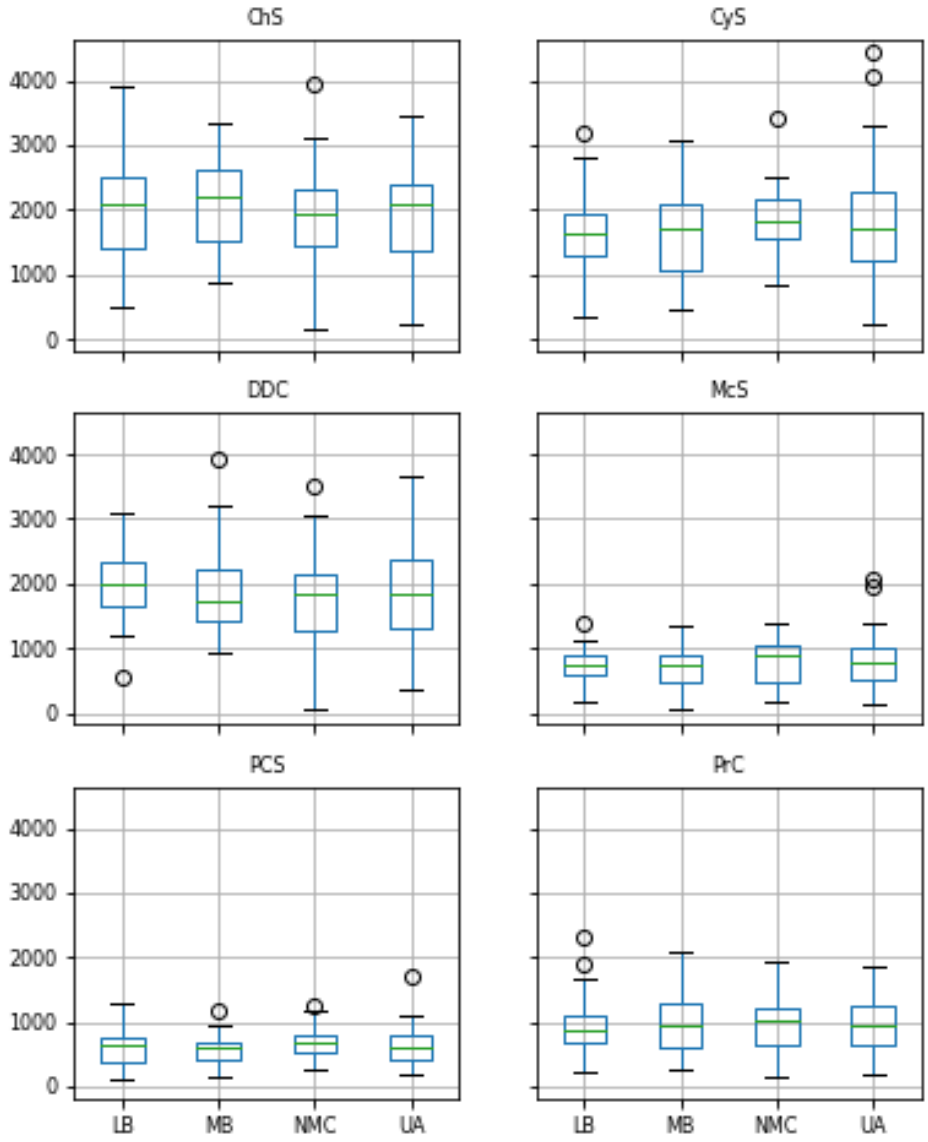


Figure 7-37: Bus Mode Share vs 2011 Average Household Car Ownership

Data Key: Budget Types:ChS: Child Safety, **CyS**: Cycle Safety, **DDC**: Drink Drive Campaign, **McS**: Motorcycle Safety, **PCS**: Promote Car Sharing, **PrC**: Promote Cycling.

Data Key: Local Authority Types: LB: London Borough, **MB**: Metropolitan Borough, **NMC**: Non-Metropolitan County, **UA**: Unitary Authority.



Appendix Figure G-1: 2009 Budget (per 10,000 population) grouped by spending type and local authority type

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