Greater Wellington Regional Council

2013 WTSM Update

Technical Note 4:
2013 Commercial Vehicle Model Development

April 2015

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Greater Wellington Regional Council

2013 WTSM Update

Technical Note

Quality Assurance Statement

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Table of Contents

Appendix A
Comparisons of Forecast vs Observed – Internal Model

Appendix B
Comparisons of Adjusted Forecast vs Observed – Internal Model

1. Introduction

The technical note is part of a series documenting the 2013 update of the Wellington Transport Models, which are maintained by Greater Wellington Regional Council (GWRC).

The transport models include the Wellington Transport Strategy Model (WTSM), which is a four stage model developed in 2001 and updated in 2006 and then again in 2011, as well as the Wellington Public Transport Model (WPTM) a more detailed public transport assignment model developed in 2011.

This technical note documents the development of a synthetic and predictive commercial vehicle model, including the tests undertaken and the recommended model form.

The analysis in this technical note follows from the development of observed commercial vehicle matrices from fleet tracking data, which is documented in Technical Note 2.

Investigation into the implementation of a synthetic predictive commercial vehicle model in WTSM was carried out for trip making in three different geographic areas:

- Internal trips, where both the origin and destination are internal to the study area;
- External trips, where one end of the trip is external to the study area; and
- Special generators, locations where travel patterns were found to be markedly different.

The synthetic models are described in terms of:

- Trip end model; and
- Trip distribution model.

These components are discussed in detail in the following sections, with the internal model described first followed by the external model, and then the special generators.

2. Internal Model - Trip Ends

2.1 Overview and Inputs

The purpose of the commercial vehicle trip end model is to determine the total number of commercial vehicle movements to/from each model zone. Based on the availability of commercial vehicle count data, and investigation into the best expansion process, the study area was divided into 14 internal sectors and two externals (SH1 and SH2) using 15 screenlines (see **Figure 1**). Note that the screenlines are not watertight as some minor roads were not counted – this is not considered a major consideration for commercial vehicle movements.

The sampled commercial vehicle trip data were factored up to screenline totals using a sequential factoring method based on screenline ranking (magnitude and geographic significance). Intra-sector commercial vehicle trips were derived from a combination of trip rates and screenline crossings (see Technical Note 2 for details). Note that whilst the intra-sector trips have no bearing on the screenline crossing totals they are important in the trip end models, as discussed later.

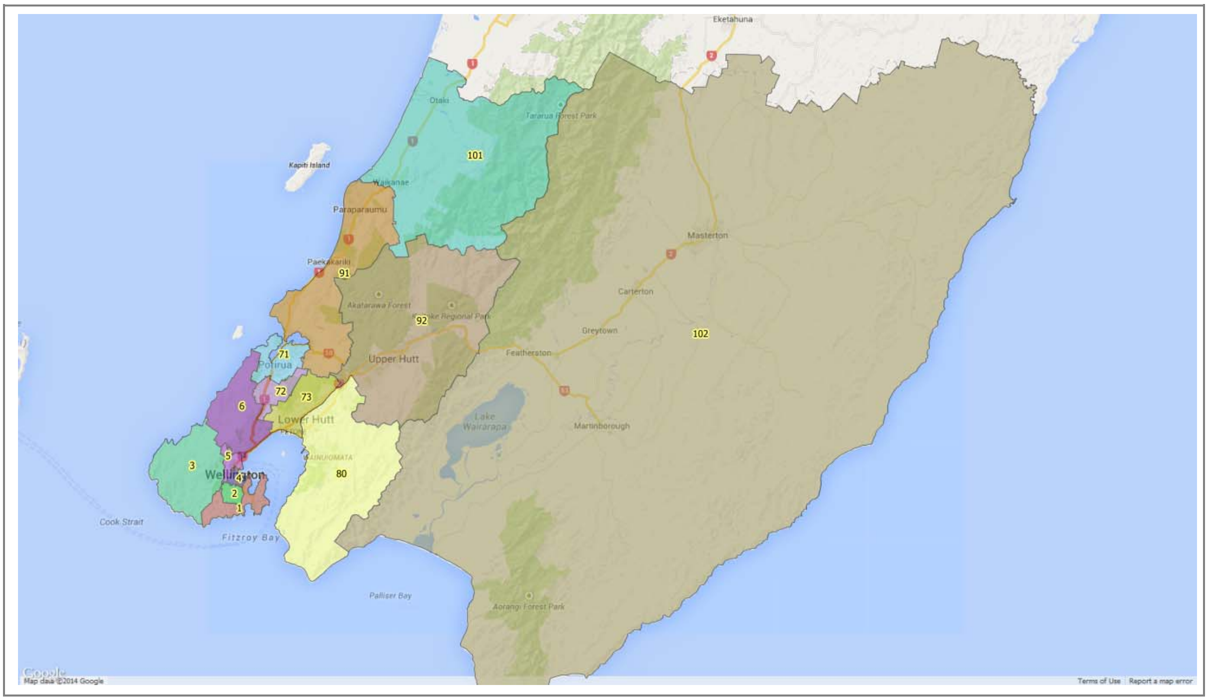

Figure 1: Sector Definition

The commercial vehicle tracking data processing produced sample matrices for the following time periods:

- AM Peak (07:00 – 09:00)
- Inter Peak (11:00 – 13:00)
- PM Peak (16:00 – 18:00)
- Overnight (18:00 – 07:00)

The time periods were selected to correspond with the assignment periods in the person model, and hence traffic count data availability. The sample matrices were then expanded to match the screenline totals and the expanded matrices are shown below in **Tables 1 to 4**. Excluding intra-sector trips the largest movements are found between sectors 4 and 5 and sectors 7 and 8. Sector 5 contains the Port and the impact of this on the linear regression is discussed later on.

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
1	156	167	15	92	22	15	1	5	7	6	0	1	0	0	0	0	487
2	179	168	28	161	30	23	1	8	4	6	0	1	0	0	0	0	609
3	6	8	57	85	36	13	0	0	4	2	0	0	0	0	0	0	212
4	153	115	5	226	245	47	2	7	29	23	0	1	0	0	0	0	854
5	24	23	3	582	114	46	5	5	16	30	4	7	1	3	10	3	876
6	47	27	11	193	115	175	15	19	37	66	4	24	1	4	10	12	759
71	2	1	0	6	3	15	302	91	4	4	57	18	7	1	4	0	517
72	6	6	1	14	6	21	79	120	9	12	14	4	3	0	13	4	313
73	13	8	3	72	20	53	3	4	93	314	8	23	0	0	2	0	616
80	13	18	1	45	80	61	7	4	390	384	4	74	2	1	8	1	1094
91	0	0	0	5	2	6	63	7	5	7	156	6	49	0	20	0	327
92	2	3	0	17	36	20	7	27	31	70	2	110	1	1	1	0	327
101	0	0	0	0	1	2	11	3	1	4	55	3	37	0	34	0	153
102	0	0	0	0	18	2	2	0	0	2	0	1	0	604	0	4	634
111	0	0	0	0	11	3	8	9	2	13	13	2	35	0	0	0	96
112	0	0	0	0	5	0	0	3	0	1	0	0	0	18	0	0	28
Total	**602**	**543**	**124**	**1498**	**744**	**505**	**505**	**310**	**634**	**945**	**318**	**275**	**138**	**633**	**102**	**25**	**7902**

Table 1: AM Peak 2hr Expanded Commercial Vehicle Trips

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
1	336	149	8	110	20	31	2	5	8	12	0	1	0	0	0	0	682
2	35	172	6	78	13	15	1	3	6	5	1	1	0	0	0	0	334
3	8	10	108	14	10	13	1	2	4	2	0	0	0	0	0	0	173
4	132	108	33	410	311	91	6	9	49	26	1	4	0	0	0	0	1179
5	26	21	23	347	192	77	7	5	19	43	4	10	1	6	5	3	790
6	13	10	6	42	34	294	15	23	46	77	7	48	1	3	6	5	629
71	1	1	0	3	3	11	532	116	4	8	57	12	8	1	5	0	762
72	2	4	2	7	4	19	138	140	8	11	8	6	4	2	9	6	370
73	10	8	3	44	26	43	5	4	148	368	3	12	0	0	1	0	676
80	17	10	2	33	91	65	7	6	330	515	4	30	1	2	2	1	1118
91	0	0	0	0	4	6	26	4	4	5	158	4	77	0	30	0	320
92	0	1	0	4	18	23	9	5	19	49	3	160	0	4	1	0	297
101	0	0	0	0	2	1	16	10	0	1	87	4	82	0	45	1	250

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
102	0	0	0	0	21	4	2	1	1	6	0	5	0	817	0	22	880
111	0	0	0	0	12	6	4	10	2	10	17	2	38	0	0	0	102
112	0	0	0	0	2	3	0	4	0	2	0	0	0	18	0	0	30
Total	**581**	**493**	**191**	**1093**	**763**	**704**	**769**	**347**	**648**	**1141**	**352**	**299**	**212**	**856**	**106**	**39**	**8593**

Table 2: Inter Peak 2hr Expanded Commercial Vehicle Trips

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
1	71	232	6	84	19	20	1	5	2	6	0	2	0	0	0	0	449
2	3	51	6	58	8	19	1	2	6	14	1	2	0	0	0	0	171
3	9	12	47	18	4	5	1	0	3	0	0	0	0	0	0	0	100
4	183	130	35	213	355	179	14	12	51	55	4	26	0	0	0	0	1258
5	21	18	9	349	118	103	4	5	12	27	6	4	1	3	7	1	687
6	13	8	18	65	78	170	13	10	31	34	3	29	0	1	4	1	479
71	1	0	0	2	2	8	215	35	2	4	60	8	10	0	6	0	355
72	1	1	2	3	8	14	75	81	2	4	17	9	6	0	10	0	234
73	9	1	1	16	9	14	3	3	85	404	2	42	0	0	0	0	588
80	5	1	0	13	35	38	4	5	352	391	3	30	0	3	4	3	887
91	0	0	0	0	3	4	16	1	1	1	83	4	35	0	21	1	173
92	2	0	0	8	4	8	6	0	23	50	4	125	0	3	1	0	235
101	0	0	0	0	2	1	12	18	0	2	41	12	20	0	35	1	146
102	0	0	0	0	4	1	1	0	1	6	0	3	0	413	1	26	456
111	0	0	0	0	5	11	5	14	3	10	13	2	24	0	0	0	86
112	0	0	0	0	2	3	0	2	0	1	0	0	1	13	0	0	22
Total	**318**	**454**	**124**	**831**	**657**	**598**	**371**	**194**	**574**	**1011**	**238**	**296**	**99**	**437**	**90**	**32**	**6325**

Table 3: PM Peak 2hr Expanded Commercial Vehicle Trips

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
1	1446	1426	50	676	132	159	10	31	41	66	4	7	1	1	0	1	4050
2	309	846	64	609	102	105	5	25	32	45	4	5	0	1	0	0	2151
3	55	75	487	181	91	82	4	9	22	17	1	1	0	0	1	0	1027
4	1131	888	180	2032	3056	631	44	61	267	186	9	52	1	2	1	0	8540
5	180	135	101	3234	1031	565	39	39	110	303	38	66	9	39	72	19	5979
6	113	73	55	445	386	1518	109	147	283	443	43	250	8	19	55	38	3985
71	8	4	2	30	20	87	2438	1115	25	45	391	75	47	5	36	2	4329
72	17	23	10	51	42	128	1298	746	46	69	100	42	26	6	108	28	2741
73	64	39	15	262	147	305	26	27	749	2350	26	158	2	2	12	1	4187
80	92	66	14	226	587	465	48	46	2078	2784	31	316	8	13	45	13	6834
91	3	3	1	10	24	44	216	39	24	36	832	32	378	1	217	5	1864
92	7	9	1	59	148	155	48	45	134	329	35	862	3	20	13	0	1869

	1	2	3	4	5	6	71	72	73	80	91	92	101	102	111	112	Total
101	1	1	0	2	12	13	97	101	3	19	502	33	362	0	297	8	1450
102	2	0	0	2	138	32	9	4	5	34	0	26	0	4050	7	142	4451
111	0	0	0	3	88	63	42	105	21	103	115	21	286	2	0	0	848
112	2	0	0	0	18	27	5	27	1	11	4	2	5	112	0	0	214
Total	**3431**	**3588**	**981**	**7822**	**6022**	**4381**	**4438**	**2568**	**3839**	**6839**	**2135**	**1946**	**1136**	**4274**	**863**	**258**	**54521**

Table 4: Daily 24hr Expanded Commercial Vehicle Trips

The form of the trip end model investigated and reported here is linear regression based on land use data being the independent variables. The sectored land use data is given in **Table 5** below. The independent variables considered consisted of two relating to residents and five relating to employment category. The two residential variables are highly correlated so only one was carried forward after testing which performed best. Models of commercial vehicle trips categorised by commodity transported were not investigated as this data was not available.

Trip end models were developed for by time period in order to retain the same level of detail output from the tracking data processing. If, however, this was found to adversely impact the accuracy of the individual peak models then the trip ends would be modelled at a daily level with appropriate factors to split back down to the peaks. One key advantage of a daily trip end model is that directionality is less of an issue as this is covered by the peak factoring process. Peak period models, built on regressions of origin and destination land use, might not capture all the directionality nuances. Conversely, the daily to peak factors would most likely be fixed and therefore not responsive to changes in land use over time.

External trips (sectors 111 and 112) are approximately 3 to 4% of the total. Regardless of the magnitude of the external trips they were (ultimately) excluded from the internal model linear regression as there is no easily defined corresponding land use data for outside the study area. External trips are therefore handled separately, which is reported in this technical note.

Sector	Population	Household	Employment Other	Manufacturing	Retail	Transport & Communications	Services
1	47387	17793	34	1545	2925	1516	6491
2	24366	9147	21	580	1116	351	7087
3	15162	5412	33	234	486	71	1939
4	25600	9609	101	3905	11838	3017	59070
5	18542	7302	15	604	1661	1827	14906
6	43572	15780	51	2564	2575	738	5722
71	43528	13824	18	2027	3070	387	7385
72	15441	5313	45	1021	1104	181	1869
73	23234	8655	28	3737	3517	790	4183
80	74447	26925	78	5050	6263	1228	15361
91	36749	14661	147	1848	2976	363	5641
92	40517	15036	142	1859	2770	323	6502
101	19554	8547	396	956	1429	109	2397
102	40911	16623	3130	3122	4058	501	6729
Total	469010	174627	4239	29051	45788	11401	145281

Table 5: Land Use by Sector

The data presented in **Table 5** is shown graphically in **Figure 2** below. As can be seen from **Figure 2** there is a high level of service related jobs in sector 4 (the CBD) and high levels of all land use types in sector 80 (Lower Hutt/Wainuiomata).

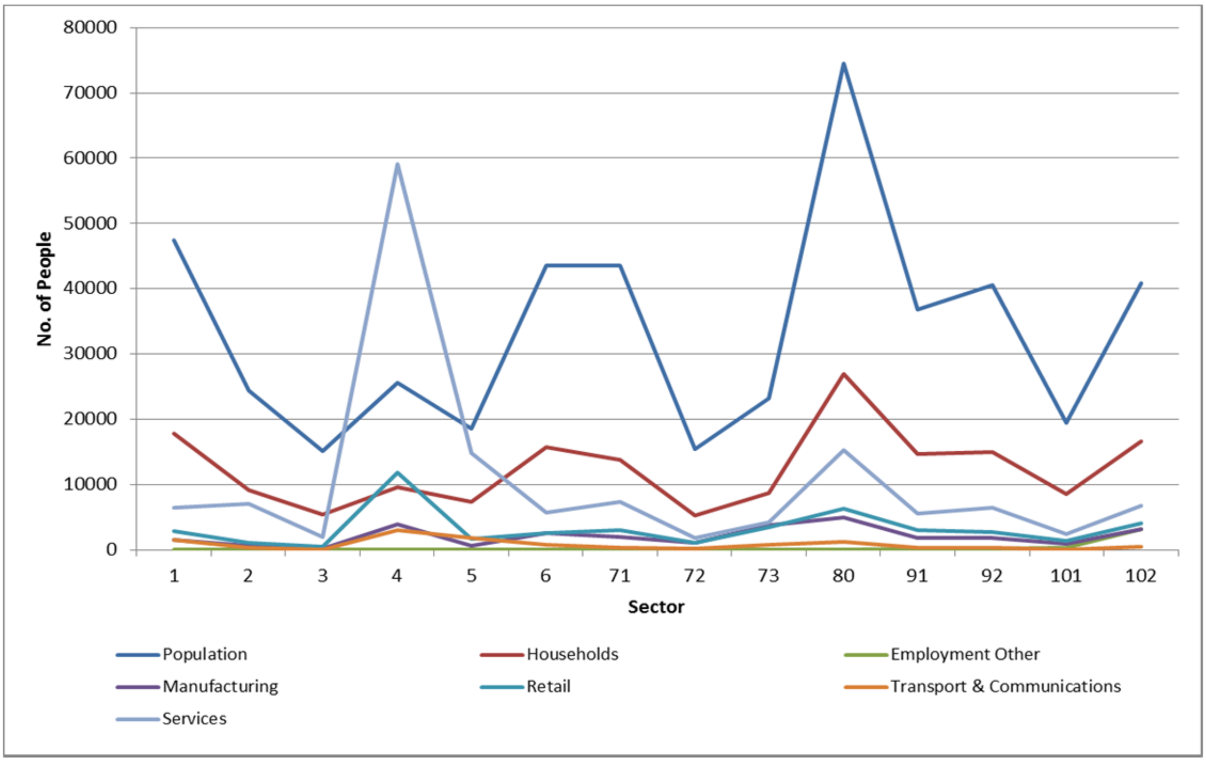

Figure 2: Land Use Data

2.2 Stepwise Linear Regression

An initial stepwise linear regression analysis was undertaken to assess which land use variables were statistically significant. The coefficients and Adjusted R Squared results are shown in **Table 6** below. Variables were included if their P value was below 0.05 (the target level of significance). As population and households are highly correlated the analysis was undertaken just using population. It is expected that Households would mimic Population in terms of inclusion or exclusion but would, of course, have different coefficient values.

Figure 3 and **Figure 4** below show the scatterplot matrix and the correlation matrix between the key explanatory variables. In the correlation matrix a higher correlation is indicated by a more elliptical shape, e.g., origin trips have a higher correlation with manufacturing employment than employment other. Plotting data is always a good first step to help determine the likely relationships between dependent and explanatory variables, e.g., straight line or curve, and the extent of outliers.

From these plots it is clear that Employment Other has a very weak linear relationship with trips but has very little correlation with other explanatory variables. Other variables exhibit a stronger relationship but there are some big outliers. The correlation between the two best variables, as detailed below, is not high. There is a higher correlation between Manufacturing and Retail indicating that the inclusion of both of these variables may not actually lead to a better (statistically speaking) model.

Results from the stepwise regression indicate that only Manufacturing is statistically significant in all periods and directions, closely followed by Transport & Communications.

Period	Direction	Population	Employment Other	Manufacturing	Retail	Transport & Communications	Services	Adj R Squared
AM	Origin	0.0032	--	0.1329	--	0.0969	--	0.58
	Destination	--	--	0.1443	0.0290	--	0.0064	0.63
IP	Origin	--	0.1135	0.1413	0.0288	0.0799	--	0.69
	Destination	--	0.1152	0.1543	0.0252	0.0689	--	0.69
PM	Origin	--	--	0.1294	--	--	0.0122	0.59
	Destination	0.0020	--	0.1012	--	0.0472	0.0047	0.63

Table 6: Coefficients Obtained from Stepwise Regression

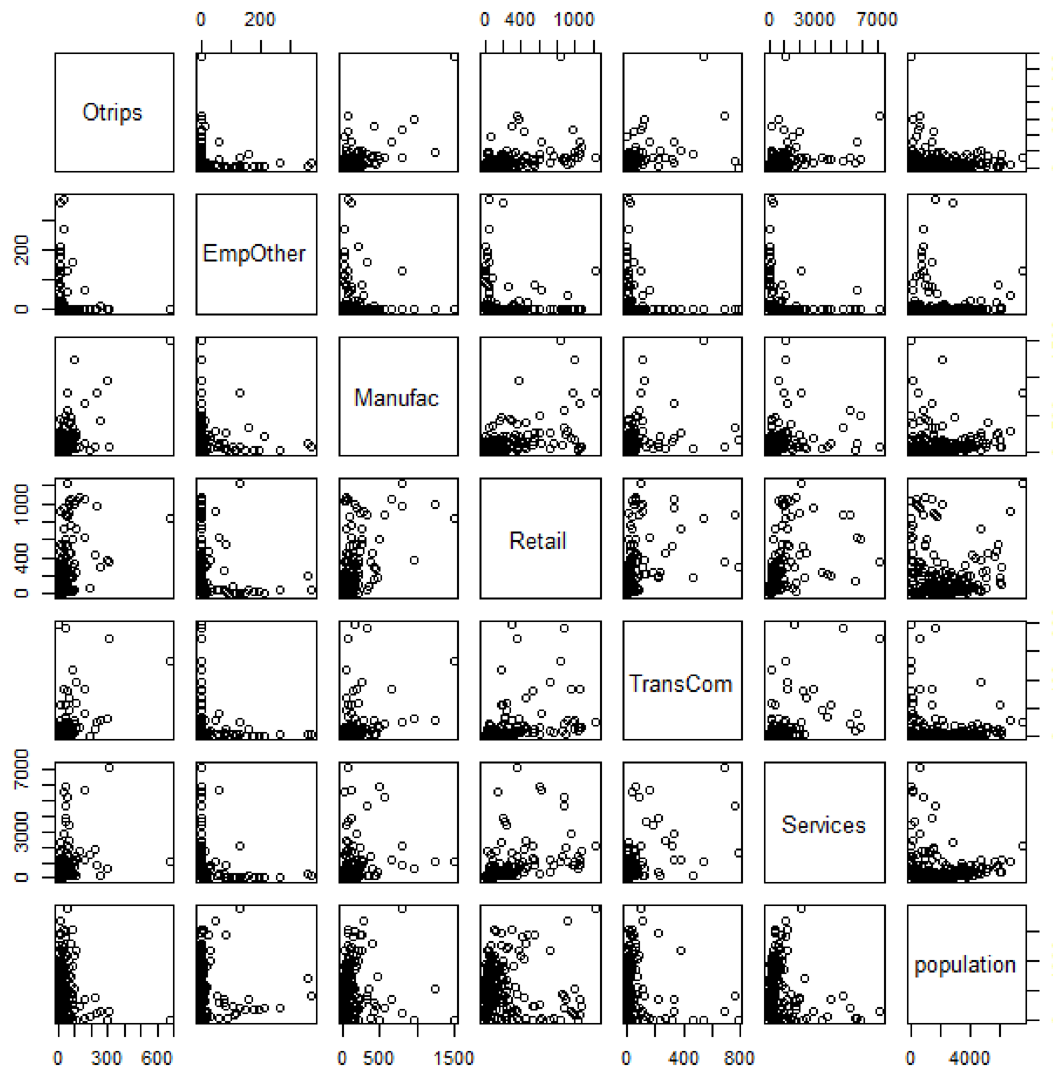

Figure 3: Scatterplot Matrix

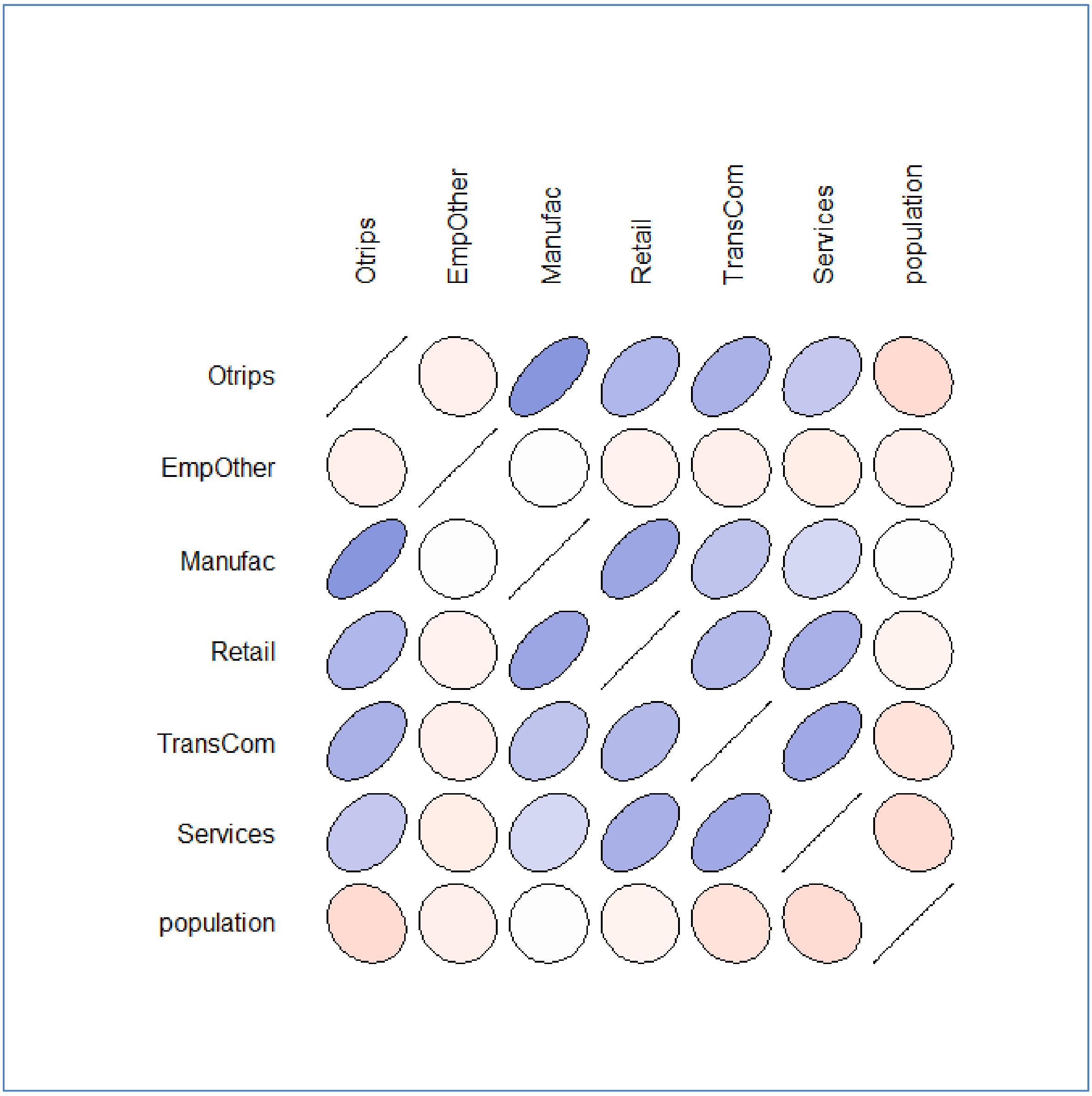

Figure 4: Correlation Matrix

2.3 Trip End Models

Whilst it is possible to build trip end models using only the statistically significant variables shown in **Table 6** it was felt desirable to produce a model that encompassed as many land use data categories as possible as omitting any category will result in a model that is unresponsive to changes in that category.

A number of models were tested using combinations of land use as the independent variables and the key models are explained in the sections below along with their results. Note that Port and Interislander trips (to/from zones 39 and 228 respectively) are excluded from the trip end models as findings from an initial analysis indicated that these movements are best dealt with separately. Sectors 111 and 112 (externals) were are also omitted as these movements will also be handled separately.

When assessing the suitability of a model the following points were considered:

- Independent variable coefficient: Should be positive. That is to say we would expect the number of commercial vehicle trips to increase when the independent variable increases. In some models the coefficient for population was found to be negative. Whilst this can be explained, i.e., residential areas are less likely to have commercial vehicle movements, it would/could result in negative trips for purely residential zones/zones with high population in relation to employment.
- Intercept coefficient: Point at which the regression line crosses the y axis when all independent variables are zero. It represents the component of the dependent value that is not explained by the independent variables. In our case it is necessary to assume the intercept equals zero, i.e., zero commercial vehicle trips if zero population and employment, as there is nothing to stop the intercept being negative and resulting in negative trips even when independent variables are greater than 0.
- P-Value: Should be less than or equal to the alpha (level of significance; taken as 0.05) value. In this case we can reject the null hypothesis (that the coefficient is zero). When this happens we say that the result is statistically significant. In other words, we are reasonably sure that there is something besides chance alone that gave us an observed sample.
- Adjusted R Squared: The R Squared statistic represents the percent of the total variation in the dependent variable that is explained by the independent variables, i.e., the model's overall “goodness of fit”. Whether a model is really a "good" fit or not depends on context. The R squared can always be increased by adding another independent variable (*any* variable) into the model. The Adjusted R squared is a modification to the R squared that accounts for the number of explanatory terms in a model relative to the number of data points.

The predicted number of trips resulting from application of the regression models was factored up to observed totals by factoring the explanatory variable coefficients. Note that this factoring does not affect the linear regression or summary statistics, such as Adjusted R Squared, but does presume that the error is constant across all variables.

2.3.1 Model 1

Structure:
Population
Total Employment

This model produced the results shown in **Figures 5 to 7** and **Table 7**. **Figures 5 to 7** compare the observed trip end totals with the modelled trip end totals from linear regression. Most sectors have comparable totals, except for Sector 4 (CBD).

Table 7 gives a summary of the key statistics from the regression model for origin and destination trip ends. All the coefficients were found to be positive and all variables were statistically significant except for Population in the PM peak for origin trips.

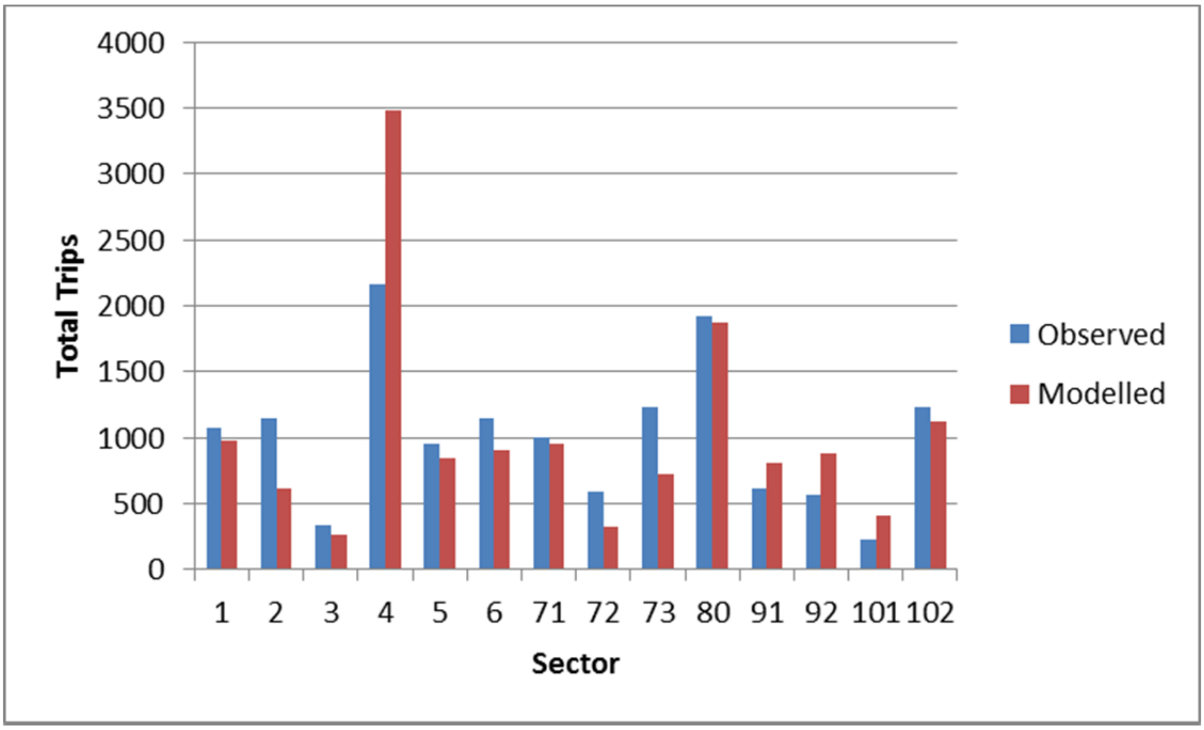

Figure 5: Model 1 – AM Trips

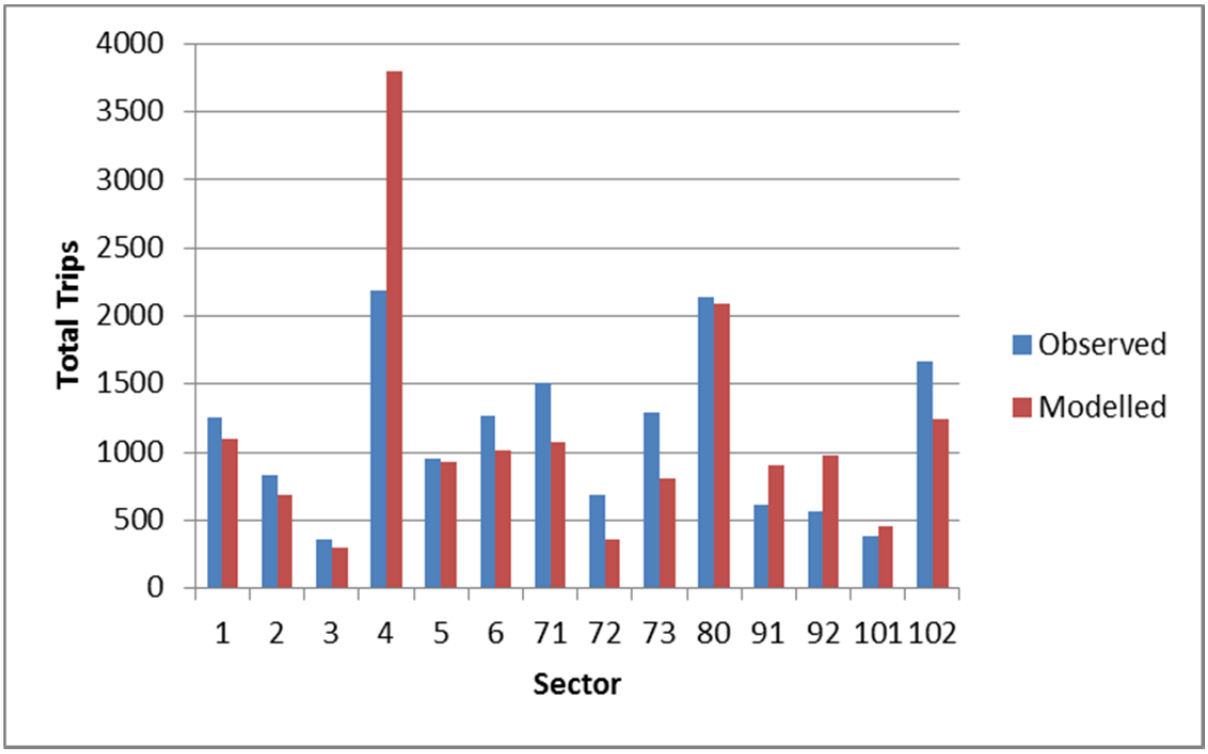

Figure 6: Model 1 – Interpeak Trips

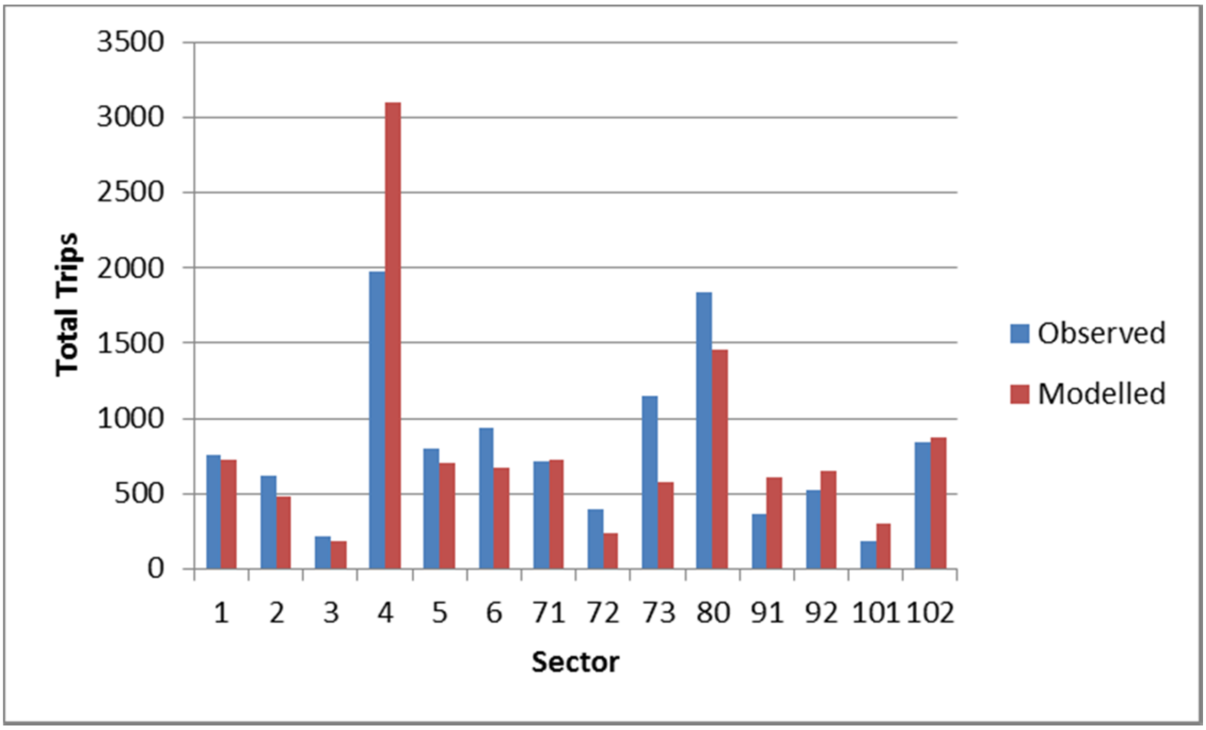

Figure 7: Model 1 – PM Trips

		Origin Trips				Destination Trips			
				Confidence Interval				Confidence Interval	
Period	**Variable**	**Coefficient**	**P-value**	**Lower 95%**	**Upper 95%**	**Coefficient**	**P-value**	**Lower 95%**	**Upper 95%**
AM	Population	0.00532	0.00004	0.00282	0.00782	0.00306	0.01596	0.00058	0.00554
	Employment	0.01615	0.00000	0.01247	0.01982	0.02004	0.00000	0.01638	0.02369
	Adjusted R Squared	0.39				0.43			
IP	Population	0.00469	0.00019	0.00226	0.00713	0.00472	0.00036	0.00215	0.00729
	Employment	0.01935	0.00000	0.01577	0.02294	0.01893	0.00000	0.01515	0.02270
	Adjusted R Squared	0.45				0.42			
PM	Population	0.00100	0.36875	-0.00119	0.00319	0.00365	0.00006	0.00190	0.00540
	Employment	0.01963	0.00000	0.01640	0.02285	0.01377	0.00000	0.01119	0.01634
	Adjusted R Squared	0.44				0.46			

Table 7: Model 1 – Regression Statistics

2.3.2 Model 2

Structure

Population
Employment Other
Manufacturing
Retail
Transport & Communications
Services

This model produced the results shown in **Figures 8** to **10** and **Table 8**. **Figures 8** to **10** compare the observed trip end totals with the modelled trip end totals from linear regression. Most sectors have comparable totals, except for Sectors 5 and 102.

Table 8 gives a summary of the key statistics from the regression model for origin and destination trip ends. All the coefficients were found to be positive except for AM Population destination and PM Population origin. A number of variables were found to be statistically insignificant (P-value > 0.05), consistent with the findings from the stepwise analysis.

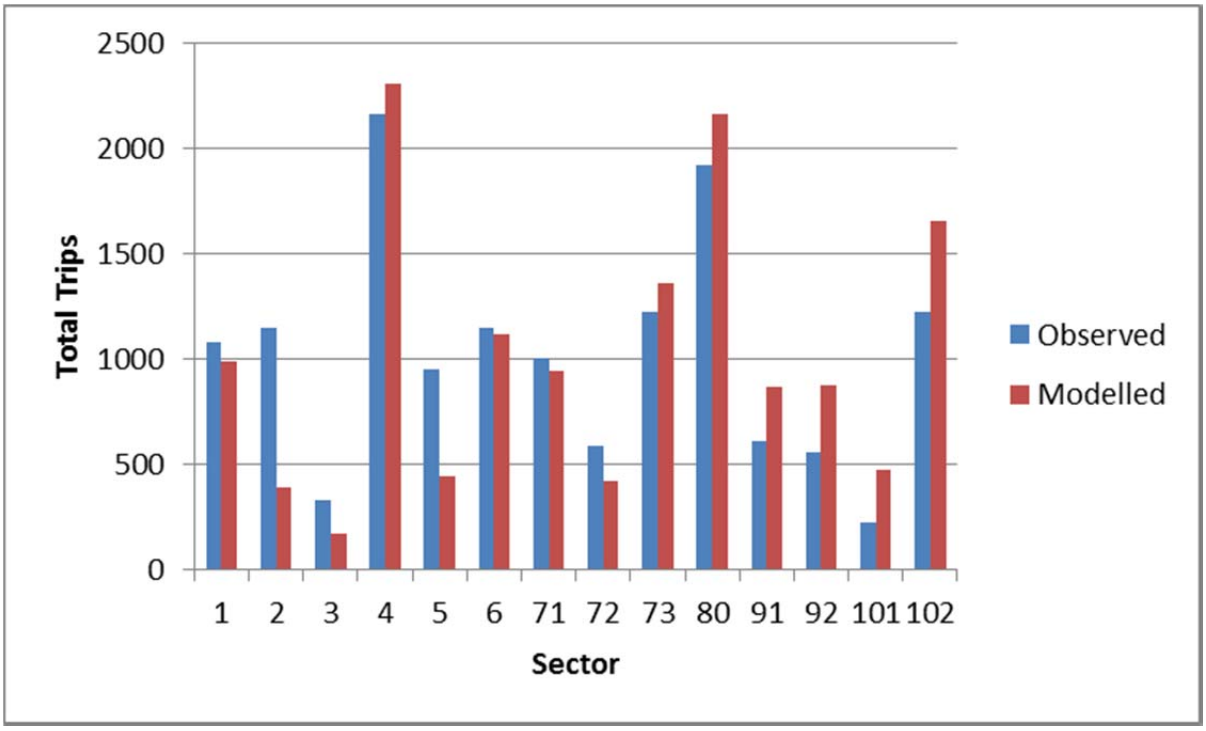

Figure 8: Model 2 – AM Trips

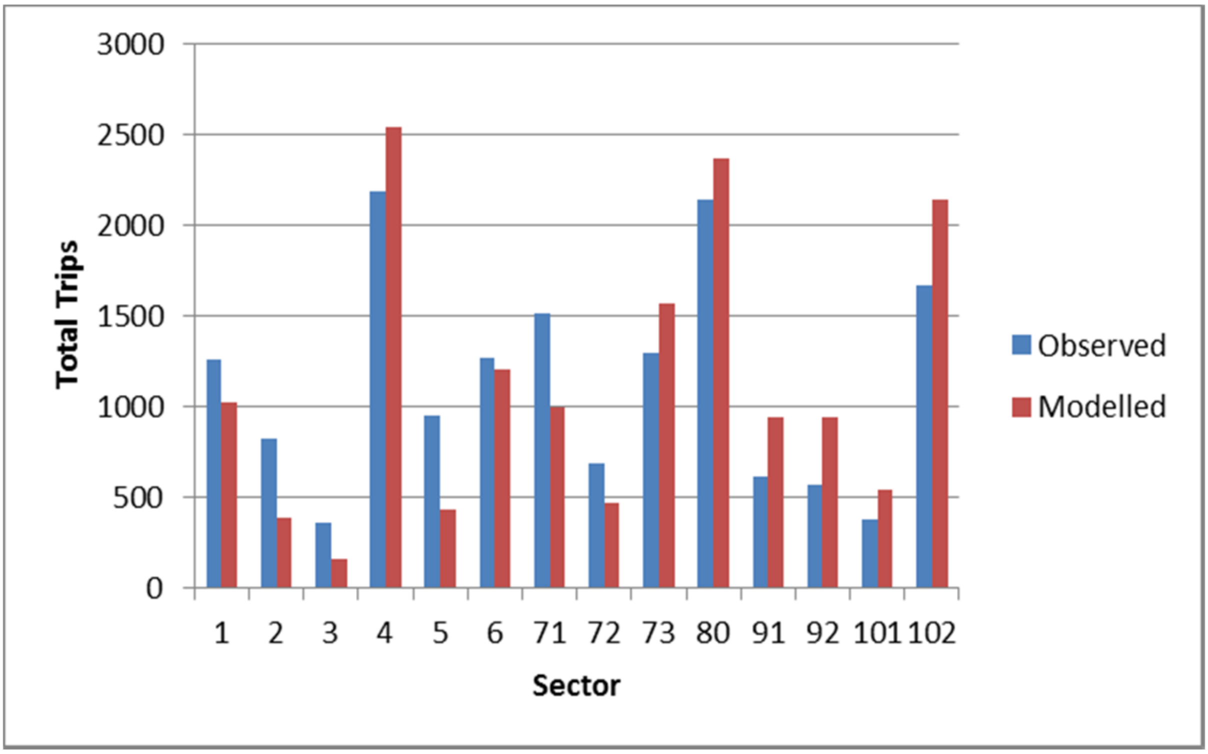

Figure 9: Model 2 – Interpeak Trips

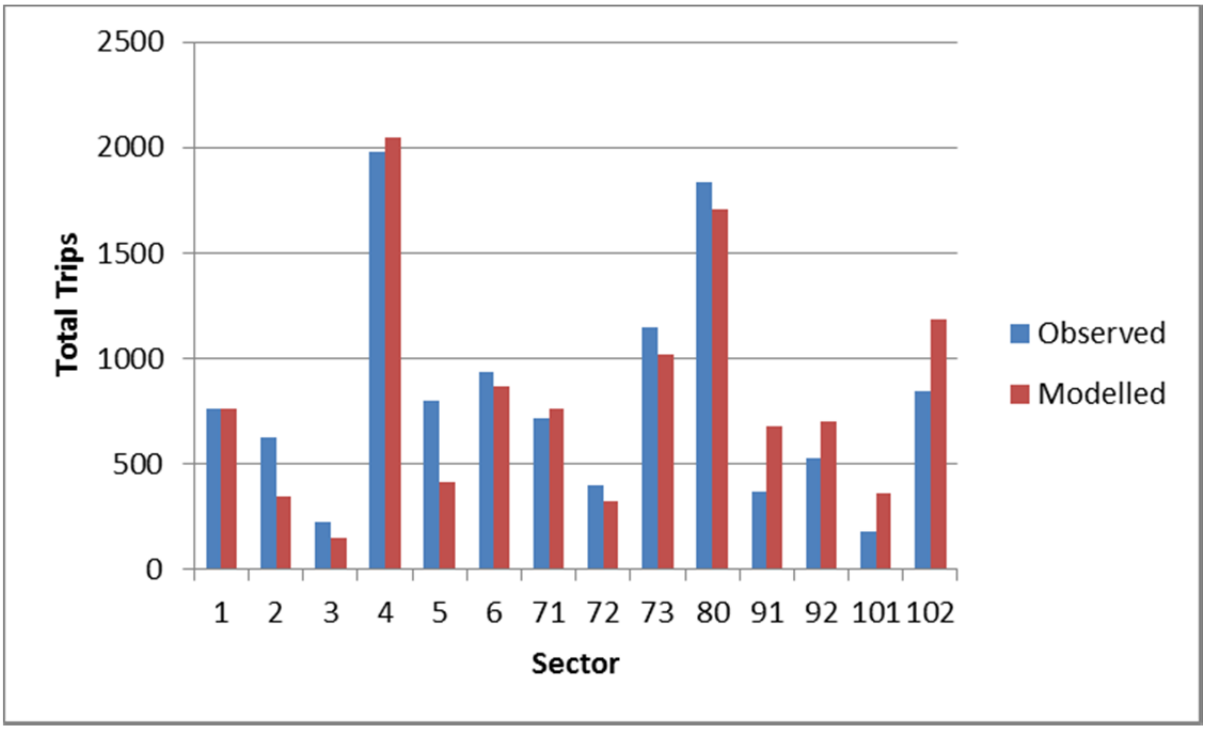

Figure 10: Model 2 – PM Trips

		Origin Trips				Destination Trips			
				Confidence Interval				Confidence Interval	
Period	Variable	Coefficient	P-value	Lower 95%	Upper 95%	Coefficient	P-value	Lower 95%	Upper 95%
AM	Population	0.00274	0.01471	0.00054	0.00493	-0.00012	0.91300	-0.00220	0.00197
	Employment Other	0.05193	0.23137	-0.03334	0.13719	0.07158	0.08310	-0.00945	0.15261
	Manufacturing	0.12418	0.00000	0.09499	0.15336	0.13591	0.00000	0.10818	0.16364
	Retail	0.01016	0.39014	-0.01309	0.03341	0.02656	0.01871	0.00446	0.04865
	Transport & Comms	0.08417	0.00334	0.02826	0.14009	0.05415	0.04583	0.00101	0.10729
	Services	0.00096	0.73387	-0.00462	0.00654	0.00390	0.14862	-0.00140	0.00920
	Adjusted R Squared	0.58				0.64			
IP	Population	0.00138	0.16373	-0.00057	0.00332	0.00106	0.29414	-0.00093	0.00305
	Employment Other	0.10457	0.00693	0.02897	0.18016	0.10881	0.00598	0.03155	0.18607
	Manufacturing	0.13916	0.00000	0.11329	0.16504	0.15202	0.00000	0.12558	0.17847
	Retail	0.02222	0.03478	0.00160	0.04283	0.02213	0.03961	0.00106	0.04319
	Transport & Comms	0.07173	0.00476	0.02216	0.12130	0.06801	0.00875	0.01734	0.11867
	Services	0.00209	0.40527	-0.00285	0.00704	0.00042	0.86904	-0.00463	0.00548
	Adjusted R Squared	0.69				0.69			
PM	Population	-0.00126	0.21264	-0.00324	0.00073	0.00178	0.02303	0.00025	0.00331
	Employment Other	0.04353	0.26758	-0.03365	0.12070	0.02749	0.36424	-0.03210	0.08708
	Manufacturing	0.11655	0.00000	0.09014	0.14297	0.09460	0.00000	0.07420	0.11500
	Retail	0.01389	0.19471	-0.00715	0.03493	0.00929	0.26114	-0.00696	0.02554
	Transport & Comms	0.04072	0.11424	-0.00989	0.09133	0.04555	0.02253	0.00648	0.08463
	Services	0.00898	0.00055	0.00393	0.01404	0.00384	0.05379	-0.00006	0.00774
	Adjusted R Squared	0.59				0.63			

Table 8: Model 2 – Regression Statistics

2.3.3 Model 2 – Implied Trip Rate Check

As explained for the commercial vehicle matrix expansion in Technical Note 2 intra-sector trips were derived from trip rates as these movements are not covered by screenline vehicle counts. A comparison of regression coefficients and trip rates at daily level are given in **Table 9** and **Figure 11**. The values for daily regression coefficients were calculated by summing the individual peak period coefficients suitably factored to represent their whole time period. In the case of the two negative coefficients for population these were set equal to the opposite direction on the assumption that commercial vehicles arrive and leave within the peak period. The daily trip rates have been normalised to the regression coefficients for easier comparison.

	Population	Employment Other	Manufacturing	Retail	Transport Communications	Services
Linear Regression Coefficients	0.0176	0.9413	1.6469	0.2733	0.9278	0.0654
Trip Rate	0.0147	0.1153	0.3490	0.1731	0.7768	0.0575
Normalised Trip Rate	0.0385	0.3020	0.9143	0.4534	2.0345	0.1505

Table 9: Comparison of Explanatory Variable Coefficients and Daily Trip Rates

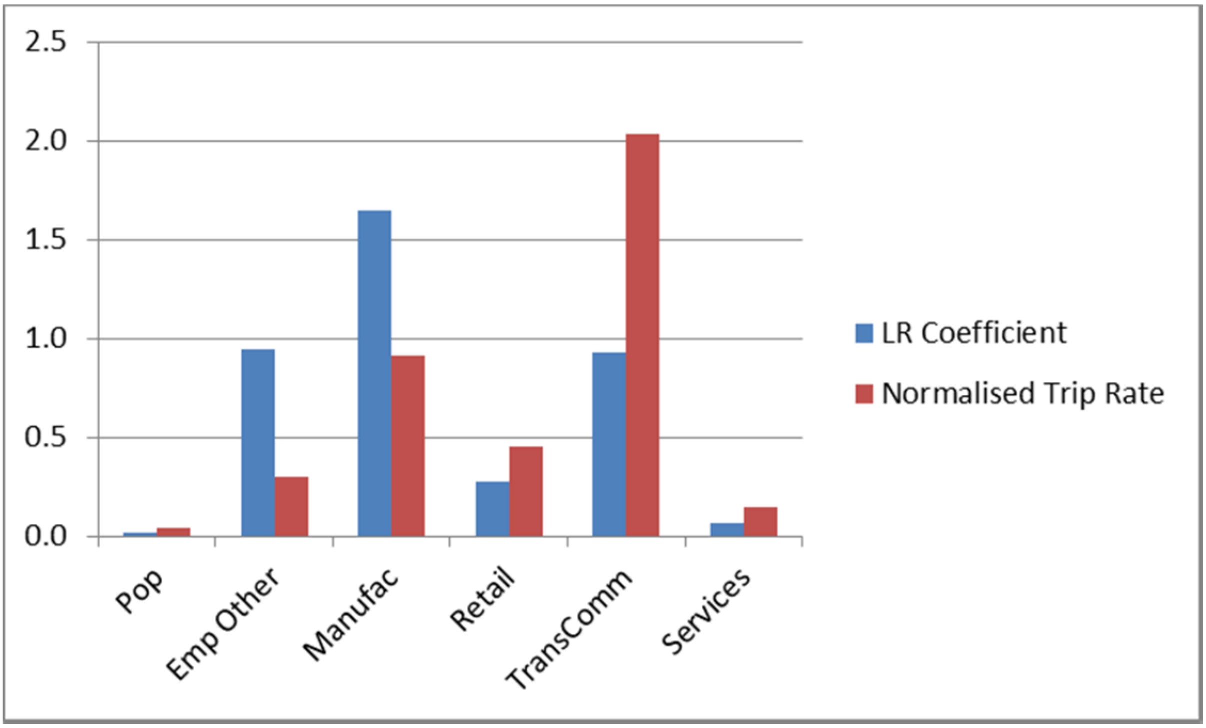

Figure 11: Comparison of Linear Regression Coefficients and Normalised Daily Trip Rates[1]

The comparisons in **Figure 11** show that the magnitudes of Manufacturing and Transport & Communications are reversed, and that Employment Other is much higher. It should be stressed that the trip rates were based on limited data but nonetheless should provide a relative order of magnitude cross check. A comparison of the daily trips calculated using Model 2 versus normalised trip rates is shown in **Figure 12**. This indicates that at daily sector level the discrepancy between regression coefficients and trip rates tend to cancel out.

A model using combined Manufacturing and Transport & Communications was tested but found to have slightly worse adjusted R square values and was therefore dropped.

[1] LR = Linear Regression

Comparison at a finer grained level will however show significant differences. This is to be expected given the broad employment type categories. From the research into published trip rates it is apparent that significant variation exists within each employment category. Zones forecast to have a relatively large component of one employment type in a mix of types, or a large increase in a single type, should be reviewed and maybe handled as special generators.

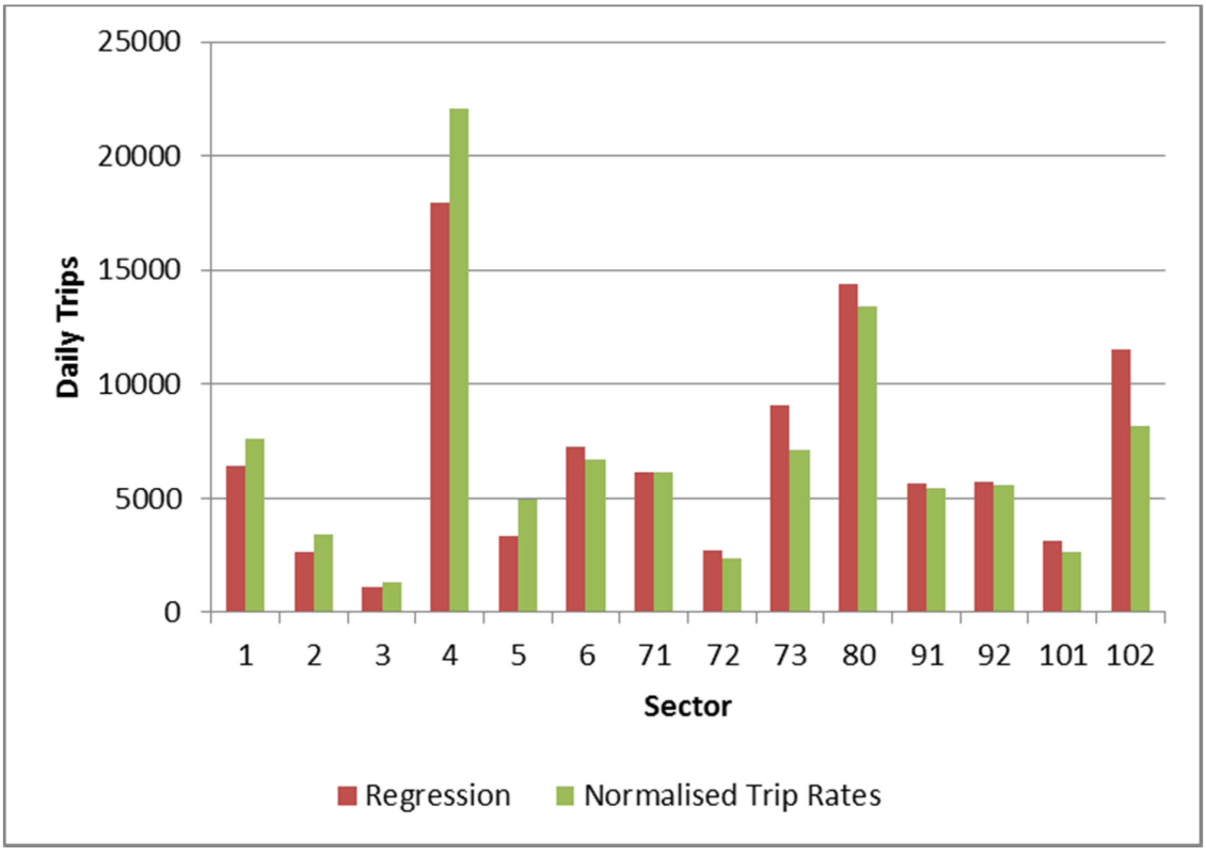

Figure 12: Comparison of Daily Trips – Regression versus Normalised Trip Rates

2.4 Conclusion – Internal Trip End Model

A large number of models were tested but the final choice came down to the two models reported here.

The results for Model 1 meet the selection criteria in terms of coefficient sign and statistical significance of the explanatory variables (discounting Population for PM peak origin trips). Comparisons of the observed and predicted trips show a good match except for Sector 4 (Wellington CBD).

The results for Model 2 meet the selection criteria in terms of coefficient sign but show more instances of explanatory variables not passing the test for statistical significance. The comparisons of observed and predicted trips show a tighter fit for Model 2 than Model 1 and Sector 4 is noticeably better.

The Adjusted R Squared values for the AM, interpeak, and PM periods for Model 2 are higher than those for Model 1.

On balance, the adopted form of the trip end model is Model 2 as this satisfies most of the selection criteria and is considered more practical in terms of implementation. This is because the inclusion of more explanatory variables is favourable as it provides the model a greater range of response, i.e., adding additional manufacturing jobs will be different to adding more retail jobs. Model 1 response would be the same in both cases. Although the regression P values do not always support the inclusion of some variables their relative coefficients are considered to be of the right order of magnitude and hence acceptable.

The adopted set of coefficients for the internal trip end model is given in **Table 10** below. The two negative coefficients for population have been set equal to the opposite direction on the assumption that commercial vehicles arrive and leave within the peak period. The origin and destination coefficients have also been factored by 1.0782 and 0.903 respectively to balance the trip end totals. Note that the application of these factors does not change the confidence statistics presented in **Table 8**.

		Coefficients	
Period	**Variable**	**Origin**	**Destination**
AM	Population	0.00295	0.00247
	Employment Other	0.05599	0.06464
	Manufacturing	0.13389	0.12273
	Retail	0.01095	0.02398
	Transport & Comms	0.09076	0.04890
	Services	0.00104	0.00352
IP	Population	0.00151	0.00117
	Employment Other	0.11444	0.11980
	Manufacturing	0.15231	0.16738
	Retail	0.02431	0.02436
	Transport & Comms	0.07851	0.07488
	Services	0.00229	0.00047
PM	Population	0.00150	0.00196
	Employment Other	0.03662	0.03033
	Manufacturing	0.09805	0.10438
	Retail	0.01168	0.01025
	Transport & Comms	0.03426	0.05026
	Services	0.00756	0.00423

Table 10: Adopted Regression Coefficients

This model will then be applied to the calibrated trip length distribution as described in the next section.

3. Internal Model – Distribution

3.1 Overview

The distribution of commercial vehicle trips has been investigated and modelled using a gravity model. This model form states that the interchange volume between a trip producing zone and trip attracting zone is directly proportional to the magnitude of the trip productions and attractions and inversely proportional to the impedance between the zones.

The impedance is usually based on skimmed distance and time from the loaded network together with one or two calibration parameters. The calibration parameters are iteratively adjusted to minimise the error between the observed and calculated origin-destination (OD) demands. The comparison between observed and modelled OD demands is accomplished by using the trip length frequency distribution.

As the calibration of the parameter is iterative the Citilabs TRIPS program MVGRAM has been used to solve the problem. This program is self-calibrating and can give estimates for up to two parameters which define the cost deterrence function as shown below.

$$F(C_{ij}) = C_{ij}^{X_1}.\exp(X_2.C_{ij})$$

Where:

$F(C_{ij})$ = cost deterrence for zone i to zone j.

C_{ij} = generalised cost for zone i to zone j.

X_1. and X_2. = coefficients to be calibrated

The effects of X_1 and X_2 on the deterrence function are illustrated in **Figure 13.**

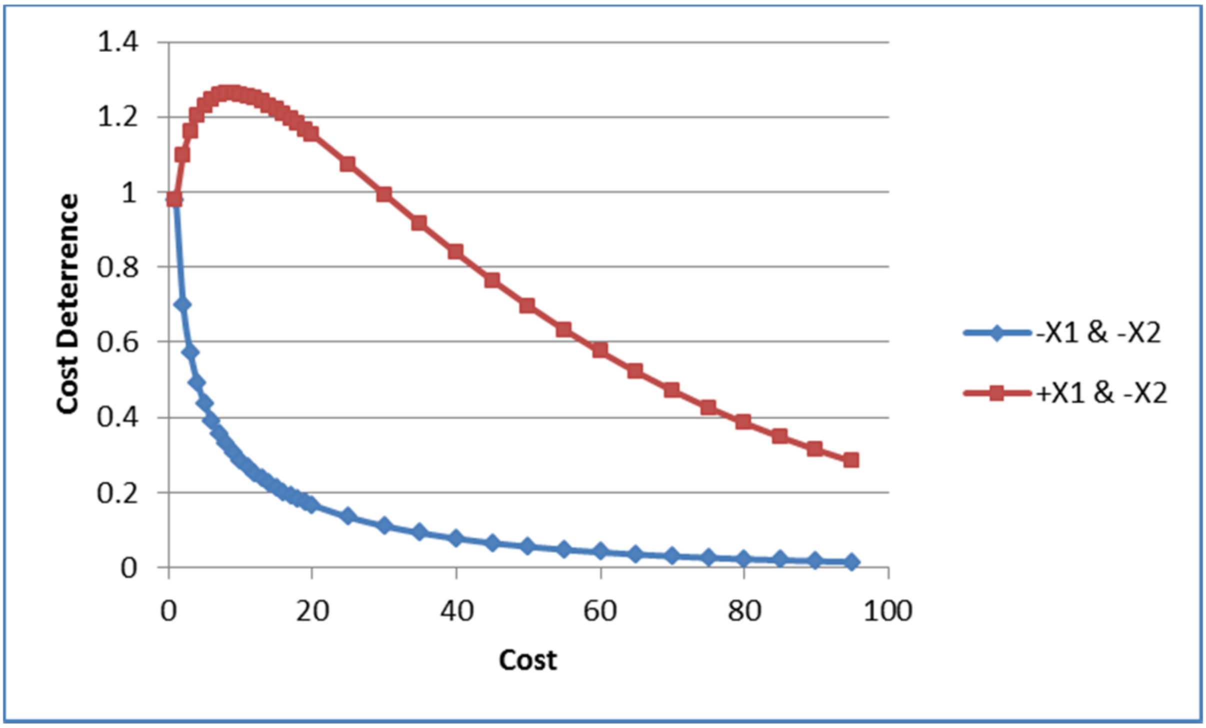

Figure 13: Illustrative Cost Deterrence Function Plots

The number of trips between each OD pair is then calculated as follows:

$T_{ij} = a_i b_j P_i A_j F(C_{ij})$

where:

T_{ij} = trips estimated from zone i to zone j

P_i = productions from zone i

A_j = attractions to zone j

a_i, b_j = row/column balancing factors

$F(C_{ij})$ = cost deterrence from zone i to zone j

3.2 Model Estimation

The inputs to MVGRAM consist of an observed demand matrix and a cost matrix. For the commercial vehicle model a cost matrix obtained by skimming distance from shortest paths was considered a suitable starting position. Omitting time from the cost avoids any potential feedback issues, i.e., updated commercial vehicle demands leading to revised cost skims. It also means in application, that small changes in travel times will not result in businesses effectively relocating – the three stage model effect.

As there is no intra-zonal distances output these values need to be calculated. Whilst there are complicated methods to obtain inter-zonal distance a simple, commonly used, GIS self-potential equation based on zone area was used:

Inter-zonal distance = 0.5 * (area / 3.141593) ^ 0.5

MVGRAM has the ability to calibrate based on full or partially observed demand matrices. For the commercial vehicle model the latter option is relevant as the data processing is based on a sample of trips. In MVGRAM the unobserved OD pairs are given negative costs and these negative cells are ignored during the calibration phase. On the last iteration of the calibration the negatives cells are made positive and trips estimated for the unobserved cells to infill the matrix. This last step was not used as the partially observed demands have already been factored to screenline totals and infilling would generate additional trips. Note that this implies that the sample data is an unbiased reflection of the true trip length distribution.

The full matrices are calculated by running MVGRAM in ***forecast*** mode. This mode takes as input the calibrated distribution parameters and the trip end totals calculated from the land use linear regression. In the following sections the term 'forecast' refers to matrices synthesised in this manner.

The calibrated coefficients for the three time periods are given in **Table 11** along with the observed and estimated average trip lengths (excluding Port and External trips). Plots of the cost deterrence functions are shown in **Figure 14**.

	AM	IP	PM
Calibrated Coefficients			
X_1	-0.3321	-0.6383	-0.2904
X_2	-0.0386	-0.0400	-0.0330
Average Trip Length (km)			
Observed	8.08	7.38	8.36
Estimated	8.08	7.38	8.36

Table 11: Gravity Model Calibration Parameters

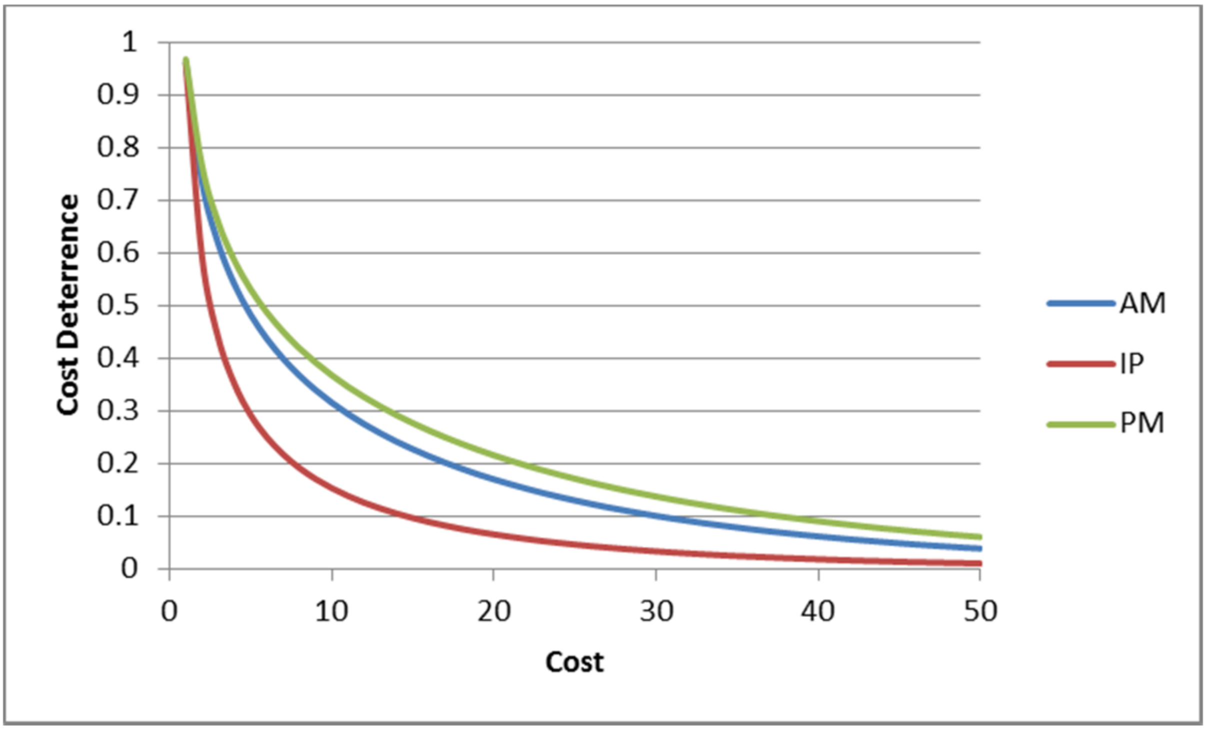

Figure 14: Calibrated Cost Deterrence Functions

Comparison plots of the calibrated trip length distributions against the input partial observed matrix trip length distribution are shown in **Figures 15 to 17**.

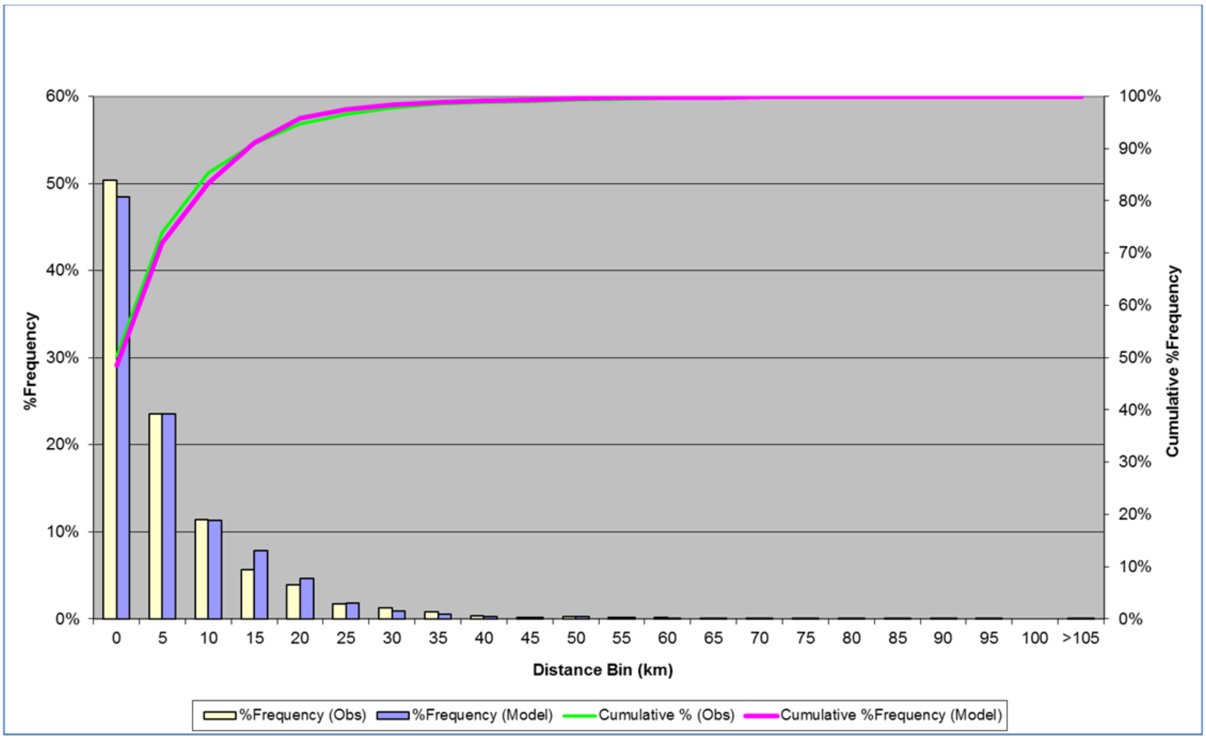

Figure 15: AM Trip Length Distribution – Observed versus Calibrated

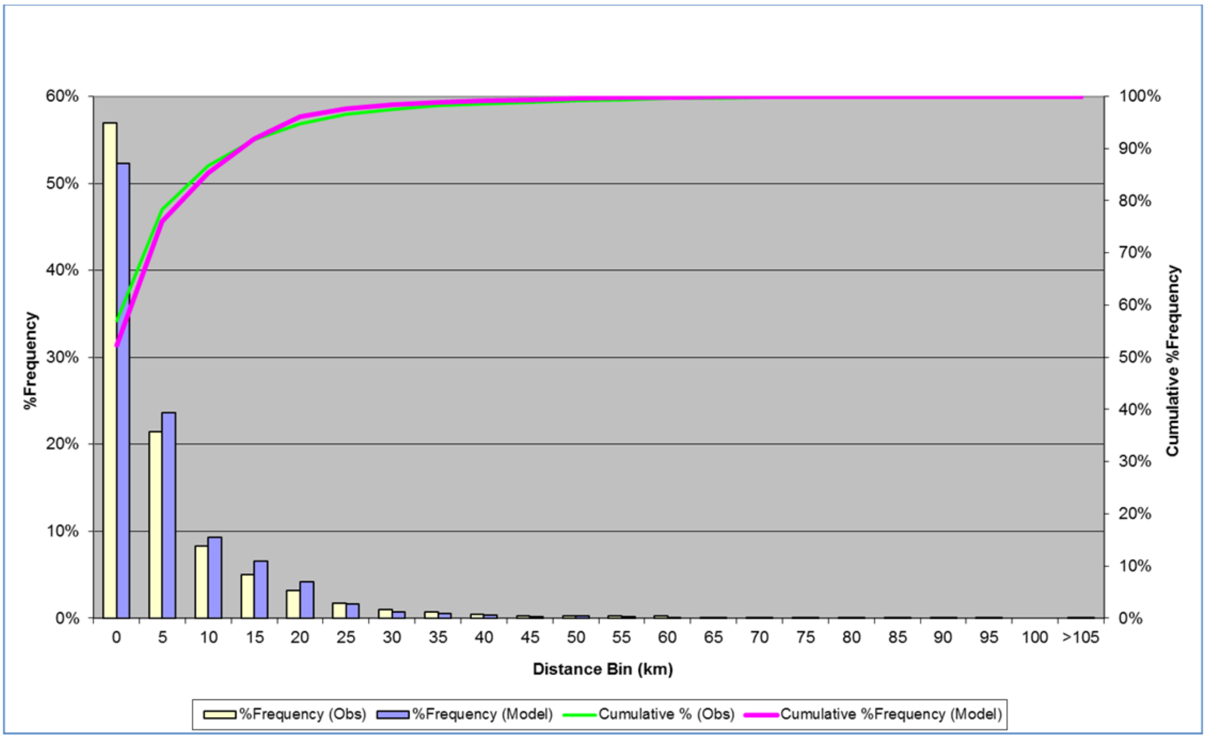

Figure 16: Interpeak Trip Length Distribution – Observed versus Calibrated

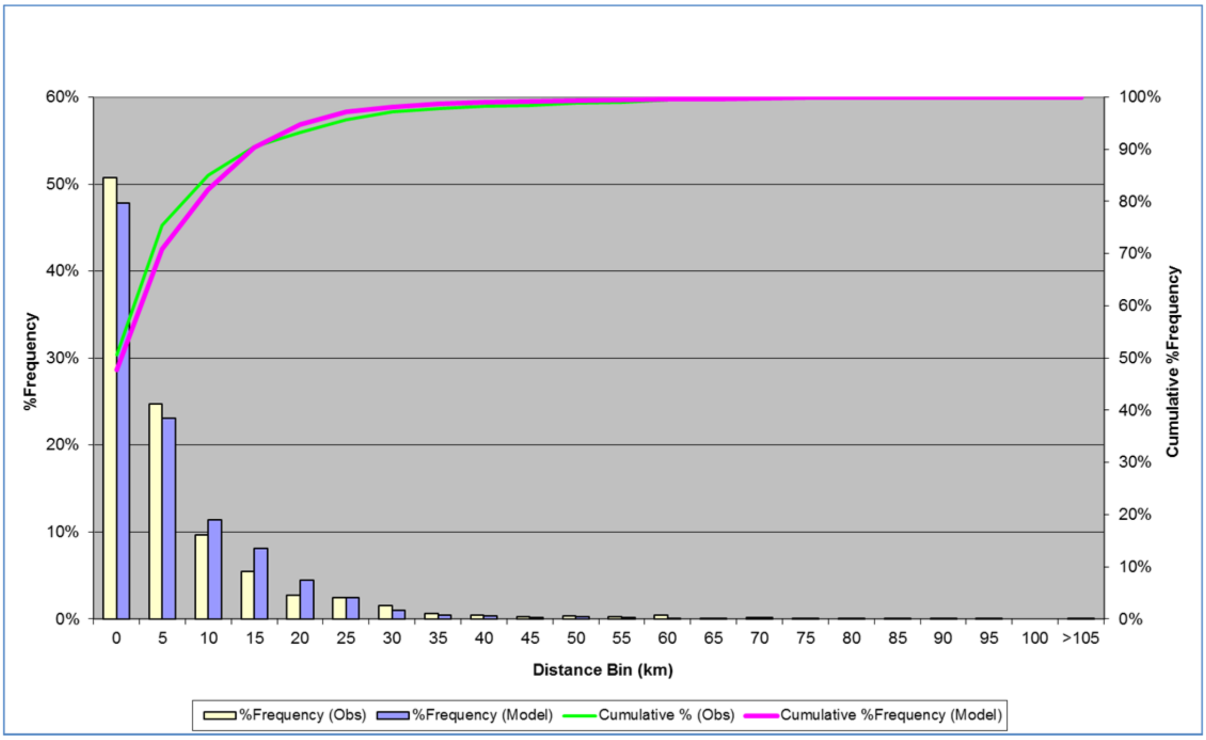

Figure 17: PM Trip Length Distribution – Observed versus Calibrated

3.3 Forecast (2013) Matrices

The trip length distributions shown in **Figures 15 to 17** are for the partially observed trip matrices, i.e., the expanded observed sample commercial vehicle trips. To obtain the full matrices, .i.e., every OD cell containing a calculated value (which may be zero due to matrix precision settings), MVGRAM was rerun in forecast mode using the calibrated coefficients (see **Table 11**) and trip end controls totals calculated using Model 2 (see **Table 10**). This is the process of applying the equations to produce synthetic matrices.

The resulting trip length distributions are shown in **Figures 18 to 23**. The first set of three figures compares the distributions based on observed OD movements only. The second set of three compares the distributions based on the whole matrix. As can be seen the partial matrix distributions based on modelled trip ends are very similar to the observed. The distributions based on the full matrix show a marked decrease in shorter length trips. The average trip length of the full forecast matrices is 15.21, 10.93 and 16.75 km for the AM, interpeak and PM respectively.

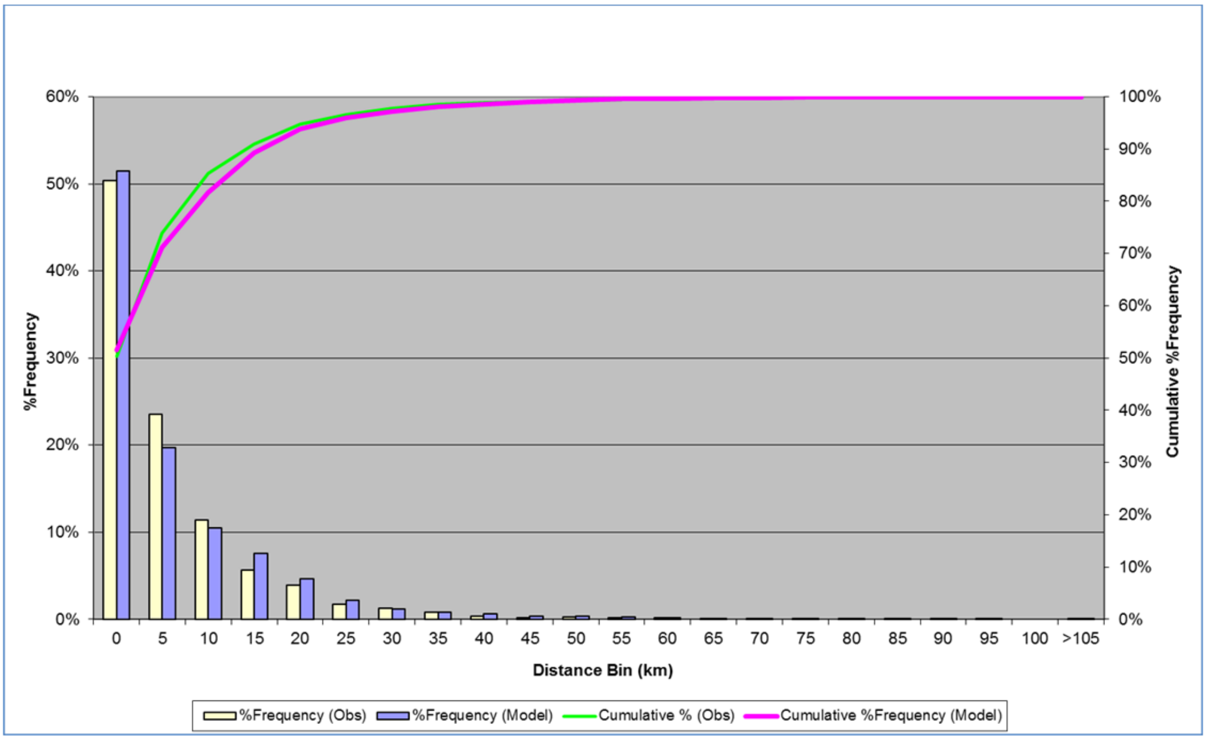

Figure 18: Forecast AM Trip Length Distribution (Partial Forecast Matrix)

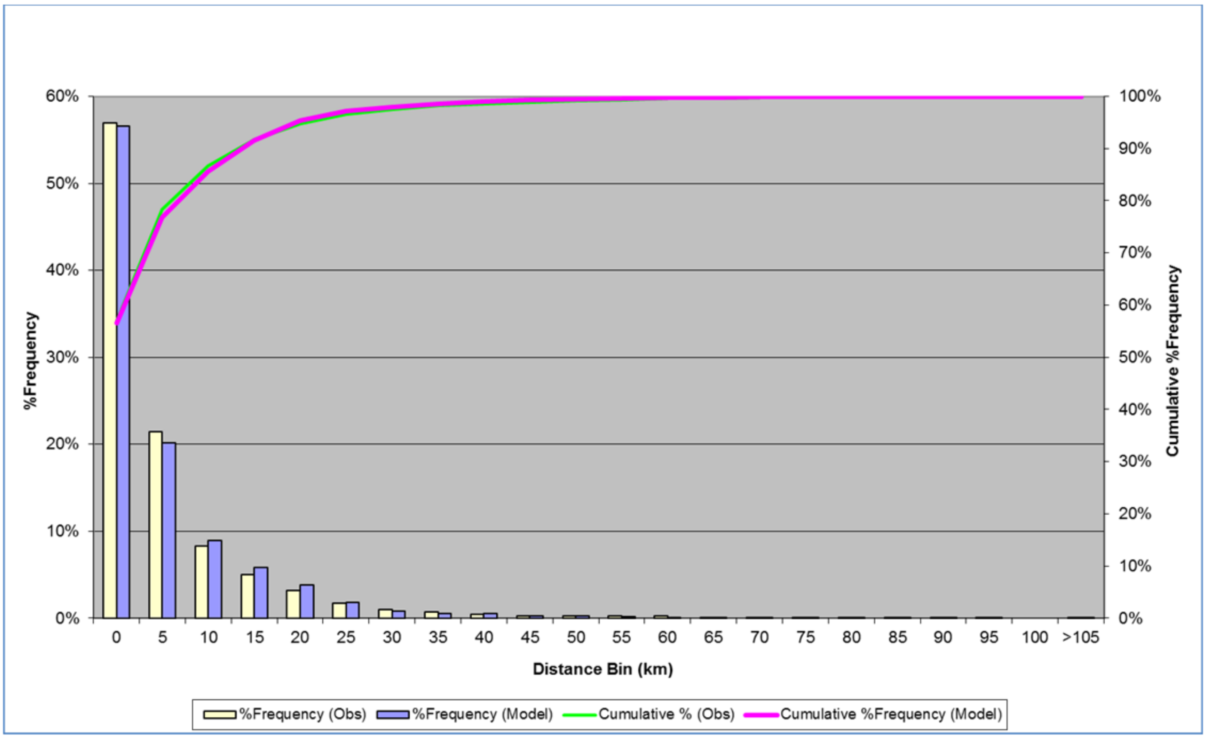

Figure 19: Forecast IP Trip Length Distribution (Partial Forecast Matrix)

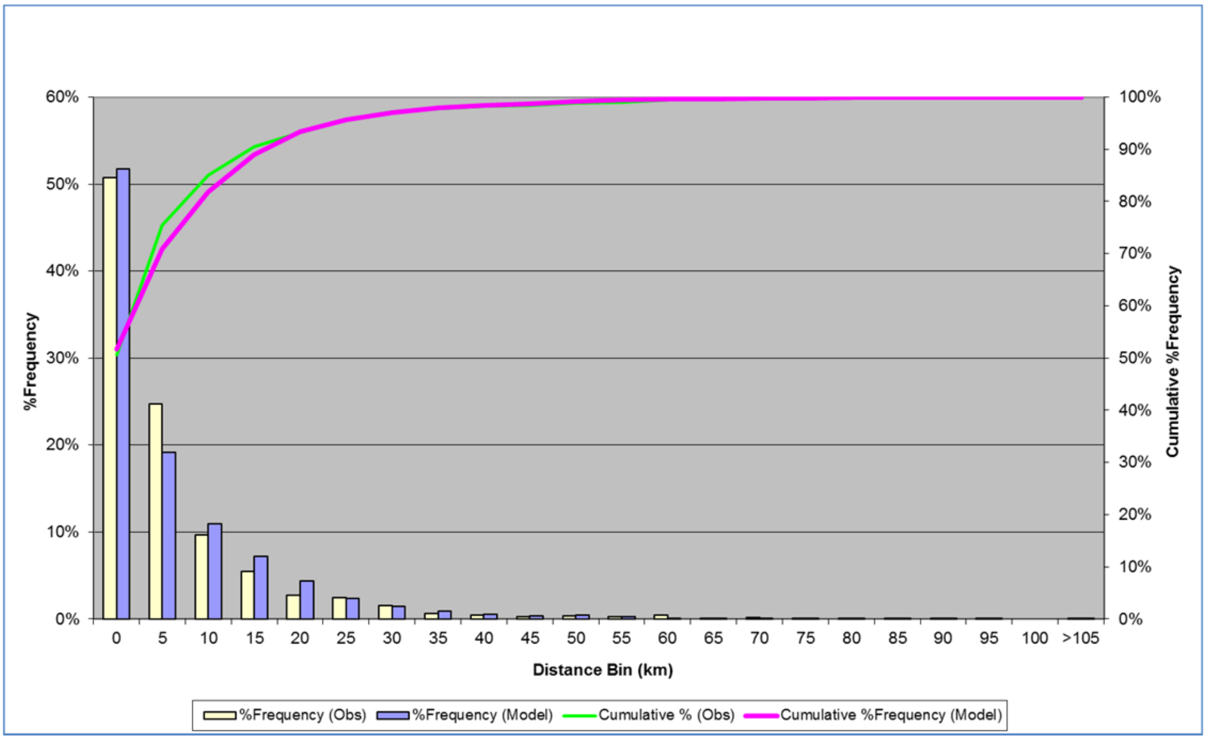

Figure 20: Forecast PM Trip Length Distribution (Partial Forecast Matrix)

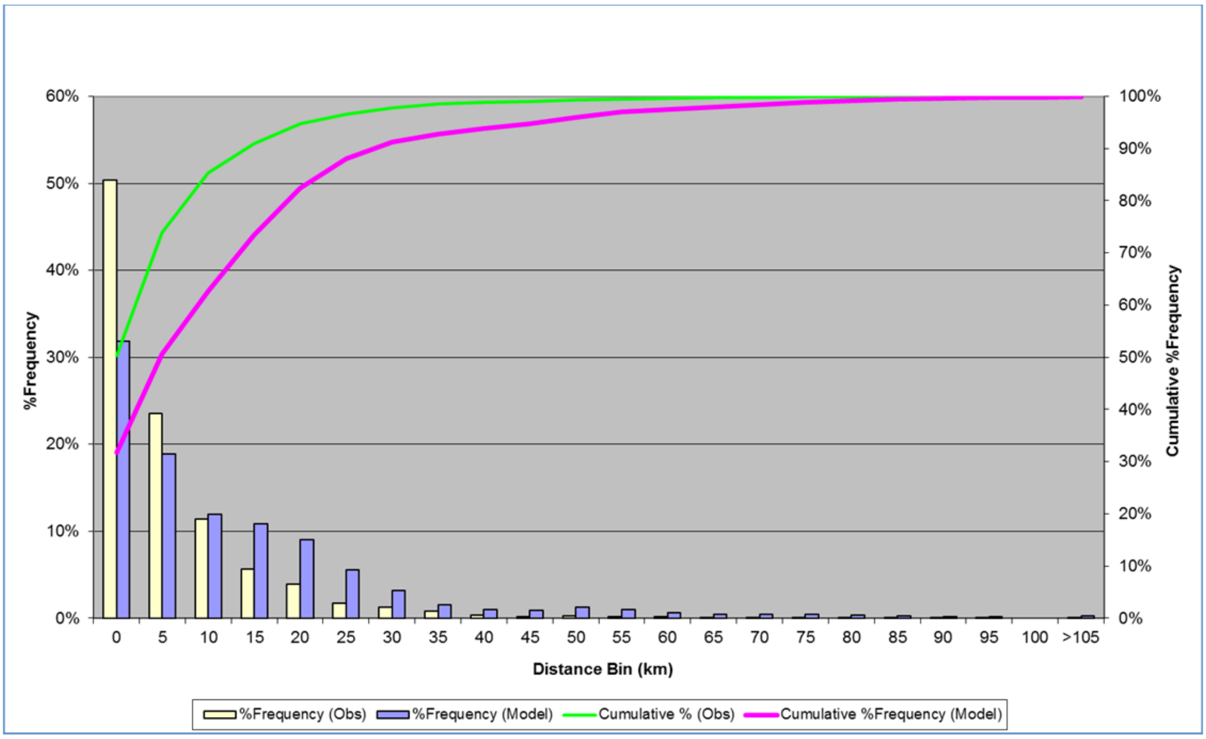

Figure 21: Forecast AM Trip Length Distribution (Full Forecast Matrix)

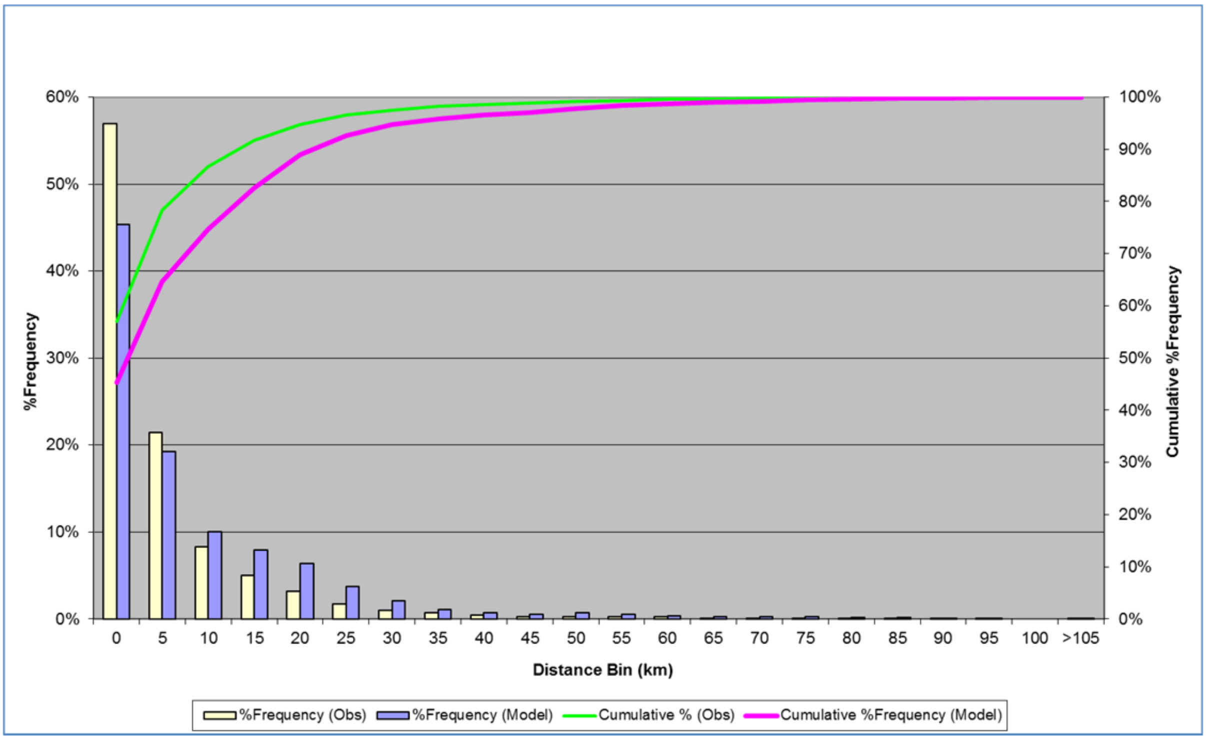

Figure 22: Forecast Interpeak Trip Length Distribution (Full Forecast Matrix)

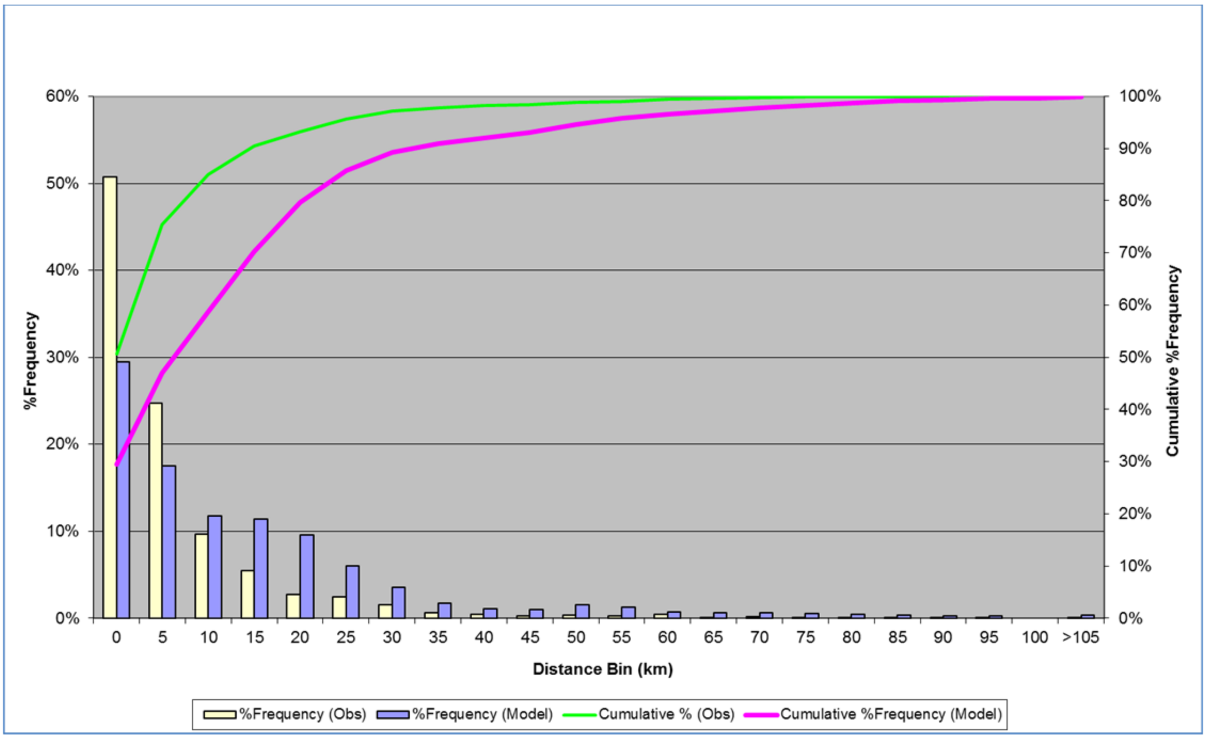

Figure 23: Forecast PM Trip Length Distribution (Full Forecast Matrix)

Comparisons of the full forecast (2013) matrix demands and observed demands are given in **Tables A1, A3** and **A5** in Appendix A. These show some significant differences on a sector-by-sector basis between the forecast and expanded observed. External sectors 111 and 112 are excluded from the tables in Appendix A as external trips are not calculated as part of the internal trip end linear regression models.

The differences between the 2013 forecast and observed screenline volumes are given in **Tables A2, A4** and **A6** respectively for the AM, interpeak and PM peak periods. Observed external trips are retained in the reported screenline volumes so as to keep the totals the same as those used in the expansion. The reported GEH values are based on one hour volumes and have been calculated using half the two hour volumes, i.e., the average hourly flow. The worst performing screenlines are 6, 14, 70 and 71, which, being centrally placed are more prone to extra trips resulting from the increase in average trip length.

3.4 Adjusted Forecast (2013) Matrices

As noted in Section 3.3 the full forecast demand matrices produce trip length distributions skewed towards longer trips and average trip lengths higher than the expanded observed. These longer trips also affect the screenline volumes leading to some screenlines with high (>12) GEH values.

To rectify this issue the gravity model coefficients were manually adjusted to produce a similar trip length distribution and average trip length to the expanded observed matrices. The adjusted coefficients and resulting average trip lengths are shown in **Table 12** – these coefficients form the internal trip distribution model (i.e., excluding external and Port trips). Plots of adjusted trip length distributions are shown in **Figures 24** to **26**.

	AM	IP	PM
Adjusted Coefficients			
X_1	-0.550	-0.770	-0.500
X_2	-0.075	-0.066	-0.075
Average Trip Length (km)			
Adjusted Forecast	8.07	7.22	8.20

Table 12: Adjusted Gravity Model Calibration Parameters

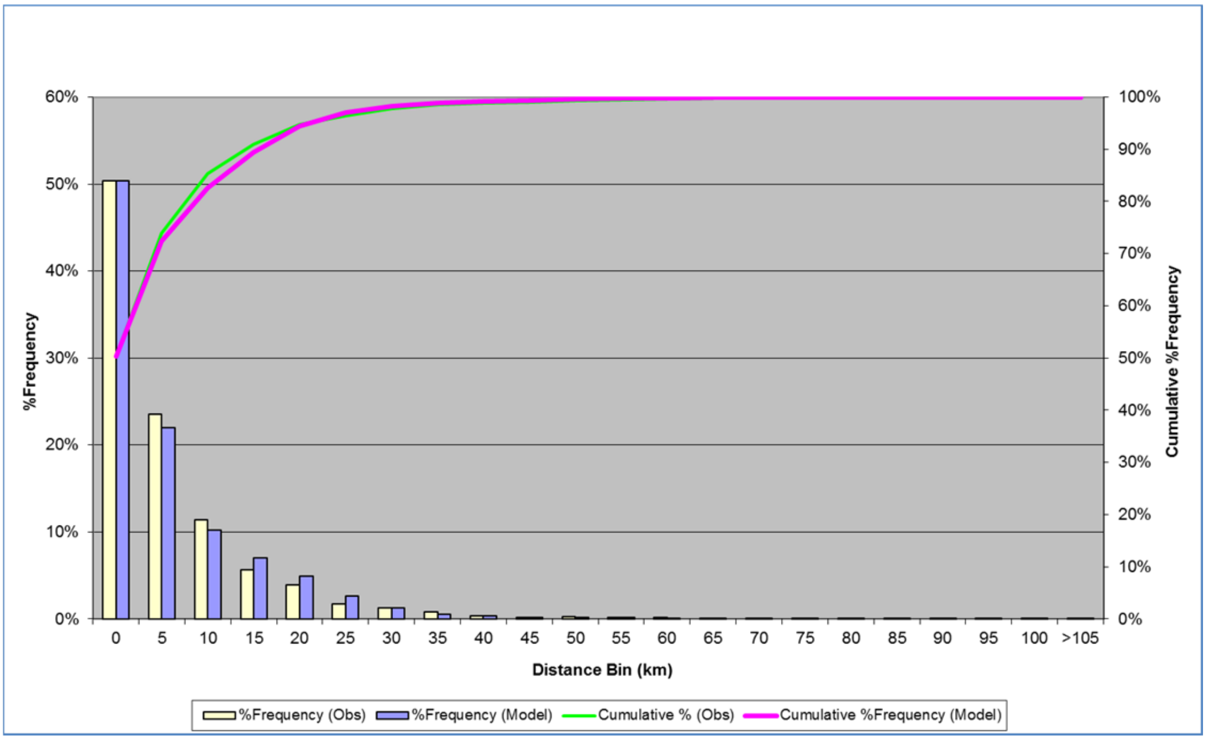

Figure 24: Forecast AM Trip Length Distribution (Adjusted Full Forecast Matrix)

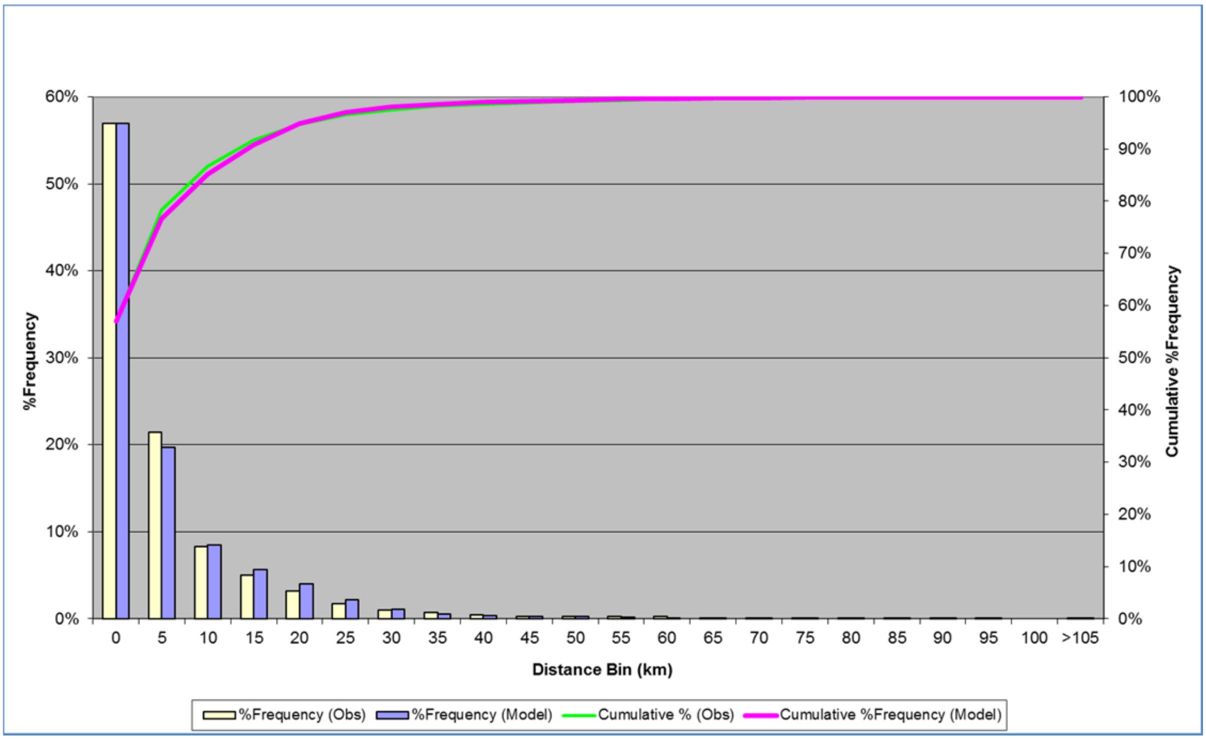

Figure 25: Forecast Interpeak Trip Length Distribution (Adjusted Full Forecast Matrix)

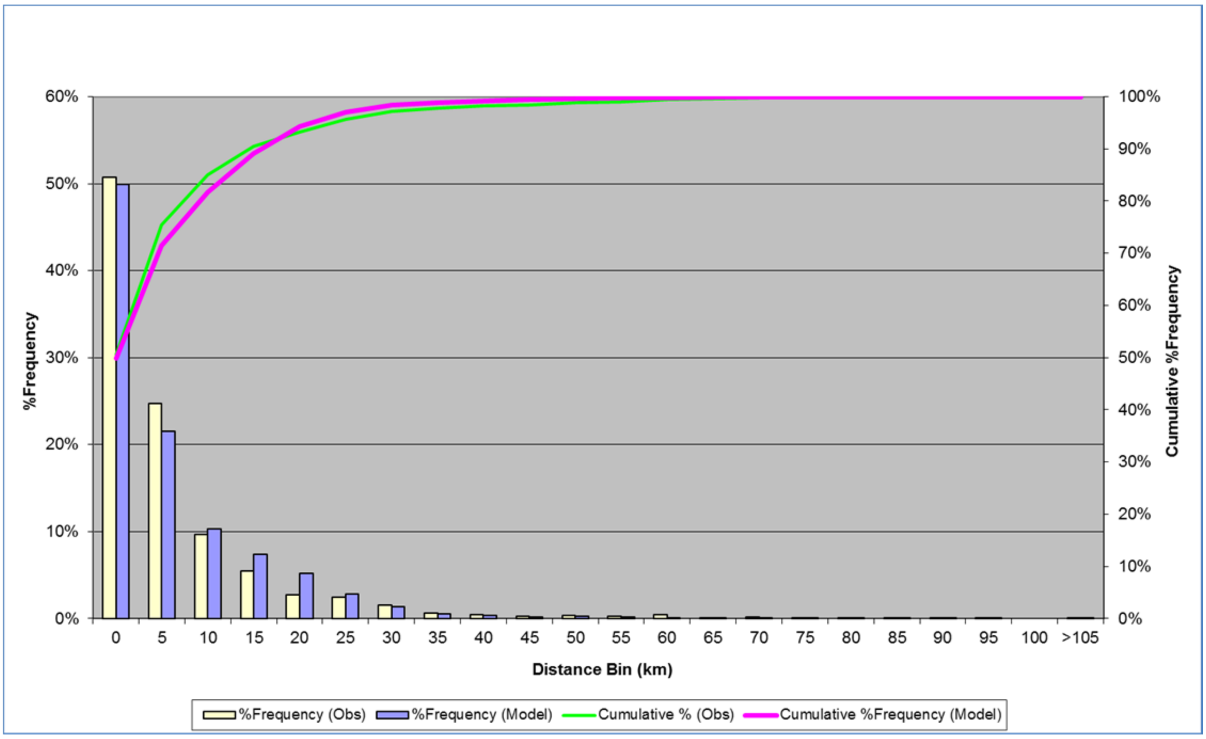

Figure 26: Forecast PM Trip Length Distribution (Adjusted Full Forecast Matrix)

Comparisons of the full adjusted forecast matrix demands and observed demands are given in **Tables B1**, **B3** and **B5** in Appendix B. These show some significant differences on a sector-by-sector basis between the forecast and expanded observed. The overall screenline GEH values are, however, very reasonable. External sectors 111 and 112 are excluded from the tables in Appendix B as external trips are not calculated as part of the internal trip end linear regression models.

The differences between the 2013 adjusted forecast and observed screenline volumes are given in **Tables B2**, **B4** and **B6** respectively for the AM, interpeak and PM peak periods. Observed external trips are retained in the reported screenline volumes so as to keep the totals the same as those used in the expansion. The reported GEH values are based on one hour volumes and have been calculated using half the two hour volumes, i.e., the average hourly flow. The worst performing screenline is 121, which is typically worse than the pre-adjusted forecast case but other pre-adjusted screenlines are much improved. **Tables 13** to **16** below compare the screenline GEH values for the three time periods for the pre and post adjusted distribution model coefficient values.

	Direction 1			Direction 2		
Screenline	**Unadjusted**	**Adjusted**	**Improved?**	**Unadjusted**	**Adjusted**	**Improved?**
5	3.0	0.3	Yes	2.6	6.1	No
11	3.4	0.7	Yes	0.5	3.7	No
90	4.3	4.9	No	1.5	0.8	Yes
121	9.0	0.3	Yes	3.1	10.7	No
6	15.5	5.8	Yes	6.8	2.0	Yes
70	14.8	6.7	Yes	13.1	4.9	Yes
14	9.7	1.1	Yes	11.6	3.1	Yes
71	13.6	3.3	Yes	10.0	0.4	Yes
100	2.0	3.8	No	4.3	1.8	Yes
102	5.3	1.7	Yes	6.6	0.5	Yes
103	5.7	1.8	Yes	7.9	0.4	Yes
81	2.0	1.8	Yes	2.8	0.7	Yes
82	7.9	1.3	Yes	9.2	4.1	Yes
GEH Summary						
<=5	5	11		6	11	
<=10	10	13		11	12	
<=12	10	13		12	13	
>12	3	0		1	0	
Total	13	13		13	13	
% <=5	38%	85%		46%	85%	
% <=10	77%	100%		85%	92%	
% <=12	77%	100%		92%	100%	
% >12	23%	0%		8%	0%	

Table 13: AM Peak Screenline GEH – Unadjusted versus Adjusted Distribution Coefficients

	Direction 1			Direction 2		
Screenline	Unadjusted	Adjusted	Improved?	Unadjusted	Adjusted	Improved?
5	0.4	3.0	No	3.6	0.9	Yes
11	4.1	1.0	Yes	1.3	1.9	No
90	0.9	0.3	Yes	1.0	1.6	No
121	2.2	3.0	No	0.6	5.0	No
6	8.4	2.8	Yes	8.6	2.7	Yes
70	11.0	5.9	Yes	10.4	5.3	Yes
14	5.5	0.2	Yes	5.1	0.3	Yes
71	7.3	1.0	Yes	5.8	0.6	Yes
100	1.8	2.3	No	0.5	3.8	No
102	4.4	0.5	Yes	4.3	0.1	Yes
103	5.0	0.1	Yes	6.3	1.8	Yes
81	1.9	4.2	No	0.3	2.4	No
82	4.9	1.2	Yes	7.2	4.7	Yes
GEH Summary						
<=5	9	12		7	11	
<=10	12	13		12	13	
<=12	13	13		13	13	
>12	0	0		0	0	
Total	13	13		13	13	
% <=5	69%	92%		54%	85%	
% <=10	92%	100%		92%	100%	
% <=12	100%	100%		100%	100%	
% >12	0%	0%		0%	0%	

Table 14: Interpeak Screenline GEH – Unadjusted versus Adjusted Distribution Coefficients

	Direction 1			Direction 2		
Screenline	Unadjusted	Adjusted	Improved?	Unadjusted	Adjusted	Improved?
5	0.4	3.0	No	3.6	0.9	Yes
11	4.1	1.0	Yes	1.3	1.9	No
90	0.9	0.3	Yes	1.0	1.6	No
121	2.2	3.0	No	0.6	5.0	No
6	8.4	2.8	Yes	8.6	2.7	Yes

	Direction 1			Direction 2		
Screenline	Unadjusted	Adjusted	Improved?	Unadjusted	Adjusted	Improved?
70	11.0	5.9	Yes	10.4	5.3	Yes
14	5.5	0.2	Yes	5.1	0.3	Yes
71	7.3	1.0	Yes	5.8	0.6	Yes
100	1.8	2.3	No	0.5	3.8	No
102	4.4	0.5	Yes	4.3	0.1	Yes
103	5.0	0.1	Yes	6.3	1.8	Yes
81	1.9	4.2	No	0.3	2.4	No
82	4.9	1.2	Yes	7.2	4.7	Yes
GEH Summary						
<=5	9	12		7	11	
<=10	12	13		12	13	
<=12	13	13		13	13	
>12	0	0		0	0	
Total	13	13		13	13	
% <=5	69%	92%		54%	85%	
% <=10	92%	100%		92%	100%	
% <=12	100%	100%		100%	100%	
% >12	0%	0%		0%	0%	

Table 15: PM Peak Screenline GEH – Unadjusted versus Adjusted Distribution Coefficients

	Direction 1			Direction 2		
Screenline	Unadjusted	Adjusted	Improved?	Unadjusted	Adjusted	Improved?
5	3.3	6.2	No	5.5	2.8	Yes
11	5.5	1.8	Yes	0.6	2.9	No
90	1.2	0.7	Yes	0.6	1.1	No
121	1.0	6.9	No	5.3	3.2	Yes
6	8.4	0.6	Yes	14.5	4.9	Yes
70	14.2	6.4	Yes	14.8	6.8	Yes
14	11.9	3.4	Yes	10.2	1.5	Yes
71	12.2	2.4	Yes	16.6	6.8	Yes
100	3.1	2.5	Yes	0.1	5.6	No
102	6.9	0.4	Yes	5.9	1.7	Yes
103	9.1	1.0	Yes	6.4	1.9	Yes

	Direction 1			Direction 2		
Screenline	**Unadjusted**	**Adjusted**	**Improved?**	**Unadjusted**	**Adjusted**	**Improved?**
81	0.7	2.9	No	2.9	0.5	Yes
82	7.7	0.2	Yes	7.6	0.1	Yes
GEH Summary						
<=5	5	10		4	10	
<=10	10	13		9	13	
<=12	11	13		10	13	
>12	2	0		3	0	
Total	13	13		13	13	
% <=5	38%	77%		31%	77%	
% <=10	77%	100%		69%	100%	
% <=12	85%	100%		77%	100%	
% >12	15%	0%		23%	0%	

Table 16: PM Peak Screenline GEH – Unadjusted versus Adjusted Distribution Coefficients

3.5 Conclusion – Internal Trip Distribution Model

Overall, the adjusted coefficients for the internal trip distribution model produce a better fit between modelled and observed in terms of trip length distributions and screenline comparisons.

The coefficients values in the following table have therefore been adopted, which are applied to distance.

	AM	IP	PM
Adopted Coefficients			
X_1	-0.550	-0.770	-0.500
X_2	-0.075	-0.066	-0.075
Average Trip Length (km)			
Adjusted Forecast	8.07	7.22	8.20

Table 17: Adopted Gravity Model Calibration Parameters

4. Internal Trips – Travel Patterns

4.1 Desire Lines

The total demand excluding intra-sector trips for 2011 is presented visually in the desire line diagram shown in **Figure 27** for the AM peak in 2011 at zonal level, and **Figures 28 to 30** for 2011 at sector level for each peak period.

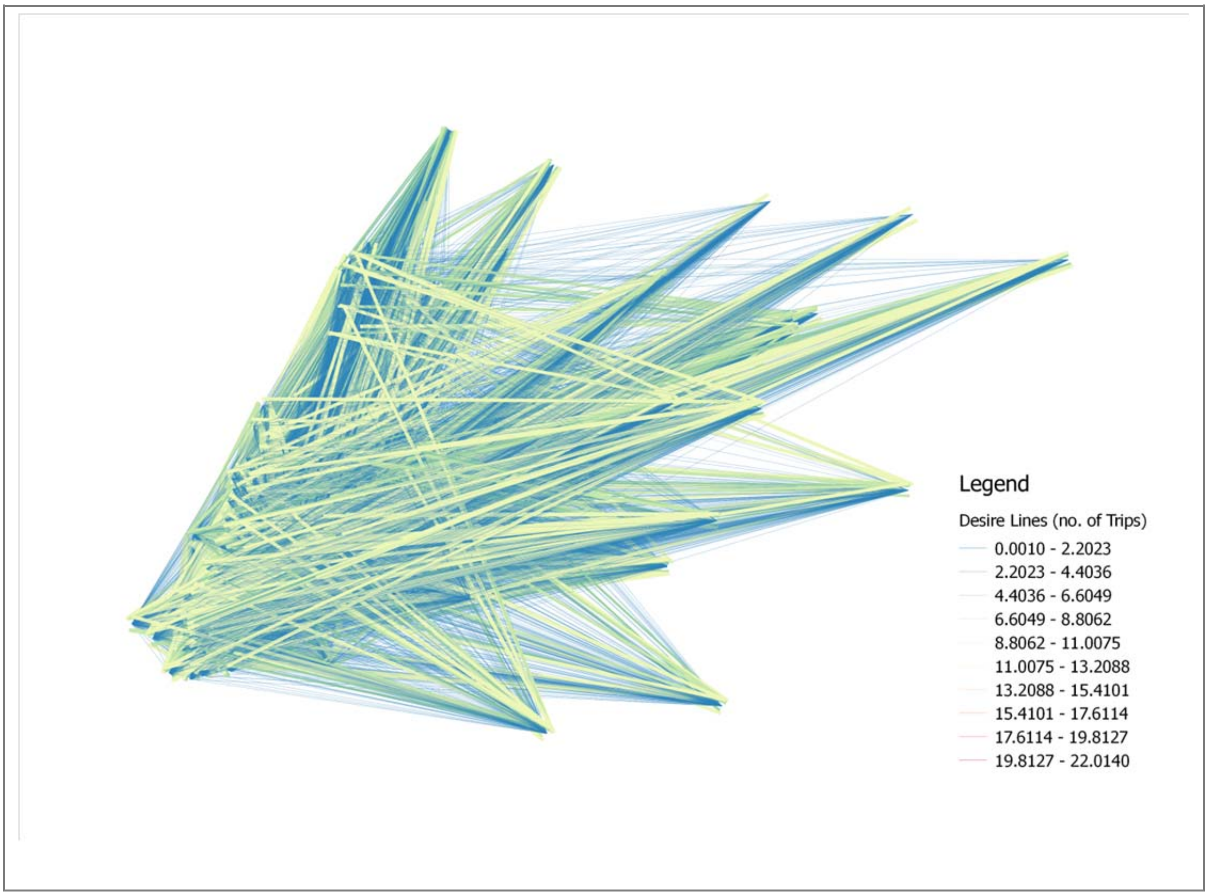

Figure 27: AM 2011 Commercial Vehicle Desire Lines (excl. intra-sector)

At zonal level, the AM peak trip making appears dispersed with no dominant origins or destinations identifiable – in fact, no trends or patterns can easily be perceived. This does show that the 2011 synthesized matrix is relatively "smooth" with trips between a large number of zone pairs.

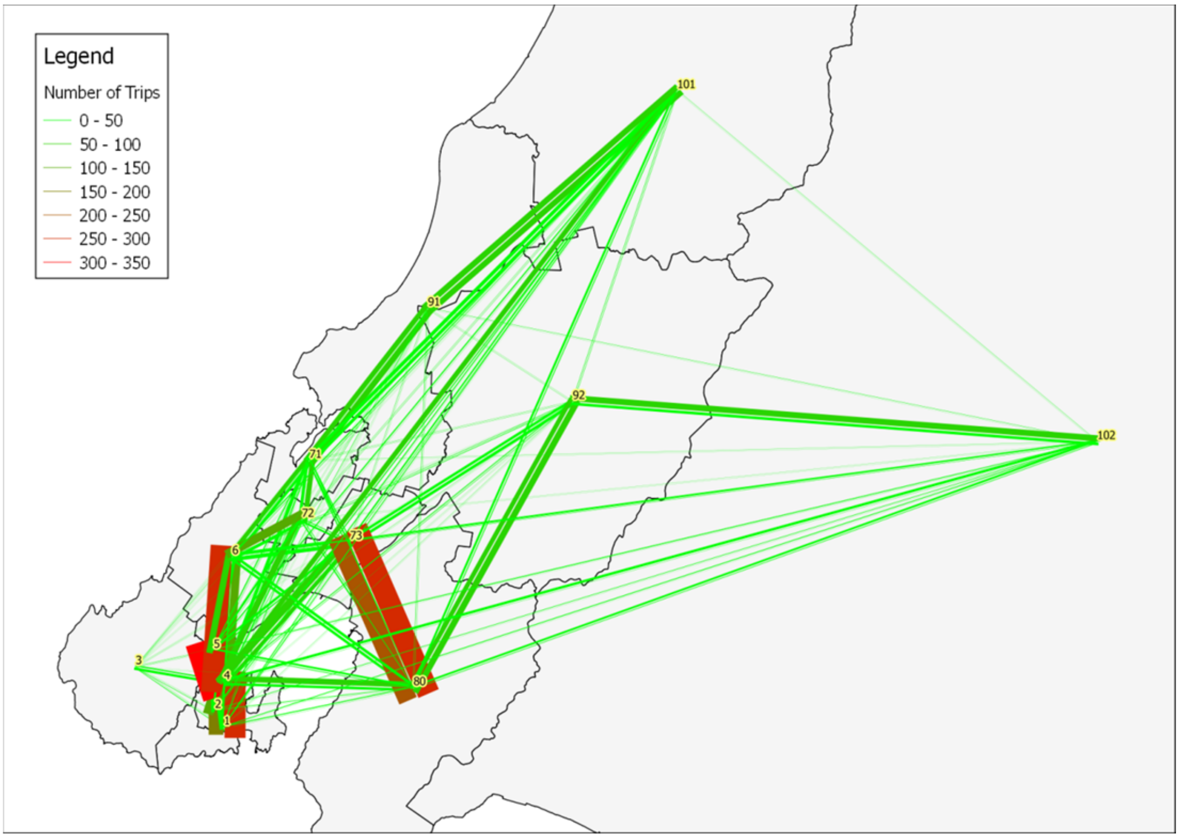

Figure 28: AM 2011 Demands Sectored Desire Lines

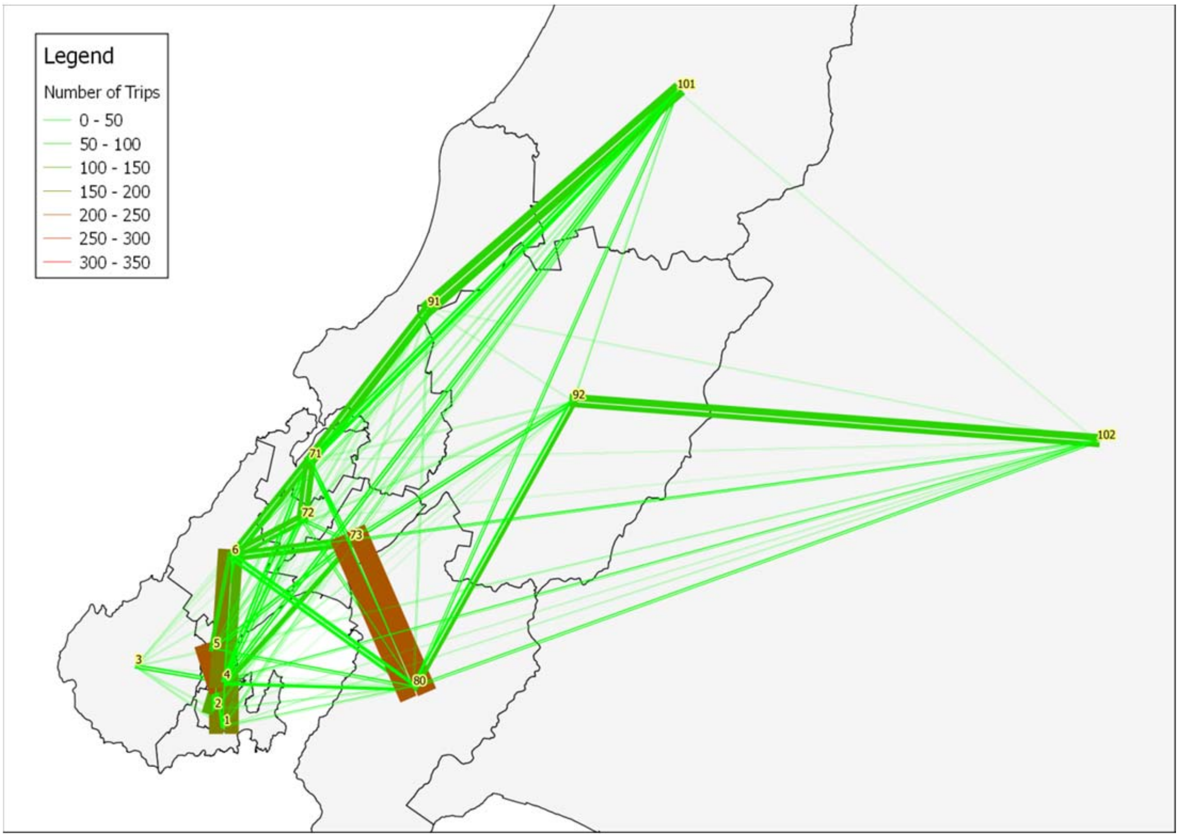

Figure 29: Interpeak 2011 Demands Sectored Desire Lines

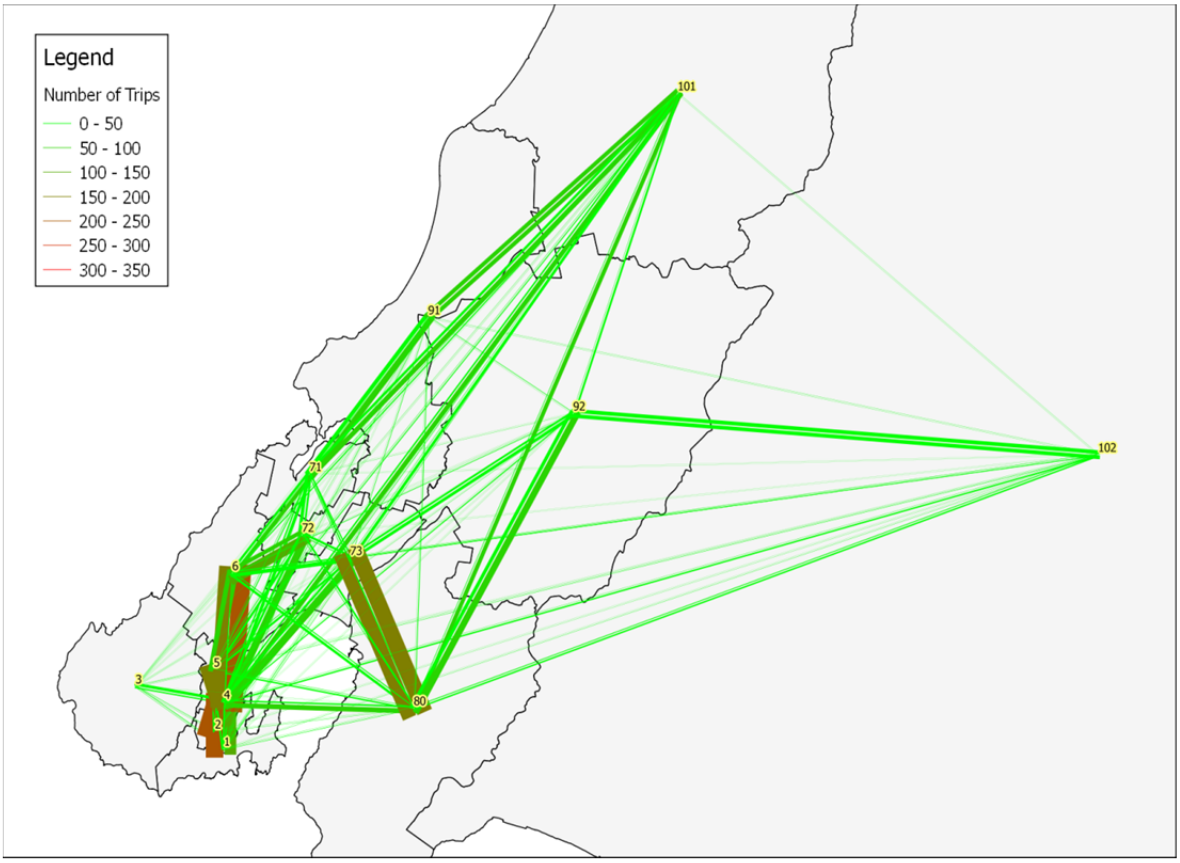

Figure 30: PM 2011 Demands Sectored Desire Lines

At sector level, the 2011 demands indicated a large number of trips between Petone and Lower Hutt in all three peak periods. There are also significant demands between the city centre and north of the city centre (Johnsonville, etc). Sector 101 (Otaki/Waikanae) also has numerous less significant connections.

Note that the sector level plots use the sector area centroid and not some sort of weighted (trip) distribution centroid. Note that the latter could still generate centroids remote from any trip making areas if more than one main area exists in a sector. The remote location of some sector centroids in relation to the employment within the sector has a lot to do with the size of the sector and lack of screenline count data to further divide the sector.

The zone based desire line plots for 2013 shown in **Figures 31** to **33** are the expanded trips from the data processing but exclude the intra-sector trips to improve the clarity of the figures.

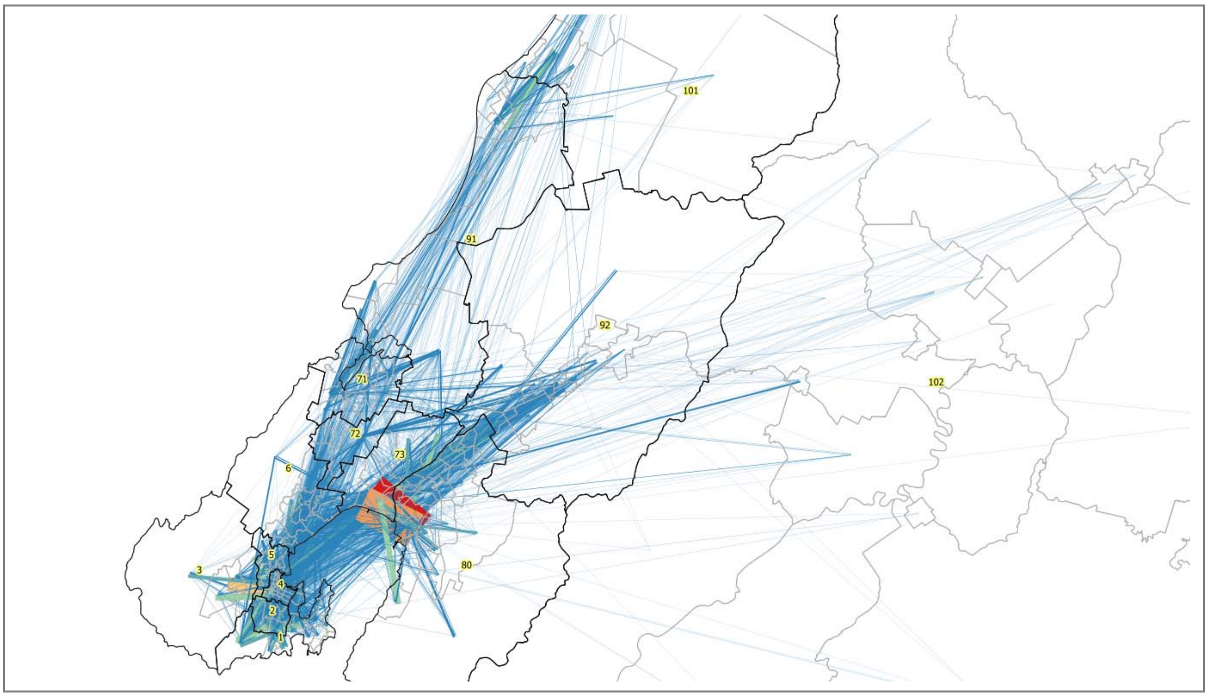

Figure 31: AM Peak 2013 Commercial Vehicle Desire Lines (Expanded Observed excl. Intra-sector)

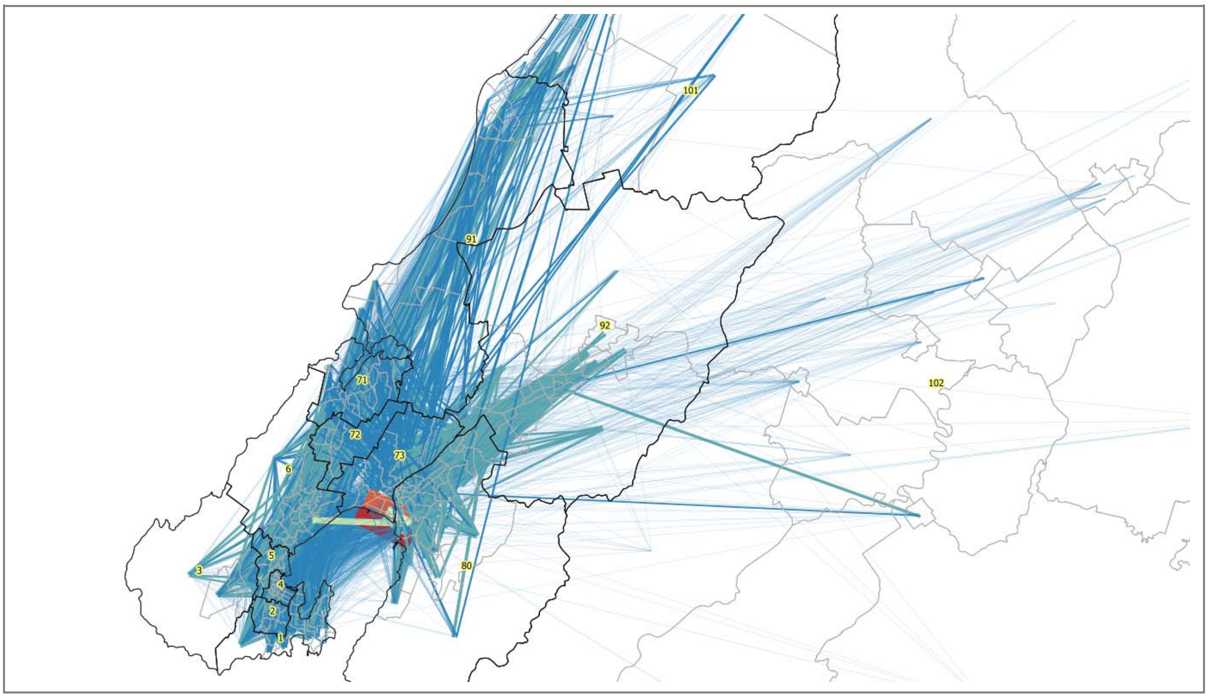

Figure 32: Interpeak 2013 Commercial Vehicle Desire Lines (Expanded Observed excl. Intra-sector)

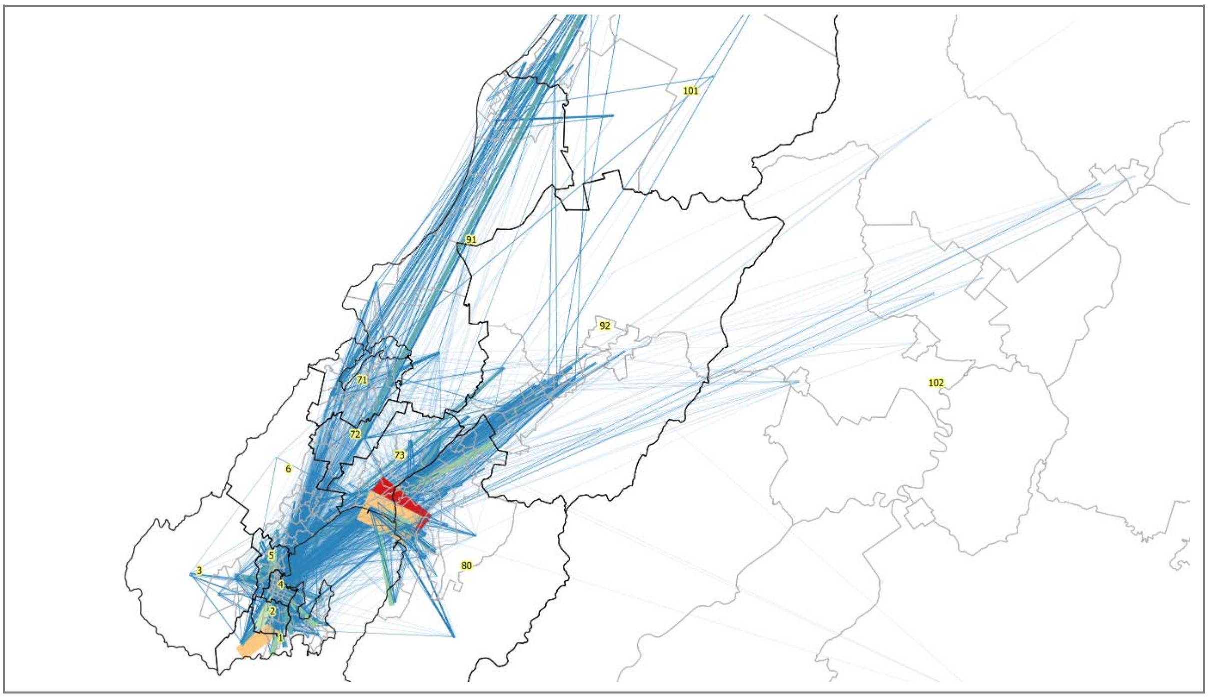

Figure 33: PM Peak 2013 Commercial Vehicle Desire Lines (Expanded Observed excl. Intra-sector)

The 2013 observed demands show a large number of trips between Lower Hutt and Petone. These movements do not have an overly large expansion factor in any of the peak periods. A significant clustering of trips was observed in the sample matrices indicating either a large demand or perhaps a greater representation in the sample.

Figures 34 to **36** show desire lines for the final adjusted forecast 2013 demands sectored to the sectors shown in **Figure 1**. These plots are the 2013 equivalent of the 2011 plots in **Figures 28** to **30**. Comparison of these two sets of figures show that the 2013 matrices have similar levels of trips between Lower Hutt and Petone (sectors 80 and 73) but lower levels between sectors 1, 2, 3, 4, 5 and 6 – which are the Wellington city sectors south of Ngauranga. They also show far less activity between the outer sectors (101 and 102) and the active inner sectors such as 80, 73, 6 and city centre sectors

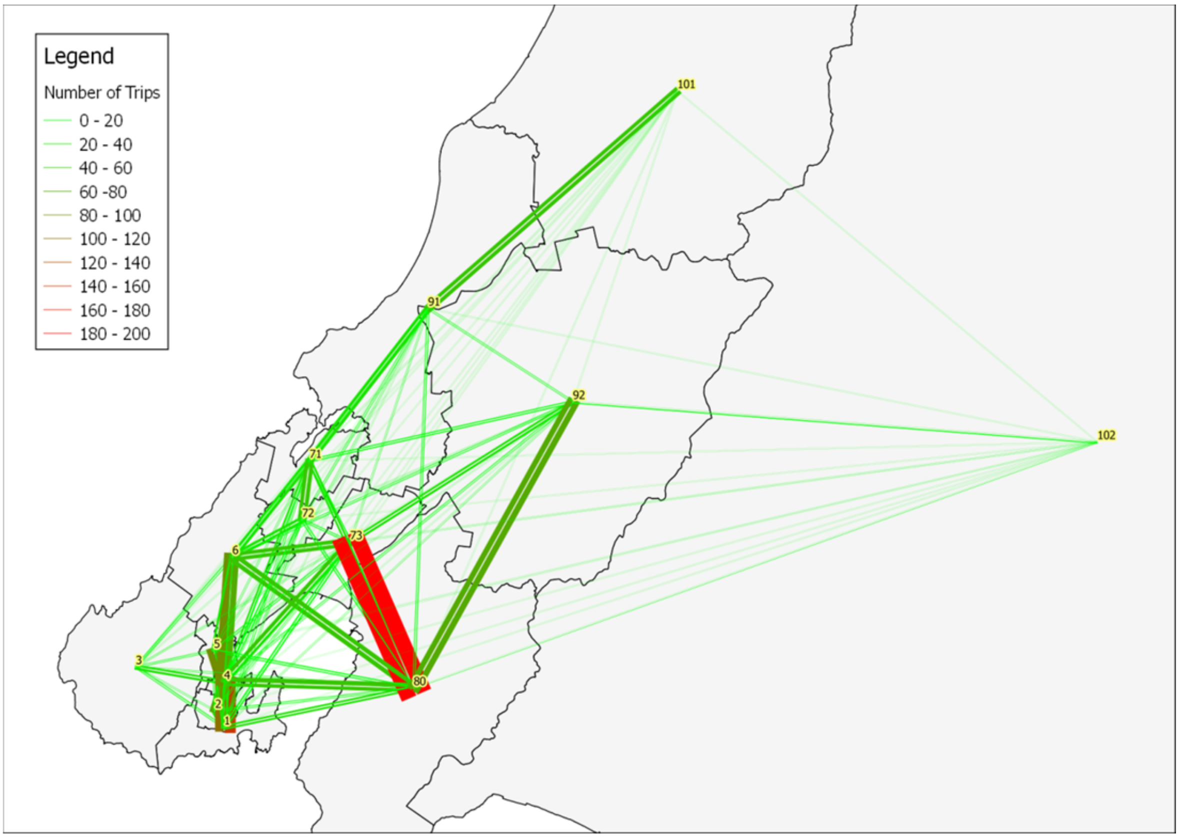

Figure 34: AM 2013 Adjusted Forecast Demands Sectored Desire Lines

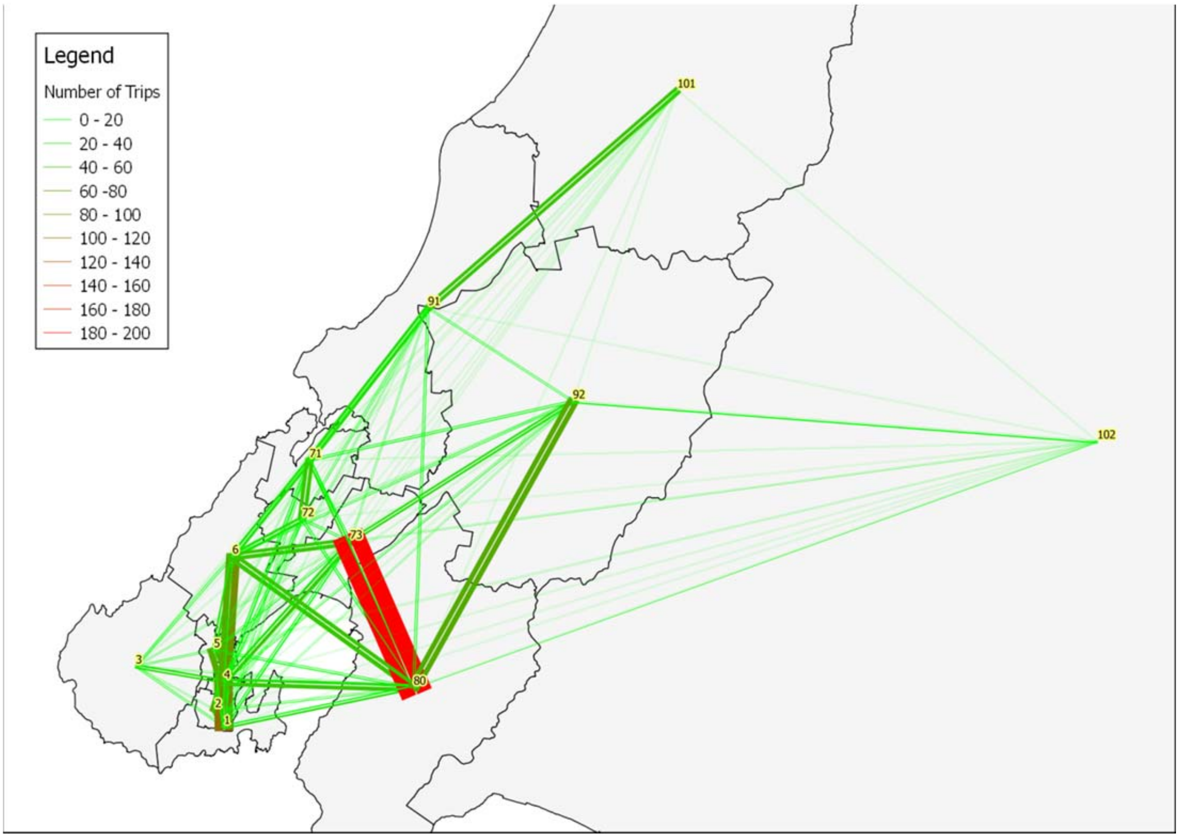

Figure 35: Interpeak 2013 Adjusted Forecast Demands Sectored Desire Lines

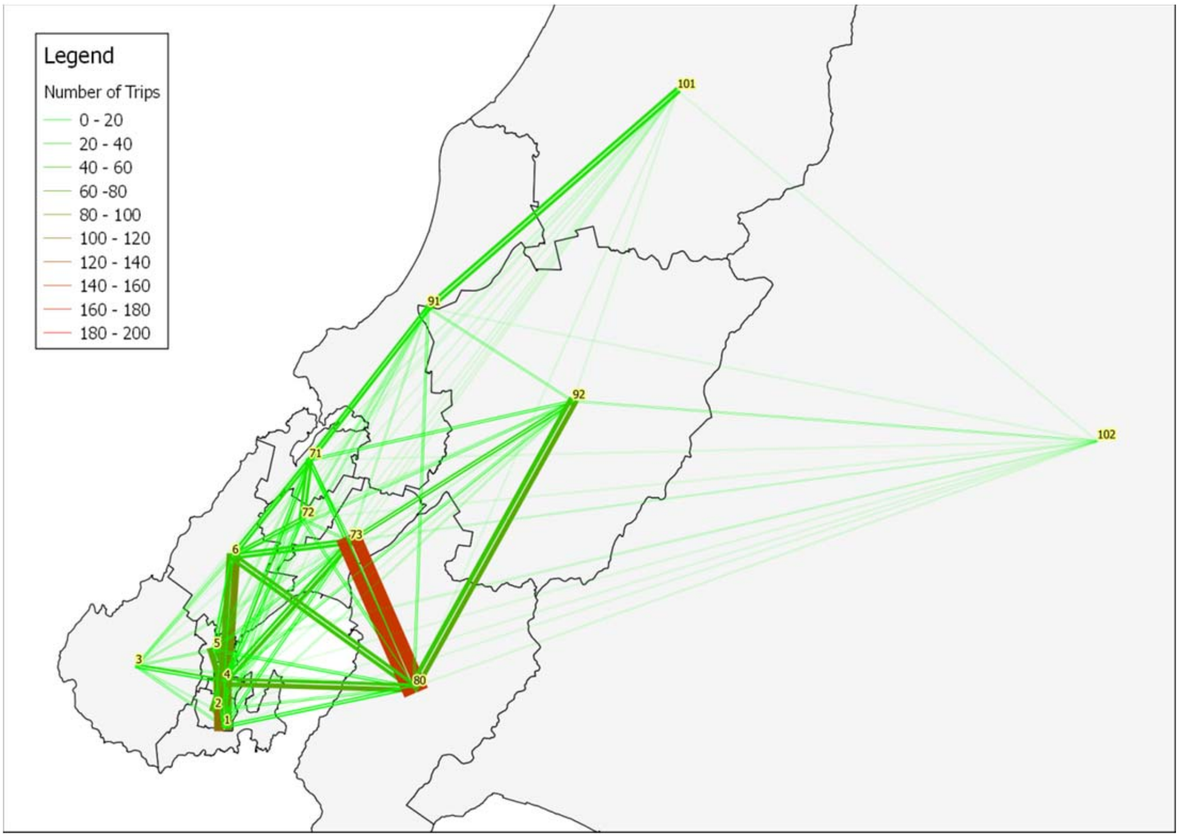

Figure 36: PM 2013 Adjusted Forecast Demands Sectored Desire Lines

4.2 Comparison of Assigned Volumes

Comparison of assigned commercial vehicle and car volumes (two hour) using adjusted forecast 2013 commercial vehicle versus 2011 commercial vehicle inputs are shown in **Figures 37 to 42** below for the AM, interpeak and PM peak periods. The assignment in WTSM is multi-user class hence the need to review both hcv and car volumes, i.e., a change in hcv volumes will result in a change in car volumes. In the figures below green bands are negative and red positive, i.e., red indicates an increase in vehicles per two hours over the 2011 case.

Note that these plots include external trips to/from SH1 and SH2.

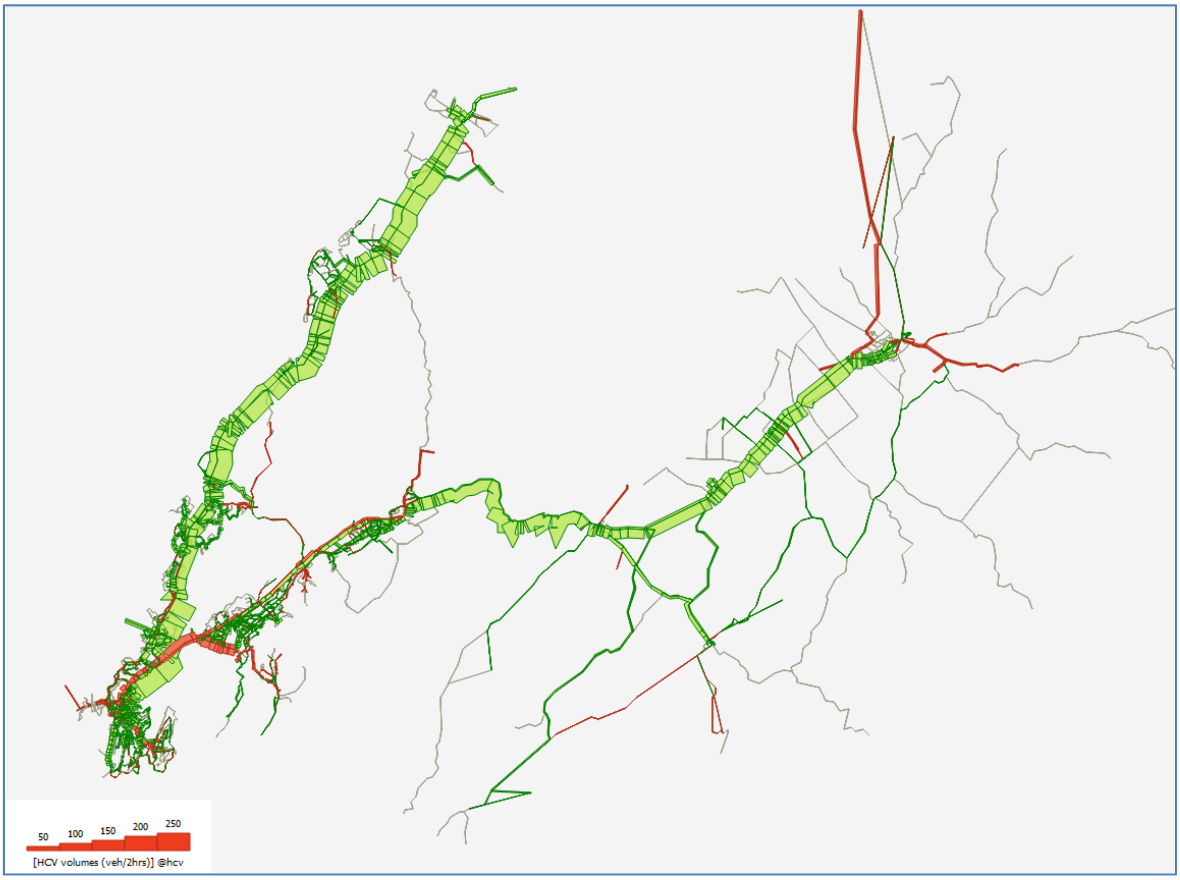

Figure 37: AM Peak 2hr Commercial Vehicle Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

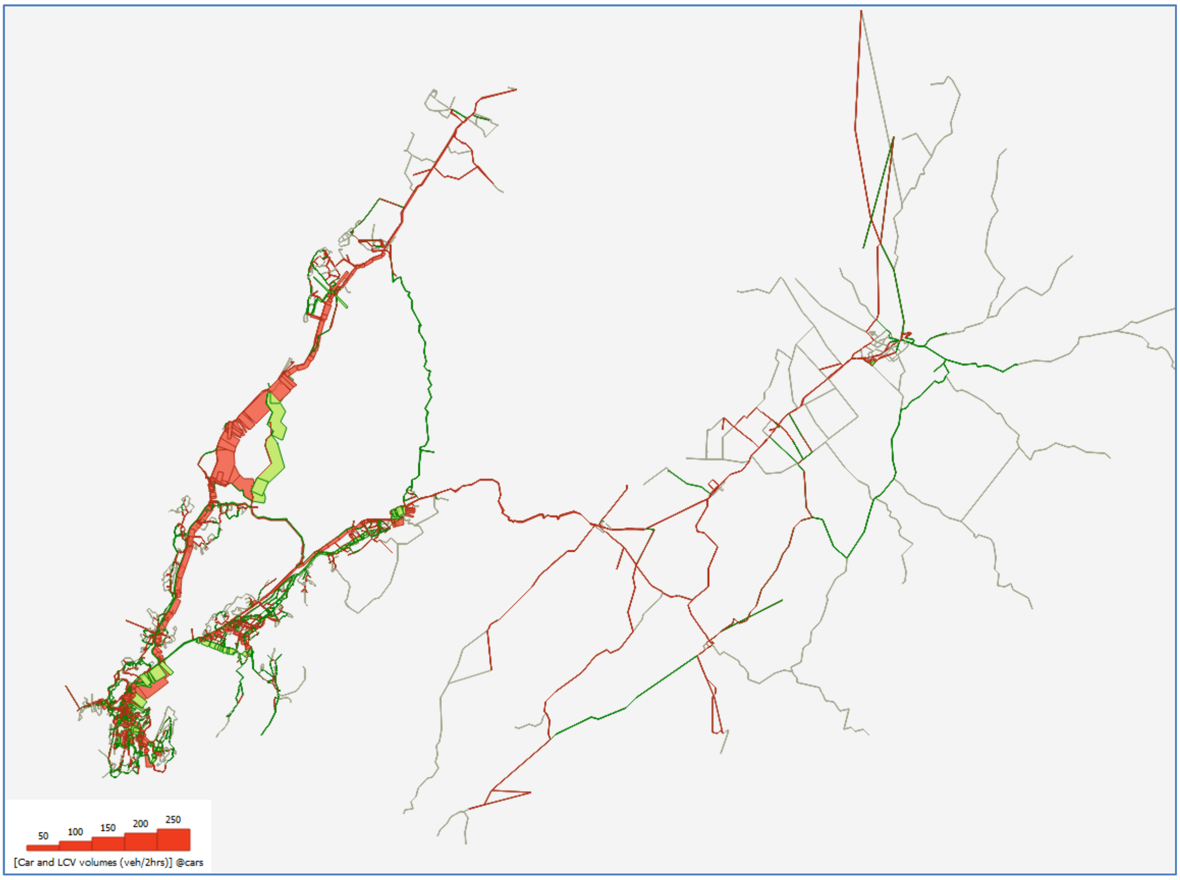

Figure 38: AM Peak 2hr Car Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

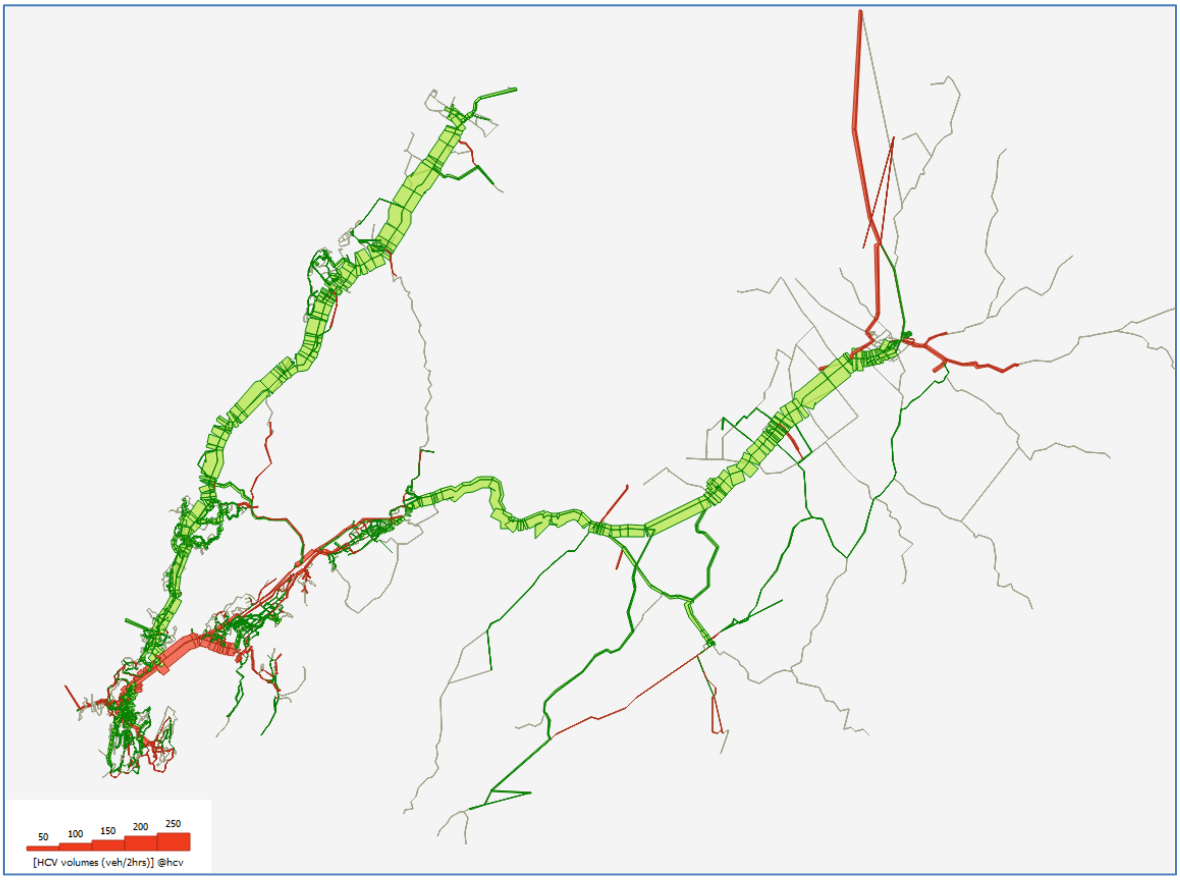

Figure 39: Interpeak 2hr Commercial Vehicle Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

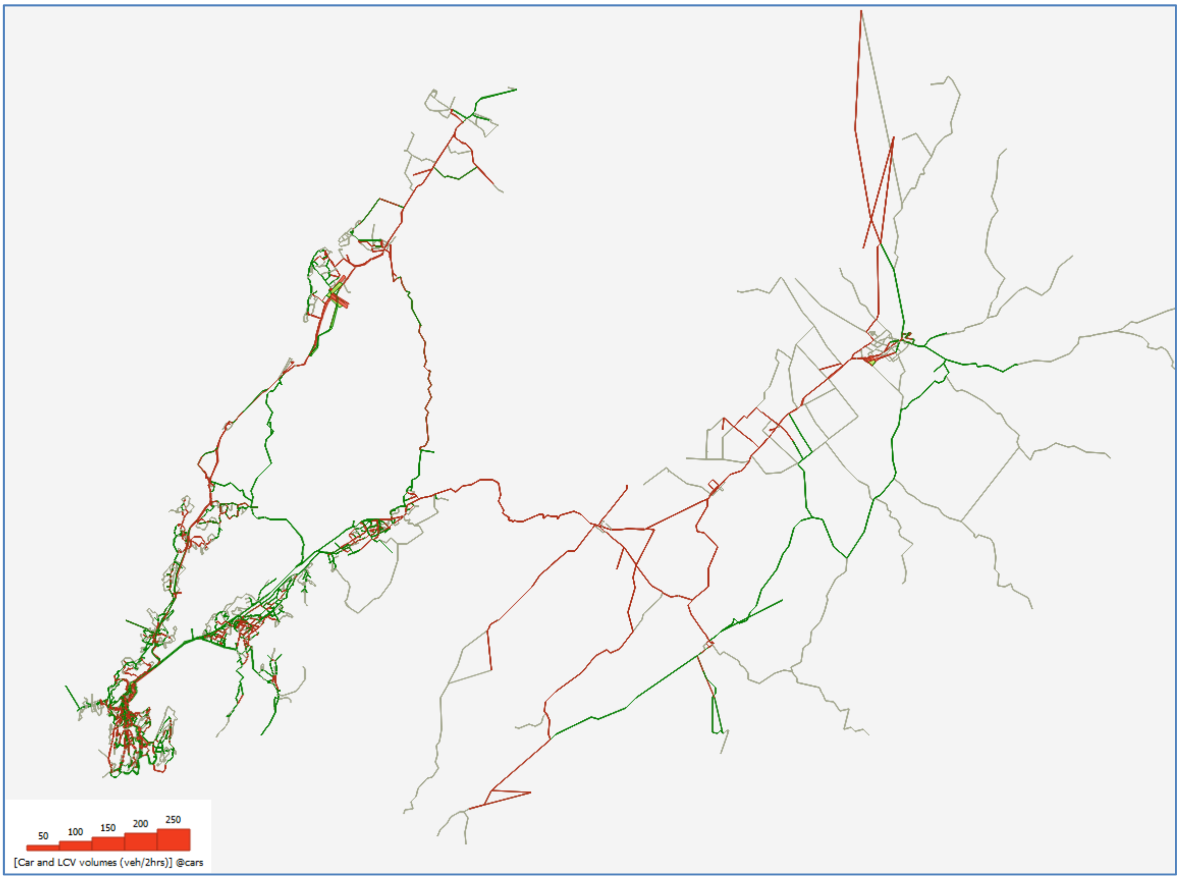

Figure 40: Interpeak 2hr Car Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

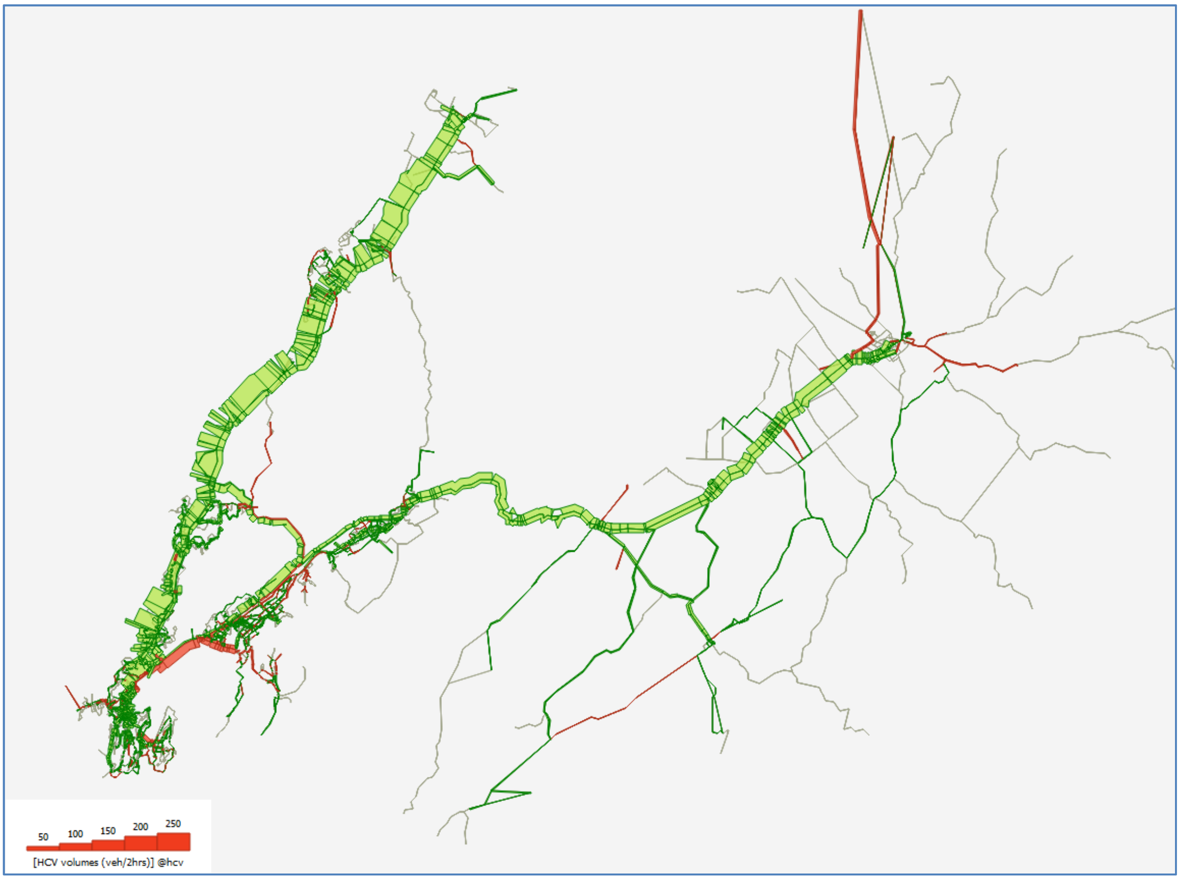

Figure 41: PM Peak 2hr Commercial Vehicle Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

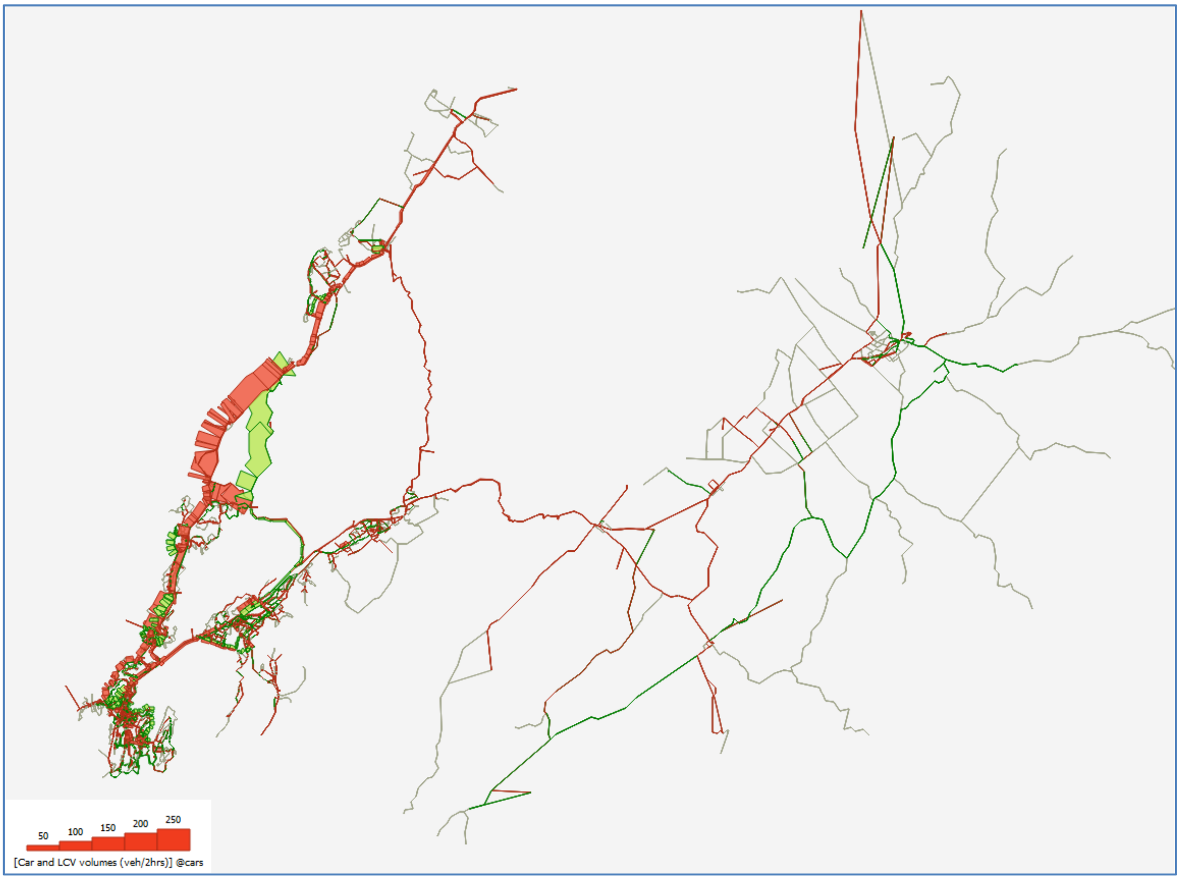

Figure 42: PM Peak 2hr Car Volumes Difference (Synthetic HCV 2013 versus 2011 HCV)

The difference in commercial vehicle volumes is quite high on some corridors (e.g. approximately 150 vph on SH1 southbound), with the difference in car volumes being slightly lower (e.g. approximately 100 vph on SH1 southbound). Unlike the HCV volumes, the volume differences for cars are chiefly a consequence of route choice changes caused by higher or lower HCV volumes on some routes. The high difference in HCV volumes on SH1 is attributed to trips to/from Otaki. A similar pattern is found on SH2 with trips to/from Masterton.

A GEH summary of observed and modelled HCV volumes across the screenlines is given in **Table 18** for the three peak periods. The GEH values all meet or exceed the Economic Evaluation Manual (EEM) target criteria except for one case in the PM peak which has a GEH value greater than 12. The results presented here are, unsurprisingly, worse than those presented in Technical Note 2, Table 8, as the latter was based on expanded sample whereas the former are fully synthesised.

Comparison of SH1 and SH2 observed counts around Ngauranga indicate that the adjusted forecast matrices are producing very good results for SH2 (GEH mostly below 5) and good results for SH1 (GEH mostly just above 5). In nearly all cases the adjusted forecast volumes are higher than the observed volumes. Given the green bandwidths shown in Figures 37, 39 and 41 this means that the 2011 demand matrices were over-estimating SH1 and SH2 volumes.

Evaluation Criteria			Target	Medium and Heavy Screenline Comparison Summary					
				AM (07:00-09:00)		IP (11:00-13:00)		PM (16:00-18:00)	
				Abs.	(%)	Abs.	(%)	Abs.	(%)
GEH	<=	5	60%	27	71%	32	84%	26	68%
	<=	10	95%	10	97%	6	100%	11	97%
	<=	12	100%	1	100%	0	100%	0	97%
	<=	Max	0%	0	100%	0	100%	1	100%
% Difference Less Than		10%	-	12	32%	7	18%	9	24%
		20%	-	20	53%	19	50%	16	42%
R^2			-	0.77		0.83		0.75	

Table 18: 2013 Observed and Modelled Screenline GEH Summaries

4.3 Conclusion

This section has tabulated and compared 2011 HCV demands, 2013 “observed” demands from sample travel pattern data expanded to the total using traffic counts, and a forecast 2013 HCV demand.

The “observed” dataset includes traffic counts, and it was noted in Technical Note 1 that there is a high degree of variability in the counts themselves, and the sample trip making data that has been expanded to the total using these traffic counts.

Overall the fully synthesized 2013 internal HCV trip model, comprised of the trip end linear regression model (Model 2) and trip distribution equations (with adjusted coefficient values), is considered to replicate “observed” sufficiently.

5. External Trips – Travel Patterns

Desire line plots for the 2011 and 2013 external commercial vehicle trips are shown in **Figures 43** to **45** and **46** to **48** for the three modelled peak periods. The 2011 travel patterns are from the matrix used in the model; the 2013 travel patterns are from the expanded sample data (i.e. not modelled data).

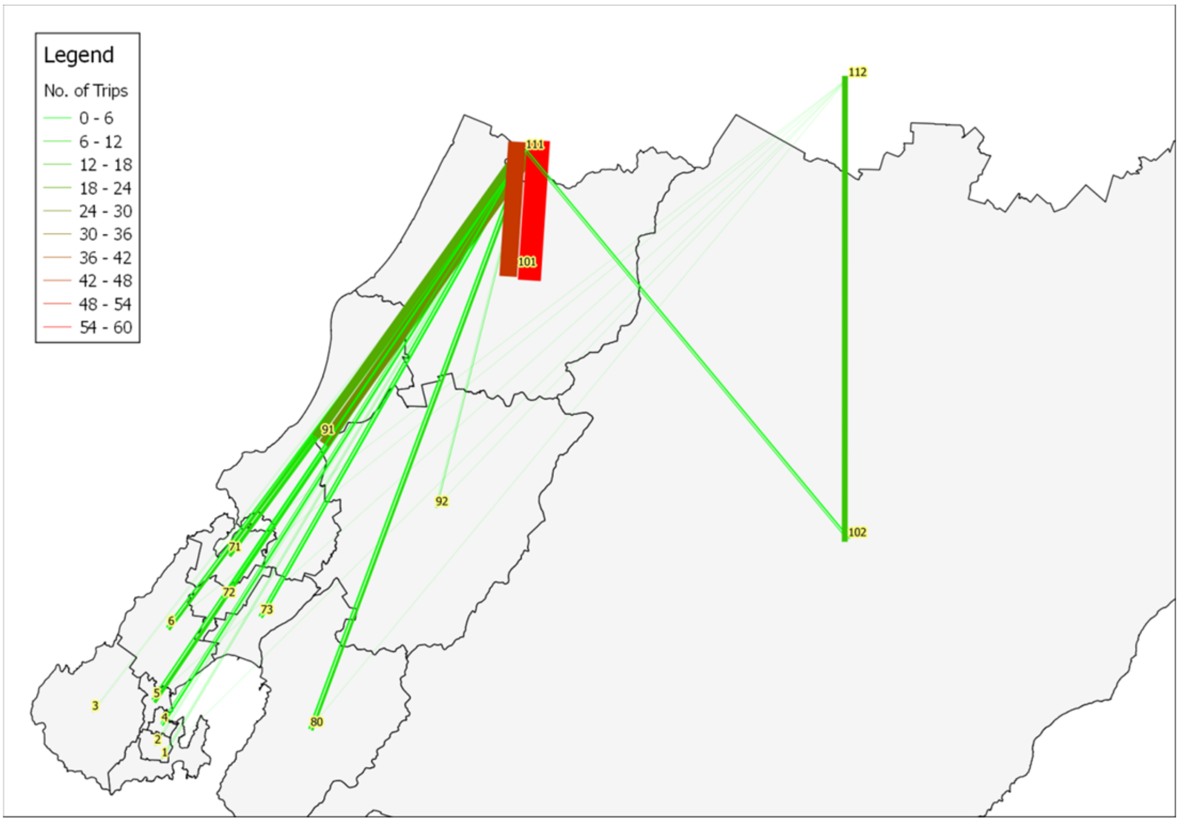

Figure 43: AM Peak 2011 External Trips Sectored Desire Lines – Modelled

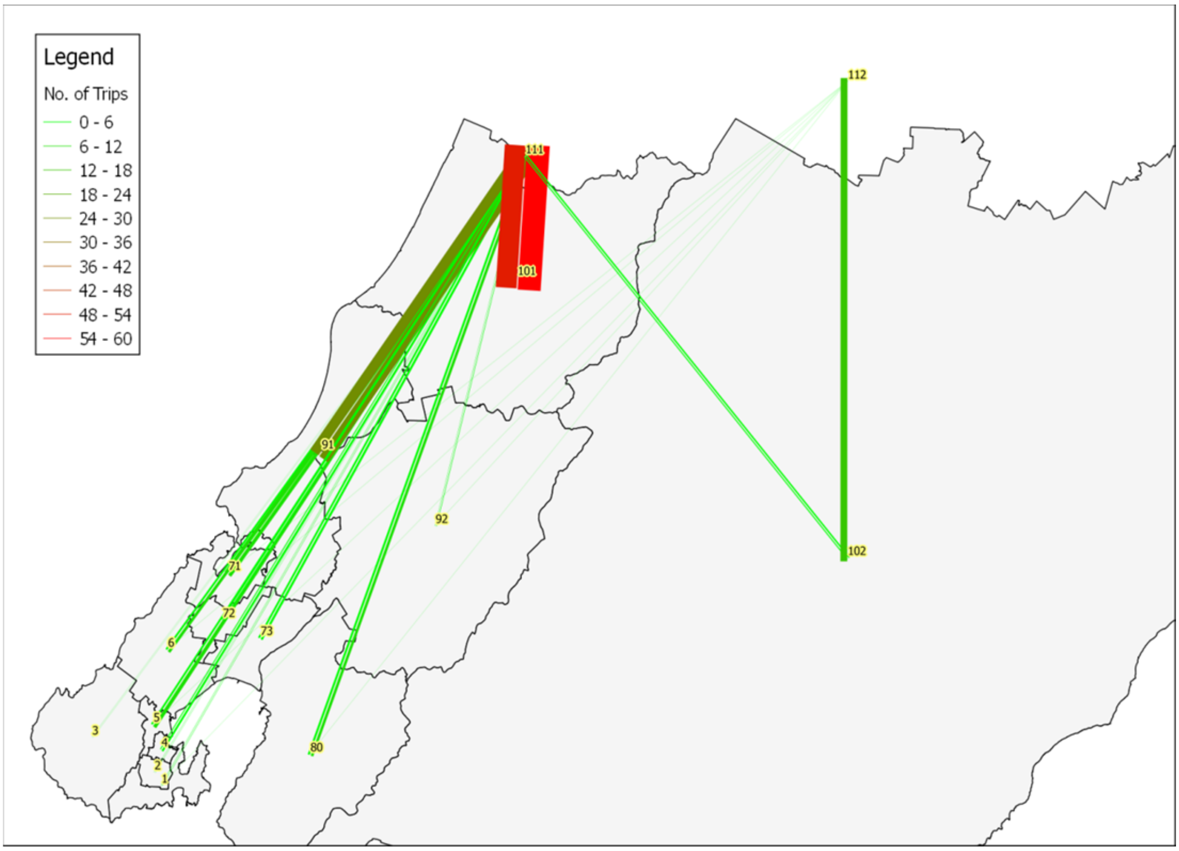

Figure 44: Interpeak 2011 External Trips Sectored Desire Lines - Modelled

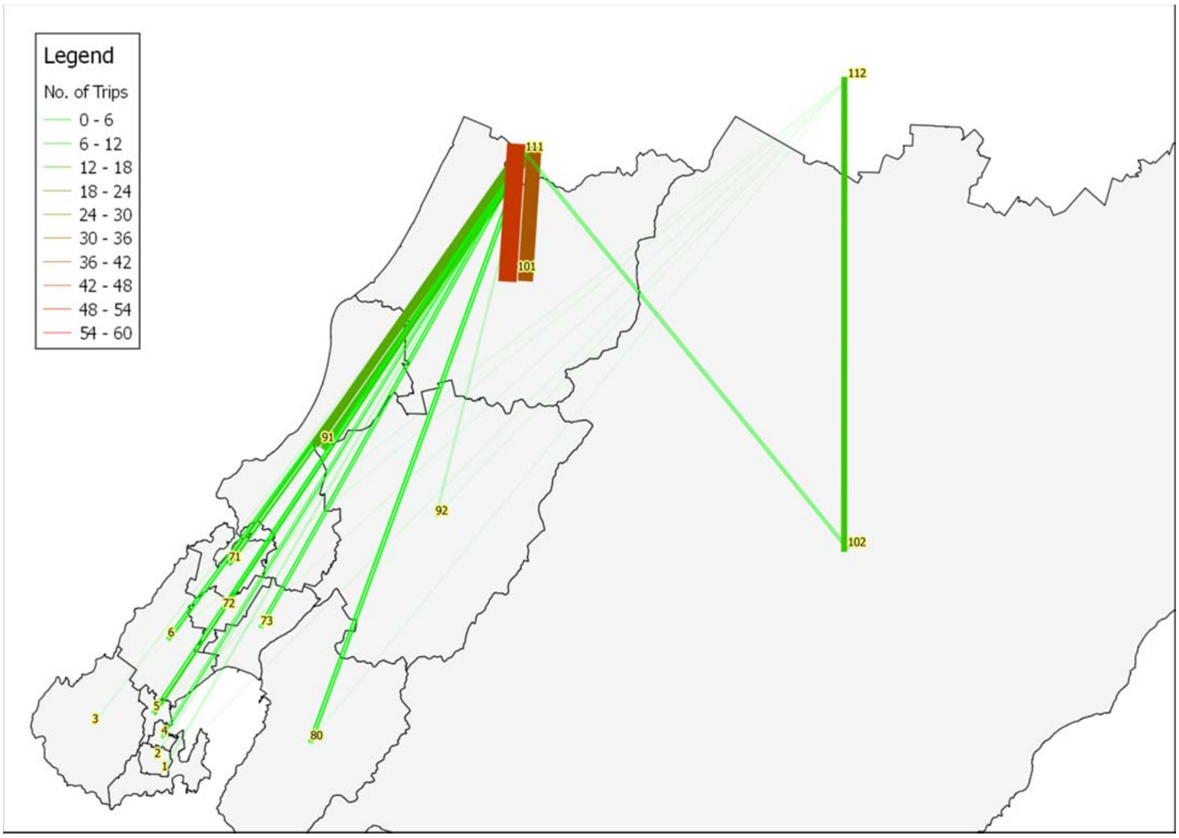

Figure 45: PM Peak 2011 External Trips Sectored Desire Lines - Modelled

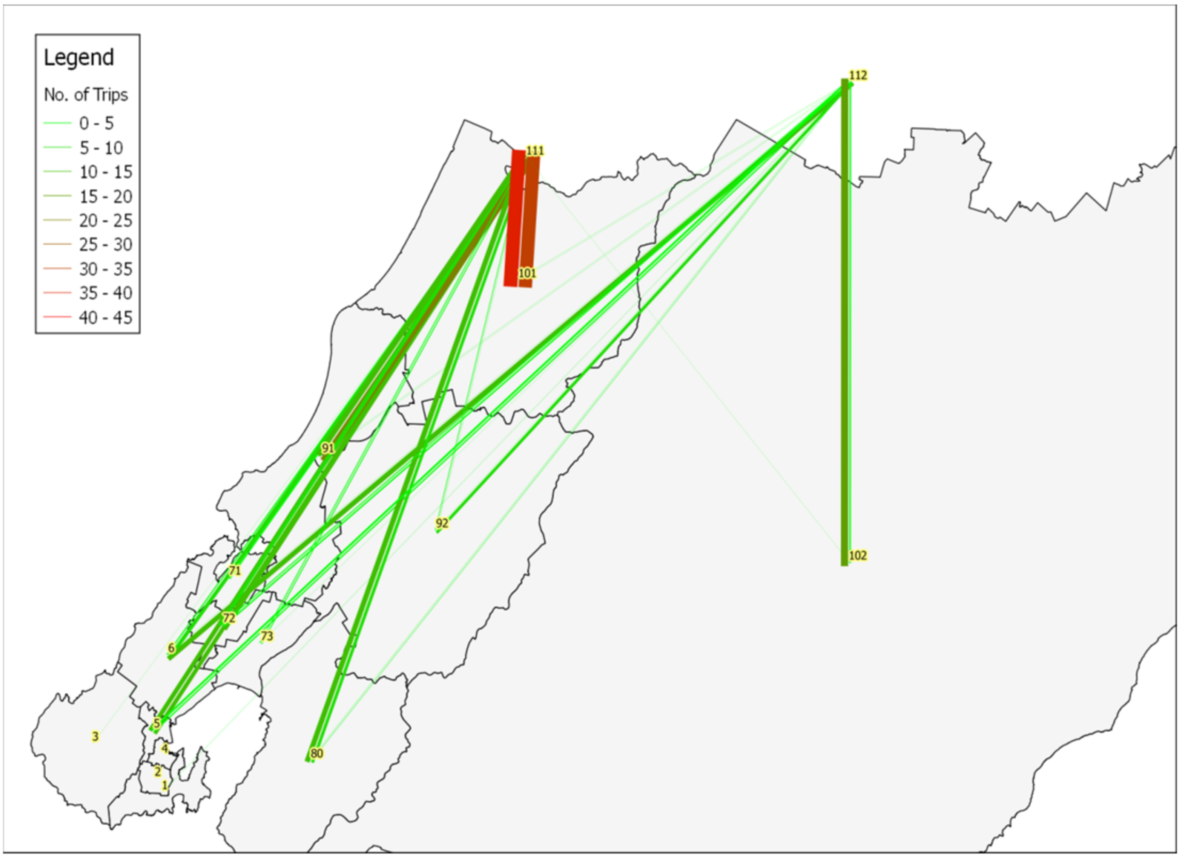

Figure 46: AM 2013 External Trips Sectored Desire Lines - Observed

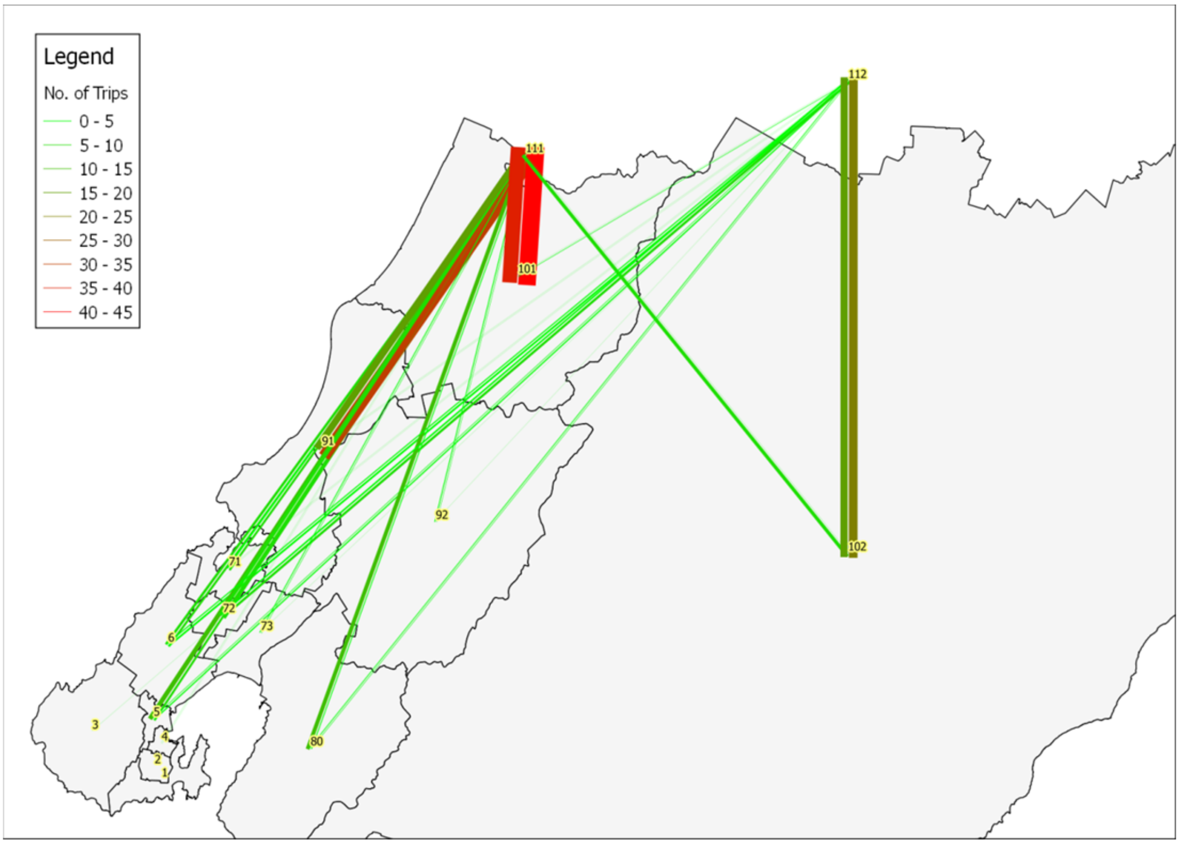

Figure 47: Interpeak 2013 External Trips Sectored Desire Lines - Observed

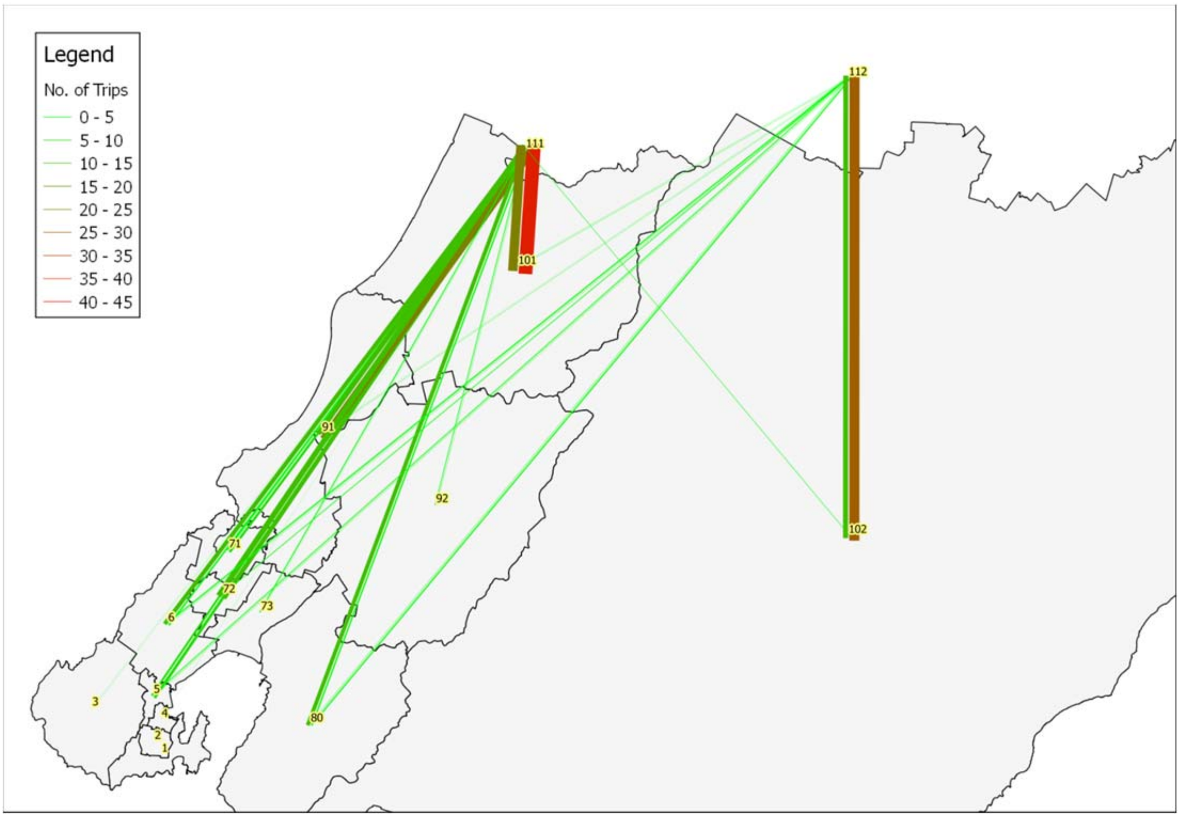

Figure 48: PM 2013 External Trips Sectored Desire Lines - Observed

The above external trip desire line diagrams show similar patterns for both 2011 and 2013.

State Highway 1 has a high volume of trips to/from Otaki/Waikanae (sector 101), plus large movements to:

- Sectors 5 and 6, covering the north of Wellington CBD, the Port, and north to Ngauranga;
- Sector 80, Lower Hutt;
- Sector 91, north of Paremata to Paraparaumu.

These movements are present in both the 2011 and 2013 matrices.

State Highway 2 has a high volume of trips to/from Masterton/Carterton (sector 102), plus large movements to:

- Sectors 5 and 6, covering the north of Wellington CBD, the Port, and north to Ngauranga;
- Sector 80, Lower Hutt.

These movements (SH2 to/from sectors 5, 6 and 80) were not very significant in the 2011 matrices.

The diagrams also suggest a different distribution pattern for SH1 and SH2 which may require separate models to be built. It should be noted however that the number of external trips on SH2 is small and hence the bias in the sample could be high.

Understanding the movements/travel patterns in the observed 2013 matrix is key in developing a predictive model, which is covered in the next section.

6. External Model

6.1 Overview

Separate synthetic models were derived for external commercial vehicle trip generation, which are defined as those entering or leaving the study area via the State Highways in the north (zones 226 or 227).

External trips to/from the Interislander (zone 228) are treated and reported separately.

Linear regression modelling techniques were applied to estimate the internal end of the external trips. The results of various regression models are reported below, with the comparison between the application of the estimated model and the observed (the expanded sample). Note that in this case, the linear regression models are used to distribute trips amongst the various internal zones.

6.2 Stepwise Linear Regression

The form of the trip end model investigated and reported is linear regression based on land use data being the independent variables. A forward stepwise linear regression analysis was undertaken to assess which land use variables were statistically significant. Variables were included if their P value was below 0.05 (the target level of significance).

As there were a relatively small number of observed external trips, the trip ends for the internal origin and the internal destination were combined.

The synthetic external trip end model, if adopted, will be applied to effectively distribute, or allocate, the internal end of external trips for both directions of travel. The actual inbound and outbound external volumes will be adopted from counts for the base year of 2013, and factored for future years, with the factors likely related to GDP.

6.3 Model 1E

6.3.1 Regression Model

In Model 1E, the trip end regression modelling was carried out separately for each of the three modelled peak periods.

Once again, trips to/from the Port (zone 39) displayed a different pattern to other trips. Tests were undertaken removing trips to/from the Port from the observed, and rerunning the trip end regression models. This marginally improved the correlation to the land use data – and, more importantly, changed the explanatory variables. For the AM peak, including the Port (zone 39) produced a positive correlation to both Manufacturing and Transport & Communications Employment. Removing the Port, dropped the correlation to Transport & Communications employment.

The Port (zone 39) was therefore excluded from the external trip end modelling and will be modelled separately.

The coefficient results are shown in the following table.

Period	Variable	Coefficient	Confidence Interval		P-value	Expanded Trips
			Lower 95%	Upper 95%		
AM	Manufacturing	0.007864	0.004887	0.010842	0.000	222
	Adjusted R^2	0.230				
IP	Emp:Other	0.013259	0.001854	0.024663	0.023	256
	Manufacturing	0.007837	0.004905	0.010769	0.000	
	Adjusted R^2	0.243				
PM	Emp:Other	0.016803	0.001937	0.031669	0.027	215
	Manufacturing	0.007417	0.004270	0.010564	0.000	
	Adjusted R^2	0.294				

Table 19: Regression Statistics – External Trip End Model (Zones 226 and 227) – Model 1E

Although various combinations of land use were tested as independent variables, the main significant explanatory variables were found to be Manufacturing and Employment Other ("Emp:Other"). Even so, the correlation is extremely poor, with Adjusted R Squared values varying from 0.23 to 0.29 over the three peak periods. This is associated with the relatively small number of observations and the "lumpiness" of the expanded sample.

6.3.2 Application of Model

The synthetic external trip end models were applied for each of the three peak periods and are compared to observed (expanded sample) in the following three graphs on a zonal basis.

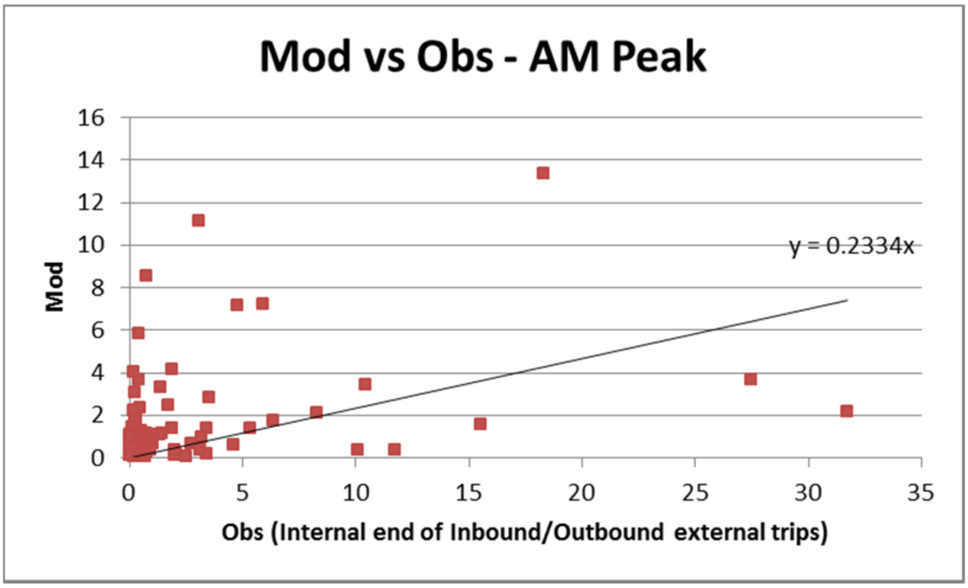

Figure 49: Comparison of Modelled and Observed Trip Ends – Zonal – AM Peak– Model 1E

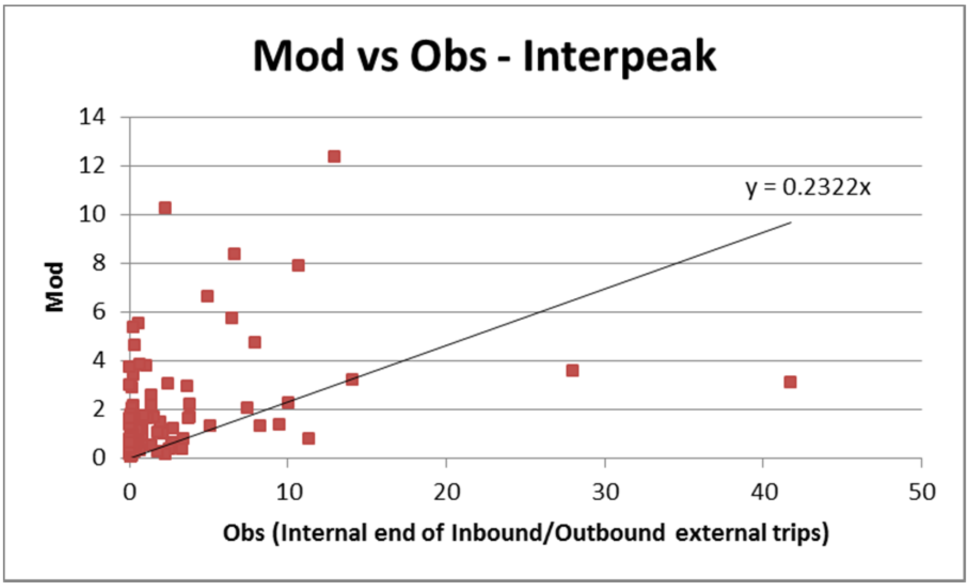

Figure 50: Comparison of Modelled and Observed Trip Ends – Zonal – Interpeak– Model 1E

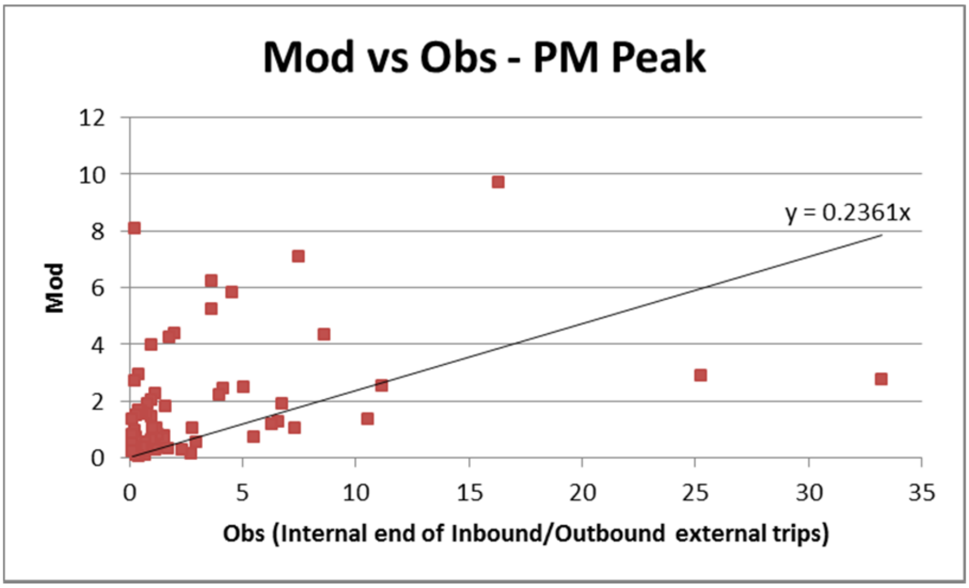

Figure 51: Comparison of Modelled and Observed Trip Ends – Zonal – PM Peak – Model 1E

As expected from the regression modelling outputs, on a zonal basis, the correlation is very poor. In each of the three peak periods, there are two points on the bottom right of the graphs with a high number of observed trips and a low modelled value. These are zones 87 and 129 in all three peak periods. Zone 87 is a large zone, mostly rural but with some industrial activity along Jamaica Drive, located on the east side of Tawa (Grenada), while zone 129 is Otaki, located near the northern external.

The poor correlation is the result of using a relatively small sample and a limited number of movements to estimate a relationship.

The modelled and observed are compared on a sector basis below in the following three graphs.

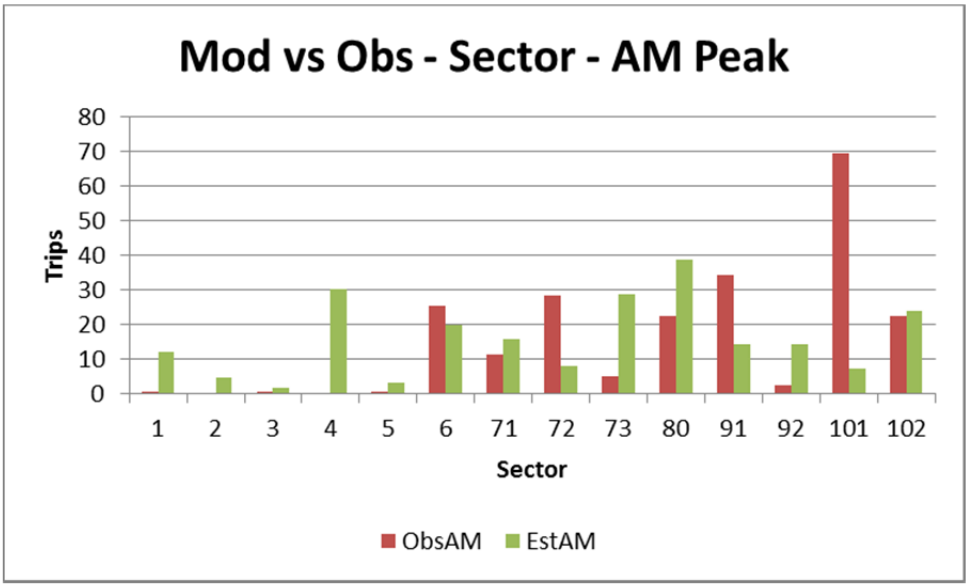

Figure 52: Comparison of Modelled and Observed Trip Ends – Sector – AM Peak – Model 1E

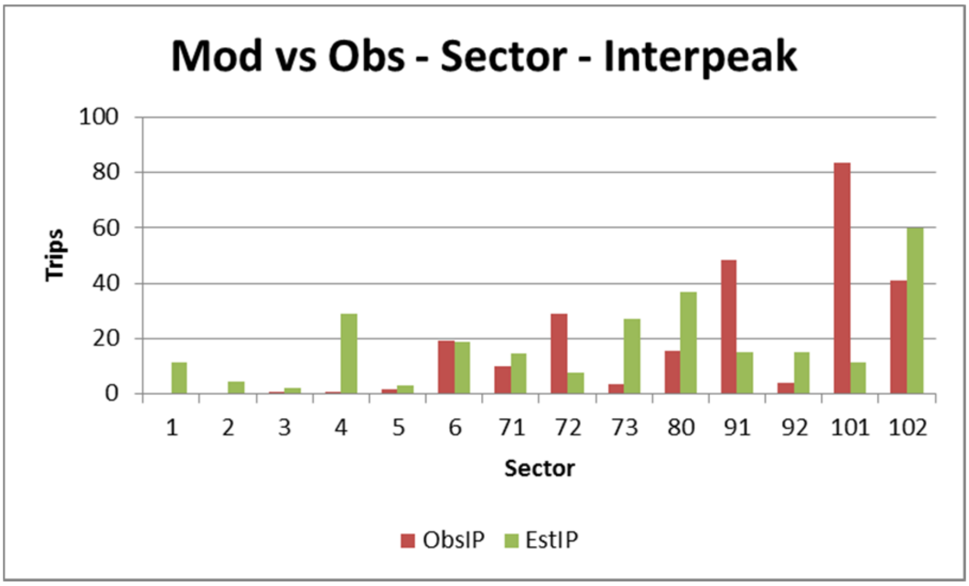

Figure 53: Comparison of Modelled and Observed Trip Ends – Sector – Interpeak – Model 1E

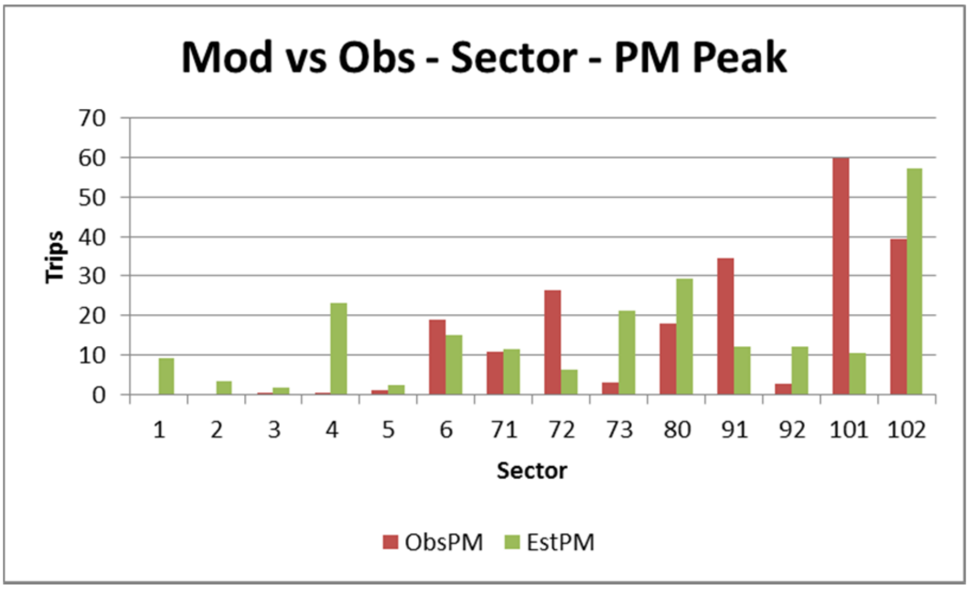

Figure 54: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model 1E

Of interest, in all three peak periods there are very few observed external trips to/from sectors 1 to 5, which is south of Ngauranga. This may be due to the sampling– since the Ngauranga screenline was one of the first to be considered in the calculation of the expansion factors, ensuring the longer distance trips are considered first.

There is also a different pattern for the north-west zones (sectors 91 and 101) compared with the north-east (sectors 92 and 102).

6.3.3 Conclusions from Model 1E

Model 1E demonstrated a relatively poor ability to replicate observed on a zonal or sector basis.

Because of the sparse nature of the observed data and the poor correlation, a test was conducted combining all three peak periods to see if a stronger relationship could be produced. This is reported as "Model 2E".

Due to the differences in observed trips in the north of the study area, a test was also conducted modelling each of the external zones separately – in case a different pattern emerged. This is reported as "Model 3E". As the Manufacturing and Employment Other land uses seemed to provide the main explanatory variables, these were forced to produce coefficients even when the P value was below 0.05.

To reduce the lumpiness of the data, Model 4E was developed to determine the relationships at the sector level rather than the zonal level. The method of determining the explanatory variables was the same as that used in Model 3E.

6.4 Model 2E

A test was carried out combining the internal trip ends of external trips for all three peak periods. Trips to/from the Port (zone 39) are excluded.

The coefficient results are shown in the following table.

Period	Variable	Coefficient	Confidence Interval		P-value	Expanded Trips
			Lower 95%	Upper 95%		
Combined	Emp:Other	0.03130	0.00277	0.05984	0.032	694
	Manufacturing	0.02212	0.01482	0.02942	0.000	
	Adjusted R^2	0.256				

Table 20: Regression Statistics – External Trip End Model – All Periods (Zones 226 and 227) – Model 2E

While the Adjusted R Squared improved marginally, it was still poor (Adjusted R Squared = 0.256) and the same significant variables were found.

The three peak periods were therefore retained and Model 2E was discarded.

6.5 Model 3E

A test was carried out examining the relationship for the trips to/from SH1 separately to those to/from SH2. Trips to/from the Port (zone 39) remain excluded.

The results of the regression are provided in the following table by time period.

Period	Variable	Coefficient	Confidence Interval		P-value	Expanded Trips
			Lower 95%	Upper 95%		
AM - SH1	Emp:Other	0.06298	0.02762	0.09833	0.001	177
	Manufacturing	0.00702	0.00389	0.01014	0.000	
	Adjusted R^2	0.358				
AM - SH2	Emp:Other	0.00476	-0.00040	0.00992	0.070	45
	Manufacturing	0.00224	0.00038	0.00411	0.019	
	Adjusted R^2	0.194				
IP - SH1	Emp:Other	0.08717	0.05193	0.12242	0.000	192
	Manufacturing	0.00594	0.00306	0.00882	0.000	
	Adjusted R^2	0.340				
IP - SH2	Emp:Other	0.00855	0.00398	0.01312	0.000	64
	Manufacturing	0.00272	0.00135	0.00409	0.000	
	Adjusted R^2	0.405				
PM - SH1	Emp:Other	0.10066	0.05469	0.14663	0.000	165
	Manufacturing	0.00582	0.00268	0.00896	0.000	
	Adjusted R^2	0.382				
PM - SH2	Emp:Other	0.01193	0.00629	0.01758	0.000	51
	Manufacturing	0.00286	0.00136	0.00437	0.001	
	Adjusted R^2	0.636				

Table 21: Regression Statistics – External Trip End Model –Zones 226 and 227 Separately – Model 3E

The interpeak and PM peaks show a strong relationship to land use for trips to/from SH2. The PM peaks show the best relationships out of all of the peak periods. The Adjusted R Squared values vary from 0.19 to 0.64.

Overall, the adjusted R Squared values are significantly better than either Model 1E or Model 2E.

6.5.1 Application of Model

The synthetic external trip end models were applied (for each of the three peak periods and two State Highways) and are compared to observed (expanded sample) in the following six graphs on a zonal basis.

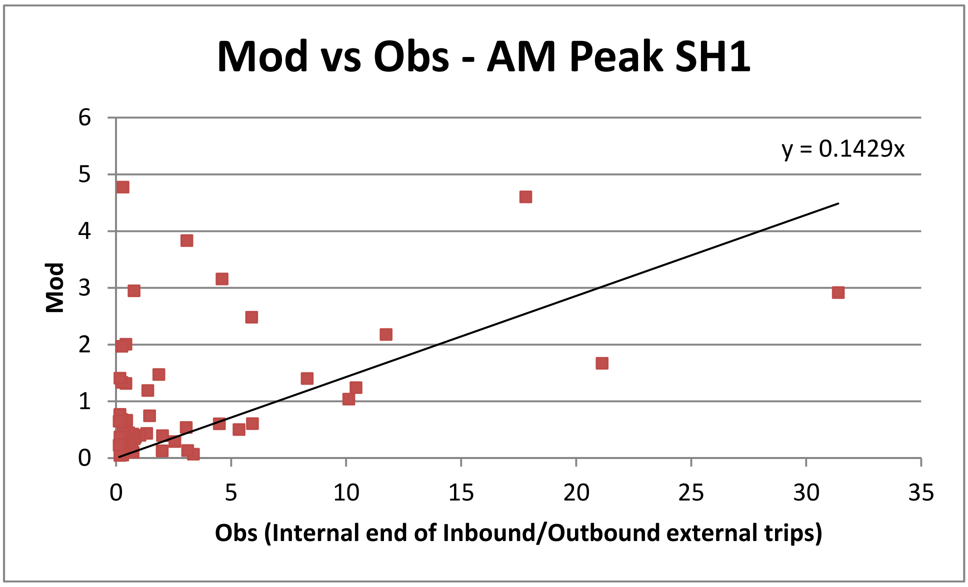

Figure 55: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 AM Peak – Model 3E

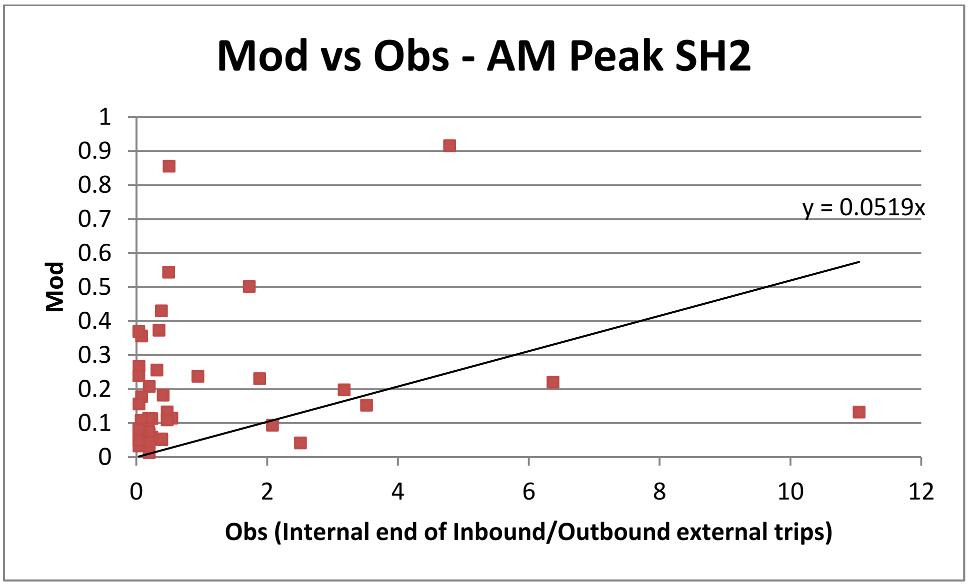

Figure 56: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 AM Peak – Model 3E

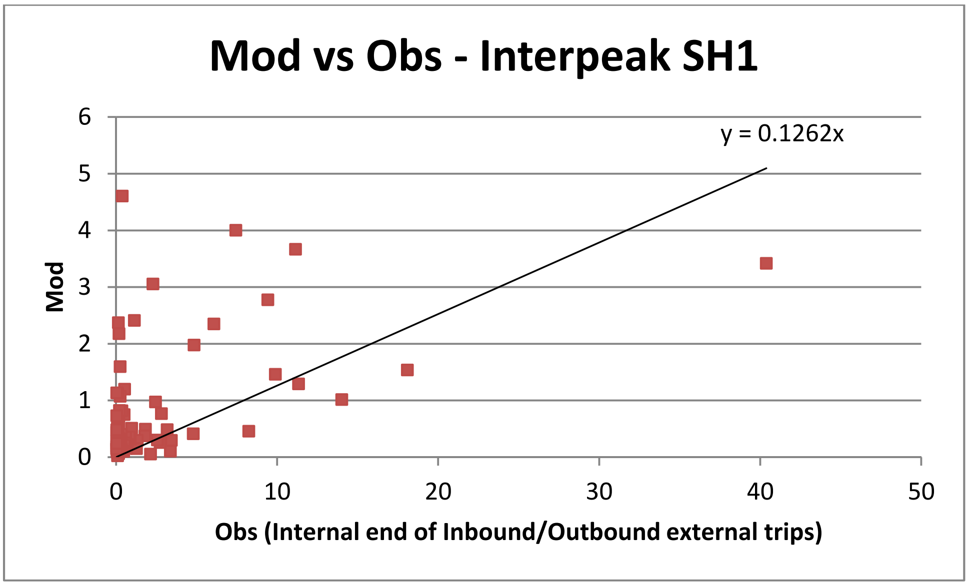

Figure 57: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 Interpeak – Model 3E

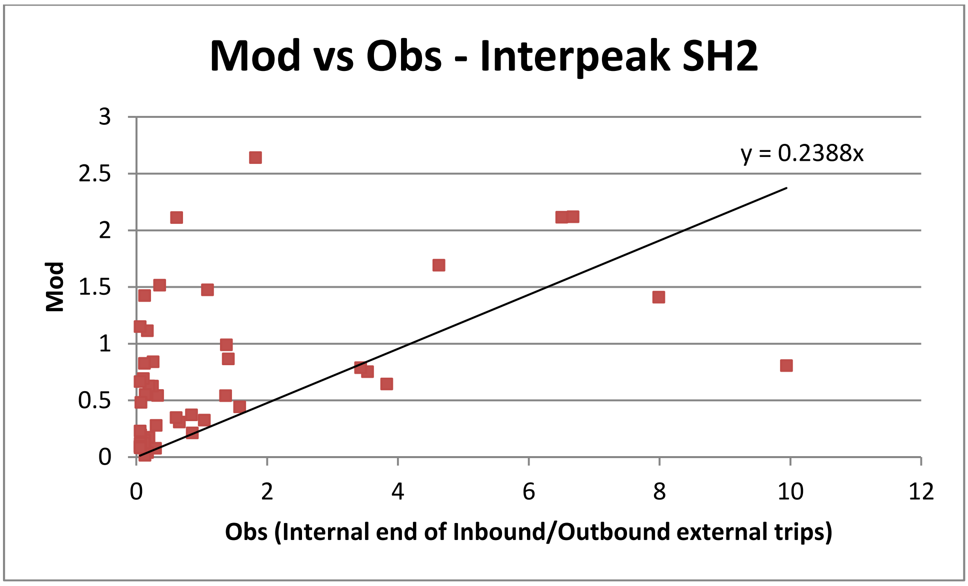

Figure 58: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 Interpeak – Model 3E

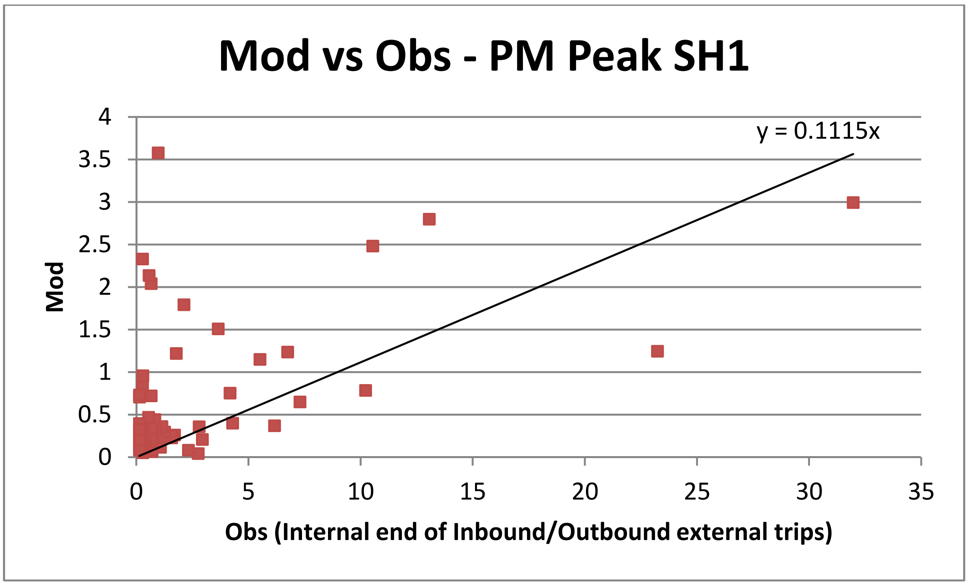

Figure 59: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 PM Peak – Model 3E

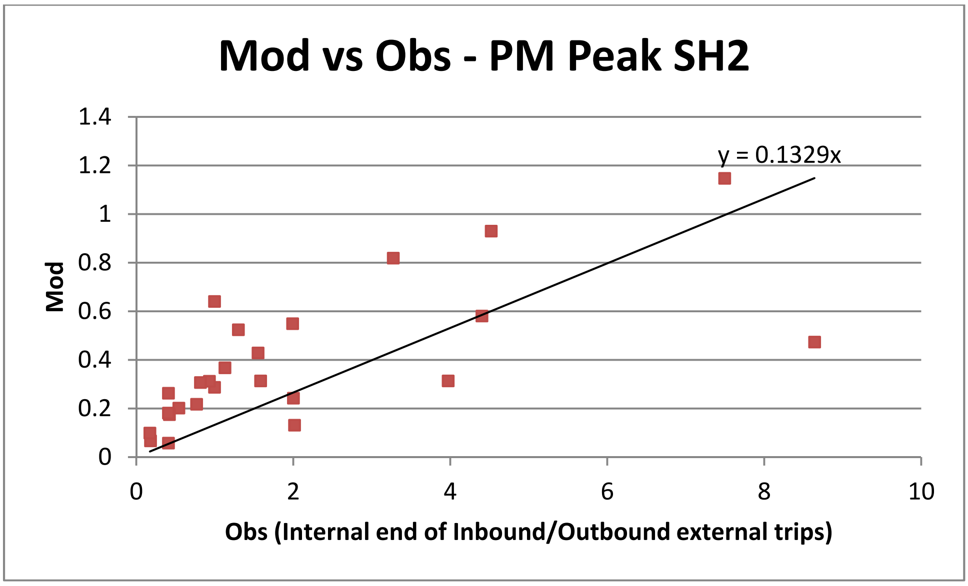

Figure 60: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 PM Peak – Model 3E

As expected from the regression modelling outputs, on a zonal basis, the correlation is poor. The graphs with particularly low correlation have a large cluster of points in the lower left hand corner of the plot. This lumping of points is due to the low number of trips observed during data collection. A small difference in land use can result in a large difference when the trips are factored up and therefore result in poor correlation.

The modelled and observed are compared on a sector basis below in the following six graphs.

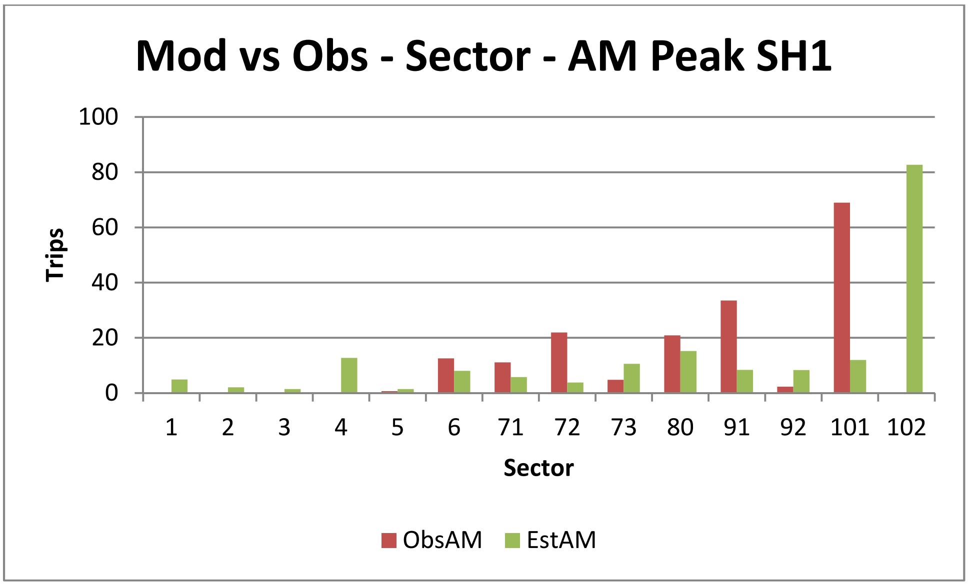

Figure 61: Comparison of Modelled and Observed Trip Ends – Sector – SH1 AM Peak – Model 3E

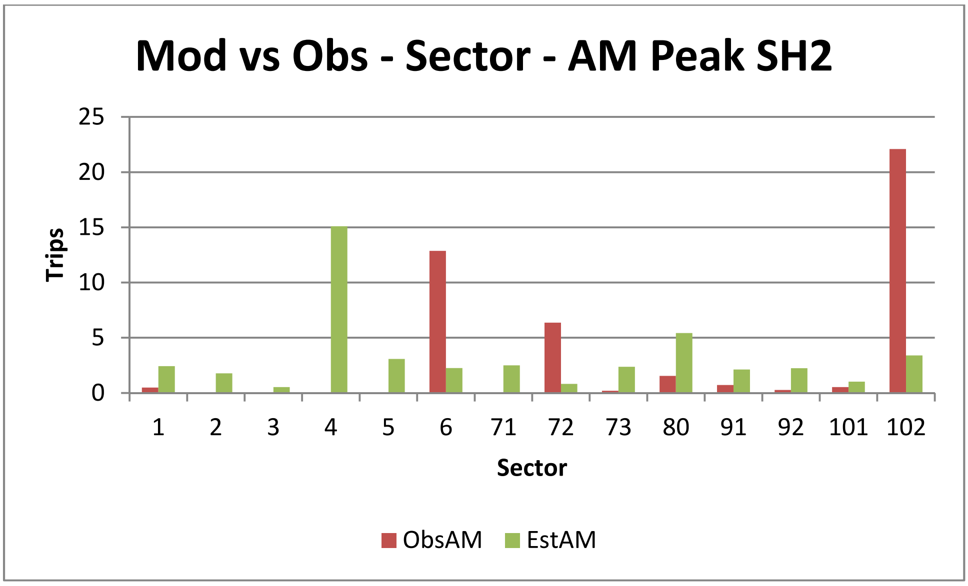

Figure 62: Comparison of Modelled and Observed Trip Ends – Sector – SH1 AM Peak – Model 3E

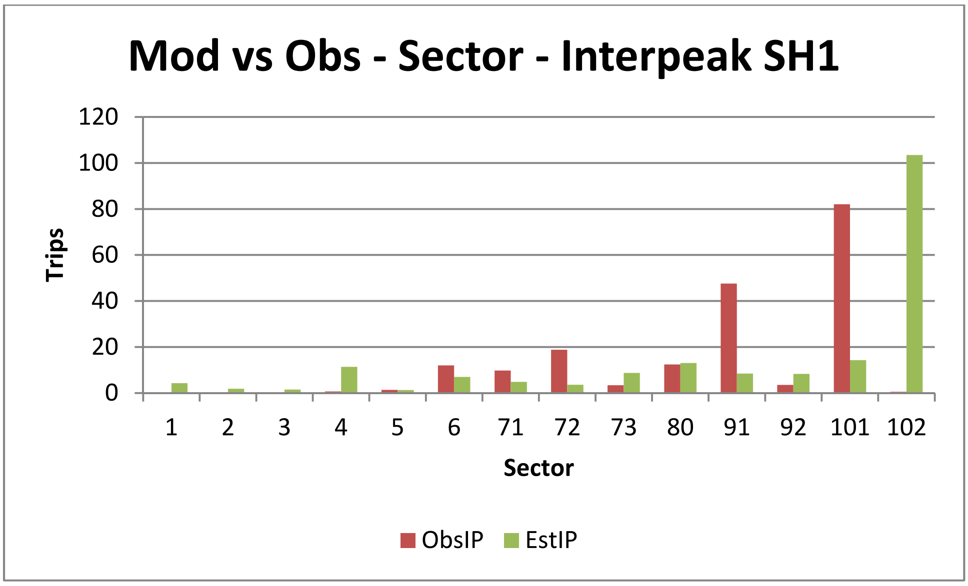

Figure 63: Comparison of Modelled and Observed Trip Ends – Sector – SH1 Interpeak – Model 3E

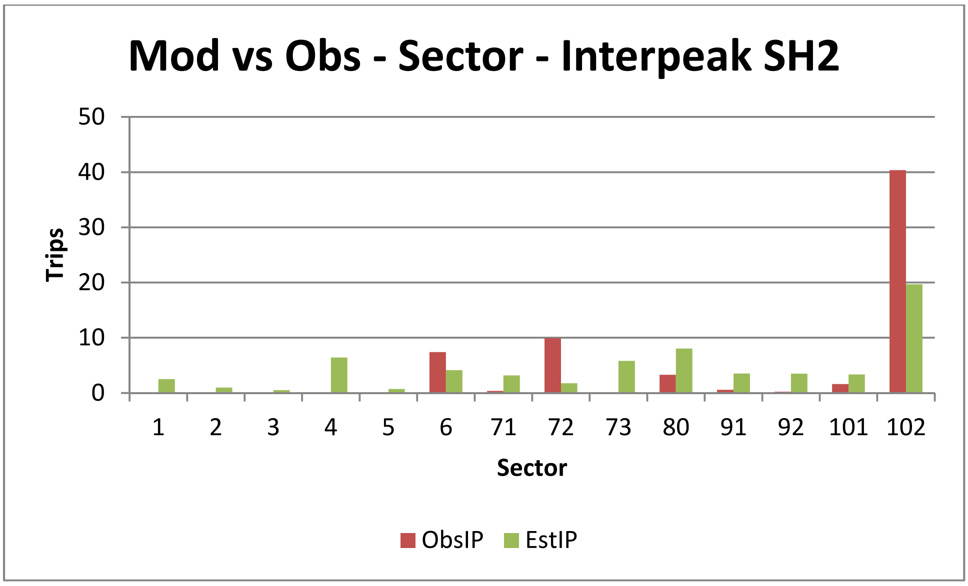

Figure 64: Comparison of Modelled and Observed Trip Ends – Sector – SH1 Interpeak – Model 3E

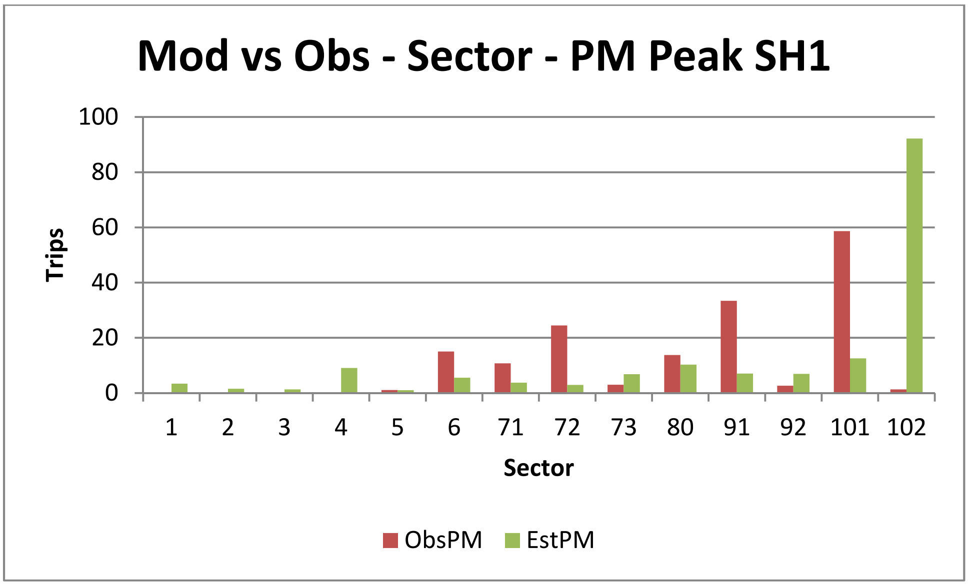

Figure 65: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model 3E

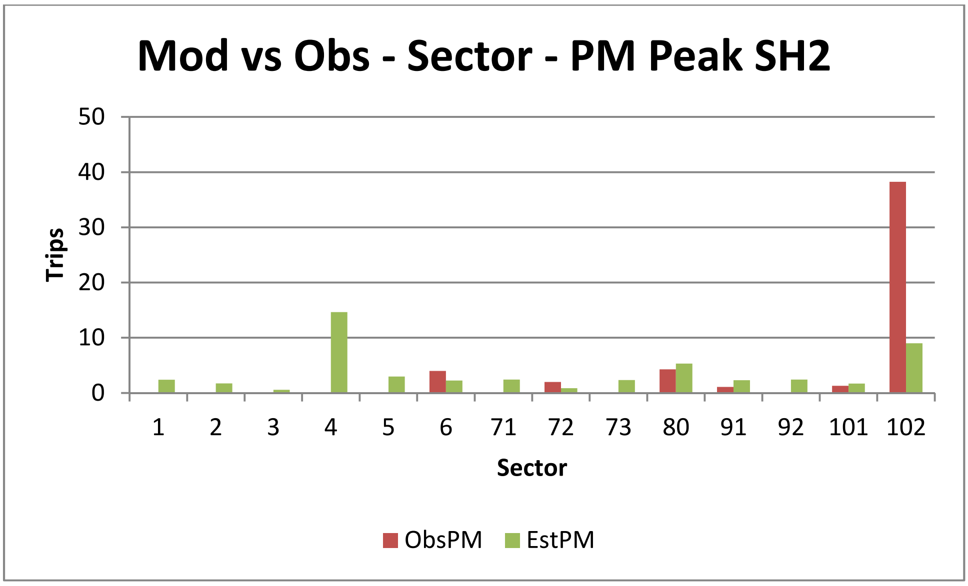

Figure 66: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model 3E

Similar to Model 1E there are very few observed external trips to/from sectors 1 to 5, which is south of Ngauranga. For similar reasons as described for Model 1E, this may be due to the sampling. The Ngauranga screenline was one of the first to be considered in the calculation of the expansion factors, ensuring the longer distance trips are considered first.

6.6 Model 4E

A test was carried out to determine if the explanatory variables were more significant at the sector level rather than the zonal level. Model 4E used the same methodology as in Modal 3E except the data was grouped and analysed at the sector level.

The results of the regression are provided in the following table by time period.

Period	Variable	Coefficient	Confidence Interval		P-value	Expanded Trips
			Lower 95%	Upper 95%		
AM - SH1	Emp:Other	-0.00224	-0.02177	0.01730	0.801	177
	Manufacturing	0.00521	-0.00223	0.01265	0.147	
	Adjusted R^2	0.063				
AM - SH2	Emp:Other	0.00622	0.00211	0.01033	0.009	45
	Manufacturing	0.00073	-0.00086	0.00232	0.312	
	Adjusted R^2	0.685				
IP - SH1	Emp:Other	-0.00011	-0.02420	0.02399	0.992	192
	Manufacturing	0.00385	-0.00446	0.01217	0.322	
	Adjusted R^2	-0.067				
IP - SH2	Emp:Other	0.01220	0.00908	0.01532	0.000	64
	Manufacturing	0.00053	-0.00066	0.00172	0.336	
	Adjusted R^2	0.905				
PM - SH1	Emp:Other	-0.00063	-0.01730	0.01603	0.934	165
	Manufacturing	0.00358	-0.00217	0.00933	0.196	
	Adjusted R^2	0.016				
PM-SH2	Emp:Other	0.01139	0.00901	0.01377	0.000	51
	Manufacturing	0.00066	-0.00043	0.00176	0.168	
	Adjusted R^2	0.978				

Table 22: Regression Statistics – External Trip End Model - Separated by Sector

The relationship between the explanatory variables and the trips to/from SH2 improved greatly in Model 4E. However the relationship between trips to/from SH1 decreased. The negative coefficients that resulted from this analysis mean that these results are unable to be used. Therefore Model 4E was rejected and Model 3E was retained.

6.7 Model 5E

The previously reported tests all suffer from poor representation of SH1 and SH2 trips to/from sectors 101 and 102. The lack of network connectivity between SH1 and SH2 near the external boundary explains why few trips were observed between SH1 and sector 102, and vice versa, SH2 and sector 101 (see Figures 46 to 48). Unlike the internal trip model no component of travel cost has been included in models 1E to 4E. This means that SH1 trips to/from sector 102 are weighted the same as those to/from sector 101.

The inclusion of Employment:Other as an explanatory variable causes further issues for SH1 model fitting due to the high number of such employment in sector 102. To rectify these issues a new explanatory variable (termed Attractiveness but note forecast trips are actually two-way) was introduced which combined the most significant employment type (manufacturing) with a function of the travel cost:

Attractiveness = Manufacturing * 1 / Distance^1.5

6.7.1 Application of Model

The synthetic external trip end models were applied at a zonal level for each of the three peak periods and two State Highways, and the comparisons of observed (expanded sample) to forecast trips are shown in the following graphs and tables.

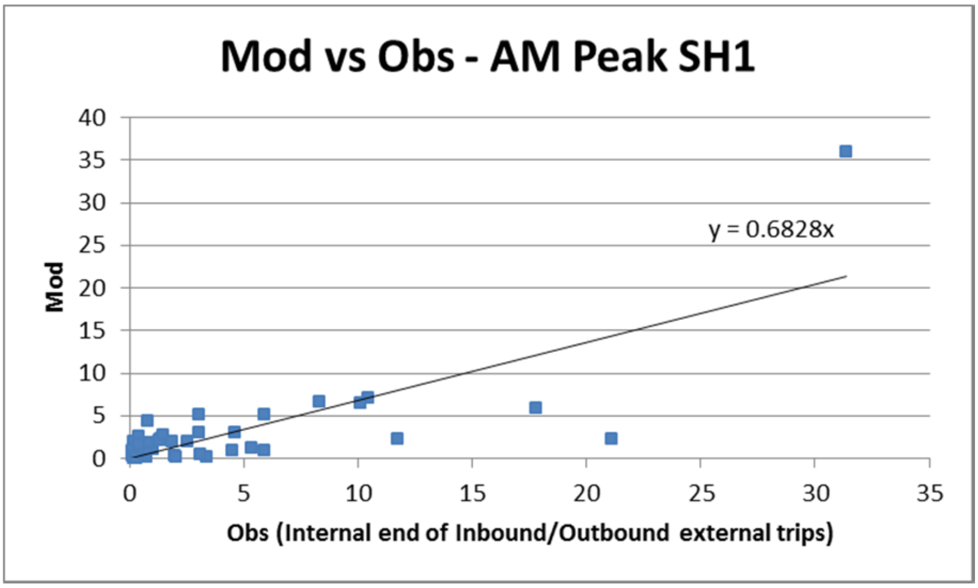

Figure 67: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 AM Peak – Model 5E

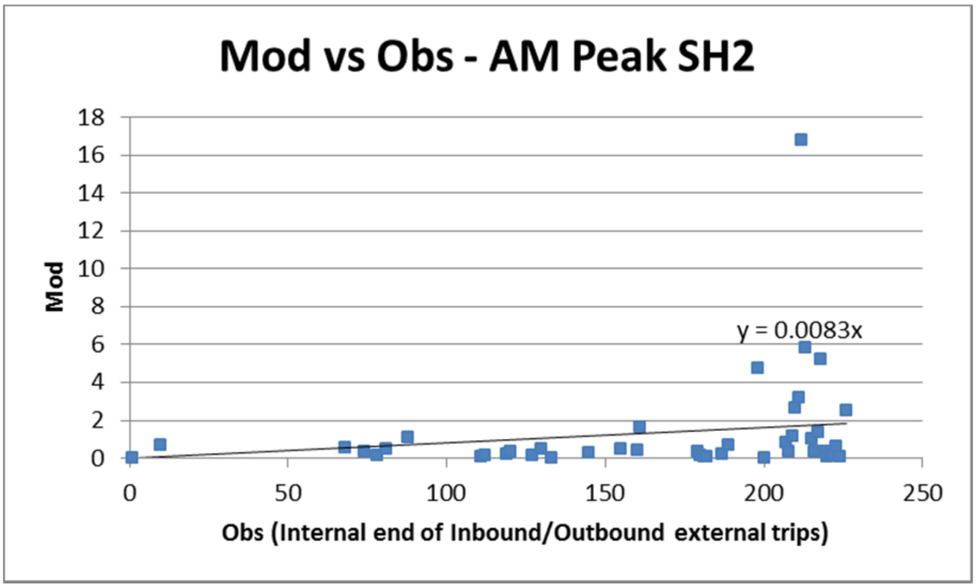

Figure 68: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 AM Peak – Model 5E

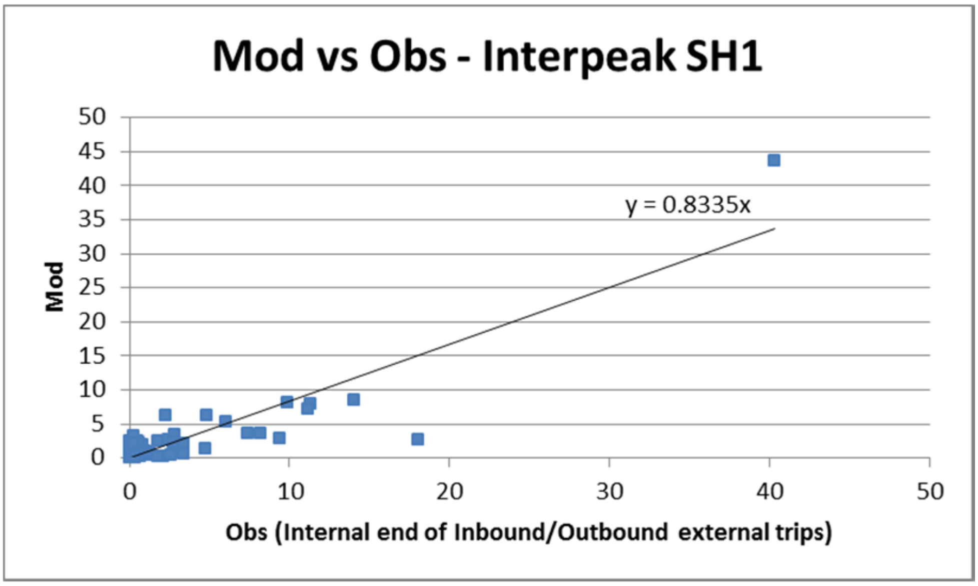

Figure 69: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 Interpeak – Model 5E

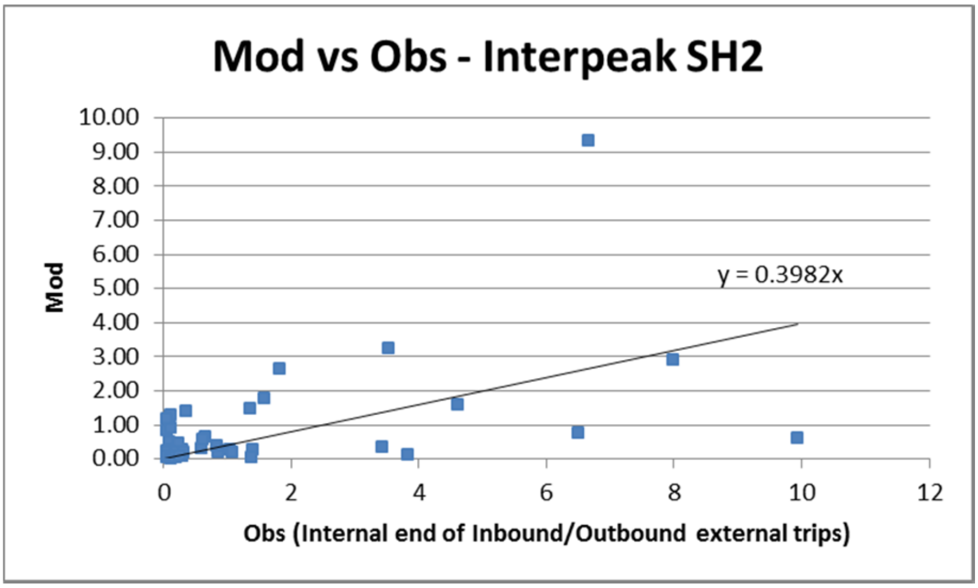

Figure 70: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 Interpeak – Model 5E

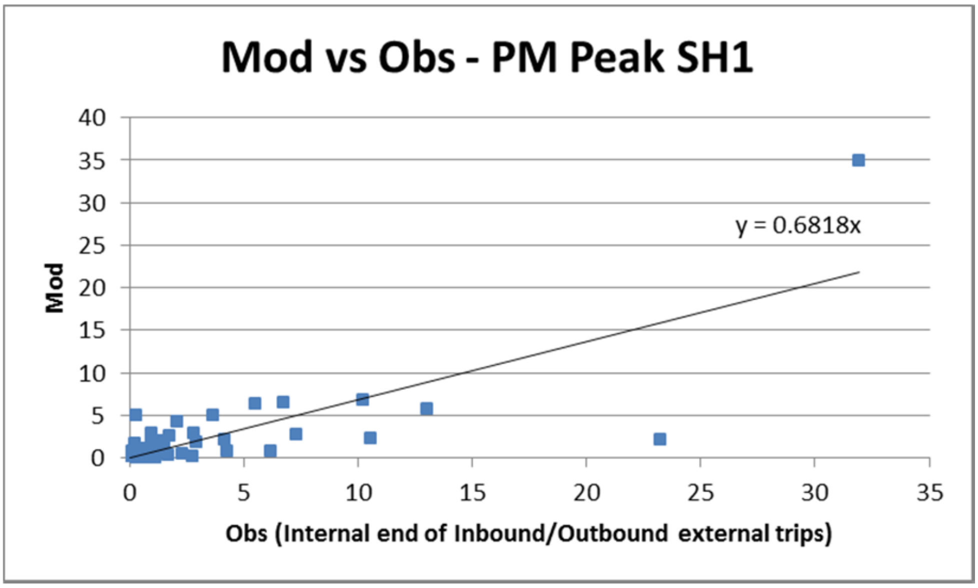

Figure 71: Comparison of Modelled and Observed Trip Ends – Zonal – SH1 PM Peak – Model 5E

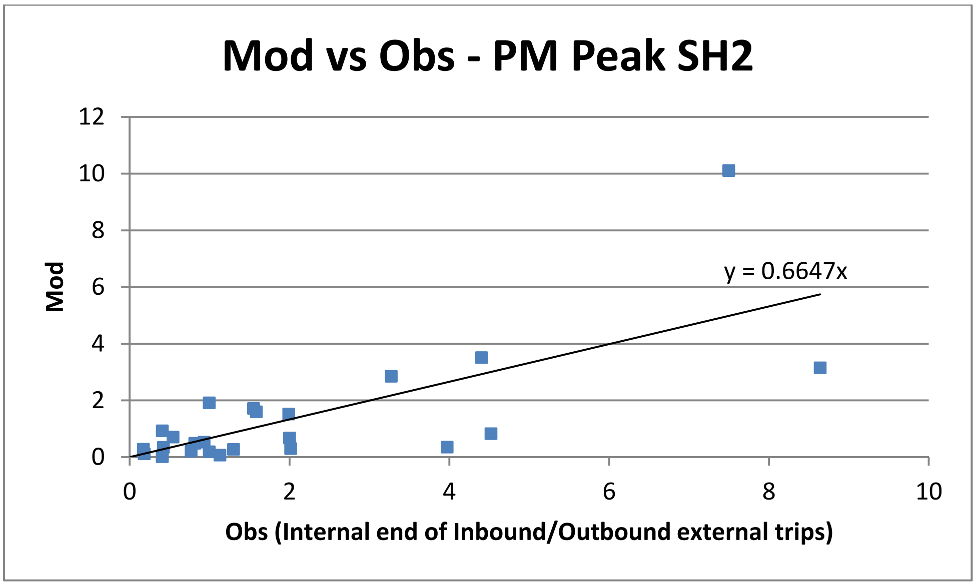

Figure 72: Comparison of Modelled and Observed Trip Ends – Zonal – SH2 PM Peak – Model 5E

The results of the regression are provided in the following table by time period and show that the new composite explanatory variable is statistically significant in all time periods for both SH1 and SH2. The adjusted R squared values are higher than those of Model 3E except for AM SH2.

Period	Variable	Coefficient	Confidence Interval		P-value
			Lower 95%	Upper 95%	
AM - SH1	Attractiveness	2.4759	2.0438	2.9080	0.000
	Adjusted R^2	0.666			
AM - SH2	Attractiveness	3.60828	0.85081	6.36575	0.012
	Adjusted R^2	0.119			
IP - SH1	Attractiveness	3.00677	2.72213	3.29141	0.000
	Adjusted R^2	0.822			
IP - SH2	Attractiveness	2.00589	1.31272	2.69907	0.000
	Adjusted R^2	0.379			
PM - SH1	Attractiveness	2.40062	1.97342	2.82781	0.000
	Adjusted R^2	0.665			
PM - SH2	Attractiveness	2.17591	1.52486	2.82697	0.000
	Adjusted R^2	0.623			

Table 23: Regression Statistics – External Trip End Model 5E

The modelled and observed trip end totals are compared at sector level in the following graphs and tables. These show a much improved fit between modelled and observed trips across the board but especially for sectors 101 and 102.

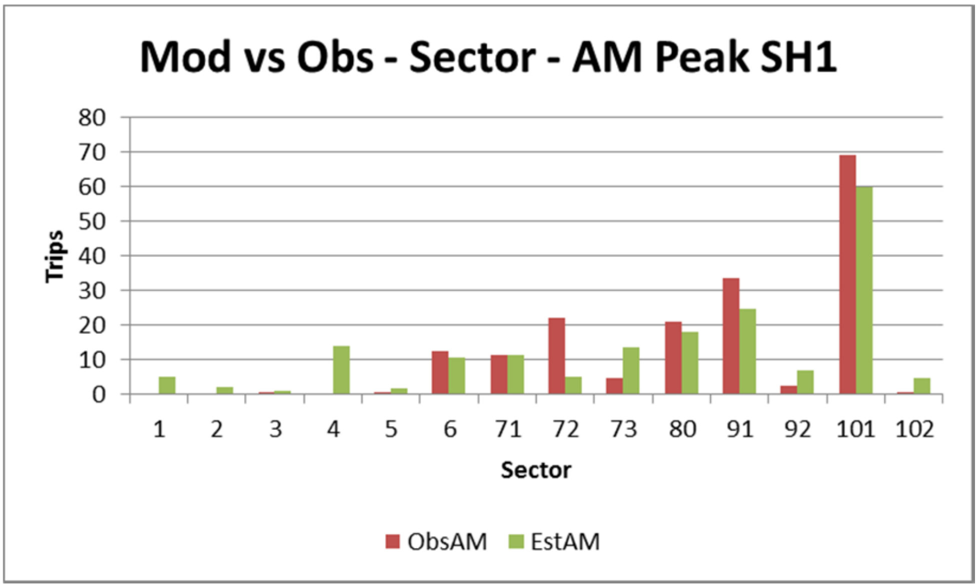

Figure 73: Comparison of Modelled and Observed Trip Ends – Sector – SH1 AM Peak – Model 5E

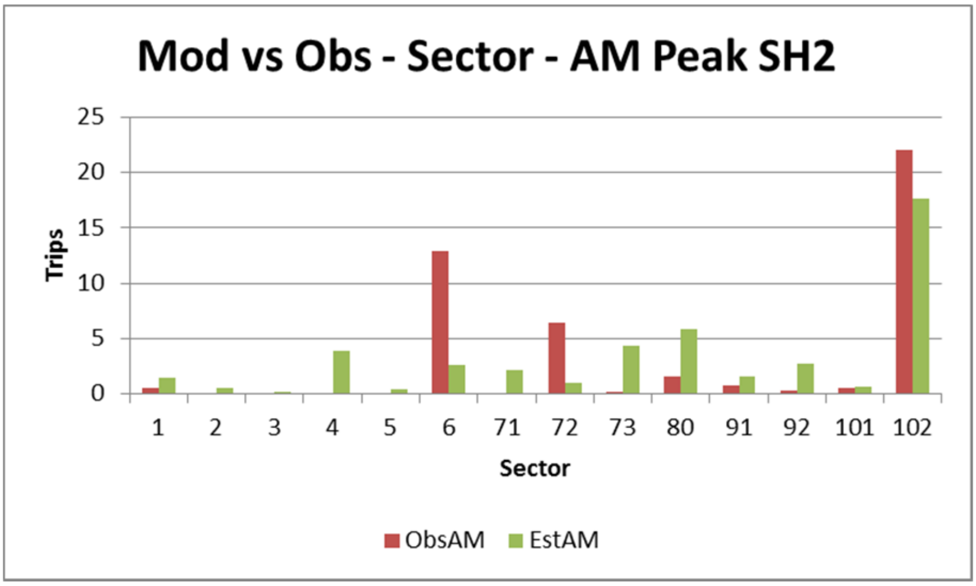

Figure 74: Comparison of Modelled and Observed Trip Ends – Sector – SH1 AM Peak – Model 5E

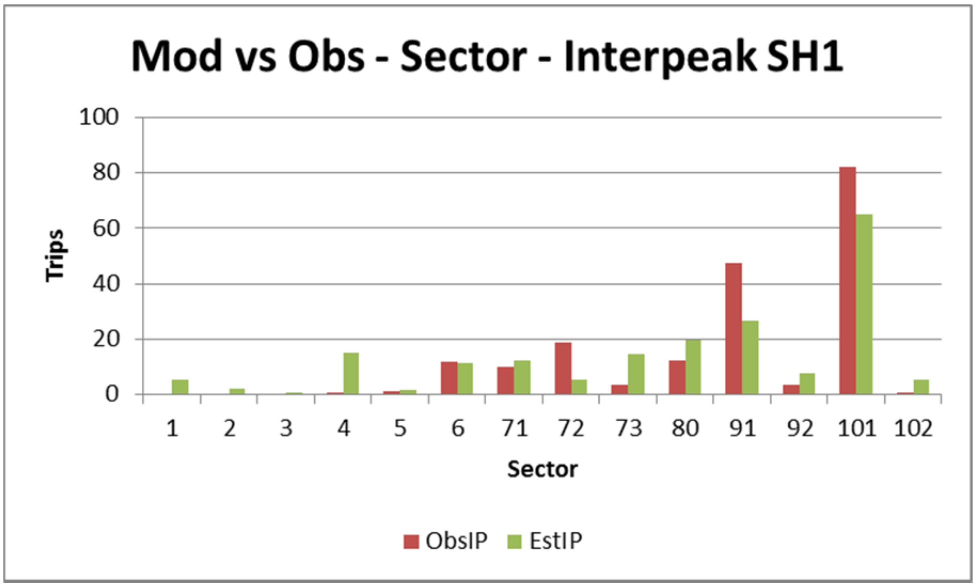

Figure 75: Comparison of Modelled and Observed Trip Ends – Sector – SH1 Interpeak – Model 5E

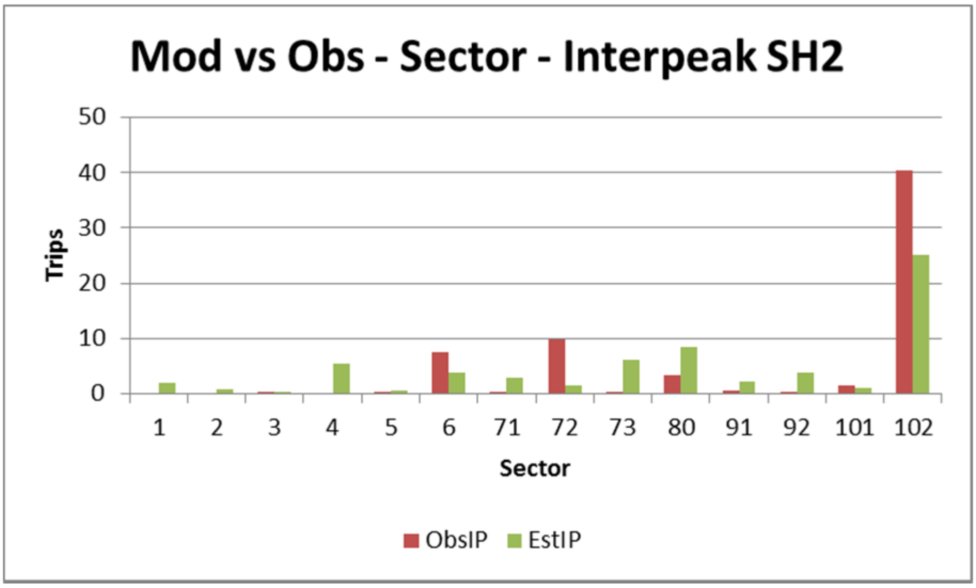

Figure 76: Comparison of Modelled and Observed Trip Ends – Sector – SH1 Interpeak – Model 5E

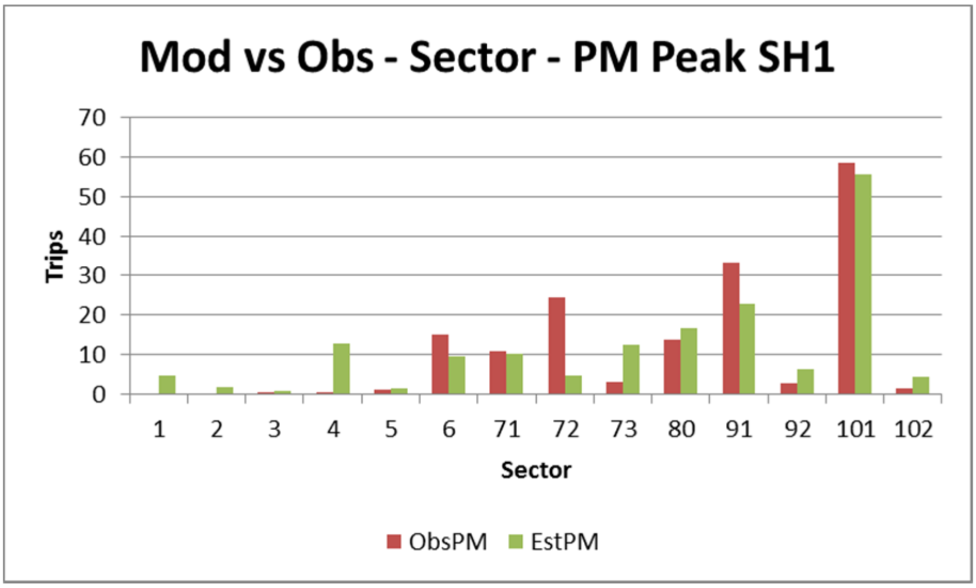

Figure 77: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model 5E

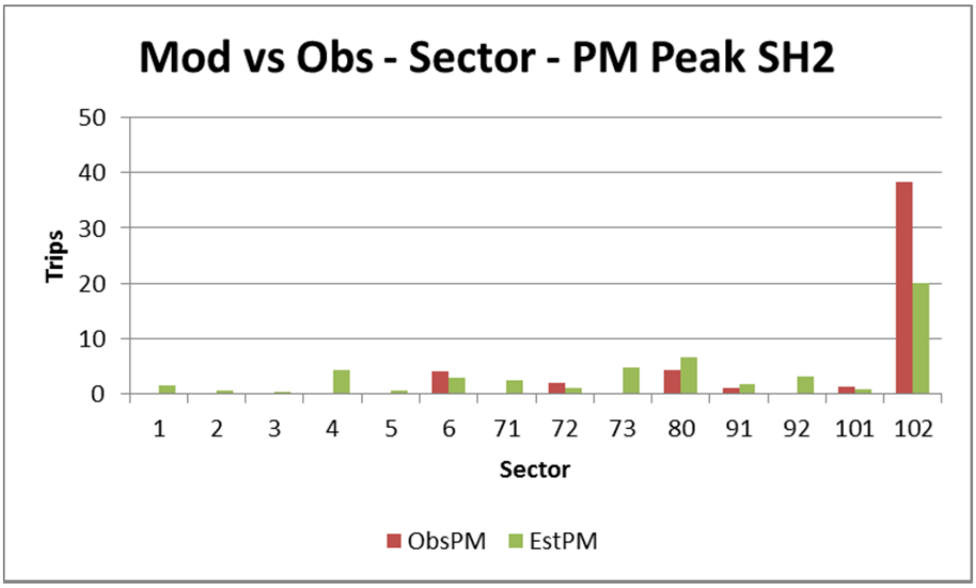

Figure 78: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model 5E

Sector	Obs AM	Mod AM	Obs IP	Mod IP	Obs PM	Mod PM
1	0	5	0	5	0	5
2	0	2	0	2	0	2
3	0	1	0	1	0	1
4	0	14	1	15	0	13
5	1	2	1	2	1	1
6	13	10	12	11	15	10
71	11	11	10	12	11	10
72	22	5	19	5	24	5
73	5	13	3	14	3	12
80	21	18	12	20	14	17
91	34	25	48	27	33	23
92	2	7	4	7	3	6
101	69	60	82	65	59	56
102	0	5	1	5	1	4
Total	177	177	192	192	165	165

Table 24: Comparison of Sectored Observed and Modelled SH1 Trips – Model 5E

Sector	Obs AM	Mod AM	Obs IP	Mod IP	Obs PM	Mod PM
1	0	1	0	2	0	2
2	0	1	0	1	0	1
3	0	0	0	0	0	0
4	0	4	0	5	0	4
5	0	0	0	1	0	0
6	13	3	7	4	4	3
71	0	2	0	3	0	2
72	6	1	10	1	2	1
73	0	4	0	6	0	5
80	2	6	3	8	4	7
91	1	2	1	2	1	2
92	0	3	0	4	0	3
101	1	1	2	1	1	1
102	22	18	40	25	38	20
Total	45	45	64	64	51	51

Table 25: Comparison of Sectored Observed and Modelled SH2 Trips – Model 5E

6.8 Conclusions – External Model

Whilst Model 1E has both positive coefficients and statistically significant variables its application leads to unsatisfactory results for key major sectors due to its combined handling of SH1 and SH2.

Combining the three peak periods to maximise the observed data (Model 2E) did not change the significance of the explanatory variables or improve the model.

Model 3E sought to retain both separation of SH1 and SH2 and time period whilst keeping (sometimes forced) as many explanatory variables as reasonably possible. Application of this model did not result in significant improvements and chiefly the fit between SH1/SH2 and the northern sectors 101/102 was still poor.

Modelling SH1 and SH2 separately but combining the zones onto their respective sectors (Model 4E) improved the SH2 relationships but the coefficients for SH1 came out negative for the Employment Other land use category. Whilst these could have been dropped and the model refitted the initial results were not promising, so this revision was not deemed worthwhile.

We therefore recommend the adoption of Model 5E, which considers the three peak periods separately, considers the external trips to/from SH1 and SH2 separately but considers origins and destinations together. This model has an explanatory variable that is statistically significant in all time periods for both SH1 and SH2. The adjusted R Squared values are also higher than those in other models (except for AM SH2). Moreover, it has a much improved fit between modelled and observed trips across all sectors but especially for sectors 101 and 102.

The adopted coefficients are shown in **Table 26** and differ from those given in **Table 23** as they include correction factors to make the synthesised trip ends match the observed external screenline volumes shown in **Table 27**. Model 5E produces total two-way trips and these will be split into inbound and outbound trips based on the observed split given in **Table 27**.

	AM	IP	PM
SH1	2.5040	2.7148	2.3245
SH2	1.4856	2.1132	1.6772

Table 26: Adopted External Regression Coefficients

		AM		IP		PM	
		Veh/2hr	% Split	Veh/2hr	% Split	Veh/2hr	% Split
SH1	Inbound	85	48.2%	91	47.5%	81	49.3%
	Outbound	92	51.8%	101	52.5%	83	50.7%
	Total	177		192		165	
SH2	Inbound	23	51.3%	29	44.5%	20	38.7%
	Outbound	22	48.7%	36	55.5%	31	61.3%
	Total	45		64		51	

Table 27: Observed 2013 External Screen Line Traffic Volumes

7. Special Generators

7.1 Overview

Analysis of both the internal and external trips highlighted the need to treat the Port (zone 39) separately from other zones. Although treated separately the structure of the model investigated for the Port zone follows the same principles used in the internal and external analysis.

Linear regression modelling techniques were applied to estimate the internal end of the Port trips. The results of various regression models are reported below noting that in this case the linear regression models are used to distribute trips amongst the various internal zones.

External Port trips (i.e., to/from zones 226 and 227) will be calculated using a fixed percentage of the total trips from the 2013 observations.

The synthetic trip end model, if adopted, will be applied to effectively distribute, or allocate, the internal end of Port trips for both directions of travel. The actual inbound and outbound volumes will be adopted from counts for the base year of 2013, and factored for future years, with the factors related to GDP.

The number of trips to/from the Interislander (zone 228) was found to be too low / sparsely distributed to achieve any meaningful regression. These trips could either be ignored, retained as is (with appropriate factoring for forecast scenarios), or estimated using the Port equations. This is addressed in section 7.4.3 of this report.

7.2 Port Trips – Travel Patterns

Desire line plots for the 2013 Port commercial vehicle trips are shown in **Figures 79** to **81**. The travel patterns are from the expanded sample data (i.e., not modelled data). The plots show strong movements between the Port and Sectors 4 (City Centre) and 80 (Lower Hutt). They also show that the sample is fairly sparse and the effect of this is covered in the following sections.

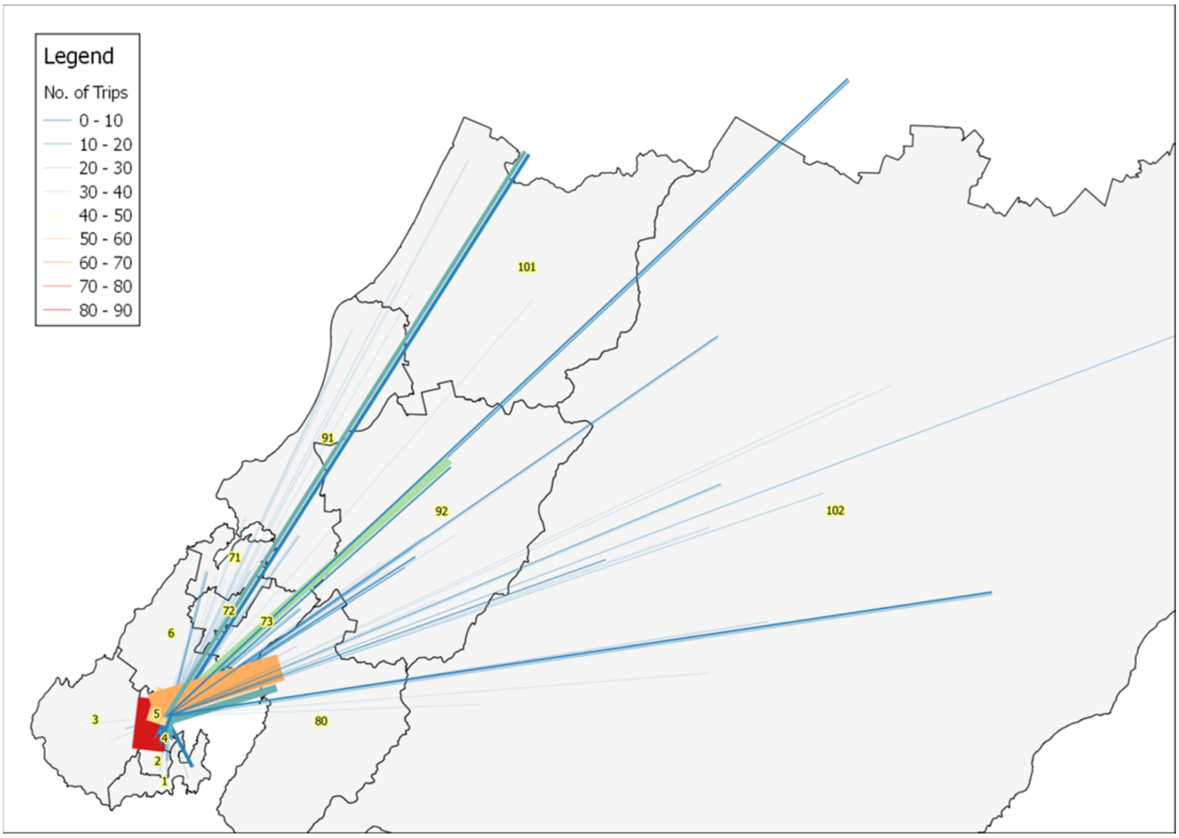

Figure 79: AM 2013 Port Trips Desire Lines – Observed Expanded Sample

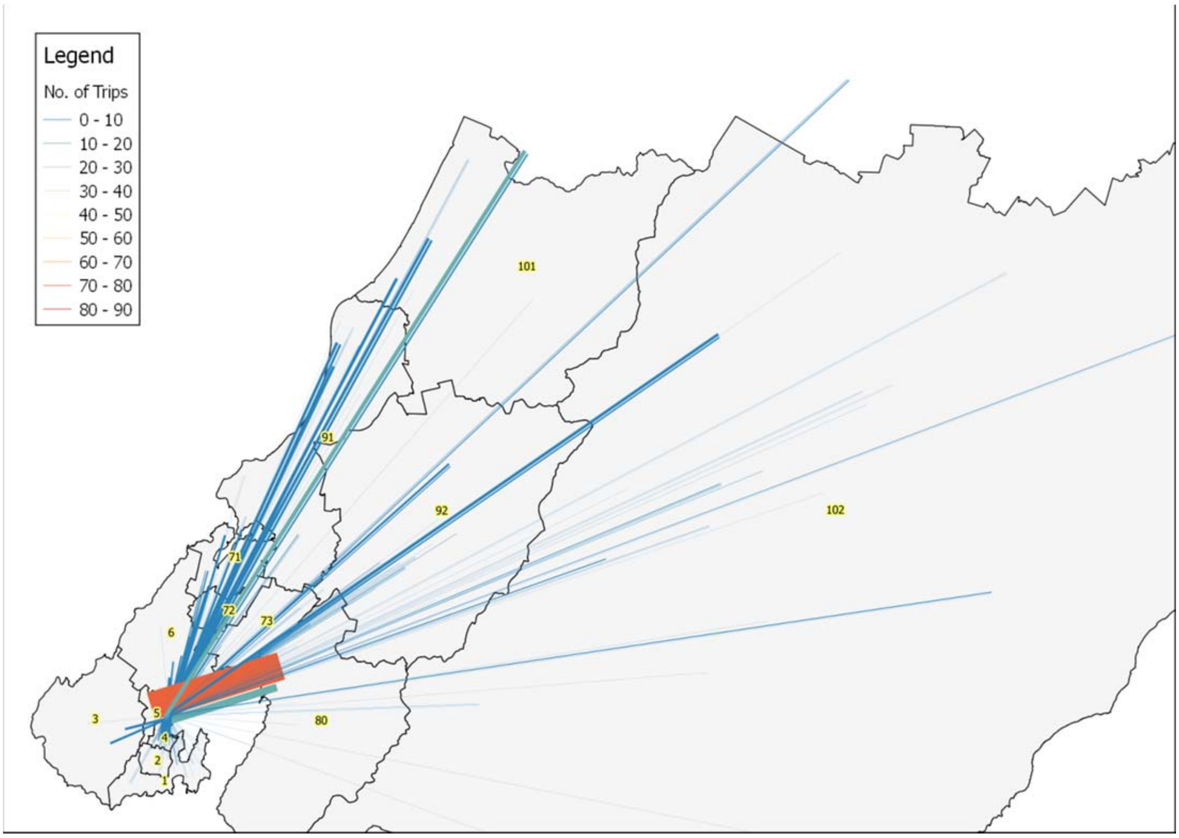

Figure 80: Interpeak 2013 Port Trips Desire Lines – Observed Expanded Sample

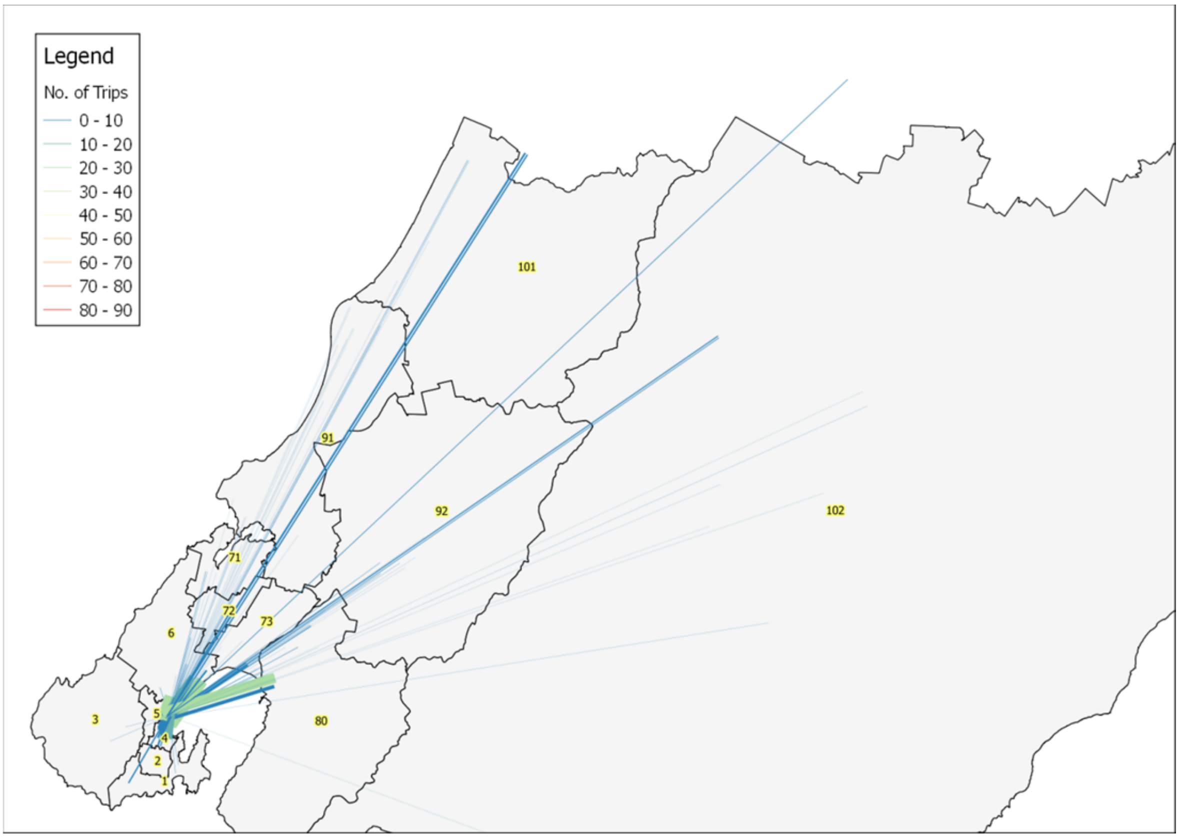

Figure 81: PM 2013 Port Trips Desire Lines – Observed Expanded Sample

7.3 Stepwise Linear Regression

The form of the trip end model investigated and reported is linear regression based on land use data being the independent variables. A forward stepwise linear regression analysis was undertaken to assess which land use variables were statistically significant. Variables were included if their P value was below 0.05 (the target level of significance).

As there were a relatively small number of observed Port trips the trip ends for the origin and destination were combined. The calculated two-way trip ends will then be split into inbound and outbound according to observed count data.

Whilst a number of models were investigated it soon became apparent that only one model had any merit (Model P1) and hence only this model is reported in detail here (along with a brief summary of other models investigated).

7.4 Model P1

7.4.1 Regression Model

In Model P1, the trip end regression modelling was carried out separately for each of the three modelled peak periods and at zonal level. The independent variables Manufacturing and Transport & Communications were found to be significant and with positive coefficient for all three periods. The adjusted R Squared were 0.22, 0.44and 0.41 for the AM, IP and

PM periods respectively. The details are given in **Table 28** and the final adopted coefficients are given in **Table 31**.

Period	Variable	Coefficient	Confidence Interval		P-value
			Lower 95%	Upper 95%	
AM	Manufacturing	0.004	0.001	0.007	0.004
	Transport & Communications	0.008	0.002	0.013	0.010
	Adjusted R^2	0.22			
IP	Manufacturing	0.009	0.007	0.011	0.000
	Transport & Communications	0.008	0.004	0.013	0.000
	Adjusted R^2	0.44			
PM	Manufacturing	0.003	0.002	0.004	0.000
	Transport & Communications	0.003	0.001	0.006	0.018
	Adjusted R^2	0.41			

Table 28: Regression Statistics – Port Trip End Model P1

Comparison of the observed and modelled trips at sector level is shown graphically in **Figures 82 to 84** and numerically in **Table 29**. Sectors 4 in the AM and PM (Wellington Central), 6 in the AM and PM peaks (Ngaio, Johnsonville) and 80 in the interpeak (Lower Hutt) were found to be poorly replicated, however the number of trips were numerically small. The alternative would be to add constants, which is not considered a good solution.

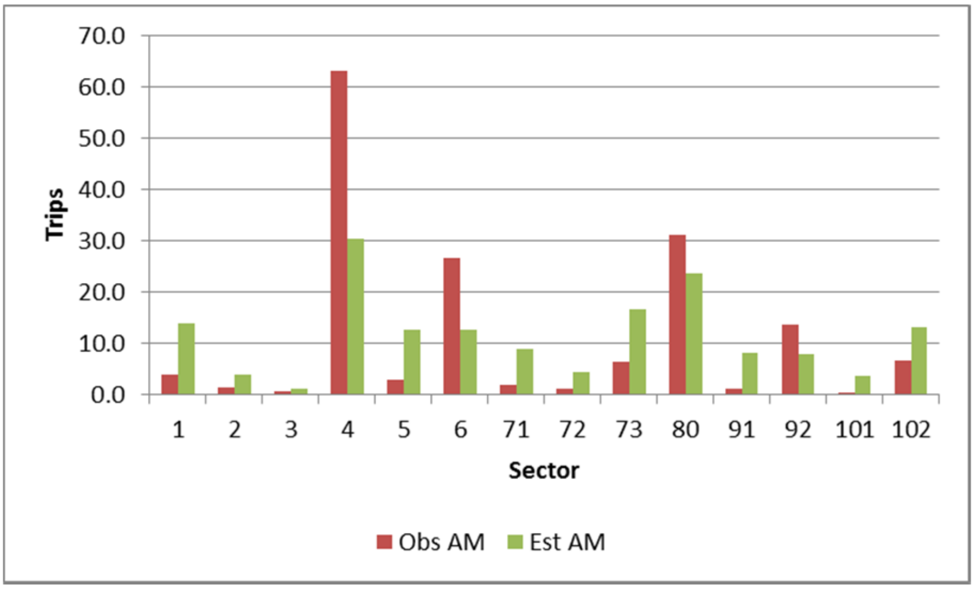

Figure 82: Comparison of Modelled and Observed Trip Ends – Sector – AM Peak – Model P1

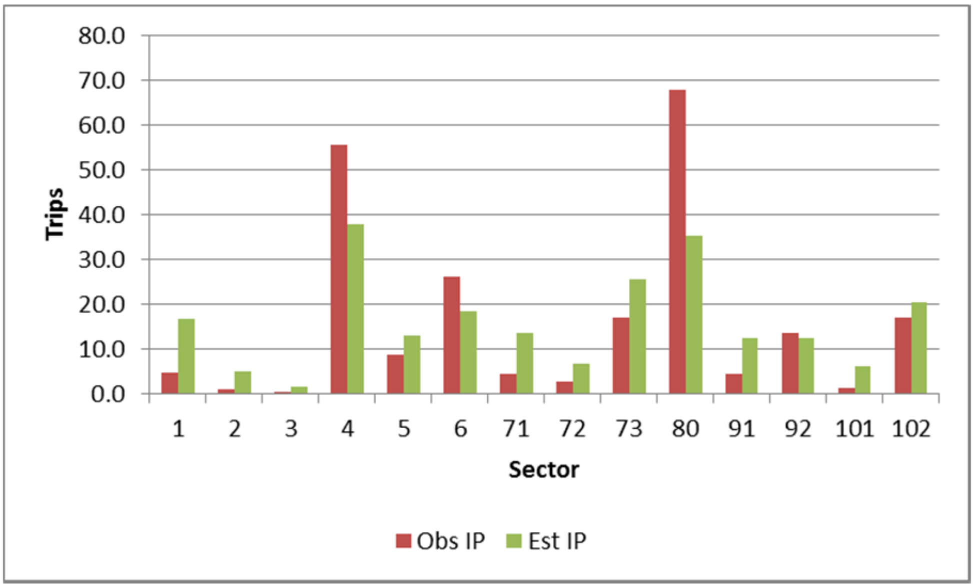

Figure 83: Comparison of Modelled and Observed Trip Ends – Sector – Interpeak – Model P1

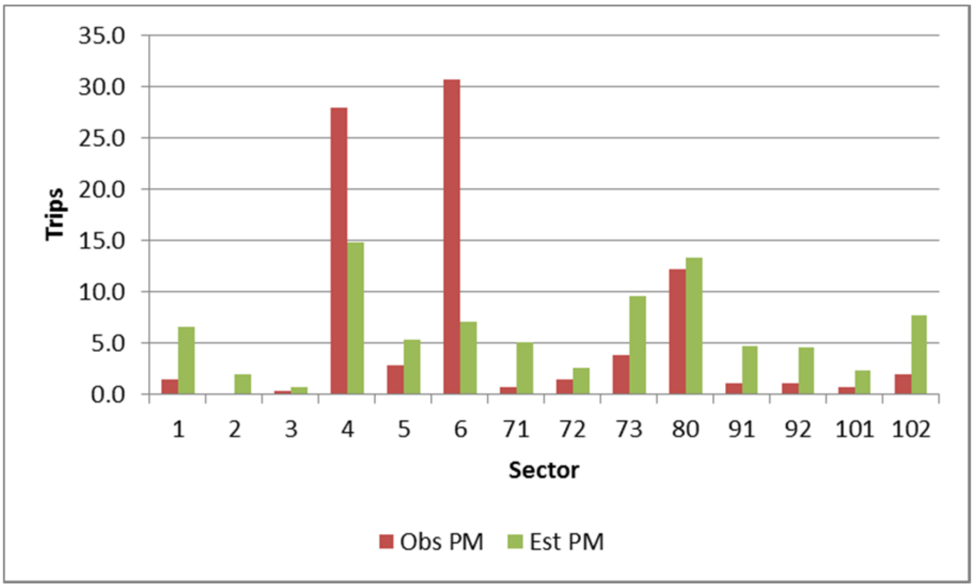

Figure 84: Comparison of Modelled and Observed Trip Ends – Sector – PM Peak – Model P1

Sector	Obs AM	Mod AM	Obs IP	Mod IP	Obs PM	Mod PM
1	3.8	13.9	4.8	16.6	1.5	6.6
2	1.4	3.9	1.1	5.1	0.0	2.0
3	0.5	1.2	0.3	1.7	0.3	0.6
4	63.0	30.3	55.4	37.9	27.9	14.8
5	2.8	12.6	8.6	12.9	2.8	5.3
6	26.6	12.6	26.0	18.4	30.7	7.0
71	1.9	8.8	4.5	13.6	0.7	5.1
72	1.2	4.4	2.7	6.8	1.5	2.5

Sector	Obs AM	Mod AM	Obs IP	Mod IP	Obs PM	Mod PM
73	6.4	16.7	17.0	25.4	3.8	9.6
80	31.0	23.5	67.8	35.2	12.2	13.3
91	1.1	8.1	4.5	12.4	1.1	4.7
92	13.5	7.9	13.6	12.3	1.1	4.6
101	0.4	3.7	1.3	6.0	0.6	2.2
102	6.7	13.0	16.9	20.4	2.0	7.6
Total	160.6	160.6	224.7	224.7	85.9	85.9

Table 29: Comparison of Sectored Observed and Modelled Port Trips – Model P1

7.4.2 Conclusions – Port Model

The calculated two-way trip ends are split into inbound and outbound directions according to the splits given in **Table 30**. Note that these splits are based on more localised, port specific, traffic counts and differ slightly from the control totals used in the linear regression. The final linear regression coefficients, which take account of the revised traffic volumes, are shown in **Table 31**.

	Observed 2hr Volume			Percentage Split	
	To Port	From Port	Total	To Port	From Port
AM	112	60	172	65.1%	34.9%
IP	131	115	246	53.3%	46.7%
PM	42	51	93	45.2%	54.8%

Table 30: Observed Directional Split

	AM	IP	PM
Manufacturing	0.00360	0.00641	0.00233
Trans & Comm	0.00651	0.00580	0.00244

Table 31: Adopted Port Regression Coefficients

Port trips to/from the external zones on SH1 and SH2 will be calculated using a fixed percentage of the total trips taken from the 2013 observations, as shown in **Table 32.**

	AM		IP		PM	
	SH1	SH2	SH1	SH2	SH1	SH2
To Ext	3.7%	3.9%	2.4%	4.6%	2.6%	2.6%
From Ext	1.2%	1.6%	1.4%	0.5%	0.0%	0.9%
Total	4.8%	5.5%	3.9%	5.1%	2.6%	3.5%

Table 32: Percentage of Port Trips to Externals (SH1 and SH2)

7.4.3 Interlander

The number of trips to / from the Interislander (zone 228) was found to be very low (29, 31 and 65 trips in the AM, IP and PM peaks respectively) and/or too sparsely distributed to achieve any meaningful regression. These trips will be hard-wired as a fixed percentage of zone 39 (see **Table 33**) and distributed using Port zone 39 distributions. There were a small number (<15 per peak) of (expanded) observed trips between zone 39 and zone 228. These movements have been omitted for reasons of simplicity and the trips subsumed into all other zones.

	AM	IP	PM
To	7.8%	6.6%	11.7%
From	3.2%	10.1%	32.5%

Table 33: Inter-Islander Zone 228 – Percentage of Port Zone 39

7.5 Discarded Models

7.5.1 Model P2

Model P2 built on Model P1 and sought to include network distance cost into the regression, in a similar manner to that used for the preferred External model (Model 5E). The results indicated that network distance was not a significant explanatory variable and this model form was therefore discarded.

7.5.2 Model P3

Given the smaller dataset and greater likelihood of sampling error at zonal level Model P1 was also analysed at sector level. The adjusted R Squared values were found to be higher than those at zonal level but these could be due to the decrease in data points. Nevertheless, visual inspection of the results indicated that whilst some gains were to be made, e.g., a better fit between AM peak observed versus modelled trips, the issues with sectors 6 and 80 remained. It was also considered that the independent variables found from the step wise regression, namely Services and Retail, were not as intuitive as Manufacturing and Transport & Communications found at zonal level. This model form was therefore discarded.

8. Future Growth

The internal, external and Port HCV models covered in the preceding sections calculate the total number of trips and distribution in each time period. This process, however, does not take into account wider economic trends and the impact on total commercial vehicle travel.

Work previously undertaken by Beca/SKM[2] found that total growth in HCVs does not appear to be well correlated to employment. HCVs were also found to have grown significantly faster than population and faster than GDP. A simple relationship to per capita Gross Domestic Product (GDP) was proposed using data available at a national level. Forecast HCV demands were obtained by the application of trip end factors calculated from employment together with the per capita GDP factor using the following formula:

$$HCV_F = HCV_{2001} \times [TE_F / TE_{2001} \times (1 + GDPPC_F / GDPPC_{2001} - TE_F / TE_{2001})^S] \qquad (Eq.1)$$

Where:

HCV_F	=	Future year HCV trip ends by zone
HCV_{2001}	=	Year 2001 HCV trip ends by zone
TE_{2001}	=	Synthesised year 2001 trip ends
TE_F	=	Synthesised future year trip ends
$GDPPC_{2001}$	=	GDP per capita year 2001
$GDPPC_F$	=	GDP per capita in future year
S	=	Sensitivity to GDP per capita growth

The previous analysis found that a value of 1.3 for the GDP per capita sensitivity factor gave a reasonable fit to the trend data in both HCV registrations and HCV VKT. The forecast year demand matrix was then obtained by furnessing the base year matrix to the forecast year trip ends. Note that trip end growth is subtracted from GDP growth to alleviate double counting arising from employment growth being reflected in GDP growth.

The above reported equation (Eq.1) is **not** the method currently used in WTSM – the reason for the difference is unknown although it is noted that the inner brackets of Equation 1 could return an invalid 'null' result depending on the ratio of GDP and trip ends. WTSM currently uses the following formula:

$$HCV_F = HCV_{2001} \times (TE_F / TE_{2001}) \times (GDPPC_F / GDPPC_{2001})^S \qquad (Eq.2)$$

While this does not consider the possibility of double counting growth (future to base GDP ratio and future to base trip end ratio), it does mean that the equation cannot return an invalid result.

In this 2013 update of WTSM, the 2013 and future distribution of HCV trips will be produced synthetically using the equations documented in this technical note. This approach also produces the total number of HCV trips for the base year of 2013. For future years, as growth in HCV trip making has been found to be not well correlated to employment, the total number of future HCV trips will be controlled to the growth in GDP per capita.

[2] WTSM TN18.1, Beca/SKM July 2003.

We will therefore use the same GDP based adjustment as Equation 2, but with the base year changed from 2001 to 2013, and the HCV distribution produced synthetically. It is noted that the relationship to GDP has not been reassessed and that this should be undertaken at some later stage. The resulting equation is shown in Equation 3 below.

$HCV_F = HCV_{F\text{-}Syn} \times (HCVTotal_{2013} / HCVSynTotal_F) \times (GDPPC_F / GDPPC_{2013})^S$
(*Eq.3)*

Where

HCV_F	=	Future year HCV trips
$HCV_{F\text{-}Syn}$	=	Future year synthetic HCV trips
$HCVTotal_{2013}$	=	2013 HCV demand total
$HCVSynTotal_F$	=	Future year synthetic HCV demand toatl
$GDPPC_{2013}$	=	GDP per capita for 2013
$GDPPC_F$	=	GDP per capita in future year
S	=	Sensitivity to GDP per capita growth, set to 1.3

This adjustment will be applied globally to the total HCV demand for future years, i.e., internal, external, and special generators combined.

9. Conclusions and Recommendations

A fully synthetic method for forecasting HCV movements has been developed. The models are based on HCV tracking data obtained from fleet management companies covering the month of March 2013. The steps involved in processing the raw tracking data to final demand matrices are covered in TDG Technical Note 2: Observed Commercial Vehicle Matrix Development.

Comparisons of observed and synthesised trip ends and distributions indicate that the synthetic models are performing satisfactorily and it is therefore recommended that the models described herein are incorporated into WTSM. An incremental approach, where changes forecast by the synthetic models are applied to the observed matrices, is not the preferred methodology.

Future updates to the synthetic model would benefit from additional HCV count data to produce more screenlines which would be positioned to split the larger sectors into smaller more distinct areas.

Appendix A

Comparisons of Forecast vs Observed – Internal Model

AM	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	-44	-134	-5	54	3	28	22	8	28	46	11	14	3	5	40
2	-149	-150	-24	-96	-19	-7	8	-3	9	13	4	5	1	2	-406
3	4	-4	-52	-58	-29	-3	5	3	3	8	2	3	1	1	-118
4	-46	-63	15	220	-138	42	39	17	40	74	19	27	6	9	261
5	7	-11	3	-365	-21	-3	10	2	9	14	3	5	1	2	-344
6	-6	-9	-2	-77	-16	-69	29	8	21	13	15	-2	5	3	-87
71	19	8	4	46	10	26	-169	-56	27	46	-15	9	4	7	-34
72	5	-2	2	17	4	5	-43	-94	9	13	-2	4	1	3	-77
73	19	6	3	13	10	1	27	13	86	-138	8	19	5	12	84
80	34	2	8	78	19	15	42	21	-214	7	26	14	7	25	84
91	10	4	2	20	4	13	-22	6	11	23	30	12	13	6	130
92	12	3	2	17	6	1	20	-18	10	17	16	32	4	30	150
101	3	1	1	8	1	4	0	0	4	5	6	2	82	2	118
102	3	1	1	8	1	2	4	2	8	16	4	20	1	125	198
Total	-129	-349	-41	-116	-165	56	-29	-91	50	158	126	164	134	232	0

Table A1: AM Peak 2hr Sectored Demands (Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	411	530	87	762	820	510	515	777	713	288	345	178	97
	Observed	331	427	155	487	341	139	251	348	710	176	251	143	22
	Error	80	103	-68	275	479	371	264	429	3	112	94	35	75
	%Error	24%	24%	-44%	57%	141%	267%	105%	123%	0%	63%	37%	24%	343%
	GEH	2.9	3.3	4.4	7.8	14.1	14.6	9.5	12.8	0.1	5.2	3.8	1.9	6.9
Direction 2	Forecast	361	479	85	830	890	510	527	793	695	297	378	183	148
	Observed	446	476	67	1129	814	174	216	548	561	158	196	134	28
	Error	-85	3	18	-299	76	336	311	245	134	139	182	49	120
	%Error	-0.2	0.0	0.3	-0.3	0.1	1.9	1.4	0.4	0.2	0.9	0.9	0.4	4.3
	GEH	3.0	0.1	1.5	6.7	1.8	12.9	11.4	6.7	3.8	6.5	7.6	2.7	9.0

Table A2: AM Peak 2hr Comparison of Observed and Forecast Screenline Volumes

IP	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	-154	-115	1	6	2	9	14	6	20	27	7	10	2	3	-164
2	1	-143	-2	-16	-4	1	5	1	5	10	2	3	1	1	-135
3	1	-6	-99	8	-5	-3	3	1	2	6	2	2	0	1	-88
4	-8	-48	-10	275	-202	11	26	14	13	56	13	17	4	6	166
5	1	-11	-17	-223	-43	-22	6	3	6	3	3	2	0	1	-291
6	23	4	3	45	7	-104	24	9	10	-6	8	-31	3	2	-4
71	13	4	3	24	6	26	-304	-71	19	29	-17	9	0	5	-256
72	8	0	1	12	3	12	-94	-84	7	10	4	0	-1	0	-123
73	13	0	2	4	2	8	16	10	184	-173	7	22	2	8	106
80	17	2	5	33	5	1	28	14	-127	74	17	50	5	16	139
91	6	2	1	10	2	7	13	8	7	16	115	10	-20	4	182
92	8	2	2	12	2	-7	11	2	15	31	11	76	3	21	188
101	1	0	0	2	0	2	-9	-7	2	4	-32	-1	102	1	67
102	1	1	0	3	1	-2	2	0	4	4	2	10	1	186	213
Total	-70	-307	-111	196	-225	-59	-261	-96	167	89	141	179	101	255	0

Table A3: Interpeak 2hr Sectored Demands (Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	334	433	75	656	691	382	389	632	588	216	251	151	58
	Observed	346	324	65	620	479	139	256	437	603	138	180	188	28
	Error	-12	109	10	36	212	243	133	195	-15	78	71	-37	30
	%Error	-4%	34%	16%	6%	44%	175%	52%	45%	-3%	57%	39%	-20%	107%
	GEH	0.5	4.0	0.9	1.0	6.2	10.6	5.2	6.0	0.4	4.2	3.4	2.0	3.2
Direction 2	Forecast	324	410	70	567	574	374	384	534	615	212	294	149	116
	Observed	245	382	83	606	442	144	263	472	626	136	168	154	32
	Error	79	28	-13	-39	132	230	121	62	-11	76	126	-5	84
	%Error	0.3	0.1	-0.2	-0.1	0.3	1.6	0.5	0.1	0.0	0.6	0.8	0.0	2.6
	GEH	3.3	1.0	1.0	1.1	4.1	10.1	4.8	2.0	0.3	4.1	5.9	0.3	6.9

Table A4: Interpeak 2hr Comparison of Observed and Forecast Screenline Volumes

PM	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	0	-209	1	10	0	12	17	4	25	36	9	11	3	5	-75
2	22	-36	-2	-6	1	-4	7	3	7	6	4	4	2	2	10
3	-1	-9	-44	1	0	3	4	2	4	9	2	3	1	1	-23
4	-75	-78	-15	172	-226	-86	34	14	25	57	21	8	9	13	-129
5	7	-8	-4	-240	0	-12	9	4	13	15	3	5	2	2	-204
6	18	6	-11	14	-4	-99	20	9	11	28	13	-11	5	5	6
71	18	7	4	40	9	26	-124	-10	24	40	-27	15	0	8	32
72	9	3	0	19	2	5	-50	-65	12	16	-7	-2	-3	2	-60
73	17	10	5	45	12	26	21	9	28	-282	12	-11	5	10	-93
80	37	16	8	83	15	24	39	15	-223	-114	24	39	9	19	-8
91	9	4	2	21	4	12	16	9	13	26	43	12	11	6	189
92	11	5	3	21	5	10	17	7	11	21	12	-31	6	21	118
101	4	1	1	8	1	5	-2	-15	5	7	5	-7	56	2	71
102	5	2	1	10	2	6	7	3	10	16	6	20	2	77	166
Total	79	-286	-51	199	-179	-73	14	-9	-34	-118	121	57	107	174	0

Table A5: PM Peak 2hr Sectored Demands (Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	290	402	67	777	832	455	457	713	570	267	317	164	114
	Observed	378	263	53	806	605	119	164	339	496	132	130	153	26
	Error	-88	139	14	-29	227	336	293	374	74	135	187	11	88
	%Error	-23%	53%	26%	-4%	37%	282%	179%	110%	15%	103%	144%	7%	339%
	GEH	3.4	5.4	1.2	0.7	6.0	14.0	11.8	11.5	2.3	6.8	8.8	0.6	7.5
	Forecast	319	427	69	676	709	436	471	653	600	273	323	156	122
Direction 2	Observed	200	415	77	539	325	100	208	198	620	154	183	110	30
	Error	119	12	-8	137	384	336	263	455	-20	119	140	46	92
	%Error	0.6	0.0	-0.1	0.3	1.2	3.4	1.3	2.3	0.0	0.8	0.8	0.4	3.1
	GEH	5.2	0.4	0.7	3.9	11.9	14.5	10.1	15.6	0.6	5.8	6.2	2.8	7.5

Table A6: PM Peak 2hr Comparison of Observed and Forecast Screenline Volumes

Appendix B

Comparisons of Adjusted Forecast vs Observed – Internal Model

AM	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	48	-121	-3	48	2	19	9	3	10	18	3	4	0	0	0
2	-140	-134	-23	-88	-18	-9	3	-5	3	3	1	1	0	0	0
3	4	-3	-43	-57	-27	-2	2	2	0	3	1	1	0	0	0
4	-47	-54	19	379	-126	29	15	7	6	21	4	7	0	0	0
5	7	-10	5	-354	-4	0	5	0	2	3	0	1	-1	0	0
6	-13	-11	0	-94	-12	22	21	14	9	-10	4	-14	0	-3	0
71	7	3	3	15	5	18	-43	-43	10	19	-17	-4	-5	0	0
72	1	-3	2	4	3	11	-29	-60	2	2	-6	-1	-2	0	0
73	5	0	2	-25	4	-7	12	7	197	-116	-2	5	0	2	0
80	10	-7	5	13	9	-6	17	10	-199	220	7	2	-1	5	0
91	2	1	1	1	1	2	-25	1	0	3	143	2	-1	1	0
92	2	-1	1	-7	1	-11	7	-23	-7	-1	6	171	-1	12	0
101	0	0	0	0	0	-1	-9	-3	0	-3	-10	-3	147	0	0
102	0	0	0	0	0	-2	-2	0	0	-1	0	1	0	202	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B1: AM Peak 2hr Sectored Demands (Adjusted Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	323	407	79	497	510	276	276	441	575	145	213	114	32
	Observed	331	427	155	487	341	139	251	348	710	176	251	143	22
	Error	-8	-20	-76	10	169	137	25	93	-135	-31	-38	-29	10
	%Error	-2%	-5%	-49%	2%	50%	99%	10%	27%	-19%	-17%	-15%	-20%	45%
	GEH	0.3	0.7	4.9	0.3	5.8	6.7	1.1	3.3	3.8	1.7	1.8	1.8	1.3
	Forecast	282	367	77	673	737	279	285	561	503	149	203	123	68
Direction 2	Observed	446	476	67	1129	814	174	216	548	561	158	196	134	28
	Error	-164	-109	10	-456	-77	105	69	13	-58	-9	7	-11	40
	%Error	-0.4	-0.2	0.1	-0.4	-0.1	0.6	0.3	0.0	-0.1	-0.1	0.0	-0.1	1.4
	GEH	6.1	3.7	0.8	10.7	2.0	4.9	3.1	0.4	1.8	0.5	0.4	0.7	4.1

Table B2: AM Peak 2hr Comparison of Observed and Adjusted Forecast Screenline Volumes

IP	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	-90	-111	1	-5	0	2	7	3	10	12	3	4	0	1	0
2	5	-131	-1	-15	-4	-1	3	0	2	5	1	1	0	0	0
3	0	-6	-93	8	-4	-3	2	0	1	4	1	1	0	0	0
4	-19	-47	-10	392	-199	-1	12	7	-7	25	5	6	1	2	0
5	-1	-11	-16	-220	-28	-21	3	2	3	-2	1	-1	0	0	0
6	16	2	2	29	7	-29	16	11	1	-22	2	-38	0	-1	0
71	6	2	1	10	3	17	-228	-68	9	13	-20	1	-5	1	0
72	4	-1	0	5	2	13	-90	-54	2	2	1	-2	-3	-1	0
73	3	-3	0	-16	-1	-2	7	5	272	-177	2	13	0	3	0
80	1	-3	2	3	-1	-17	12	7	-132	218	7	37	1	6	0
91	2	0	0	3	0	1	9	5	2	6	180	4	-33	1	0
92	3	0	1	2	0	-15	2	-2	4	14	5	160	0	14	0
101	0	0	0	0	0	0	-14	-9	0	0	-46	-3	139	0	0
102	0	0	0	0	0	-4	-1	-1	0	-5	0	-2	0	226	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B3: Interpeak 2hr Sectored Demands (Adjusted Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	272	351	69	517	570	257	260	467	526	146	182	115	38
	Observed	346	324	65	620	479	139	256	437	603	138	180	188	28
	Error	-74	27	4	-103	91	118	4	30	-77	8	2	-73	10
	%Error	-21%	8%	6%	-17%	19%	85%	2%	7%	-13%	6%	1%	-39%	36%
	GEH	3.0	1.0	0.3	3.0	2.8	5.9	0.2	1.0	2.3	0.5	0.1	4.2	1.2
	Forecast	265	331	64	443	527	248	255	453	499	138	202	115	82
Direction 2	Observed	245	382	83	606	442	144	263	472	626	136	168	154	32
	Error	20	-51	-19	-163	85	104	-8	-19	-127	2	34	-39	50
	%Error	0.1	-0.1	-0.2	-0.3	0.2	0.7	0.0	0.0	-0.2	0.0	0.2	-0.3	1.6
	GEH	0.9	1.9	1.6	5.0	2.7	5.3	0.3	0.6	3.8	0.1	1.8	2.4	4.7

Table B4: Interpeak 2hr Comparison of Observed and Adjusted Forecast Screenline Volumes

PM	1	2	3	4	5	6	71	72	73	80	91	92	101	102	Total
1	63	-202	1	6	-1	6	6	1	13	14	2	2	0	0	0
2	31	-23	-1	-1	1	-6	2	1	1	-5	0	0	0	0	0
3	-1	-9	-38	1	1	3	2	2	1	5	1	1	0	0	0
4	-65	-65	-10	355	-209	-88	9	5	-4	5	2	-14	0	1	0
5	7	-7	-2	-228	16	-8	4	3	7	4	-1	0	0	-1	0
6	12	3	-10	-1	-2	-34	15	15	6	13	4	-21	0	-1	0
71	6	3	2	13	4	18	-20	3	10	16	-28	4	-8	0	0
72	4	1	0	9	0	9	-37	-39	7	7	-10	-6	-5	0	0
73	4	5	3	15	6	20	9	5	122	-253	3	-20	0	0	0
80	13	6	4	27	4	6	17	7	-198	66	7	30	1	-1	0
91	1	1	0	3	0	2	13	5	2	7	143	2	3	0	0
92	1	1	1	-1	0	-1	6	2	-2	9	2	87	1	2	0
101	0	0	0	0	0	0	-11	-18	0	-2	-4	-12	114	0	0
102	0	0	0	0	0	-1	0	0	0	-4	0	2	0	174	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B5: PM Peak 2hr Sectored Demands (Adjusted Forecast – Observed)

Screenline		5	11	90	121	6	70	14	71	100	102	103	81	82
	Statistic													
Direction 1	Forecast	226	306	61	552	583	241	232	405	419	126	146	106	24
	Observed	378	263	53	806	605	119	164	339	496	132	130	153	26
	Error	-152	43	8	-254	-22	122	68	66	-77	-6	16	-47	-2
	%Error	-40%	16%	15%	-32%	-4%	103%	42%	20%	-16%	-5%	12%	-31%	-6%
	GEH	6.2	1.8	0.7	6.9	0.6	6.4	3.4	2.4	2.5	0.4	1.0	2.9	0.2
	Forecast	261	337	64	438	464	222	241	359	436	126	149	102	31
Direction 2	Observed	200	415	77	539	325	100	208	198	620	154	183	110	30
	Error	61	-78	-13	-101	139	122	33	161	-184	-28	-34	-8	1
	%Error	0.3	-0.2	-0.2	-0.2	0.4	1.2	0.2	0.8	-0.3	-0.2	-0.2	-0.1	0.0
	GEH	2.8	2.9	1.1	3.2	4.9	6.8	1.5	6.8	5.6	1.7	1.9	0.5	0.1

Table B6: PM Peak 2hr Comparison of Observed and Adjusted Forecast Screenline Volumes