1. PURPOSE

The purpose of this note is to document the procedure followed to choice parameters and check the validation of the Four Step model. It assumes that other technical notes have covered Generation, Distribution and Mode Split.

2. INTRODUCTION

Once the trip matrices by mode have been formed, the final step is the assignment of the public transport trips to the bus services, at which time a number of validation checks can be performed. The public transport services have been coded onto the vehicle network, and the loaded network speeds and times have been used to determine bus running speeds.

The routes coded are shown in **Appendix One** as Figure 1 for those within Hamilton, and **Figure 2** for those serving the area around Hamilton from Ngaruawhahia to Te Awamutu and Cambridge. These are the services in place in July 2008, which is consistent with the time at which the bus intercept survey was undertaken. It was not plausible to model the bus services at base year (2006) conditions because there was no detailed data available to validate against for 2006. The corresponding timetables for both modelled periods are included as Appendix Two.

The fare structure is presented in **Table 1**.

Modelled Waikato Region Bus Services and Fares		Table 1	
No.	**Location & Provider**	**Fare**	
1	Hamilton (Hamilton Urban Services)	$2.00	
2	Cambridge (Cambridge Travel Lines)	I section	$3.00
		2 Sections	$5.50
		3 Sections	$6.00
3	Te Awamutu (Go-bus Hodgsons)	$6.00	
4	Orbiter Hamilton	$2.00	
5	CBD Shuttle	Free	

3. PUBLIC TRANSPORT ASSIGNMENT

The following section briefly details the development of the public transportation model. There is much technical detail included and no attempts have been made to simplify the text beyond its technical status.

The Assignment Process

The PT assignment model is analogous to the vehicle assignment and is used for assigning PT trips onto the network.

Unlike conventional vehicle assignment, PT assignment assigns the bus passenger matrix onto a fixed set of routes. Similar to vehicle assignment the decision of which route is taken is based on least cost algorithm. The main difference between the vehicle and public transport assignment is in the way the matrix is loaded.

Public transport represents a dynamic assignment model where the modelled period and the matrix are divided into slices and passengers are released in intervals starting from the beginning of the modelled period. A dynamic assignment approach is necessary because of the way that buses run following a fixed timetable. The decision is made by each passenger as to which service or services will be taken, given the time that a service is available, and the time between two or more services connecting.

a) The single ride trip will occur if:

$$T^1_A > T^i_S + T_F + T_C$$

Where:

T^1_A = the time at which the first available bus arrives at the bus stop A.

T^i_S = slice release time where the number of slices is i.

T_F = access and egress time by foot.

T_C = access time by car to/from the park'n'ride station

The difference between the left and right hand side in the inequality above represents the waiting time T_W:

$$T_W = T^1_A - T^i_S + T_F + T_C$$

The waiting time has to be greater or equal to 0 and less or equal to maximum waiting time otherwise the trip can not occur.

$$T_{W(max)} \geq T_W \geq 0$$

b) The multi ride trip will occur if the single ride trip condition is satisfied for the first bus service used, and

$$T^2_B \geq T^1_B + 30sec$$

Where:

T^1_B	is the time at which the first bus arrives at the bus stop B.
T^2_B	is the time at which the second bus departs at the bus stop B.
30sec	is the minimum time allowed for the passenger transfer.

The difference between the first bus arrival and the second bus departure represents the waiting time:

$$T_W = T^2_B - T^1_B$$

Therefore TW and has to be greater or equal to 30 seconds and less or equal to maximum waiting time TW(max) for the trip to occur:

$$T_{W(max)} \geq T_W \geq 30sec$$

If the maximum number of transfers is 3, then another condition has to be met for the trip to occur:

$$T^3_C > T^2_C + 30_, \text{ and}$$

$$T_{W(max)} \geq T_W \geq 30sec$$

Where:

T^2_C	=	the time at which the second bus arrives at the bus stop C.
T^3_C	=	the time at which the third bus departs at the bus stop C.
T_W	=	$T^3_C - T^2_C$
$T_{W(max)}$	=	the maximum waiting time.

Further constraints are the maximum inter-zonal cost and the maximum number of transfers. They cannot exceed values specified in the parameter file.

The inter-zonal cost for PT trips is derived as the weighted sum of several components:

- wait time cost
- walking time cost at each end of the trip
- park'n'ride cost (if used)
- fare cost
- a penalty for transferring between services

All bus routes are divided into a number of fare sections and the bus fare is derived depending of which fare section crossed. In the base model, a new ticket has to be purchased if a transfer is needed.

If a car is used as part of a PT trip (for example a park'n'ride trip) then the car cost is added and it consists of:

- In vehicle time cost, and
- In vehicle distance cost
- Parking cost

Time and distance costs are derived from the loaded vehicle network. During the assignment the link time is multiplied by 1.3 to allow for the time lost at bus stops where the boarding and alighting of buses occurs. The route file defines express routes where passengers can board buses only on certain stations, and no additional allowance is made for pick up times.

Public Transport Model Outputs

The public transport assignment outputs a series of matrices representing various time and cost components, and are a weighted average of the cost of all trips between each zone pair.

- In vehicle time.
- Average walk time
- Average wait time
- Average car cost
- Average fare cost

Other matrices output by the public transport assignment are:

- Average number of fare sections crossed
- Average number of transfers.

It is also possible to establish the services used between each zone pair for each slice of loading. Also available are the origin and destination nodes for each bus service used and the park'n ride nodes if these facilities are used to complete the trip. The path file also contains information about each of the slices loaded, the release time and the cost in dollars for that trip portion. If the trip happens to be the one where passengers transferred from one bus to another, then the node at which the transfer occurs is recorded.

Passenger patronage per service with the time component included is reported in a separate file, which lists all services and the number of passengers getting on and off the buses along the route.

Similar to vehicle assignment a loaded network is produced at the end of each run, and depending on the switch used in the parameter file loaded network will contain either PT passenger numbers or the number of buses. The number of buses is a graphical check on the coding and is a direct reflection of input.

4. VALIDATION CRITERIA

The checks on the Public transport model as included in the Model Specification report are:

Public Transport Distribution and Assignment

Model Output:	Bus numbers
Check:	That the number of buses on each link matches observed. This is essentially a check on service coding
Criteria:	Absolute match
Model Output:	Bus journey times
Check:	That the journey time for each service matches observed. In part a check on timetable coding and in part that the stopped and network travel times are correct
Criteria:	Journey times within ± 5% of expected for each service
Model Output:	Passenger numbers per service
Check:	That the number of passengers on and off for each service match observed
Criteria:	Overall within +/- 10%, R^2 >0.6, and +/- 40% on most services.
Model Output:	Screenline link passenger volumes
Check:	That the number of passengers on each and all links in a screenline match observed
Criteria:	That each screenline is within ± 20% of observed and most individual links are within ± 50% of observed
Model Output:	Elasticities
Check:	That the modelled response to changes is in accordance with international experience
Criteria:	Fare change has an elasticity of - 0.3, and frequencies -0.1 in peak periods and slightly highly elasticities off peak.
Model Output:	Three step vs Four Step traffic volume comparison
Check:	That the two models are consistently replicate traffic volumes
Criteria:	Overall R^2 > 0.95 for counts and R^2 > 0.95 for sector to sector trip totals. Most screenline GEH statistics < 4.

5. MODEL CONVERGENCE

Assignment and Validation Loop

Time and distance matrices are required as inputs for trip distribution. As assigning the trips to the network generates these matrices, after each assignment the trip distribution needs to be re-run and the trips re-assigned until the time and distances matrices converge.

In practice, it is unlikely that absolute convergence occurs. The assignment and distribution steps are run iteratively until the totals of both the time and distance matrices between successive runs remain close to each other and relatively constant.
The totals for the time and distance matrices for two successive Assignment/Distribution Loops (after many previous runs) are shown below in **Table 2** where:

TVM = Total Vehicle Minutes
TVK = Total Vehicle Kilometres

Model Convergence				Table 2
PERIOD	AM Peak		Interpeak	
	TVM	TVK	TVM	TVK
Last Run	2680702	2574091	2614257	2603947
Difference from Prev Run	900	666	2708	857
% Diff	<0.1%	<0.1%	0.1%	<0.1%

The percentage change in generalised user cost between consecutive loops should be less than 1%. As the total vehicle minutes and total vehicle kilometres change less than 1% between runs (shown above), and unit time and distance costs are constant between runs, generalised user cost also changes less than 1% between runs.

When validating the model it is difficult to get a long series of runs prior to convergence because of the continual changing of the model components to get a better fit, even though these changes were often small. In general the model re-converged after two or three iterations. The periods were then run several times after convergence and remained stable.

For any model, if the network is heavily congested, convergence may not occur. Although the network is currently stable, when any changes are made to the network (e.g. option testing or land use), then convergence must be checked to ensure the network is still stable. In the unlikely event of the network not stabilising, modifications will have to be made to the network so that it will converge. These modifications should then be incorporated into the option or year being tested.
Another check on the assignment convergence stability is that the proportion of links in the entire network with flows changing less than 5% from the previous iteration, and consecutive iterations with proportions greater than 95% (EEM Worksheet 8.4).

Link Flow Convergence

The EEM requirement for link flow stability details that 95% of all links should not change by more than 5% between the ultimate and penultimate distribution/assignment convergence loops. The percentage of total links with changes of less than 5% for the three modelled periods is shown in **Table 3** below.

Of those links with more than 5% change between runs, only 164 of the 495 trips in the AM Peak changed by more than 10 vehicles in total, and only 89 of the 180 interpeak trips. This indicates that most of the links experiencing some variability had relatively low traffic volumes.

Model Convergence				Table 3
Period	**Criteria**	**Links**	**Percentage**	**Less than 5%**
AMP	0% - 2.5%	17077	95.7	97.2%
	2.5% - 5%	262	1.5	
	> 5%	495	2.8	
Total		**17834**	**100**	
INP	0% - 2.5%	17451	97.9	99.0%
	2.5% - 5%	203	1.1	
	> 5%	180	1.0	
Total		**17834**	**100**	

6. MODEL VALIDATION

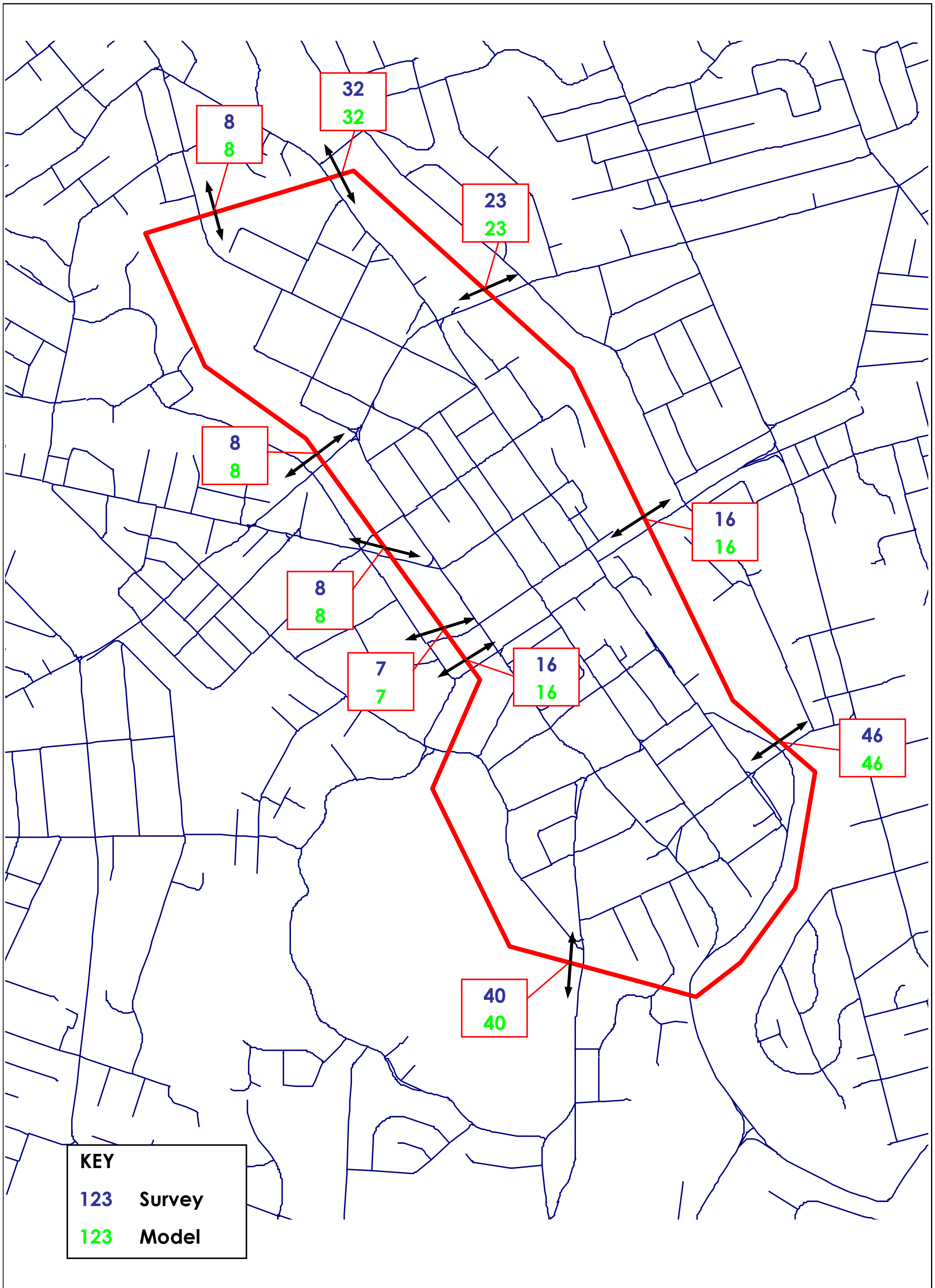
Bus Numbers

The number of buses passing a particular point during the modelled time period is a function of the service routes, the frequency of the service, and the extent to which a bus driver has managed to keep to the timetable.

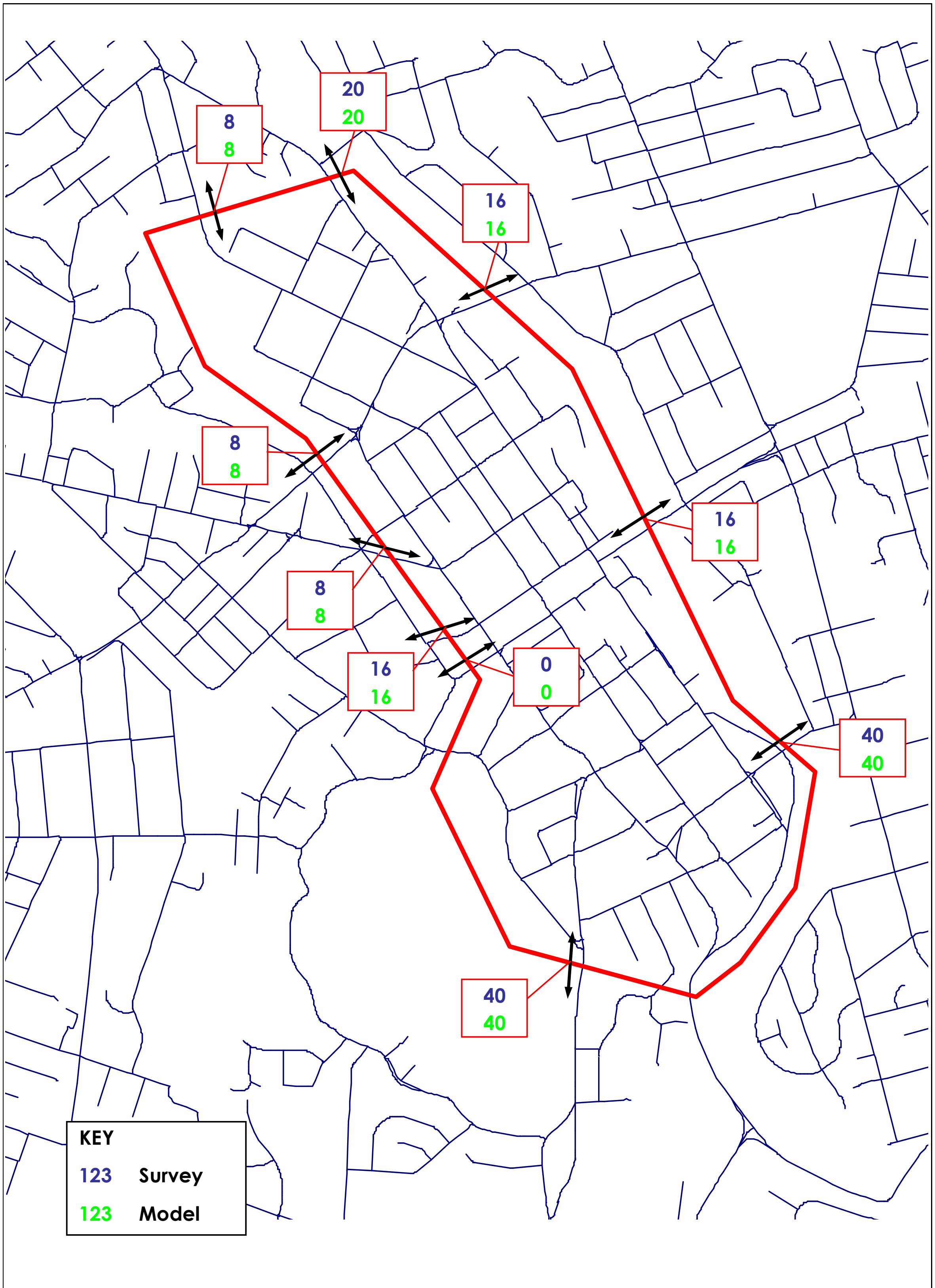
The check that the model is assigning busses to the correct routes and in the correct numbers is a check on input service coding, and can be derived from an analysis of the timetables. Alternatively, the number of buses on a link can be derived directly from a classified count.

In Hamilton, the latter course was not followed as the automatic classified counts available to the study identified buses as a vehicle class, but these do not distinguish between buses, coaches and school buses, with only scheduled public services included in the model.

Accordingly, the number of buses that should have been on the links around a CBD cordon was calculated from the timetables and checked back against the modelled bus vehicle assignment. The CBD cordon used in this analysis and the AMP and INP bus number validation is shown in **Figure 1** and **Figure 2**. These figures indicate that the model is replicating the timetables correctly.



Waikato Regional Transportation Model	Hamilton CBD Cordon AM Peak Bus Vehicle Validation	Figure 1
Gabites Porter Traffic Design Group		



Waikato Regional Transportation Model	Hamilton CBD Cordon Inter Peak Bus Vehicle Validation	Figure 2
Gabites Porter Traffic Design Group		

Bus Journey Times

The model specification report suggested a check against bus journey times. It was initially intended that this data be extracted from the Environment Waikato electronic bus data and it was understood that this would be readily available. Unfortunately time-specific data, which is available from EW is limited to the time at which patrons boarded services, therefore it is not possible to extract an arrival time for the bus reaching the last stop. It is also evident that patrons may board the service at the first stop a number of minutes prior to the start of a run.

The WRTM assumes that bus travel times in urban areas are 30% longer than travel times in private vehicles when no bus priority measures are imposed. The 30% is an allowance for the time taken for boarding and alighting the service. This value was calibrated in 1971 in Christchurch and has recently been confirmed using real-time GPS data in both Dunedin, Christchurch and Kuala Lumpur. Analysis of the public transport assignment outputs confirmed that the model is accurately calculating bus travel times on this basis.

Unfortunately there was insufficient recorded data from the GPS data collected by Environment Waikato to verify the 30% figure on the local services. However, this assumption could be tested using GPS units on a selection of Hamilton City bus services if required. In any event, this assumption has invariably held when it has been tested in urban areas.

Screenline link passenger volumes

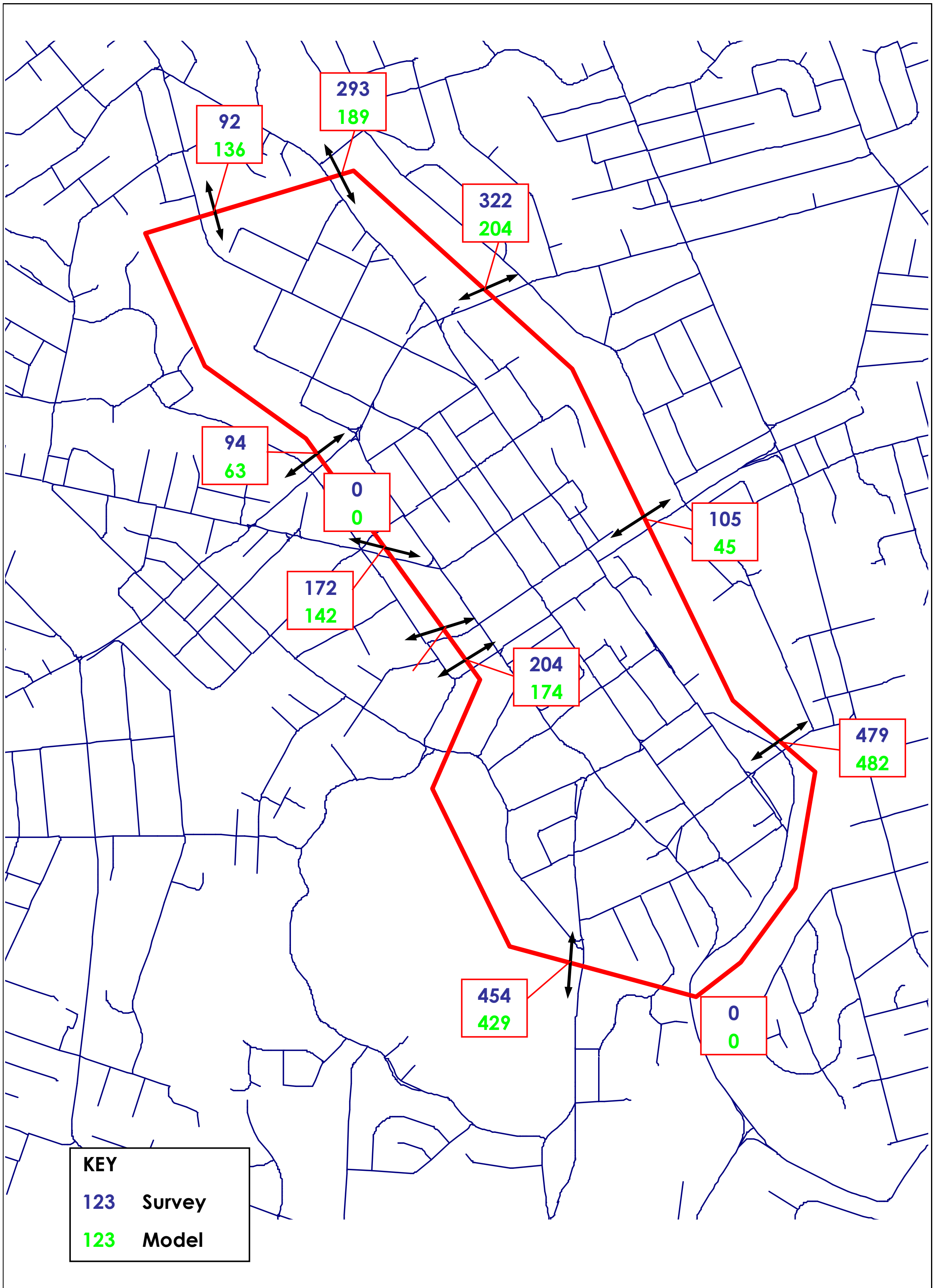
The number of bus passengers passing a particular point during the modelled time period is again a function of the service routes, the frequency of the service, and the extent to which a bus driver has managed to keep to the timetable. The check that the model is assigning bus passengers to the correct routes and in the correct numbers is a check on input service coding, and was derived from an analysis of the expanded bus intercept survey undertaken as part of this study.

Accordingly, the number of bus passengers that should have been on the links around a CBD cordon was calculated from the bus intercept survey data and checked back against the modelled bus vehicle assignment. The CBD cordon used in this analysis and the AMP and INP bus number validation is shown in **Figure 3**and **Figure 4**.

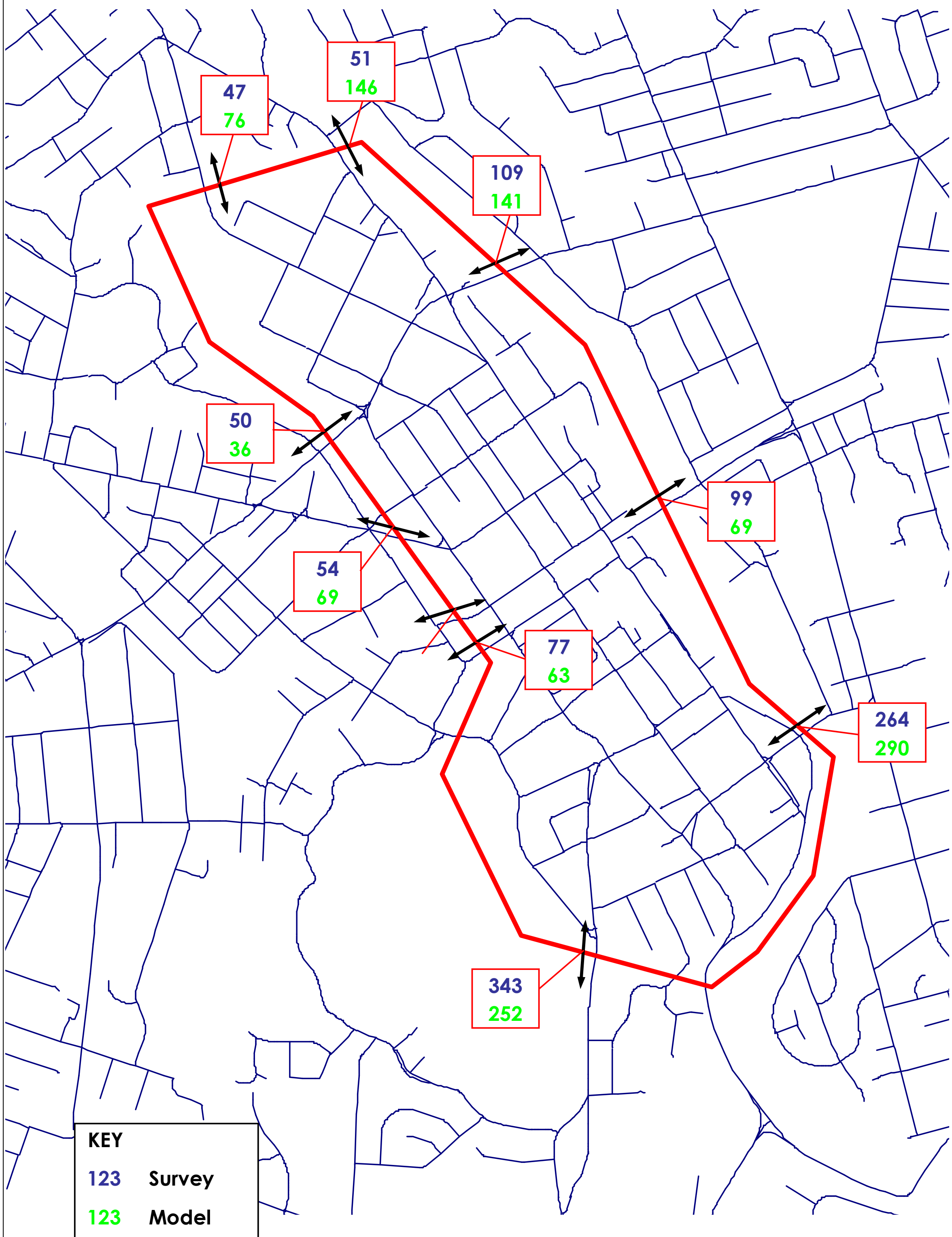
Passenger Numbers per Service

Another check is a comparison of surveyed service use against modelled service use. In this instance the total number of passengers for all services during each period was compared as well as the number of passengers on each route during each period. **Table 4** details the total passenger numbers by route and overall for each period.

A scatterplot of surveyed versus modelled patronage by route for each time period is also presented in **Figure 5.** The R-Squared measure of fit is R^2 = 0.794 and 0.651 for the AM Peak and Interpeak respectively.



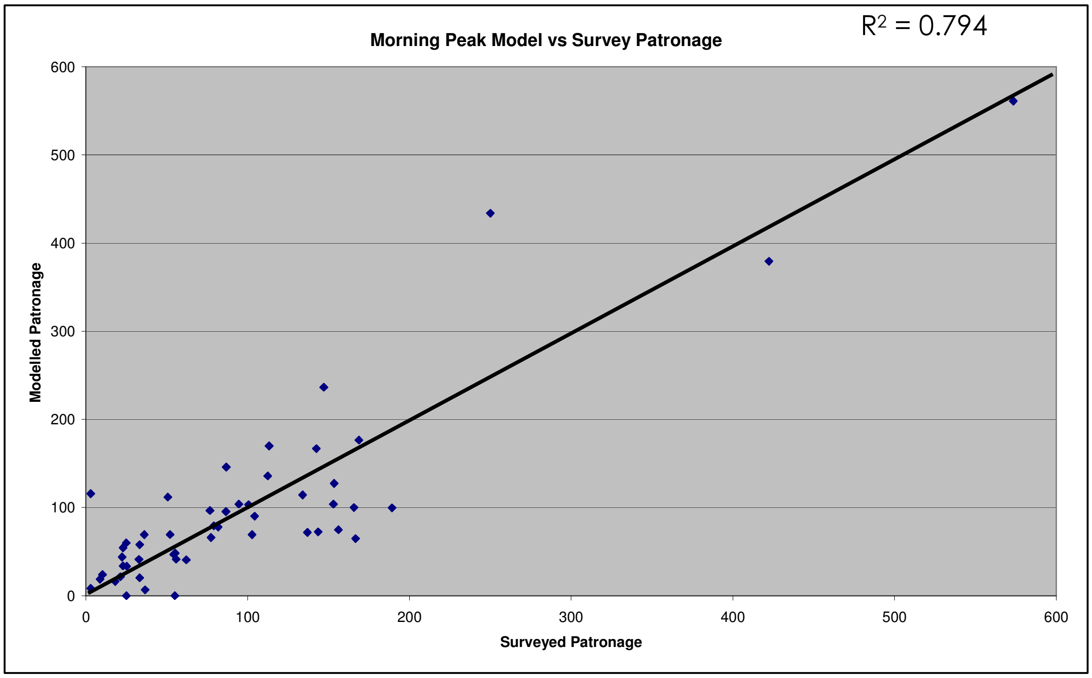
Waikato Regional Transportation Model	Hamilton CBD Cordon AM Peak Bus Passengers	Figure 3
Gabites Porter Traffic Design Group		

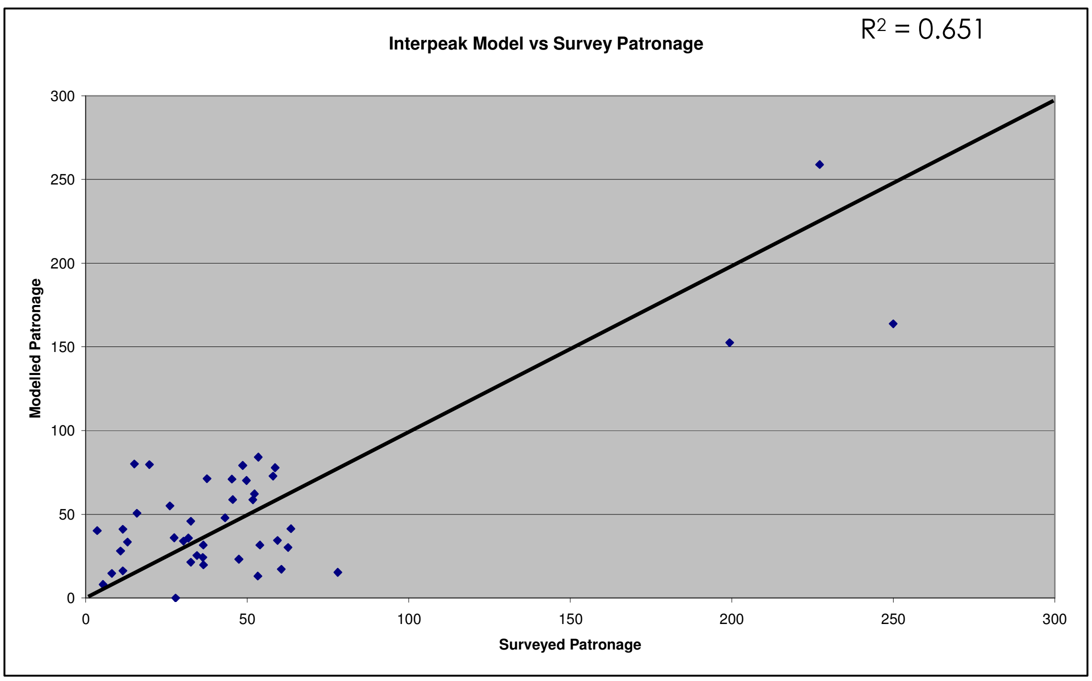


Waikato Regional Transportation Model	**Hamilton CBD Cordon Inter Peak Bus Passengers**	**Figure 4**
Gabites Porter Traffic Design Group		

Total Bus Patronage Comparison							Table 4
		Morning Peak			Interpeak		
ROUTE	**ROUTE NAME**	**Survey**	**Model**	**Difference**	**Survey**	**Model**	**Difference**
1	Pukete In	166	100	-66	13	33	21
1a	Pukete Out	21	22	0	49	79	31
2	Silverdale In	153	127	-26	36	24	-12
2a	Silverdale Out	51	112	61	15	80	65
3	Dinsdale In	156	75	-81	33	21	-11
3a	Dinsdale Out	18	16	-2	50	70	20
4	Flagstaff In	134	114	-20	30	34	4
4a	Flagstaff Out	52	70	18	16	51	35
5	Chartwell In	79	79	0	11	41	30
5a	Chartwell Out	23	34	11	28	0	-28
6	Mahoe In	144	72	-71	58	73	15
6a	Mahoe Out	23	54	32	59	34	-25
7	Glenview In	153	104	-49	53	13	-40
7a	Glenview Out	56	41	-14	59	78	19
8	Frankton In	147	237	89	38	71	34
8a	Frankton Out	87	96	9	53	84	31
9	Nawton-TC IN	101	103	3	36	32	-5
9a	Nawton-TC OUT	77	66	-11	32	36	4
10	Hillcrest-TC IN	82	78	-4	47	23	-24
10a	Hillcrest-TC OUT	112	136	23	52	59	7
11	Fairfield-TC IN	113	170	57	45	59	13
11a	Fairfield-TC OUT	33	41	8	27	36	9
12	Fitzroy-TC IN	169	177	8	78	15	-63
12a	Fitzroy-TC OUT	25	60	35	63	30	-32
13	University-TC IN	87	146	59	33	46	13
13a	University-TC OUT	95	104	9	43	48	5
14	Claudelands-TC IN	103	69	-33	36	20	-17
14a	Claudelands-TC OUT	33	58	25	26	55	29
15	Ruakura-TC IN	33	20	-13	11	28	17
15a	Ruakura-TC OUT	36	69	33	4	40	37
16	Rotoruna-TC IN	189	100	-90	64	41	-22
16a	Rotoruna-TC OUT	55	48	-7	45	71	26
17	Hamilton East Uni-TC IN	62	41	-21	11	16	5
17a	Hamilton East Uni-TC OUT	167	65	-102	61	17	-43
18	Te Rapa-TC IN	142	167	24	52	62	10
18a	Te Rapa-TC OUT	77	97	20	20	80	60
26	Bremworth/Temple View-TC IN	104	90	-14	34	25	-9
26a	Bremworth/Temple View-TC OUT	54	47	-7	54	32	-22
30	Northerner-TC IN	25	34	8	5	8	3
30a	Northerner-TC OUT	10	24	14	8	15	7
16rd	Rototuna Direct In	137	72	-65	0	0	0
16rda	Rototuna Direct Out	9	19	10	0	0	0
51	CBD Shuttle	250*	434	184	250*	164	-86
20	Cambridge to Hamilton	25	0	-25	0	0	0
24	Hamilton to Te Awamutu	3	0	-3	0	0	0
24a	Te Awamutu to Hamilton	55	116	61	0	0	0
52a	OrbiterC: University-University-Base	574	561	-12	227	259	32
52	OrbiterA: Univeristy-University-Base	422	380	-43	199	153	-47
1pd	Pukete Direct In	37	7	-30	0	0	0
1pda	Pukete Direct Out	22	44	22	0	0	0
3dd	Dinsdale Direct In	3	8	5	0	0	0
3dda	Dinsdale Direct Out	0	4	4	0	0	0
Trips with no transfer		4357	4275	-103	1999	2085	86
Trips with transfer		313	363	50	83	86	3
TOTAL TRIPS		4670	4638	-53	2082	2172	90

** these routes were not surveyed but patronage has been estimated*





Waikato Regional Transportation Model Gabites Porter Traffic Design Group	**Hamilton Service Patronage Validation by Route Scatterplot**	**Figure 5**

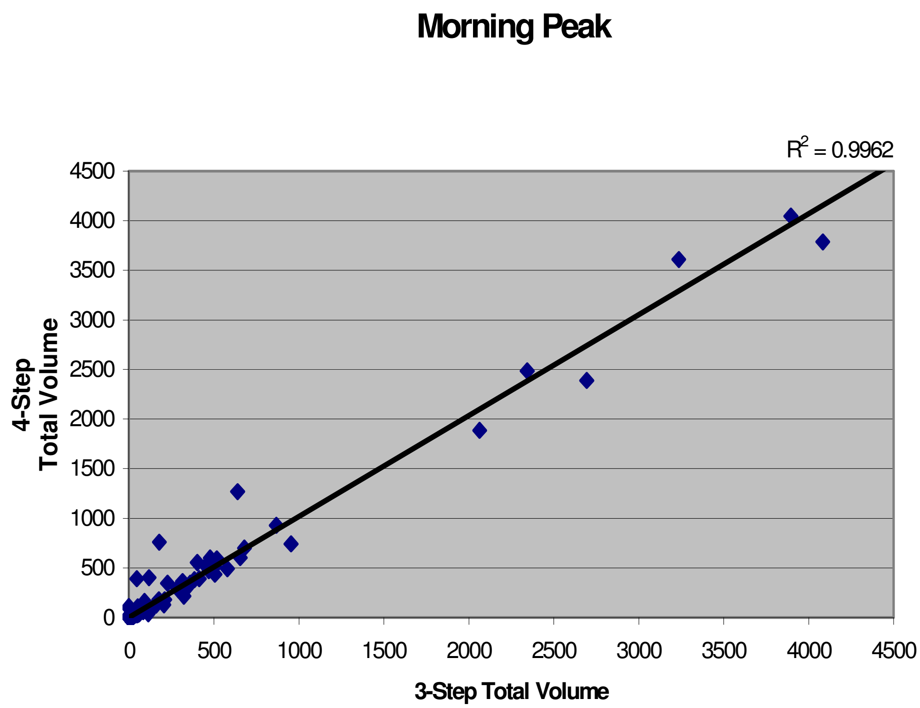
Correlation with the Three-Step vehicle driver matrix

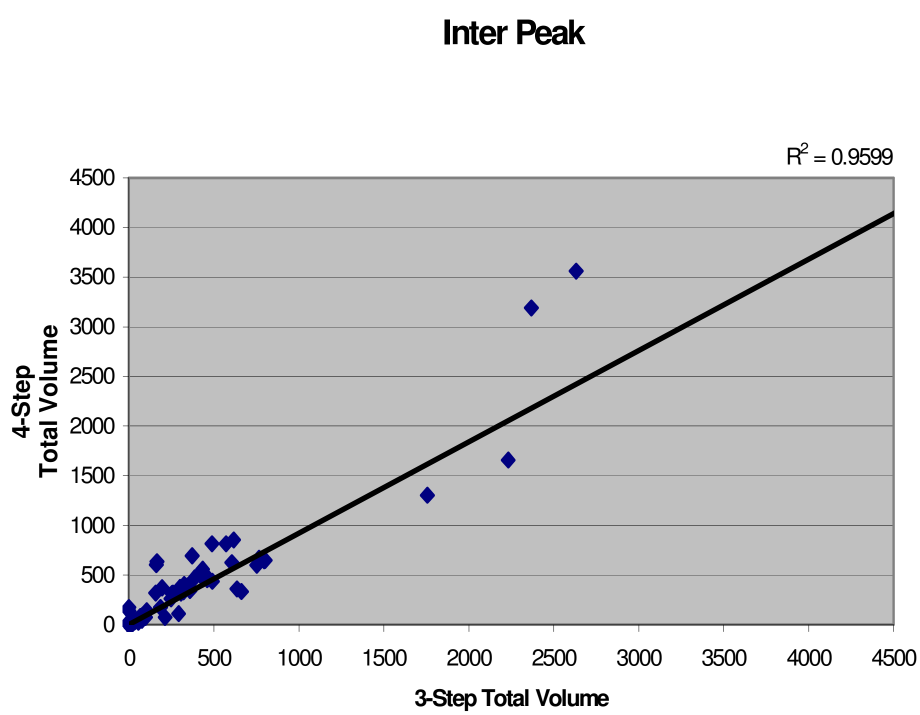
The intention of this section is to establish that the vehicle driver matrices resulting from the AMP and INP mode split processes are statistically similar to those produced in the three step processes. The three and four step vehicle driver matrices have been aggregated into TLA areas and compared on a sector-to-sector level. The results of those comparisons are shown in **Figure 6**, and yield correlation coefficients of R^2=0.996 and 0.986 for the AMP and INP respectively.

An overview of the validation statistics for the Four Step model screenlines are presented in **Table 5** with GEH statistics included by direction. A scatterplot showing the three step and four step modelled counts is also included as **Figure 7** with R-squared statistics of 0.988 and 0.959 for each period. The cordon list files for the four step models are included as Appendix 3.

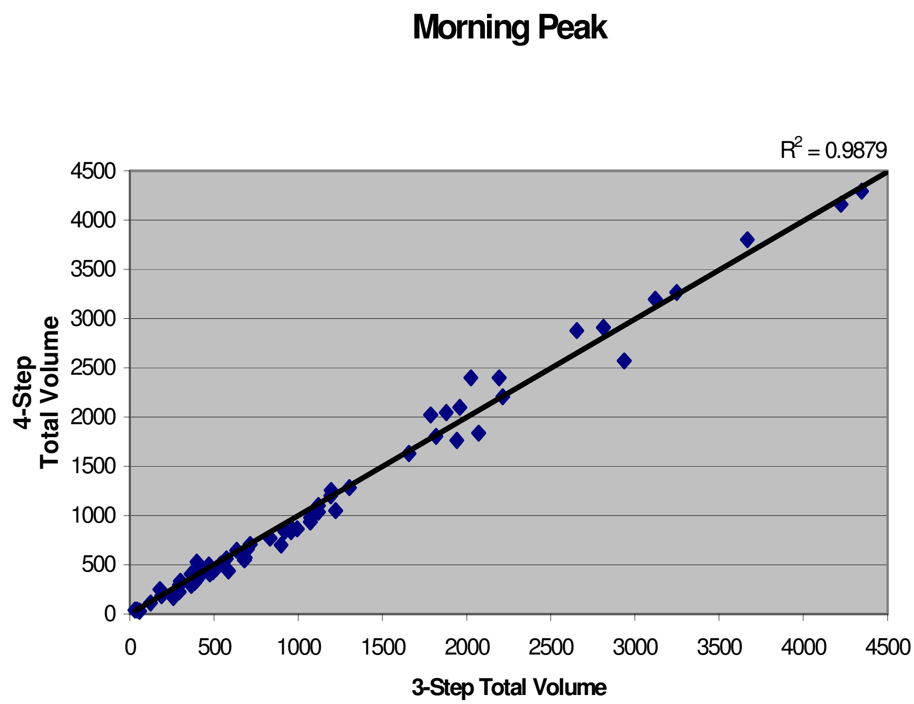
Four Step Screenline Validation Overview									**Table 5**
Screenline	**Description**	**Morning Peak**				**Inter Peak**			
		Forward %	**Forward GEH**	**Back %**	**Back GEH**	**Forward %**	**Forward GEH**	**Back %**	**Back GEH**
1	Waikato River Bridges	97	2.5	103	2.5	99	0.9	109	6.9
2	Hamilton Model External	102	1.1	88	5.4	96	1.8	107	3
3	Waikato Model External	98	0.9	98	1.1	99	0.4	99	0.5
4	Rest of Hamilton	100	0.2	90	4.4	108	3	107	2.7
5	North	124	9.4	98	0.7	84	7.4	85	7.2
6	Tauranga	98	0.9	86	5.6	109	3.1	115	5.3
7	South	99	0.6	120	8	105	2.4	90	5.1
8	All RSI	102	2.2	97	3.9	99	1.8	103	3.6
9	Railway	95	4.1	92	5.6	95	3	94	3.8
10	Waikato River Bridges	98	2.1	106	4.2	100	0	112	8.1
11	East Two	95	1.3	87	4.8	115	4	116	4.3
12	North One	97	1.5	108	4.7	103	1.7	101	0.7
13	South One	98	1.3	107	3.5	109	4.4	96	2
14	Cambridge Counts	87	5.5	95	2	113	4.4	105	2
15	Te Awamutu Counts	100	0	97	1.1	106	2.2	108	2.8

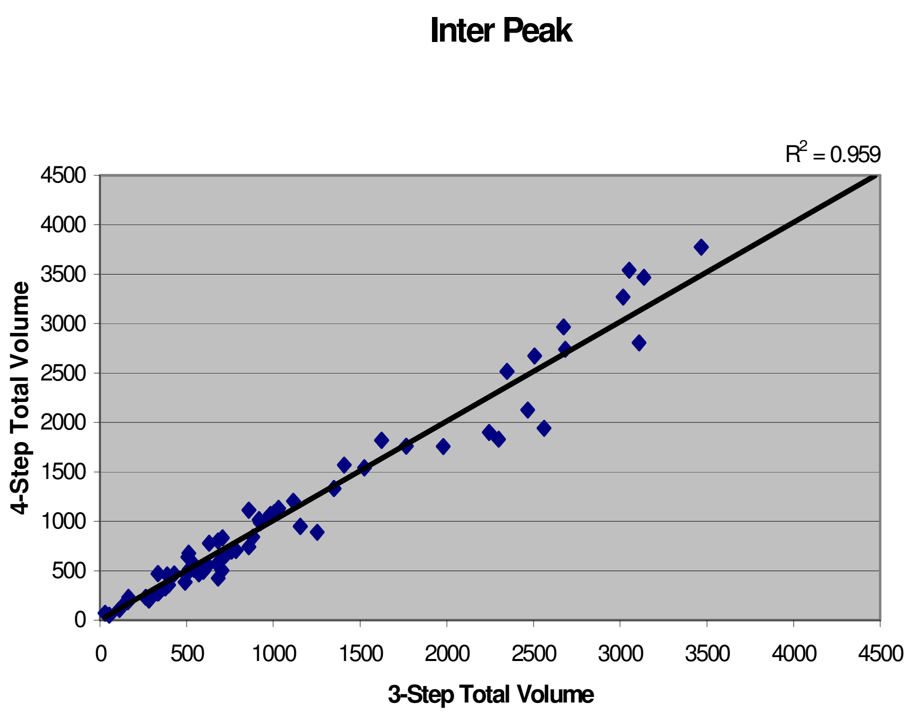
The morning peak and interpeak hourly volume changes between the three and the four step models are shown in **Figure 8** though **Figure 13**. A cut-off of 100 vehicles per hour, which is approximately 1000 vehicles per day has been applied.



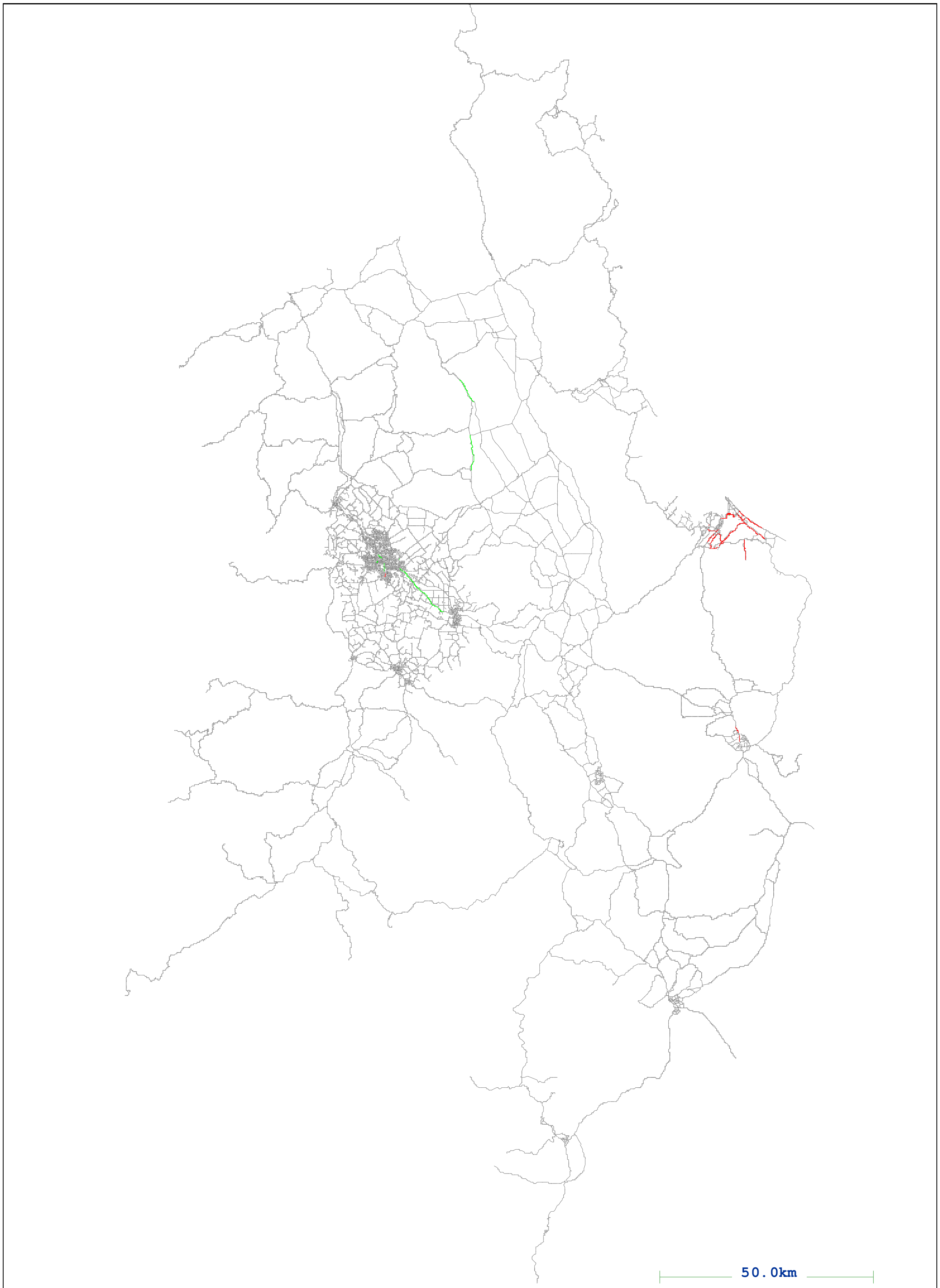


Waikato Regional Transportation Model	Three Step vs Four Step Sector Level Comparison	Figure 6
Gabites Porter Traffic Design Group		



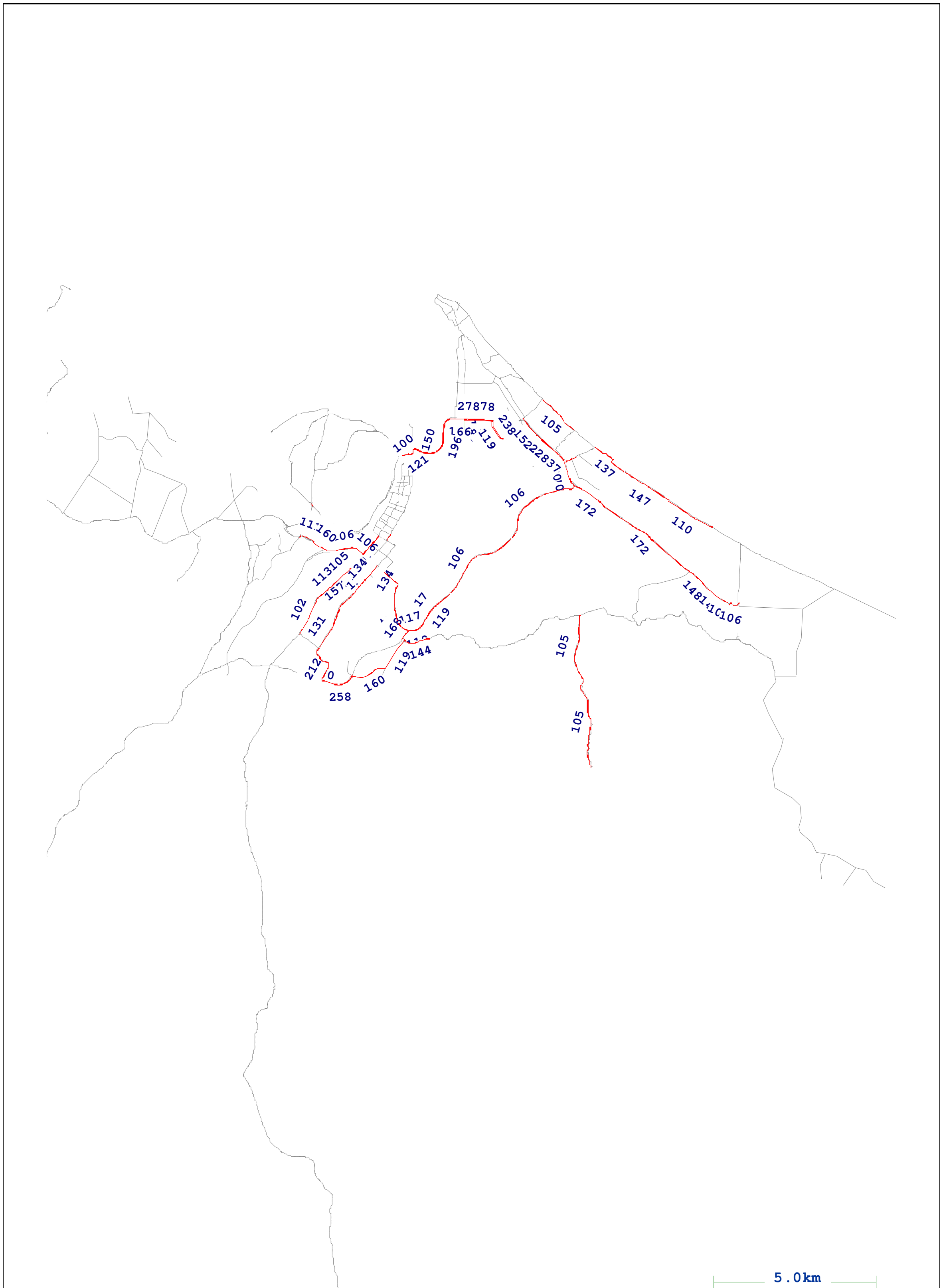


Waikato Regional Transportation Model	**Three Step vs Four Step Modelled Volumes Comparison**	**Figure 7**
Gabites Porter Traffic Design Group		

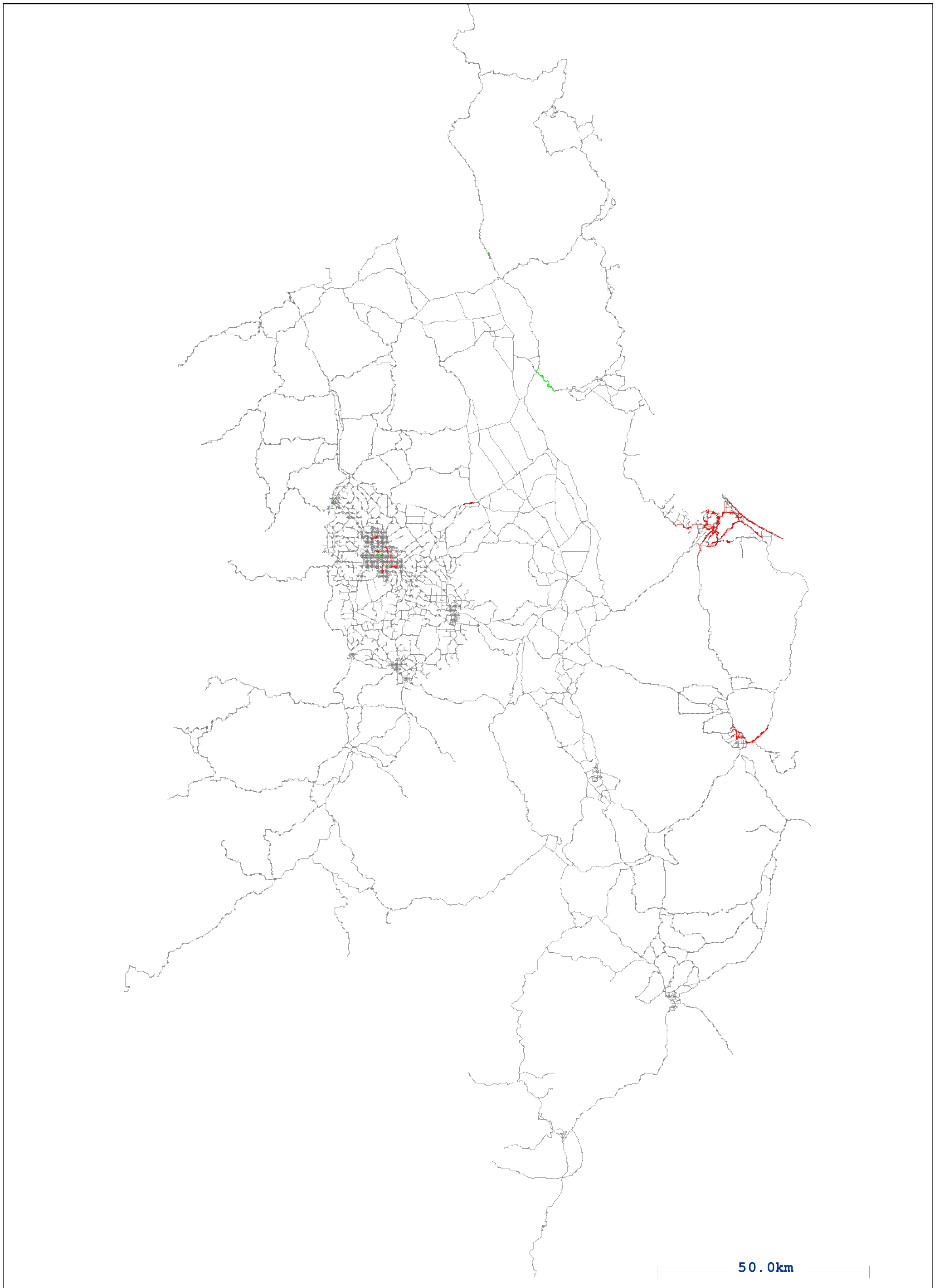


Waikato Regional Transportation Model	**Three Step vs Four Step Hourly Volume Changes Study Area Overview - Morning Peak**	**Figure 8**
Gabites Porter Traffic Design Group		

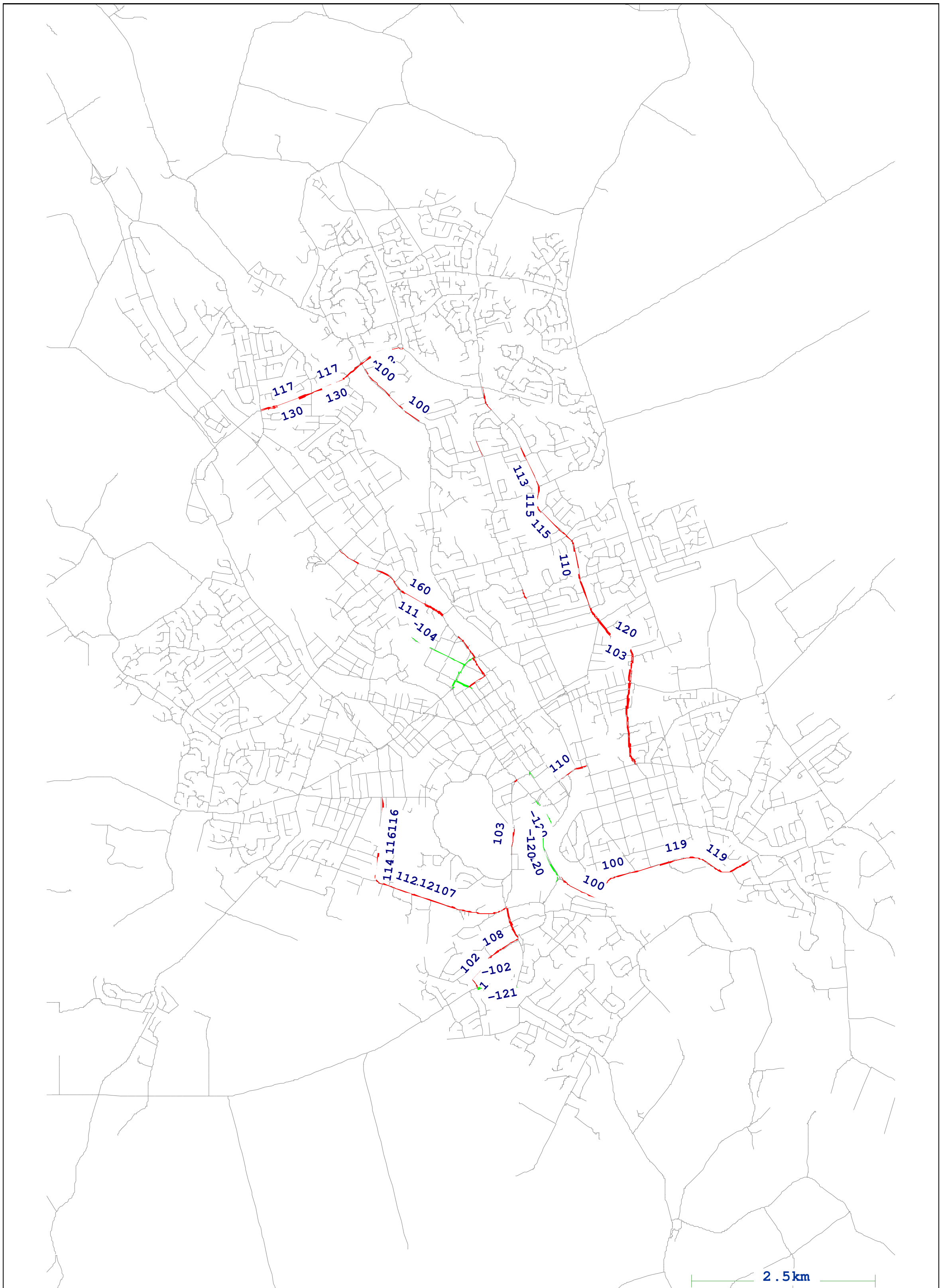
Waikato Regional Transportation Model	Three Step vs Four Step Hourly Volume Changes Hamilton - Morning Peak	Figure 9
Gabites Porter Traffic Design Group		



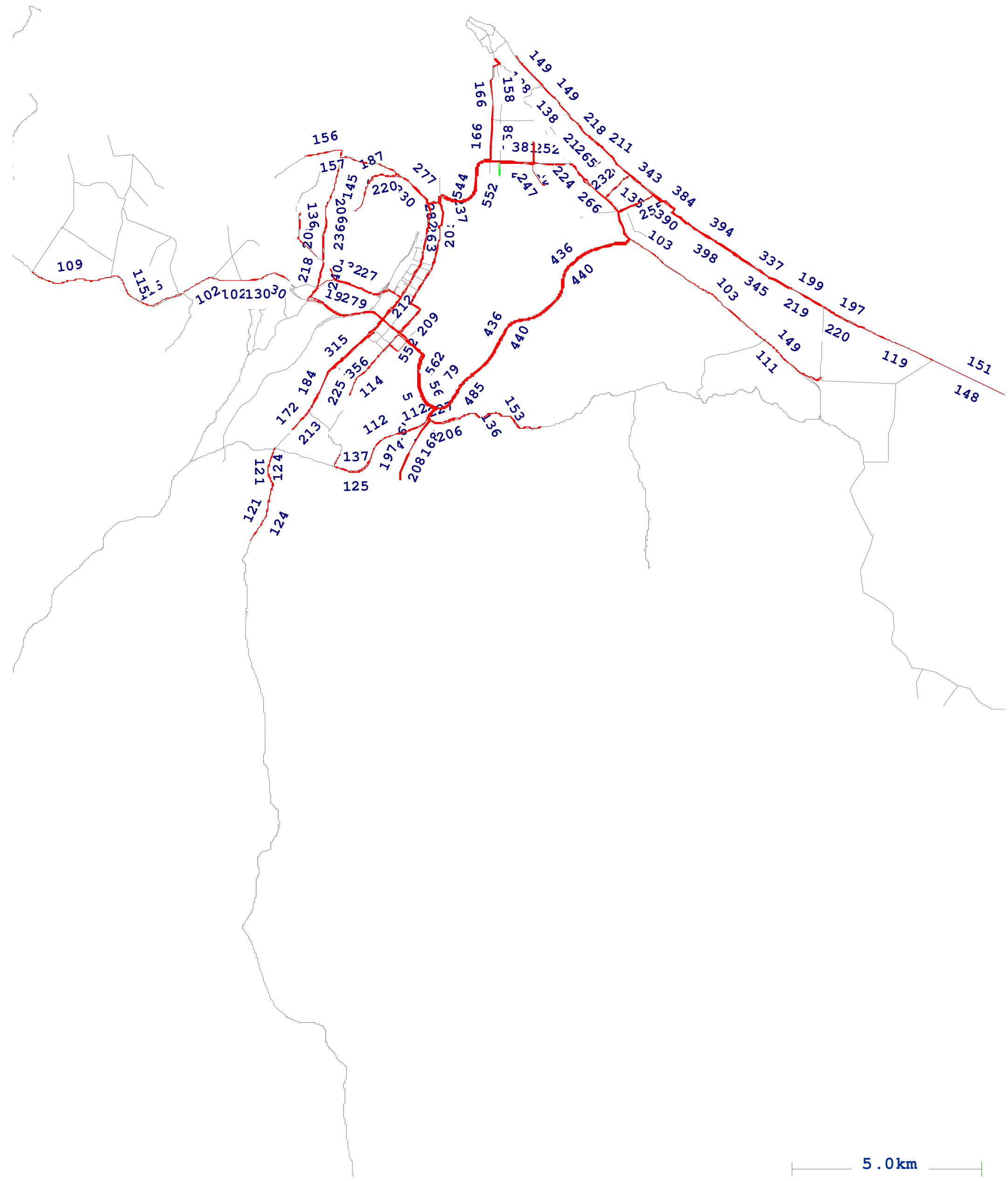
Waikato Regional Transportation Model	Three Step vs Four Step Hourly Volume Changes Tauranga - Morning Peak	Figure 10
Gabites Porter Traffic Design Group		



Waikato Regional Transportation Model	Three Step vs Four Step Hourly Volume Changes Study Area Overview - Inter Peak	Figure 11
Gabites Porter Traffic Design Group		



Waikato Regional Transportation Model	**Three Step vs Four Step Hourly Volume Changes Hamilton - Inter Peak**	**Figure 12**
Gabites Porter Traffic Design Group		



Waikato Regional Transportation Model	Three Step vs Four Step Hourly Volume Changes Hamilton - Inter Peak	Figure 13
Gabites Porter Traffic Design Group		

7. ELASTICITY CHECK

The final check on the public transport model, including both Mode Split and assignment is the check that the model will respond as expected when a change is made.

Two checks were carried out. The first was to double all fares which is a reasonably straightforward analytical test and the expected response was a 30% reduction in bus patronage. When this was applied to all bus services, the patronage dropped from 4638 to 3290 in the morning peak – a reduction of 29%. The response in the inter peak two hours was from 2172 to 1260 a reduction of 41%.

The second test was to increase the frequencies over all services such that the headway was halved and an increase in patronage of 10% was expected. When this was applied to all bus services, the patronage increased from 4638 to 5085 in the morning peak – an increase of 10%. The response in the inter peak two hours was from 2166 to 2434 an increase of 11%.

In both cases the interpeak model response is greater than the morning peak model. This is consistent with public transport elasticity literature *(Transfund New Zealand Resarch Report No. 248)*.