AECOM

M6T Research Study – Modelling Report

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Table of Contents

1 Introduction 2

2 Demand Model 4
2.1 Principles 4
2.2 Specification 5
2.3 Inputs and Operation 6
2.4 Results 10

3 Network Model 22
3.1 Network Model Structure 22
3.2 Calibration and Validation - 2005 30
3.3 Modifications to Network Model to Accommodate Demand Model 34
3.4 Summary of Results 38

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1 Introduction

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The first task in the current project was to explore the evidence from the M6T experiment for factors affecting toll road demand, identifying which of these are most important, how they interact and so on. The M6T experiment consisted of collecting information concentrated on a sub-set of users, being those who were making journeys which would use the entire length of the tolled facility, should the traveller in fact choose to pay the toll rather than use the conventional network. This biases results towards longer distance travellers.

A particular focus of the study was to identify factors in the route-choice decision over and above time and cost. This concern follows observations that conventional route choice models, using conventional values-of-time, have needed the inclusion of a large, positive toll-road constant to match observed demand. Given the need to generalise results to other potential toll-road situations, the study seeks to understand the causal factors behind this bias.

The evidence for the value of the 'other factors' came from the SP experiments; issues such as the importance of safety, reliability, density of freight vehicles, etc were investigated on the basis of this evidence. A methodology was developed to predict the cumulative effect of these factors in other contexts, or in different time period.

There is, however, another potentially important 'factor' which the study addresses. This is the possible influence of bias in perceptions of route conditions. The imbalance between conventional models and observed toll-road demand has in the past been used to postulate a 'toll-road constant' – but it could equally have been attributed to misperceptions of the travel conditions on the alternative routes. Probably both effects exist to some degree.

The study design has been devised to allow an investigation of hypotheses like these. The results of the research may indicate that misperception has only a trivial effect, it may suggest that it substantially accounts for the observed bias by itself, with no 'toll-road constant' needed, or perhaps something in between.

The Stated Preference experiments and their analysis involved the testing of the size and variation of large number of variables which could account for individuals' route choices. These variables included driver characteristics such as age, gender, and income; journey characteristics such as length, duration, purpose and time and fuel costs; and road network conditions such as speeds, reliability, information availability, %age HGV in the traffic flow, road surface and journey ambience.

Two types of model were used to test the sensitivity of M6T, M6 and A-road flows to these parameters:

(a) A so-called "demand" model, Excel-based, which has embedded within it a series of demand relationships which can assess the sensitivity of M6T (and the alternative M6 and A road) flows to a large number of variables. For a practical application this pre-supposes that the value of these variables would be known or could be measured; and

(b) A "network" model, which is conventionally based around a network representation and a series of trip matrices for a variety of user classes and time periods, with the added sophistication of route allocation by Logit models within an equilibrium-seeking assignment.

2 Demand Model

2 Demand Model

2.1 Principles

The basic application system is envisaged to be a 'sample enumeration' approach. From the RP/SP/TP analysis, we have models to split the target potential demand group (through-travellers) between the three alternatives, M6T, M6 and 'best A-road'.

The models include distributed tastes for time and/or money. Thus, for one example, the cost co-efficient scaling toll (and running costs in some variants) could come with a measured inter-population variance, and possibly some co-variance with other factors.

The basic idea of a distributed taste model is that factors affecting the attractiveness of an option are not fixed across the population, but have some sort distribution around a mean value. The analyst must specify the distribution (normal and log-normal are popular) which will include some unknown parameters. These parameters are estimated at the same time, and in the same way, as the other unknown parameters, such as the mean marginal utilities of time and cost.

Forecasting with such models involves integrating the predictions of choice over the possible distribution of taste-parameters. If the distribution is simple enough (particularly in dimensionality), this can be simply approximated by a summation of forecasts at a number of 'points' in the taste-parameter space, weighted together by the probabilities with which these 'points' would observed following a random draw from the taste-parameter distributions.

For illustration – suppose we have a binary logit model with just one explanatory variable, X. the probability of choice 1 can then be written as

$$p(1) = \exp(U(1)) / [\exp(U(1)) + \exp(U(2))]$$

and with the usual linear assumption about the formulation of the utility function

$$= 1 / [1 + \exp(\alpha + \beta(X_2 - X_1))] \qquad \text{.....} \qquad (1)$$

The standard model takes this specification, calculates the likelihood function for the experimental dataset conditional on assumed values of α and β, and then searches for those values which maximise the likelihood.

A simple distributed taste model might be developed on the same data. First, a choice of which variables are to be random, and which type of distribution they are to follow, must be made (this can be tested later against other choices). In this case, let us assume β is to be allowed to vary over the population, following some distribution f (β , θ), where θ is some unknown parameter to be estimated from the data at the same time as α and β.

Equation (1) is then replaced by an integral over f (.)

$$p(1) = \int \left\{ 1 / [1 + \exp(\alpha + \beta(X_2 - X_1))] \; f(\beta) \; d\beta \right\} \qquad \text{.....} \qquad (2)$$

As mentioned above, a practical simplification is available in cases where the integral can be replaced by a summation over a number of discrete values of β.

After the models have been developed, was written to turn these into forecasts. We refer to this software as an 'application system', and it is used to generate aggregate demand forecasts for different scenarios.

The basic inputs to the system are the model coefficients and the survey records, held at a disaggregate level, vehicle by vehicle. The user is then able to vary key assumptions such as costs, speeds, other factors found to be important in the analysis, perhaps volume of traffic in different categories such as journey purpose for passenger.

The first step was to develop expansion factors for each vehicle in the sample – passenger car and freight – such that the base pattern of demand is reproduced by the RP model. Given that our focus is a subset of total demand (through-traffic), a base-year aggregate flow picture was developed from existing knowledge on trip matrices. These through traffic movements were derived from the trip matrices used in the network modelling.

The application system then processes the data vehicle by vehicle, predicting demand for the three alternatives, expanding, and accumulating aggregate demand.

The type and role of the Application System that is prposed here is somewhat different to a normal Sample Enumeration system, at least in emphasis. The task is to explore the practical consequences of complex predictive models, without necessarily being tied to the 'realities' of the M6T corridor. Where the SP experiment has explored issues such as reliability, the conclusions are reported in the form of a utility component with a t-statistic. The size of the component is an indication to modellers of its importance – but of little help to non-specialists.

The objective of the Application stage in the M6T project is to make the models more accessible to a non-modelling-specialist audience, by translating the models into practical consequences for traffic on the 3 different routes (M6T, M6, A-roads) and for revenues on the toll road.

2.2 Specification

The data base contains descriptions of the trip and the traveller for each vehicle, along with an expansion factor and an indication of which route was chosen. The focus is on models 13.1 in the Final Report. These contain some factors irrelevant for our purposes (such as ASCs for yet other routes, and extended M6T networks).

For each of the M6T, M6 and A-road alternative, the models are used to generate probabailities of choice, which are weighted by the expansion factor and will build up to predict total demand. Actual choice will not be used, although there is a need for an external to check that, when applied to a 'realistic' base, the models recover actual demand to an acceptable degree.

Starting from this, the experiment requires that we simulate varying conditions. It may be useful to imaging different 'typical' conditions, eg where A-roads are very poor (or good), where the travelling population is very poor (or living in the South-East), where HGV movements are much heavier (or negligible) and so on. In each case, we want to generate some key reporting statistics to identify which effects are significant, and which minor.

The Mixed Logit model replaced two fixed logit co-efficients with independent log-normal distributed co-efficients. To implement this model, we want to find the expected values of the resulting model predictions for the probabilities of choice amongst the 3-option choice set.

The implementation involves integration over the joint distribution of the two parameters. For our purposes, the simplest approach is to make a discrete approximation to the joint log-normal distribution, so that we evaluate the model at a number of points in the joint plane of the distribution, and taking a weighted average of the results obtained at those points

For complex distributions, we get into the realm of choosing these points by randomly generated a number of possible draws from the distribution. For our simple case, we approximate the continuous joint distribution by a discrete distribution and use summation (the simplest integration approach).

For example, suppose we have two Normal variables, X and Y, and both are N(0,1) distributed. We could make a simple approximation to X by taking 5 points, say, being mid-points of sections of the distribution. We could take the points -5, -2, 0, 2, 5 to approximate the values of X in the sections of the distribution ($-\infty$, -3), (-3, -1), (-1, +1), (+1, +3), (+3, $+\infty$). The '5's are just an illustrati ve representative point; we can probably find advice I n the literature for a better choice. The probabilities of X falling in any of these can be taken from standard tables, giving us $PX_{1,,}$ ....,, PX_5 to go with each section.

For two independent variables, we generate an approximation by taking the 25 point 'pairs' generated crossing the two sets of points to get

(-5, -5), (-5,-2), (-5, 0), (-5, 2), (-5,5), (-2, -5), (-2,-2),....etc...(0, 0),....(5, 5).

To these 25 points, we can attach the 25 probabilities

$(PX_1.PY_{1,}),(PX_1.PY_2) ,(PX_1.PY_{3),}) , ...$ etc.

We now evaluate the choice probabilities conditional on the two co-efficients, taken as fixed, iterating over the observations. The next step is to iterate over a number of point-pairs for each observation, weighting and summing to generate the 'expected' value, and simply to use this as the fixed value was used.

We now translate the reported mean and standard deviations of the log-normal variables into sets of representative points, and to calculate the weights for each point.

Step 1: Interval means and Interval Probabilities for N(0,1)

Using the 5 intervals set out for the exposition, we get too much weight of probability in the (-1, +1) region – around 68% of the probability weight. Yet we are interested in the tails of the distribution. We can take the probabilities of a N(0,1) variable falling in these 7 regions from standard tables – Table A from *Davies 'Design and Analysis of Industrial Experiments'* Oliver and Boyd, 1967 (an old reference, but N(0,1) has not changed) was used to generate the values below. The probabilities, regions and suggested average values are

Probability	**Region**	**Average Value (AV)**
P1 = 0.00135	for (-∞, -3)	-5
P2 = 0.15735	for (-3, -1)	-1.5
P3 = 0.1498	for (-1, -0.5)	-0.65
P4 = 0.3830	for (-0.5, +0.5)	0
P5 = 0.1498	for (+0.5, +1)	+0.65
P6 = 0.15735	for (+1, +3)	+1.5
P7 = 0.00135	for (+3, +∞)	*+5*

note: average values are judgemental, given the shape of the N(0,1) dn, and may need optimising.

Step 2: transforming to logNormal (logN).

Formulae to move between μ and σ and M and S are available - the Web gives

$\mu = \ln M - ½. \ln (1 + S^2/M^2)$

$\sigma^2 = \ln (1 + S^2/M^2)$

Using these, the range of AV values of Memo 6 v3 van be derived from the M and S values reported.

2.3 Inputs and Operation

The inputs to the demand model are shown in Table 2.1 below.

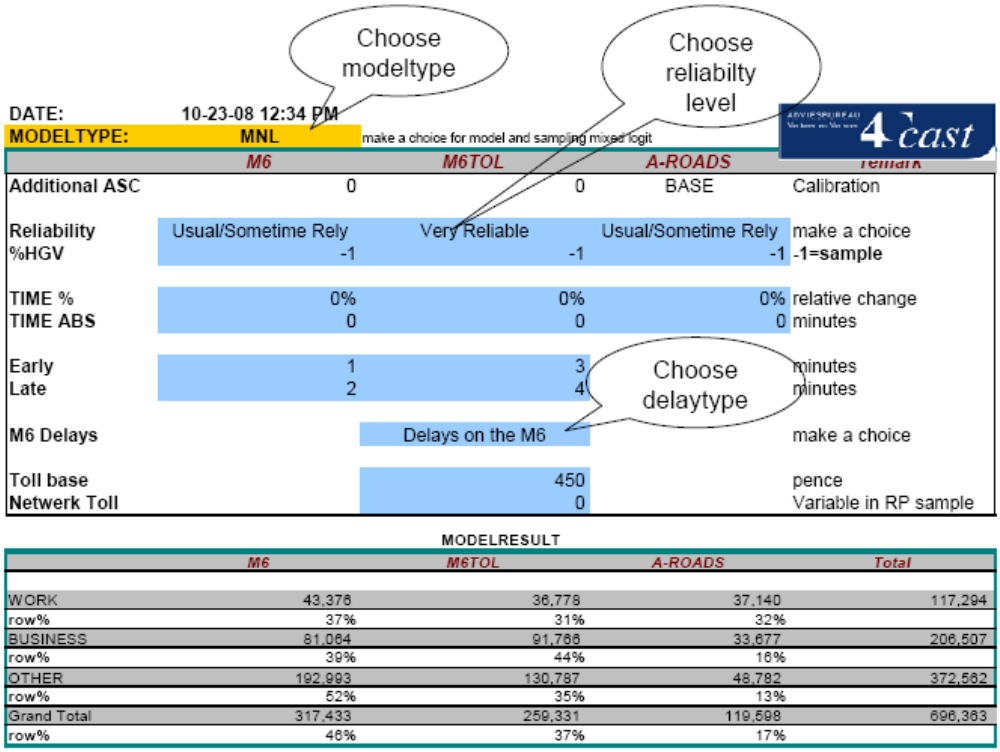
Table 2.1: Parameters of the Implemented Demand Models

	Simultaneous RP-SP Models		Random Parameters Model			
	Coeff	T	Coeff	T	SD	T SD
$ASC_{M6T\text{-}RP}$	1.7227	10.2	3.0059	-17.1	1.5824	-28.6
$ASC_{A\text{-}RP}$	0		0.1686	-1.7		
$ASC_{M6TCorridor}$	1.1032	8.1	1.7042	-12.9		
$ASC_{M6TStoke\text{-}M1}$	1.4779	10.2	2.0098	-14.2		
$ASC_{M6TExtended}$	1.3145	3.9	1.931	-7.4		
$ASC_{M6TLong}$	0.9406	7.1	1.2774	-7.0		
ASC_{NTH}	-1.2026	6.1	-2.1391	-12.1		
ASC_{STH}	-2.6554	4.7	-3.711	-11.3		
ASC_{M6TNTH}	0.7956	4.8	1.6387	-13.8		
ASC_{M6TSTH}	-1.4324	4.7	-0.6154	-2.7		
ASC_{NTHSTH}	-1.1529	3.2	-1.158	-6.6		
ASC_{ALL3}	1.4982	7.6	2.5278	-17.2		
Never M6T	-1.216	8.3	-2.0899	-15.6		
M6T*Male	-0.2632	3.3	-0.4517	-5.0		
M6T*Age65+	0.4643	3	0.8396	-5.1		
M6T*Others	0.3814	6.2	0.3978	-4.1		
M6T*ObjectTolls	-0.4026	5.2	-0.3416	-5.4		
Very Reliable	1.182	11.1	1.4343	-18.7		
Reliable	0.8428	8.3	1.1655	-16.2		
Usual/Sometime Rely	0.5441	8.9	0.7431	-16.0		
Unreliable	0.2127	2.8	0.325	-5.5		
%HGV	-0.0049	2.5	-0.0016	-1.1		
Time M6	-0.0508	22.8	-0.0837	-44.8		
Time M6T	-0.0528	16.1	-0.0809	-39.1		
Time A	-0.0565	27.7	-0.0896	-46.4		
Time Bits	-0.0466	14.6	-0.0589	-22.2		
Time*Acttim**λ (=1.1)	-0.000037	3.3	-0.000018	-3.5		
OthAdults	0.0077	2.8	0.0097	-4.5		
Time-Reported	-					
Early	-0.0249	17.3	-0.036	-28.2		
Late	-0.0233	11.7	-0.0331	-20.9		
Late*EB	-0.0037	2.3	-0.0043	-2.7		
Late*Comm	-0.0064	2.3	-0.0109	-6.0		
Adj*HolsSB	0.0077	2.6	0.0118	-5.0		
Adj*VFR	0.0051	2.7	0.0067	-4.8		
Adj*Male	0.0034	2.5	0.0042	-3.5		
Delays M6	Base		Base			
M6 delays due to	0.3055	4.2	0.982	-7.4		
Exp 25m delays	1.0395	5.9	2.3686	-15.3		
No M6 Delays	-0.4436	3.5	-0.4315	-3.4		
Toll	-0.0061	13.4	-0.0096	-21.5	0.00450	-38.2
Toll-Inc£20k-39k	0.0003	1	0.0001	-0.3		
Toll-Inc£40k-59k	0.0007	1.8	0.0008	-1.7		
Toll-Inc£60k-79k	0.001	2.4	0.0015	-3.1		
Toll-Inc£80k-99k	0.0013	3.5	0.0017	-2.7		
Toll-Inc£100k+	0.002	4.3	0.0033	-5.8		
Toll-IncDK	0.0005	1.1	0.0006	-1.4		
Employer pays toll	0.0013	9.2	0.0025	-10.4		
Toll> £3.50	-0.0008	4.9	-0.0015	-9.9		
Toll New M6	0.0025	4.6	0.0025	-2.2		
Toll Extended M6T	0.0009	3	0.0008	-2.3		
FuelYes	-0.0056	10.1	-0.0052	-16.3		
q_{RP}	1.5627	13.7				
q_{SP1A}	1					
q_{SP1C}	1					
$q_{SP1B\text{-}1}$	1					
$q_{SP1B\text{-}2\text{-}8}$	1					
$q_{SP2A\text{-}1}$	1					
$q_{SP2A\text{-}2\text{-}3}$	1					
q_{SP8A}	1					
q_{SP8B}	1					
q_{SP2C}	1					
q_{SP2B}	1					
r^2	0.248		0.374			
Log Likelihood	-22820.3		-18784.5			
Observations	32188					

The model is Excel-based and driven off of a menu style front page. The parameter values and model type are selected from drop down menus.

This is illustrated below on Figure 2.1

Figure 2.1 Input Sheet for Demand Model



Results from the model vary not only with the parameters but with the chosen model type. There are three model types:

In the policy sheet the model type can be chosen:

- Multi-Nomial Logit (MNL) = Base model from simultaneous estimation
- Random Parameter Model (RPM) = with distributed values as described in section 2.2
- Random Parameter Model (RPM GH)= with optimised distributed values from Gauss Hermite approximation

The values used are in the sheet "Random Parameter" in the Excel model.

It should be noted that results vary considerably with the type of model chosen, as illustrated below:

Figure 2.2: Variation in Results from MNL, RPM and RPM GH Models

MODELTYPE: MNL
DATE: 10-23-08 12:50 PM

MODELRESULT

	M6	M6TOL	A-ROADS	Total
WORK	43376	36778	37140	117294
row%	37%	31%	32%	
BUSINESS	81064	91766	33677	206507
row%	39%	44%	16%	
OTHER	192993	130787	48782	372562
row%	52%	35%	13%	
Grand Total	317433	259331	119598	696363
row%	46%	37%	17%	

MODELTYPE: RPM
DATE: 10-23-08 12:50 PM

MODELRESULT

	M6	M6TOL	A-ROADS	Total
WORK	33560	46377	37358	117294
row%	29%	40%	32%	
BUSINESS	62454	114248	29805	206507
row%	30%	55%	14%	
OTHER	156231	174705	41625	372562
row%	42%	47%	11%	
Grand Total	252244	335331	108788	696363
row%	36%	48%	16%	

MODELTYPE: RPM GH
DATE: 10-23-08 12:49 PM

MODELRESULT

	M6	M6TOL	A-ROADS	Total
WORK	33410	46772	37113	117294
row%	28%	40%	32%	
BUSINESS	62890	113814	29803	206507
row%	30%	55%	14%	
OTHER	156070	175064	41427	372562
row%	42%	47%	11%	
Grand Total	252370	335650	108342	696363
row%	36%	48%	16%	

2.4 Results

A series of tests with the Demand Models were run to test the sensitivity of the models to various changes in conditions (for example % HGV on the M6) or policy (such as changes in toll level or the impact of information on journey time reliability on the M6).

Results below are given for the Random Parameter Model (RPM), but the tests were repeated for the RPM + Gauss Hermite and Multinomial Logit models. These are reported in Appendix A.

A range of values was chosen for each parameter and the model was queried to provide the proportion of vehicles using each of three route classes (M6, M6T and A roads) for value of the parameter as each of the others remained constant. This provides an indication of the sensitivity of the output results to each variable. The range and data are shown in tables below with an accompanying graph.

Finally some scenarios were tested. These explore the effects of changes in linked variables.

Test 1: Proportion of HGVs on the M6

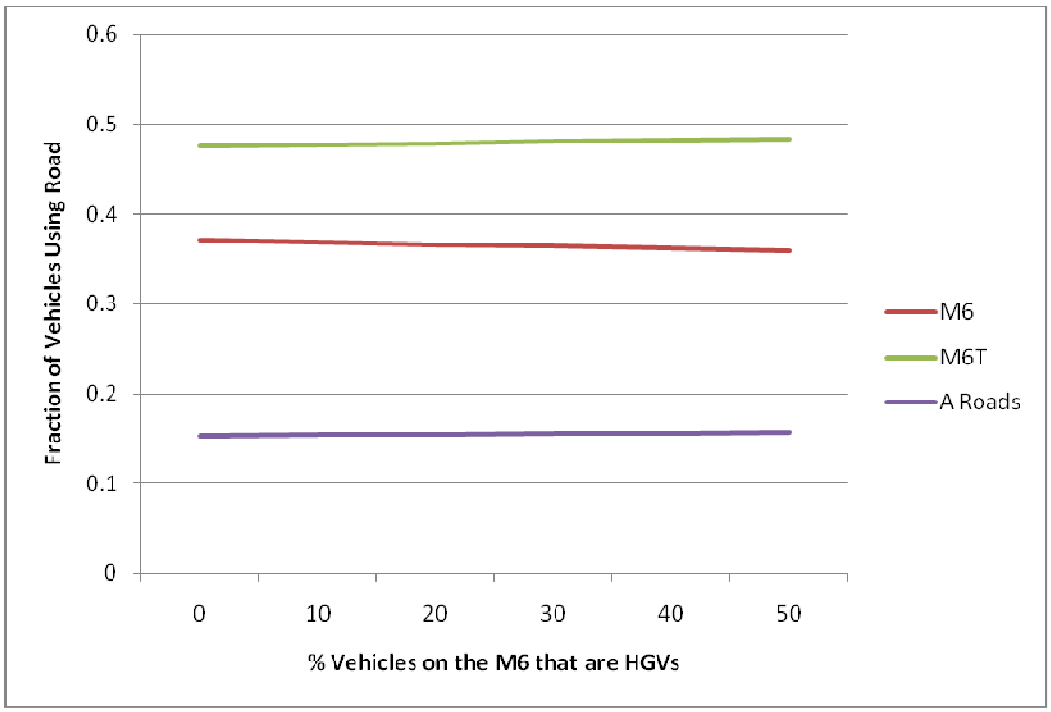
HGV percentages between 0% and 50% on the M6 were tested. The outcomes are shown on Table 2.1.1, and Figures 2.1.1.

Table 2.4.1 Impact of HGV % on M6 on M6, M6T, and A Roads

HGV % M6	M6	M6TOLL	A-ROADS
0	37.14%	47.61%	15.26%
10	36.89%	47.75%	15.35%
20	36.65%	47.90%	15.45%
30	36.41%	48.04%	15.55%
40	36.17%	48.19%	15.64%
50	35.93%	48.33%	15.74%

Figure 2.4.1 shows that the proportion of vehicles using the M6, A roads or M6 Toll is only weakly dependant on the proportion of vehicles on the M6 that are HGVs.

Figure 2.4.1 Impact of HGV % on M6 on M6, M6T, and A Roads



The RPM model is very insensitive to the proportion of HGV on the M6. The MNL model is more sensitive to this parameter. There is a very minor shift away from the M6 when a higher proportion of the vehicles on it are HGVs.

Test 2: Proportion of HGVs on the M6T

This test is similar to test 1 in that is shows the effect of adding more HGVs to a road replacing other vehicles. The models output is constant with test 1 which showed that, across the proportions considered, the number of HGVs had little effect on people's choice of route.

Table 2.4.2 Impact of HGV % on M6T on M6, M6T, and A Roads

HGV % M6T	M6	M6TOLL	A-ROADS
0	36.05%	48.39%	15.56%
5	36.12%	48.29%	15.58%
10	36.19%	48.20%	15.61%
15	36.27%	48.10%	15.64%
20	36.34%	48.00%	15.66%

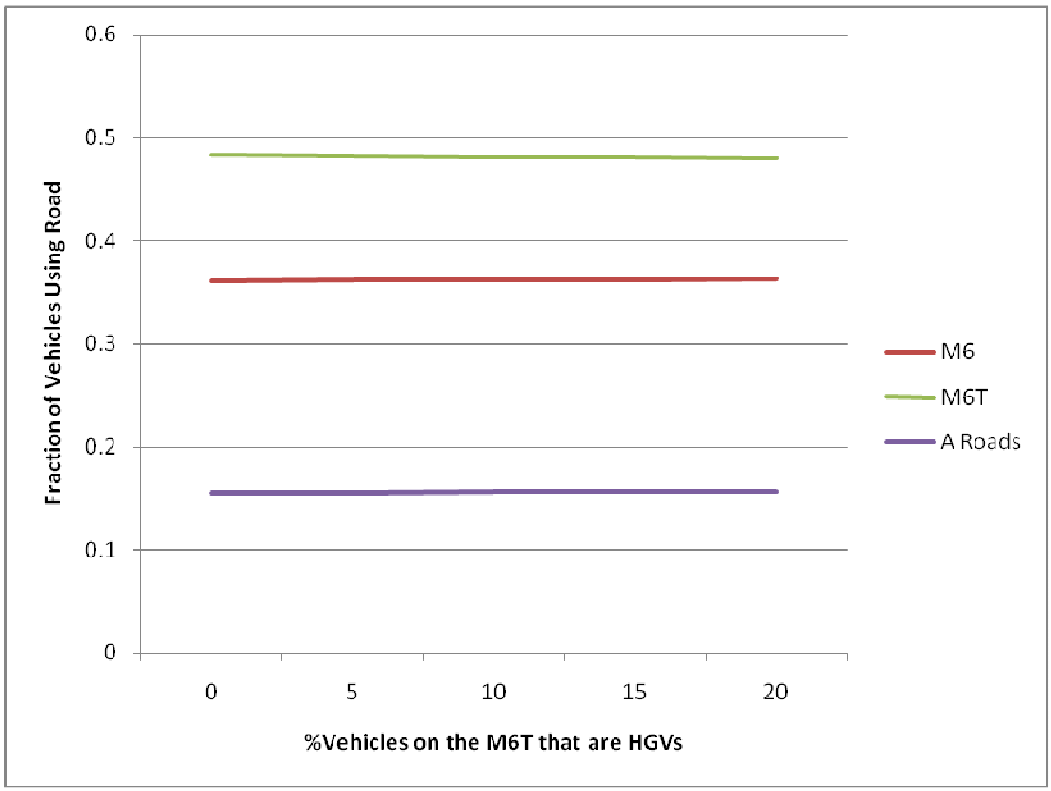


Figure 2.4.2 Impact of HGV % on M6T on M6, M6T, and A Roads

The RPM model is not very sensitive to changes in the fraction of traffic that is HGVs on the M6T. There is a slight shift away from the M6T with increasing numbers.

Test 3: Perceived Reliability of the M6

This test shows how the model would expect patterns of road use to change on the basis of a given level of perceived reliability on the M6. This measure is slightly more subjective as it relies on respondent's interpretations of the different reliability classes that they were presented with.

Table 2.4.3 Reliability of M6

Reliability M6	M6	M6TOLL	A-ROADS
Very Reliable	47.01%	41.52%	11.47%
Reliable	42.75%	44.18%	13.07%
usually/sometimes reliable	36.22%	48.15%	15.62%
Unreliable	30.16%	51.77%	18.07%
Very Unreliable	25.81%	54.33%	19.87%

Figure 2.4.3 illustrates the response that the model predicts for a given level of reliability on the M6.

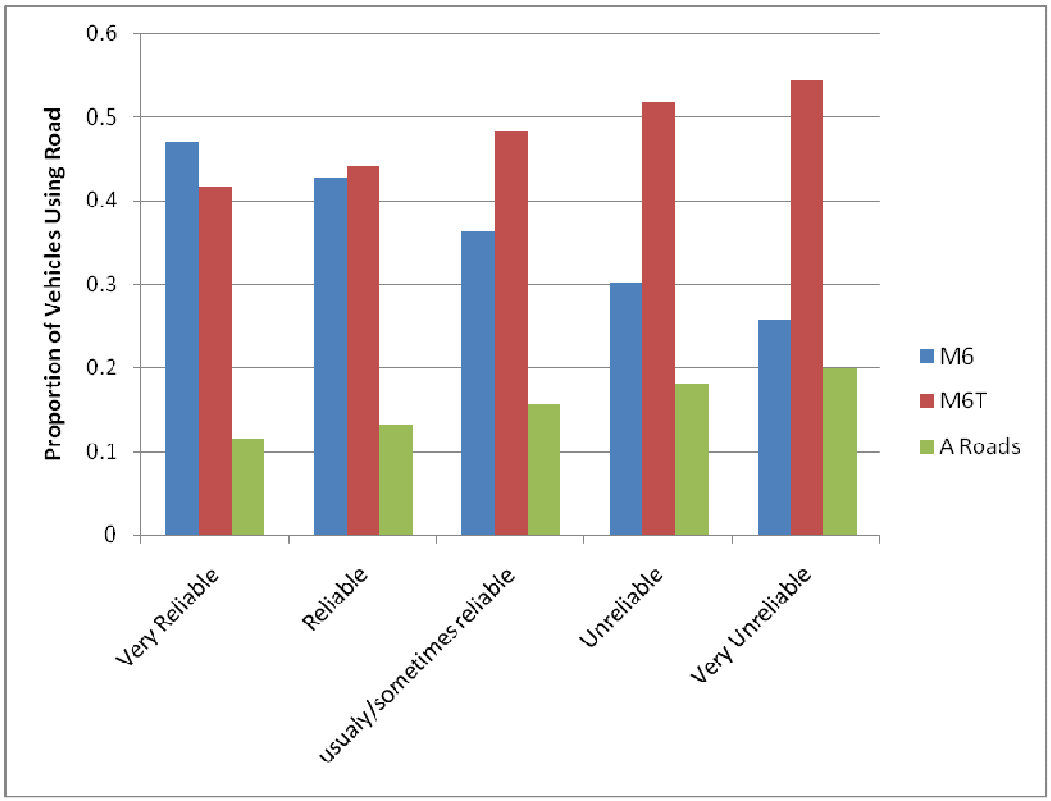


Figure 2.4.3 Proportion of people using each route with different reliabilities of journey time on the M6.

Reliability is a major concern and as people's perception of the reliability of the M6 degrades the number of people using other routes (primarily the M6T) increases at the expense of the M6.

Test 4: Perceived Reliability of the M6T

Much like test 3 this test illustrates the response that the model expects people to have to different levels of reliability; this time by changing the levels of reliability expected on the M6T.

Table 2.4.4 Reliability of M6T

Reliability M6T	*M6*	*M6TOLL*	*A-ROADS*
Very Reliable	36.22%	48.15%	15.62%
Reliable	38.66%	44.84%	16.50%
usually/sometimes reliable	42.45%	39.70%	17.85%
Unreliable	46.10%	34.79%	19.11%
Very Unreliable	48.84%	31.13%	20.04%

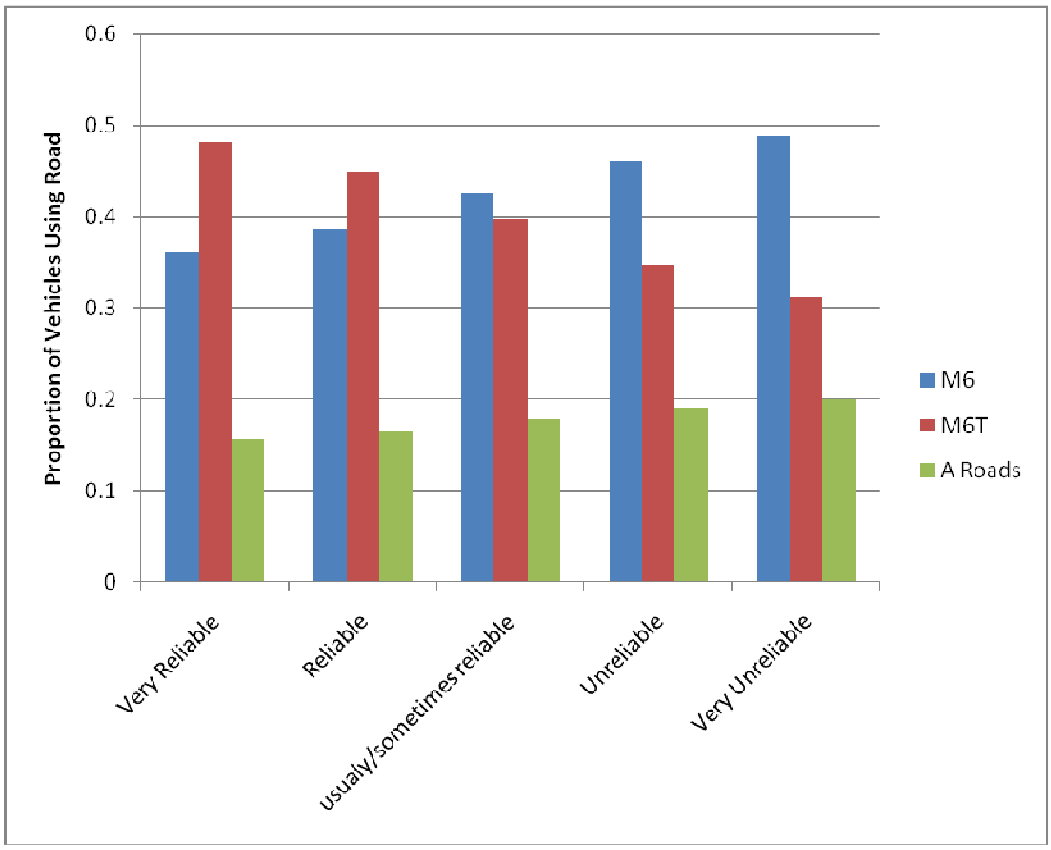


Figure 2.4.4 Reliability of M6T

The outputs of the spreadsheet model are sensitive to changes in reliability. Declining perceptions of reliability on the M6T are reflected by outputs that show decreasing use and increased use of the M6 and A roads. This, coupled with test 3, shows that people's perceptions of reliability are important to route choice on Motorways.

Test 5: Perceived Journey Time Change to Travel on the M6

This test provides the model outputs for a situation where the expected journey times on the M6 are different to what they are at present. These range from -10%, i.e. a reduction in travel time through to +50%, a very significant increase in travel time.

Table 2.4.5 Sensitivity to Journey Time on the M6

Journey Time Change on the M6 (%)	*M6*	*M6TOLL*	*A-ROADS*
-10	51.57%	36.47%	11.95%
-5	44.02%	42.30%	13.68%
0	36.22%	48.15%	15.62%
5	28.70%	53.48%	17.82%
10	21.92%	57.87%	20.21%
15	16.27%	61.15%	22.59%
20	11.86%	63.44%	24.70%
25	8.61%	64.97%	26.42%
30	6.27%	65.98%	27.75%
35	4.60%	66.65%	28.74%
40	3.41%	67.10%	29.49%
45	2.56%	67.40%	30.04%
50	1.94%	67.61%	30.45%

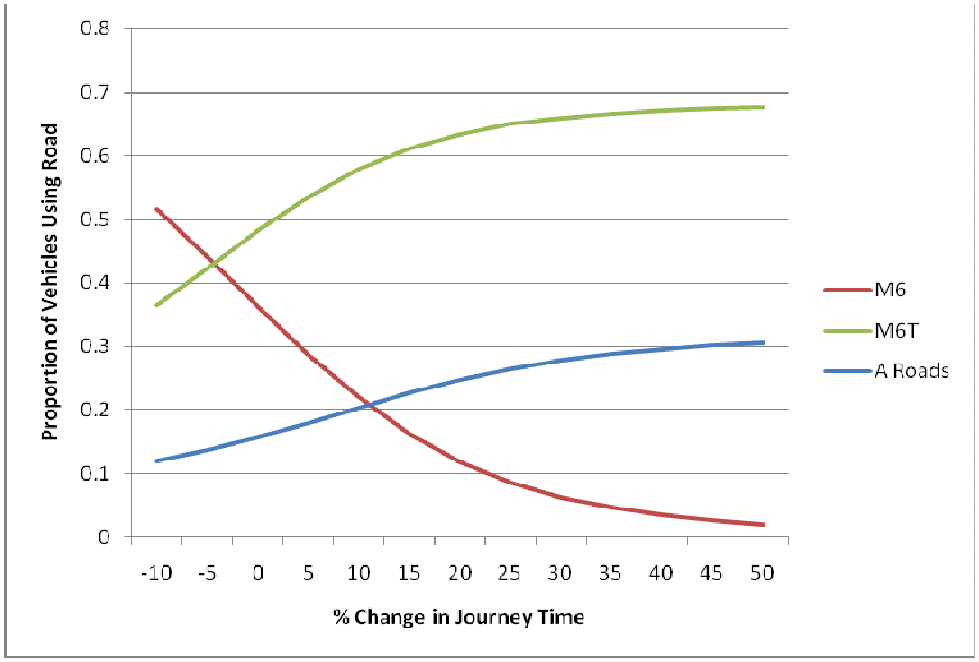


Figure 2.4.5 Sensitivity to Journey Time Changes on the M6

There is a high level of sensitivity to journey times on the M6. As journey times increase on the M6 the model suggests users quickly move to alternative routes.

Test 6: Perceived Journey Time Change to Travel on the M6T

Like test 5 this test examines model outputs in the case of journey time changes, this time on the M6T. The scope of changes here is more limited. As the road is uncongested there are no opportunities for lower journey times so the scale begins at the base case of 0% change. The upper limit is similarly constrained; there would need to be an unfeasibly high increase in the number of vehicles using the road for there to be a 50% increase in journey time.

Table 2.4.6 Sensitivity to Journey Time on the M6T

Journey Time Change on the M6T (%)	*M6*	*M6TOLL*	*A-ROADS*
0	36.22%	48.15%	15.62%
2	38.32%	45.69%	15.99%
4	40.42%	43.22%	16.36%
6	42.49%	40.78%	16.73%
8	44.52%	38.39%	17.09%
10	46.49%	36.07%	17.44%

Figure 2.4.6 illustrates the expected effects that a change in journey time on the M6T would have on the distribution of trips between different paths.

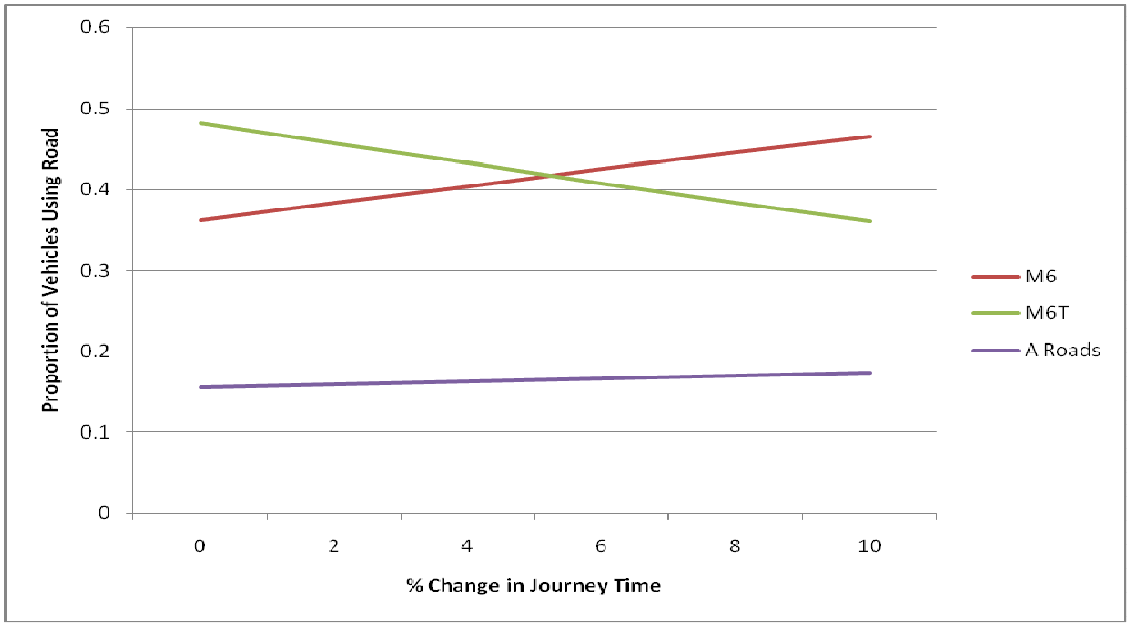


Figure 2.4.6 Sensitivity to Journey Time on the M6T

This graph indicates that we would expect a change in journey time on the M6T to contribute to a shift to the untolled M6. There is high sensitivity to this. Whilst there is also a corresponding shift to A roads with increased travel time on the M6T this is less pronounced.

Test 7: Reaction to Delay Message

This test is used to represent the effects of a delay message being posted to motorists prior to their decision on which route to use. This question may also be slightly subjective as each respondent will have had different experiences of the different types of delay presented in this question.

Table 2.4.7 Response to Delay Messages

Delay Message	*M6*	*M6TOLL*	*A-ROADS*
Delays on the M6	36.22%	48.15%	15.62%
Delays on the M6 Due to Roadworks	27.49%	60.17%	12.34%
Roadworks on the M6: Expect 25 minute Delay	16.73%	75.28%	7.99%
No Delays on M6	40.13%	42.84%	17.03%

Figure 2.4.7 shows the modelled proportion of people using each route type following different signs.

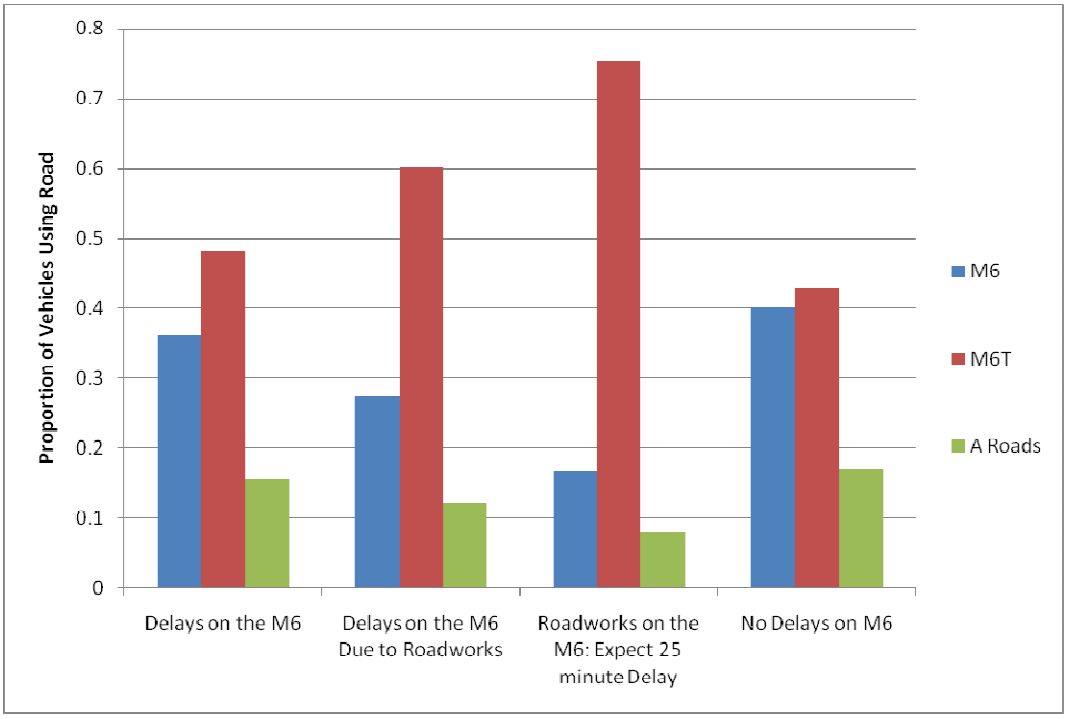


Figure 2.4.7 Response to Delay Messages

Traffic is very sensitive to information given to users on delays. Providing delay information on the M6 greatly increases the model output for the number of people who would use the toll road. Of interest is that there is relatively little sensitivity to “Delays on the M6” relative to “No Delays on M6”.

Test 8: Sensitivity to Toll on the M6T

This test is used to examine the model output when the tolls on the M6T are adjusted. These figures range from cutting the toll to £2 through to the very large £10 toll.

Table 2.4.8 Sensitivity to Tolls on the M6T

Toll Rate (P)	*M6*	*M6TOLL*	*A-ROADS*
200	14.74%	77.70%	7.55%
250	18.53%	72.35%	9.12%
300	22.62%	66.65%	10.72%
350	26.82%	60.89%	12.29%
400	31.65%	54.32%	14.03%
450	36.22%	48.15%	15.62%
500	40.42%	42.55%	17.03%
550	44.18%	37.56%	18.26%
600	47.48%	33.20%	19.32%
650	50.34%	29.44%	20.22%
700	52.80%	26.21%	20.99%
750	54.90%	23.47%	21.63%
800	56.68%	21.15%	22.17%
850	58.18%	19.18%	22.63%
900	59.46%	17.52%	23.02%
950	60.55%	16.10%	23.36%
1000	61.48%	14.87%	23.64%

Figure 2.4.8 illustrates the models output under different toll assumptions.

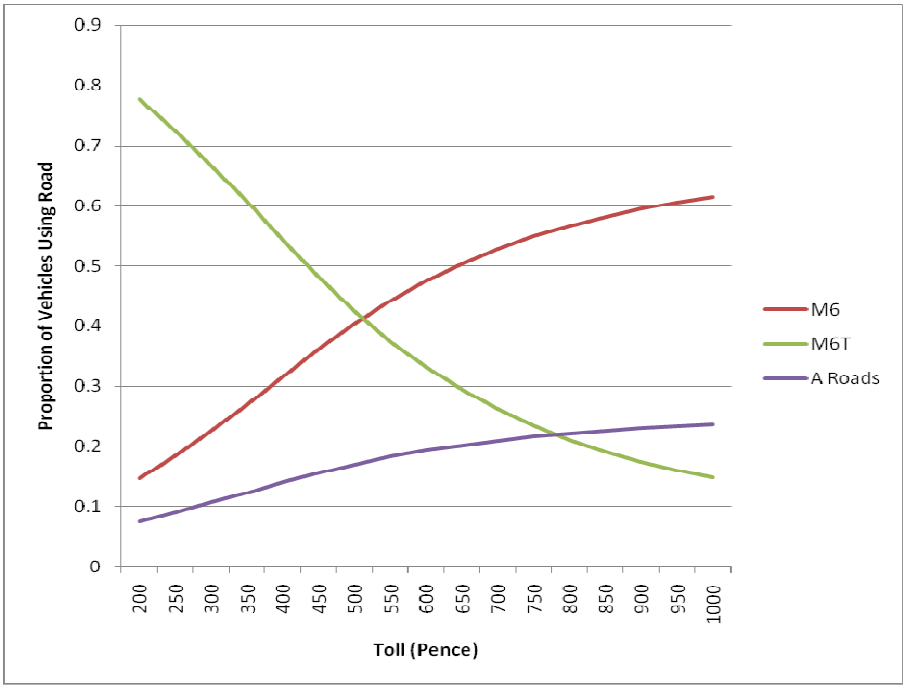


Figure 2.4.8 Sensitivity to Tolls on the M6T

The RPM model shows that there is, as expected, significant sensitivity to toll rate. At present the toll is 450p, a region of response where there is a great deal of sensitivity to toll usage and where flow elasticity is approaching -1..

Scenarios

This section examines three different scenarios for the routes in question. These are outlined below.

1) An increase in traffic that results in a 10% increase in journey time on the M6 and a 1% increase in journey time on the M6 Toll

2) An increase in traffic that results in a 15% increase in journey time on the M6 and a 1% increase in journey time on the M6 Toll. Journey time reliability falls represented by a setting of "Unreliable"

3) An increase in traffic that results in a 15% increase in journey time on the M6 and a 1% increase in journey time on the M6 Toll. Journey time reliability falls represented by a setting of "Unreliable". Toll increases to 650 pence.

These scenarios are tested using data from the Multinomial Logit Model and the Random Parameter Model.

Table 2.4.9 Multinomial Logit Model Results

Scenario	*M6*	*M6TOLL*	*A-ROADS*
Base	45.58%	37.24%	17.17%
Scenario 1	30.58%	48.56%	20.86%
Scenario 2	18.85%	57.01%	24.15%
Scenario 3	30.36%	33.55%	36.10%

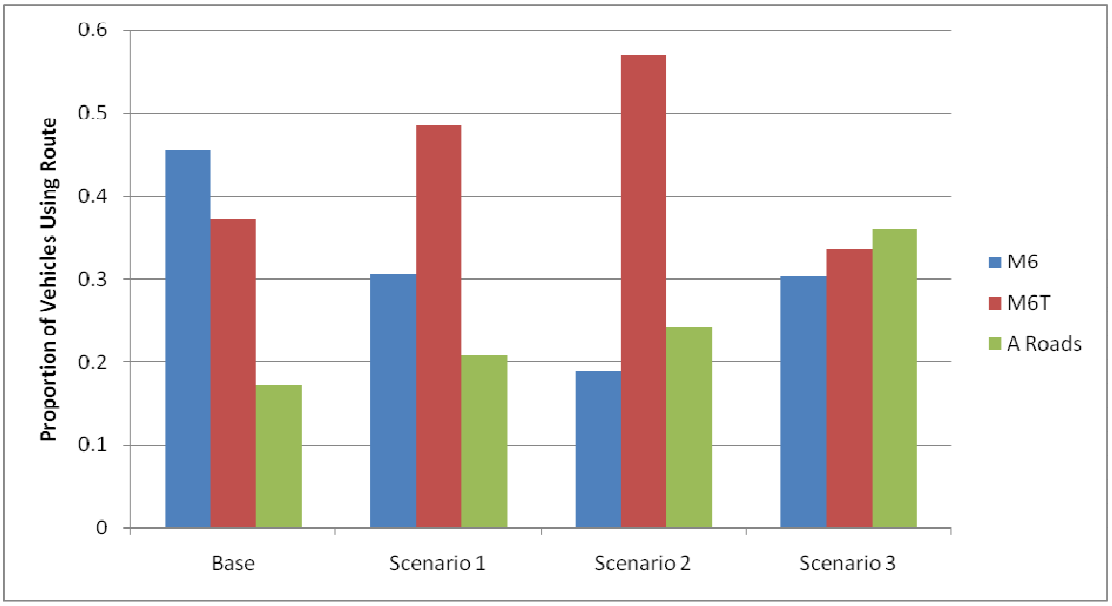


Figure 2.4.9 Multinomial Logit Model Results

Table 2.4.10 Random Parameter Model Results

Scenario	M6	M6TOLL	A-ROADS
Base	36.22%	48.15%	15.62%
Scenario 1	22.63%	56.79%	20.58%
Scenario 2	12.63%	62.05%	25.32%
Scenario 3	20.68%	41.54%	37.78%

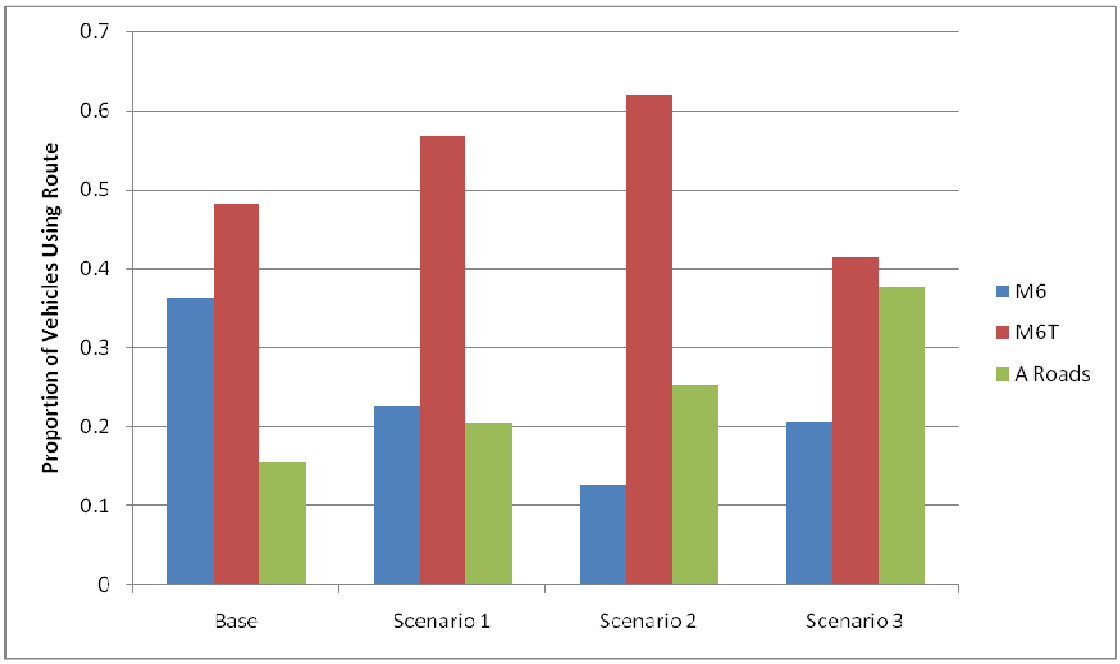


Figure 2.4.10 Random Parameter Model Results

3 Network Model

3 Network Model

3.1 Network Model Structure

The M6T Network model which is being used in this Study was originally developed to assess traffic volumes and revenues on the M6T. The emphasis was therefore on the primary factors that influence M6T volumes, and not on secondary effects within the complex road network, and the potential effects on mode choice, in the West Midlands conurbation, which we judge to minor and come into the category of model “noise”.

The analytical method for the M6 Toll forecasts was designed to accommodate the following features:

- The ability to reflect the different conditions on the M6 during different times of the day and at different times of the week
- The ability to distinguish between the various market segments that make up potential M6 Toll traffic, since these different markets have different responses to tolls. Not only is the through traffic market composed of several different sub-markets, but the intermediate traffic market (which uses the junctions on the M6 Toll for part journeys) is different in composition and response from the through traffic market;
- The ability to identify optimum tolls for the various toll classes.

A network-based traffic model was built which incorporated these features. Its structure is described in the following section.

The overall structure of the traffic model for the M6 Toll is shown on Figure 3.1.

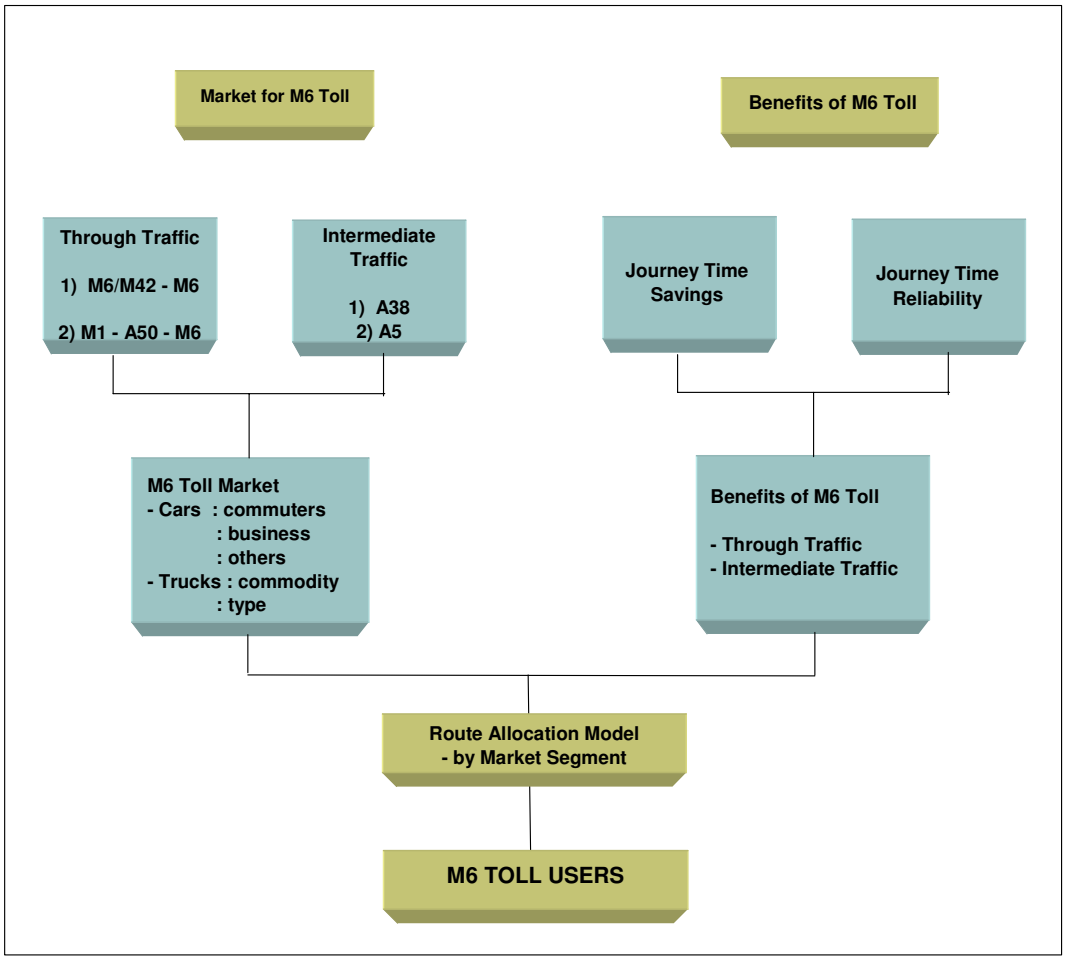


Figure 3.1 Overall Structure of the M6 Toll Traffic Model

3.1.1 Model network

A network was built which describes the routes across the West Midlands conurbation for the in-scope M6 Toll traffic. The network contains the M6, the M42, the M5 and the A38/A5 that run parallel to the M6 Toll. The M42 and M5 are included because these routes form an alternative for through traffic from the M40 to the M6 and M54 north.

The link lengths were checked against mapping and data supplied by M6 Toll. Each link was assigned a volume/delay function. These functions represent the rate at which speeds decrease with increasing traffic flow. The volume/delay functions are shown in Table 3.1.

Table 3.1 Parameters of the Volume/Delay functions

number	Type of road	Max speed (kph)	Min speed (kph)	Capacity (veh/hr per direction)	Power*	Location (Urban/ suburban / rural)	Road allocation
1	D5M	120	67	10000	3.9	Rural	M6T / M42
2	D4M	120	67	8000	3.9	Rural	M6T/M6/M42
3	D3M	120	67	6000	3.9	Rural	M6T/M6 etc
4	D3M	110	40	5600	4.5	Urban	M6/M42/M5
5	D2M	110	60	3800	2.7	Urban/ Rural	M42/M54
6	Sliproads	90	40	3800	2.5	Urban/ Rural	M Junctions
7	D2	100	40	3800	2.5	Rural	A38 etc
8	D2	91	48	1759	2.5	Urban	
9	D2	70	25	4000	2.5	Suburban	Brownhills
10	S2	90	40	1700	3.9	Rural	A446 / A5
11	S2	48	20	1200	2.5	Urban	Cannock
12	S2	70	20	1500	2.5	Suburban	Cannock

* refers to the power function used in the mathematical representation of the speed-flow curve

Source: Consultants Study

3.1.2 *Time Periods*

The time periods to be modelled were selected based on three criteria:

- Traffic flows and journey times on the M6 through the West Midlands conurbation
- The daily and weekly profile of flows on the M6 Toll (these are not the same as on the M6);
- The potential in the future to represent differential tolls at different times of the day.

Six time periods were defined which represented more or less homogenous conditions with regard to flow conditions and types of user. The allocation of hours of the day to these time periods is set out in Table 3.2

The periods are defined as:

1. Weekday peak
2. Weekend peak
3. Off peak
4. Weekend day
5. Evening
6. Overnight

This is similar in concept to the COBA “Flow Groups”, that is time periods where flow conditions are similar.

Table 3.2 Allocation of hours to Time Periods

Hour ending:	Mon - Thurs	Friday	Saturday	Sunday
1	Overnight	Overnight	Overnight	Overnight
2	Overnight	Overnight	Overnight	Overnight
3	Overnight	Overnight	Overnight	Overnight
4	Overnight	Overnight	Overnight	Overnight
5	Overnight	Overnight	Overnight	Overnight
6	Overnight	Overnight	Overnight	Overnight
7	Off Peak	Off Peak	Weekend Days	Weekend Days
8	Weekday Peak	Weekday Peak	Weekend Days	Weekend Days
9	Weekday Peak	Weekday Peak	Weekend Days	Weekend Days
10	Weekday Peak	Weekday Peak	Weekend Days	Weekend Days
11	Off Peak	Off Peak	Weekend Days	Weekend Days
12	Off Peak	Off Peak	Weekend Days	Weekend Days
13	Off Peak	Off Peak	Weekend Days	Weekend Peak
14	Off Peak	Off Peak	Weekend Days	Weekend Peak
15	Off Peak	Weekend Peak	Weekend Days	Weekend Peak
16	Off Peak	Weekend Peak	Weekend Days	Weekend Peak
17	Weekday Peak	Weekend Peak	Weekend Days	Weekend Peak
18	Weekday Peak	Weekend Peak	Weekend Days	Weekend Peak
19	Off Peak	Weekend Peak	Weekend Days	Weekend Peak
20	Evening	Weekend Peak	Evening	Weekend Peak
21	Evening	Weekend Peak	Evening	Evening
22	Evening	Evening	Evening	Evening
23	Evening	Evening	Evening	Evening
24	Overnight	Overnight	Overnight	Overnight

3.1.3 Market Segments

The model segmentation of ‘through’ and ‘intermediate’ traffic is shown in Table 3.3 below. The Principal purpose of this segmentation is to allow their different willingness-to-pay characteristics to be built into the toll diversion model. Through trips were divided into 3 categories for cars and three categories for commercial vehicles. For immediate traffic (i.e. those using only a section of the M6 Toll) three categories only were defined.

Table 3.3 Definition of Market Segments

Through Traffic	
Cars	Commuting
	Social and Recreational Journeys, e.g. visiting friends and family, leisure and holidays
	Employers Business
Trucks	Vans (LGV) Coaches
	HGV Logistics
	HGV General Haulage
Intermediate Traffic	Cars
	Vans
	HGV

The proportion of traffic in each time period and market segment is shown on Table 3.4 based upon our analysis of the hourly and daily flow profiles observed on the M6 and summarised in the previous chapter in Figure 4.5

3.1.4 Journey Purposes

Trip purpose and vehicle category information is available from the West Midlands Regional Model for AM, PM, Off-Peak and 24 hour periods. Manual classified traffic count information on the M6 for the period 6am to 9pm has been utilised to provide information in relation to light vans. M6 automatic classified count information has also been used to establish % HGVs at weekends and overnight. It has therefore been possible to use observed information to derive trip purpose and vehicle categories for most flow groups. For flow groups where no information is available for trip purpose proportions have been interpolated. This has generally affected the weekend and overnight situation.

Table 3.4 Time Periods and Market Segments, Through Traffic

Time Period	Hours	hours per day	days per year	No of hours per year	% of AADT	Contribution of Market Segments to Each Time Period (%)					
						Commuting	Other (inc Soc/Rec)	Employers Business	Vans (LGV)	HGV Logistics	HGV General Haulage
Weekdays Peak											
Mon - Fri	0700-1000	3	260	780	22.1%						
Mon - Thurs	1600-1800	2	208	416							
Sub Total				**1196**		32	22	24	5	4	13
Off Peak Weekdays					32.4%						
Mon - Thurs	0600-0700	1	208	208							
	1000-1600	6	208	1248							
	1800-1900	1	208	208							
Friday	1000-1400	4	52	208							
	0600-0700	1	52	52							
Sub Total				**1924**		6	27	33	7	8	19
Weekend Days					11.7%						
Saturday	0600-1900	13	52	676							
Sunday	0600-1200	6	52	312							
Sub Total				**988**		4	82	2	3	6	3
Weekend Peaks					14%						
Friday	1400-2100	7	52	364							
Sunday	1200-2000	8	52	416							
Sub total				**780**		15	59	9	5	6	6
Evenings					11.3%						
Mon - Thurs	1900-2300	4	208	832							
Friday	2100-2300	2	52	104							
Saturday	1900-2300	4	52	208							
Sunday	2000-2300	3	52	156							
sub total				**1300**		4	68	4	4	10	10
Overnight					8.4%						
Weekdays	2300-0600	7	260	1820							
Weekend Days	2300-0600	7	104	728							
Sub total				**2548**		5	47	10	4	16	18
Total Year				**8736**	100%						

3.1.5 *Trip Matrices*

The trip matrices were developed from the following sources:

- Through Traffic: 2001 Through Traffic survey carried out by the Jacobs Consultancy for the Department of Transport, updated to 2005; and
- Through Traffic survey carried out in 2004 by Count on Us using number plate recognition for Midland Expressway Limited.

The matrices were developed at an AADT level at flow levels equivalent to the year 2005, and then disaggregated into the time periods and market segments using the proportions set out in Table 6.2.

Trip matrices for each time period and market segment are available, but the most important element is the through traffic. Table 6.2. gives the total through traffic matrix. The total year 2005 through trip matrix contains 62,200 trips per day, AADT. This includes trips from junctions 4 and 5 on the M42 and junctions 2 and 3, and 11 and 12 on the M6. These are, of course, through traffic as far as the M6 Toll is concerned. The flows on the M6 before the opening of the M6 toll were between 113,000 vehicles per day (J12-13), and 171,000 vehicles per day (J9-10). This means that, at these two points, M6 through traffic makes up 55% and 36% respectively of total M6 volumes.

The principal flows in the through traffic are:

- Between M6 South and M6 North;
- Between M6 South and M54;
- Between the M40 and M6 North; and
- Between the M40 and M54.

These are shown on Table 3.5, and total 50,200 vehicles, or 81% of the through traffic. This is a significant volume of traffic: these trips represent journeys that are at least 90 kms long. In fact the Utilisation Survey suggested that the average journey length for Mt users was 250 kms. Putting this into context, the average length for car journeys was 11 kms (6.8 miles) according to the (National Travel Survey 2004). Thus the M6 Toll does indeed cater for inter-regional and National Traffic.

The intermediate traffic in this context is in-scope traffic which could join or leave at the junctions along the M6 Toll. The volume of traffic joining and leaving at each junction was provided by a combination of traffic count loop data and transaction data. The volumes are low in comparison with traffic at the main line barriers, and represent capture rates of 10-15%. We made the logical assumption that intermediate traffic choosing to use the M6 Toll junctions travel beyond the end points of M6 Toll, that is north of junction 11A and south of junction3 3A/7A, since the toll rates are prohibitive for short distance journeys within the M6 Toll. The total market for intermediate trips was estimated from the capture rates at the individual junctions.

Table 3.5 Through Traffic Matrix, 2005, AADT, All Vehicles

	Zone	M6(N) 11	M6J11 32	M6J12 21	M54 331	M54J1 321	M54J2 341	M6J2 121	M6J3 111	M6 (S) 122	M42J6 132	M42J5 142	M42J4 152	M40 203	M69 201	TOTALS
M6 North	11	0	0	0	10	0	0	125	79	12218	935	459	287	9079	407	**23599**
M6 J11	32	0	0	0	0	0	0	42	62	305	68	25	33	132	17	**684**
M6 J12	21	0	0	0	0	0	0	25	25	136	26	17	8	126	0	**362**
M54	331	10	0	0	0	0	0	152	356	2054	162	109	49	1754	331	**4977**
M54 J1	321	0	0	0	0	0	0	17	62	246	17	42	8	268	34	**693**
M54 J2	341	0	0	0	0	0	0	8	28	255	59	16	59	272	85	**782**
M6 J2	121	125	42	25	152	17	8	0	0	0	0	0	0	0	0	**369**
M6 J3	111	79	62	25	356	62	28	0	0	0	0	0	0	0	0	**611**
M6 South	122	12218	305	136	2054	246	255	0	0	0	0	0	0	10	0	**15224**
M42 J6	132	935	68	26	162	17	59	0	0	0	0	0	0	0	0	**1267**
M42 J5	142	459	25	17	109	42	16	0	0	0	0	0	0	24	0	**692**
M42 J4	152	287	33	8	49	8	59	0	0	0	0	0	0	0	0	**445**
M40	203	9079	132	126	1754	268	272	0	0	10	0	24	0	0	0	**11665**
M69	201	407	17	0	331	34	85	0	0	0	0	0	0	0	0	**873**
TOTALS		**23599**	**684**	**362**	**4977**	**693**	**782**	**369**	**611**	**15224**	**1267**	**692**	**445**	**11665**	**873**	**62244**

Table 3.6 Through Traffic matrix, 2005, AADT, All Vehicles, Main Movements

		M6 North of J12	M54 West of J2	M6 South of J2	M40	Total
M6 North of J12				12218	9079	**21297**
M54 West of J2				2054	1754	**3809**
M6 South of J2		12218	2054			**14272**
M40		9079	1754			**10833**
Total		**21297**	**3809**	**14272**	**10833**	**50210**

3.1.6 *Non M6 Toll Traffic*

We define residual traffic on the M6 as being traffic which is not "in scope" for the M6 Toll. It is traffic with either an origin or destination within the conurbation, or both origin or destination within the conurbation. Such traffic has no advantage in using the M6 Toll, and its precise origin and destination has no direct influence on usage of the M6 Toll. This traffic does, however, influence conditions on the M6, and therefore the journey times on the M6. In our network model, this traffic was pre-loaded onto the M6 section by section, so that the model correctly reflected observed flows on the M6, and then through the volume delay functions, the correct journey times.

The experience since opening the M6 Toll was that about 2/3 of the released capacity on the M6 was taken up by intermediate and local traffic. Into the future, this residual traffic was increased to account for a continuation of this phenomenon.

3.1.7 *Route Allocation*

For each market segment, a Logit curve was developed which allocates a proportion of traffic to the M6 Toll for each origin and destination pair, depending on the journey time saving, the value of time, and any route constant associated with "comfort" factors such as journey time reliability, safety and driver stress. These relationships were calibrated using the known capture of through traffic together with the already observed reaction to toll changes and the implied elasticities.

3.1.8 *Assignment Procedure*

The assignment procedure in the network model is a multi-user class assignment which iterates until it reaches equilibrium. The method has been specially developed by Faber Maunsell for toll road analysis. In real life, when traffic is diverted from an existing road by a new (toll) road, conditions on the existing road improve and the time advantage of the new road reduces. This new situation produces two effects: first, there is new balance between the existing road and the new (toll) road, and secondly traffic may be attracted back to the existing road. This continues until an equilibrium position is reached. This is well illustrated by the M6 and M6 Toll. The relief to the M6 was less than the volume of traffic attracted to the M6 Toll, because local and intermediate traffic was attracted back to the M6. The assignment procedure developed by Faber Maunsell is designed to replicate this observed behaviour.

The software used for the Traffic Study is EMME/2.

3.2 Calibration and Validation - 2005

The traffic model was calibrated in three areas:

(a) **Journey times** on the M6 and M6 Toll

(b) **Capture Rates** for through traffic and intermediate traffic

(c) **Flows** on the main sections of the M6 Toll and slip roads, and on the M6.

In reality, of course, all three of these criteria are inter-linked. However, in practical terms there has to be a hierarchy to the calibration process. The procedure followed was therefore an iterative one: the modelled and observed journey times were analysed first, followed by adjustments to the logit models to replicate capture rates and observed flows. The overall impact on journey times was then assessed.

3.2.1 *Journey Times*

The critical section of the M6 and M6 Toll is between the start and finish points of the M6 Toll, that is between junction 3A and junction 11A. From data collected for the M6 Toll Post Project Opening Study Interim Report June 2005, W S Atkins, for the Highways Agency, and M6 Toll Journey Time Analysis, October 2004, Faber Maunsell for M6 Toll and iTIS Holdings, it was possible to estimate average journey time savings in the weekday peak and off peak periods.

The journey times in the other time periods have to be judged in the light of the relationship of flows and overall conditions in these time periods to those in the weekday peak and off peak periods.

The comparison between observed and modelled average journey times in different time periods is shown in Table 3.7. The model replicates travel times well within the observed level of variation observed.

Table 3.7 Observed and Modelled Journey Times

Time period	Weekday Peaks (1)				Weekday Off peak (2)				(3)	(4)	(5)	(6)
	Modelled	Observed	Difference		Modelled	Observed	Difference		Modelled	Modelled	Modelled	Modelled
M6 SB	37.9	40.3	-2.5	-6%	29.8	31.3	-1.5	-5%	23.8	27.9	23.2	22.9
M6 Toll SB	21.8	21.4	0.4	2%	21.8	21.4	0.4	2%	21.8	21.8	21.8	21.8
A5/A446 SB	28.7	30.5	-1.7	-6%	24.4	26.0	-1.6	-6%	23.6	25.7	19.9	19.8
M6 NB	33.3	31.5	1.8	6%	28.1	30.9	-2.7	-9%	23.5	26.3	22.9	22.5
M6 Toll NB	21.1	21.9	-0.8	-4%	21.1	21.2	-0.1	0%	21.1	21.1	21.1	21.1
A5/A446 NB	28.8	30.5	-1.7	-6%	24.3	26.0	-1.7	-7%	23.6	26.0	19.9	19.8

Source: M6 Toll Post Project Opening Study and Consultants Traffic Model

Note: Time periods are

1=Weekday peak
2=Weekday off-peak
3=Weekend peaks
4=Weekend off-peak
5=Evenings
6=Overnight

Observed journey times were available only for the time periods 1 and 2 (weekday peak periods and weekday off-peak periods). Overall, the model is replicating journey times well, and reacting plausibly to changes in flow conditions. It is worth noting that at no time is the M6 faster route than the M6 Toll for through traffic.

Capture Rates

Traffic capture is controlled by the Logit models. The starting point for the model parameters were the values of time from a previous study of the M6 Toll by consultants MVA for Midland Expressway Limited, and parameter values used elsewhere. The values of time in this study were obtained from a Stated Preference survey of potential M6 Toll users. In order to calibrate these models, there were two pieces of information available:

- First, actual flows on the M6 Toll; and
- Secondly, the observed reaction to the toll increase between June 2004 and July 2005.

The models were run with different parameters and with different toll levels to assess both the match between observed and modelled flows, and the price elasticity.

The parameters set out in Table 3.8 below represent those values which provided the best overall fit.

Table 3.8 Calibrated Logit Model Parameters

Parameter	Class 1, Cars Commuting	Class 2, Cars Social	Class 3, Cars Employers Business	Class 4, Vans (LGV's)	Class 5, Coaches	Class 6, HGV Logistics	Class 7, HGV General Haulage	Class 8, Cars inter	Class 9, vans inter	Class 10, HGV inter
time coefficient (min^{-1})	-0.15	-0.06	-0.08	-0.12	-0.10	-0.10	-0.10	-0.15	-0.12	-0.10
toll transaction delay	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
route constant (mins)	3.00	25.00	20.00	10.00						
toll (mins)	22.50	15.00	12.70	25.50	28.00	28.00	28.00	15.00	21.80	24.00
toll (£)	3.50	3.50	3.50	7.00	7.00	7.00	7.00	2.50	6.00	6.00
VOT (£/hour)	9.40	14.00	16.50	16.50	15.00	15.00	15.00	10.00	16.50	15.00

The Logit curves are shown in Figure 3.2 below:

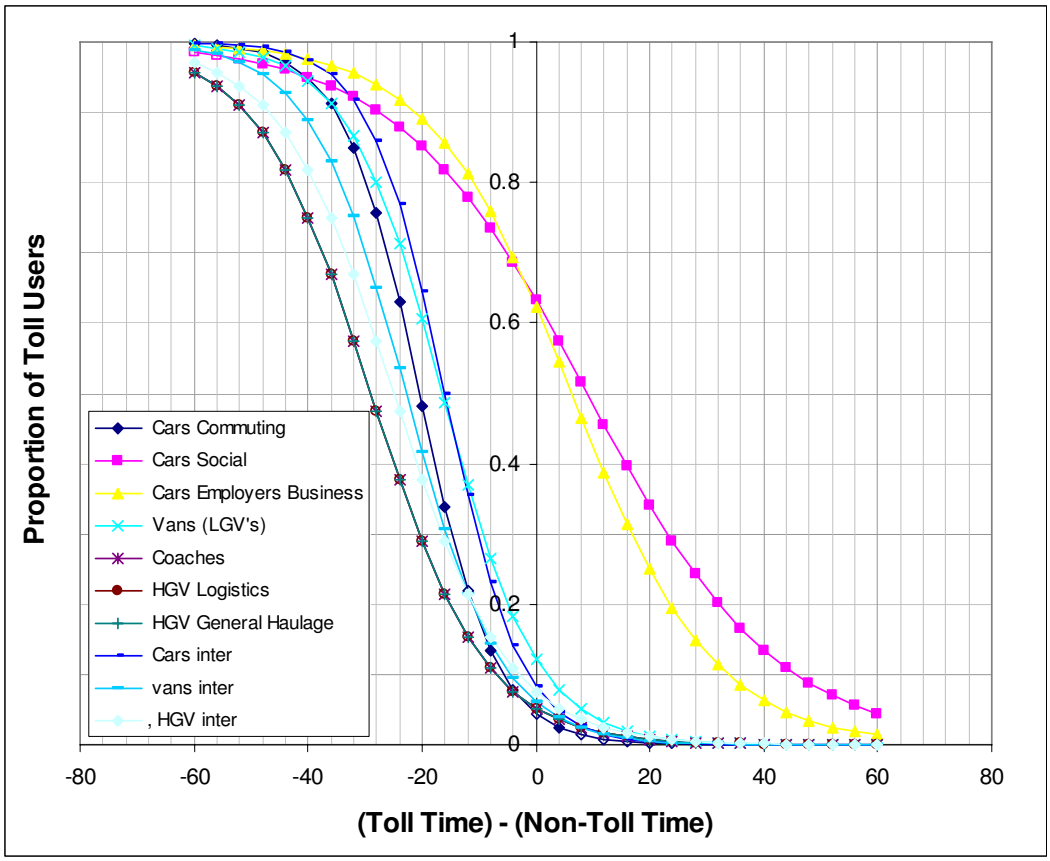


Figure 3.2 Calibrated Logit Curves

The main changes from the starting point values were the route constants and the time coefficients for cars. The M6 Toll exhibits relatively unusual characteristics for a toll road. First, the capture rates are high given the fairly modest average journey time savings, and secondly, the price elasticity for cars is low. There are of course good reasons for these effects.

This description of the estimates of the value of route constants were made before the M6T Research programme, and was based on a comparison of what the capture would be using established values of time, and what it was observed to be. The difference was attributed to non "value of time" components such as reliability, ease of driving, perceived safety benefits of the M6T, lower HGV proportions, less weaving traffic and so on. Limited market Research undertaken on behalf of the operator suggested that the scale of the time savings offered by the M6T were a secondary consideration for car drivers. In fact, the estimates of the overall value of the values of time (from previous surveys) and route constants made in an empirical fashion in 2005 showed values of time higher, and route constants lower than those which emerged from the SP analysis.

The shape of the Logit curves imply a low price elasticity for cars. In 2005 this was estimated at -0.21 at the toll rates then prevailing - £3.50 for cars in 2005 prices - and this elasticity was replicated almost exactly by the subsequent tests with the network model using the Stated Preference-derived values of time and route constants (see section 3.5)

The *a priori* reasoning for significant route constants were as follows. First, the proportion of commuters is low, about 13%. The remainder of the traffic is employers business and long distance social/recreational traffic. For these users, the toll is a relatively small proportion of the cost of the journey, or, in the case of journeys for leisure purposes, the cost of the whole experience, for example a holiday, of which the travel cost may be a relatively small proportion.

Thus, both the high capture and low elasticity represent entirely rational outcomes in this case.

Traffic Flows

The comparison between the modelled and observed flows at flows equivalent to June 2005 is shown in Table 3.9 below, for flows at the mainline plazas and ramps. The model is slightly underestimating flows, and, therefore, revenues. As part of the calibration process to ensure that the model represents a sound base for forecasting, the flows were scaled to match observed flows, and revenues calculated accordingly.

Table 3.9 Observed and Modelled Traffic Flows

Location	Count	Model	Difference	% Difference
Main Toll Plaza NB	18,873	18,002	-871	-4.6%
Main Toll Plaza SB	20,230	18,713	-1,571	-7.5%
Total Mainline Plazas	**39,103**	**36,715**	**-2,388**	**-6.1%**
M6 Junctions 4 – 3A	113,000	112,900	-100	-0.08%
M6 Junctions 4A - 5	131,900	131,400	-500	-0.4%
M6 Junctions 9 - 10	143,300	143,000	-300	-0.2%

Source: Consultants Traffic Model
Note: The number of locations for which comparisons are available in restricted by the availability of complete count data on the Motorway network

Because of its structure, the model can take into account changes in demand and tolls for different market segments and time periods. The validation is good bearing in mind the nature and constraints of the data.

3.3 Modifications to Network Model to Accommodate Demand Model

The existing network model contains an assignment and toll choice procedure developed and calibrated by AECOM as part of an earlier study.

The new demand model developed from the SP surveys is significantly more complex than the existing demand model. It has therefore been necessary to revise the network model procedures to accommodate the requirements of the new demand model. The enhancements that have been made fall into two key areas:

1. An increase in the level of vehicle class stratification including split by income bands (willingness to pay)

2. Ability to skim costs for a range of additional trip attributes (such as fuel costs and route reliability) which are inputs into the calculation of the toll choice.

The detailed enhancements required to allow the assignment model to reflect the demand model in all its elements are discussed below.

Vehicle Stratification

The existing model classifies travel demand by vehicle type and, for cars, by trip purpose. The new demand model includes a further split for cars into household income bands.

The differential periodic vehicle type and trip purpose split proportions have been retained from the exiting model with cars further split into five income bands based on the split observed in the SP surveys. Table 3.10 below outlines the revised vehicle stratification.

Table 3.10 Revised vehicle classes

Revised Vehicle Class		split
Car - Commuting - Income band 1	< £40k	32%
Car - Commuting - Income band 2	£40-60k	32%
Car - Commuting - Income band 3	£60-80k	19%
Car - Commuting - Income band 4	£80-100k	9%
Car - Commuting - Income band 5	> £100k	8%
Car - Other - Income band 1	< £40k	54%
Car - Other - Income band 2	£40-60k	23%
Car - Other - Income band 3	£60-80k	11%
Car - Other - Income band 4	£80-100k	5%
Car - Other - Income band 5	> £100k	7%
Car - Employers business - Income band 1	< £40k	29%
Car - Employers business - Income band 2	£40-60k	31%
Car - Employers business - Income band 3	£60-80k	22%
Car - Employers business - Income band 4	£80-100k	10%
Car - Employers business - Income band 5	> £100k	8%
Vans		As in Existing Network Model
Buses & Coaches		
HGV-Primary		
HGV-Distribution		
HGV-Services		
Car Intermediate – Potential ramp plaza users		
Van Intermediate – Potential ramp plaza users		
HGV Intermediate - Potential ramp plaza users		

Cost Skims for additional trip attributes

The existing network model calculates the split between toll users and non-toll users at an individual OD movement level by comparing the trip attributes of the two possible route choices:

A. Non-toll user trip – quickest (pure time) journeys using only non-tolled links

B. Toll user trip – quickest (pure time) journey using any links (including tolled links)

The following trip attributes are assessed for each of the route choices in the existing network model:

		Non-toll User Route	Toll User Route
Travel time	In minutes	✓	✓
Toll	In pence	zero	✓
ASC	In minutes per km	zero	✓
Toll transaction delay	In minutes	zero	✓

The range of trip attributes has been extended in the new demand model to cover a greater range of trip characteristics. The trip attributes considered by the revised model are outlined below.

		Non-Tolled user route	Toll user route
Travel time	In minutes	✓	✓
Time interaction term	to reflect effect of journey duration (travel time)^2	✓	✓
Fuel cost	In pence	✓	✓
Toll	In pence	zero	✓
Level of user information	• no info then • M6 delays caused by *** • M6 delays of X mins, • No M6 Delays.	✓	✓
Reliability	• Very reliable • Reliable • Usually Reliable • Unreliable	✓	✓
ASC	In minutes per km	zero	✓
Toll transaction delay	In minutes	zero	✓

Following assignment ***route travel times*** have been skimmed for each origin destination pair and for each route option. A **travel duration term** has been given by calculating the square of the travel time. This gives an increased weighting to longer distance trips.

Fuel cost has been calculated for each route option and for each origin-destination movement separately. The cost calculation is driven by the trip length, trip time and average trip speed (given by trip distance / trip time). The relationship has been taken from WebTAG unit 3.5.6: 'Values of Time and Operating Costs' and takes the form:

$$L = a + b.v + c.v2 + d.v3$$

Where:

L = consumption, expressed in litres per kilometre;

v = average speed in kilometres per hour;

a, b, c, d are parameters defined for each vehicle category in WebTAG unit 3.5.6

A toll value is allocated to links at plazas based on the vehicle class toll. Differential Toll factors have been applied to ramp plaza links to reflect the reduce ramp tolls. Following the assignment an additional options assignment is run to skim the ***total toll cost*** for each OD movements. This ensures that each movement is allocated the actual toll it would encounter and is different for movements that pass through the main line plaza and movements that pass through a ramp plaza. Toll value is only calculated for toll user route options.

The ***level of user information*** is an external input to the model procedure, and as such there is an implicit assumption that all trips, irrespective of origin and destination, experience the same level of user information.

Volume to capacity ratio has been taken as a proxy for route reliability. Following assignment volume to capacity ratios have been calculated for each link in the network. For each OD movement a distance weighted average has been taken of the V/C ratios on all the links along which the route passes. The route has then been allocated a ***reliability band*** based on this value. Reliability band definitions are shown below.

A	*Very Reliable*	V/C < 50%
B	*Reliable*	50%< V/C < 75%
C	*Usually Reliable*	75%< V/C < 85%
D	*Unreliable*	V/C > 85%

The ASC represents a perceived benefit of using the toll road that is not due to any of the quantified trip characteristic included in the model. It has been assumed that this benefit is perceived to be associated with the use of the infrastructure rather than with the specific payment of the toll. Therefore the ASC value has been allocated to all the M6T links, including both tolled and non-tolled links, based on the link lengths and the vehicle class ASC per km. This has been done in such a way as to give a trip that travels along the whole length of the M6T a combine ASC value equal tom that derived from the SP surveys.

Following the assignment an additional options assignment has been run to skim the total ***ASC*** for each OD movement. This ensures that each movement is allocated an ASC proportional to the length of toll road it uses and the value is different for movements that pass along the whole length and movements that pass along only a part of the M6T 9for example to reach a ramp plaza). ASC values have only been calculated for toll user route options as non-toll users are unable to use any of the M6T links.

Toll transaction delay is an external input to the model procedure, and as such there is an implicit assumption that all trips, irrespective of trip purpose or vehicle type, experience the same average delay in paying. In the existing calibrated network model this value has been assumed to be zero. This value has therefore been retained.

The new parameters of the Logit models are shown in Table 3.11 below:

Table 3.11 Logit Model Parameters – Modified Network Model

Vehicle Class	time coefficient (min $^{-1}$)	time^2 coefficient Factor (min $^{-2}$)	Value of Time		Mode Constants (minutes)								
			Paying toll (£/hour)	Fuel factor	ASC	Additional Info Penalty				Additional Reliability Penalty			
						No info	*M6 Delays due to**	*M6 25 min delay*	*No M6 Delays*	*Very Reliable*	*Reliable*	*Usually Reliable*	*Unreliable*
Car - Commuting - Income band 1	-0.060	0.002	4.94	8.2%	34.6	0.0	7.0	14.2	-8.0	-24.4	-12.6	-7.1	-2.9
Car - Commuting - Income band 2			5.08	8.5%									
Car - Commuting - Income band 3			5.55	9.2%									
Car - Commuting - Income band 4			6.44	10.7%									
Car - Commuting - Income band 5			6.44	10.7%									
Car - Other - Income band 1	-0.047	0.001	4.43	9.4%	67.0	0.0	8.8	31.1	-3.3	-35.0	-26.2	-17.8	-10.0
Car - Other - Income band 2			4.64	9.8%									
Car - Other - Income band 3			5.15	10.9%									
Car - Other - Income band 4			4.88	10.3%									
Car - Other - Income band 5			5.45	11.5%									
Car - Employers business - Income band 1	-0.051	0.002	5.22	6.9%	45.3	0.0	0.0	7.6	-19.1	-26.4	-19.0	-11.3	-4.0
Car - Employers business - Income band 2			5.83	7.7%									
Car - Employers business - Income band 3			6.45	8.5%									
Car - Employers business - Income band 4			6.89	9.1%									
Car - Employers business - Income band 5			8.19	10.8%									

3.4 Summary of Results

As discussed above, prior to modification, the network model was capable of modelling responses to:

Driver Characteristics:

- Changes in the proportion of journey purpose
- Changes in composition of lows at different times of the day (this is an external input – the original model had no mechanism of shifting demand from one time period to another)

Route Characteristics

- Changes in tolls for different vehicle types, and different times of day
- Changes in willingness to pay in respect of values of time and (aggregated) route constants
- Changes in demand
- Changes in capacity on the M6 and main A roads in the M6T corridor
- Toll transaction time

Additionally, as a result of the modifications described in section 3.5, the network model can now accommodate changes in the following parameters:

Driver Characteristics

- Distribution of drivers within income bands for each journey purpose

Route Characteristics

- Fuel Costs
- Journey duration
- Driver Information – this is an component of the route constant
- Reliability – this is a component of the route constant

The initial test that was done with the modified model was to examine the impact of a change in toll charges, for light vehicles.

Tolls were tested in £0.50 increments between £2.00 and £5.50 for toll classes 1 and 2 (cars and motorcycles), and between £6.00 and £9.50 for classes 3-6 (commercial vehicles and buses/coaches). The route allocation model for these latter classes was not changed from the previous models described in section 3.2. The price base is 2007.

The model was run in full equilibrium mode with additional user classes for the income bands shown in Table 3.11, with 2008 trip matrices.

The results of the tests are shown on Table 3.12, and graphically in Figures 3.3 and 3.4 for light vehicles, and 3.5 and 3.6 for commercial vehicles and buses (using the original model Logit parameters).

For toll classes 1 and 2 (motorcycles and cars) flows decline smoothly as tolls increase – this is the overwhelming advantage of using a probabilistic method for route allocation rather than generalised cost. With increasing price elasticity also increases from -0.3 at £2.00 to -1 between £4.50 and £5.00. Consistent with the flow data, revenues increase with increasing tolls but with declining positive elasticities, until the revenue maximising toll, indicated by an elasticity of 0, is reached when tolls are just above £5.00.

Comparisons with Demand Model

The outcomes from the network model and demand model (Test 8, Table 2.4.8 and Figure 2.4.8) can be compared. Table 3.13 shows flow elasticities from the two models over the same range of tolls.

Table 3.13 Flow Elasticities from the Demand and Network Models

Toll Increase, Classes 1 and 2	Flow Elasticities	
	Demand Model	Network Model
£2.00 to £2.50	-0.28	-0.28
£2.50 to £3.00	-0.39	-0.38
£3.00 to £3.50	-0.52	-0.53
£3.50 to £4.00	-0.76	-0.69
£4.00 to £4.50	-0.91	-0.72
£4.50 to £5.00	-1.05	-0.95
£5.00 to £5.50	-1.17	-1.08

These results are extremely interesting for practicioners.

For most of the toll range, the elasticities from the two models are very similar, apart from the increase between £4.00 to £4.50. Further examination of the network model may reveal why this is so: it is possible that since the route choice in binary, at a toll of £4.50 an alternative route becomes unviable for some O-D pairs. Leaving this point aside, the results imply that network models can capture most of the variability in route choice for toll roads. This is provided that the network model used is of sufficient sophistication. Most network models have complex networks (we suspect because these are relatively easy to gather data for and build), and relatively simple matrix structures and assignment routines. This work demonstrates that, for toll road studies at least, the important factors are not complex networks, but appropriate matrix structures and assignment methods.

Table 3.12 Results from network Model Toll Tests – 2007 Prices

Class 1-2								
Toll	**£2.00**	**£2.50**	**£3.00**	**£3.50**	**£4.00**	**£4.50**	**£5.00**	**£5.50**
Main Line AADT Flow M6T	46,530	43,284	39,963	36,452	32,878	29,921	26,755	23,864
Annual Main Line Revenue (£)	35,237,470	40,678,619	44,850,265	47,563,431	48,899,373	49,962,825	49,557,661	48,558,767
Average Travel Time (minutes)	134.7	135.0	135.3	135.6	136.0	136.3	136.6	137.0
Flow Elasticity (price increase)		-0.3	-0.4	-0.5	-0.7	-0.7	-1.0	-1.1
Flow Elasticity (price decrease)	-0.4	-0.5	-0.7	-0.9	-0.9	-1.2	-1.3	
Revenue Elasticity (price increase)		0.6	0.5	0.4	0.2	0.2	-0.1	-0.2
Revenue Elasticity (price decrease)	0.6	0.5	0.4	0.2	0.2	-0.1	-0.2	
Class 3-6								
Toll	**£6.00**	**£6.50**	**£7.00**	**£7.50**	**£8.00**	**£8.50**	**£9.00**	**£9.50**
Main Line AADT Flow M6T	4,239	3,720	3,284	2,899	2,505	2,270	2,008	1,774
Annual Main Line Revenue (£)	9,467,125	8,987,355	8,532,585	8,062,065	7,423,652	7,140,405	6,682,242	6,230,097
Average Travel Time (minutes)	135.4	135.6	135.9	136.1	136.4	136.7	136.9	137.2
Flow Elasticity (price increase)		-1.5	-1.5	-1.6	-2.0	-1.5	-2.0	-2.1
Flow Elasticity (price decrease)	-1.8	-1.9	-2.0	-2.5	-1.8	-2.4	-2.5	
Revenue Elasticity (price increase)		-0.6	-0.7	-0.8	-1.2	-0.6	-1.1	-1.2
Revenue Elasticity (price decrease)	-0.6	-0.7	-0.8	-1.2	-0.6	-1.1	-1.2	

Figure 3.3 Network Model, Flow Changes with Increasing Tolls, Classes 1-2

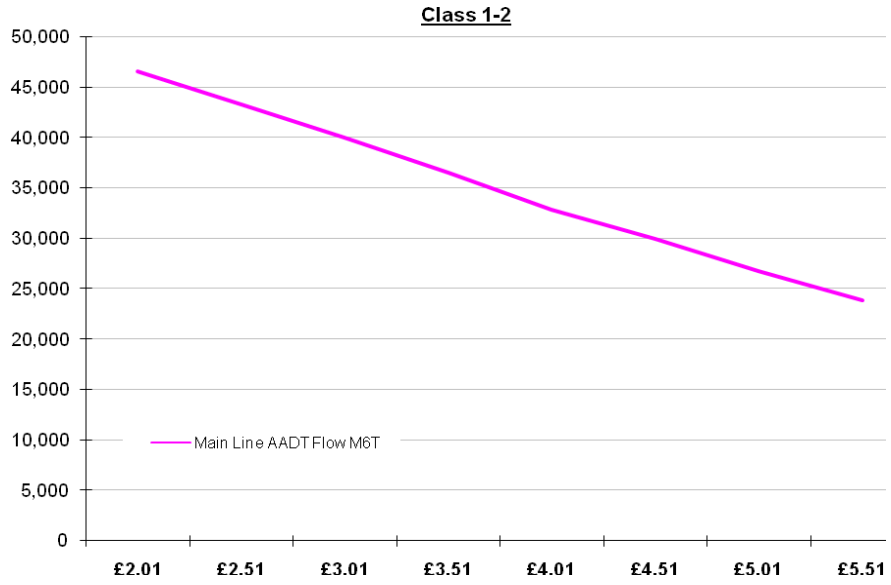


Figure 3.4 Network Model, Revenue Changes with Increasing Tolls Classes 1-2

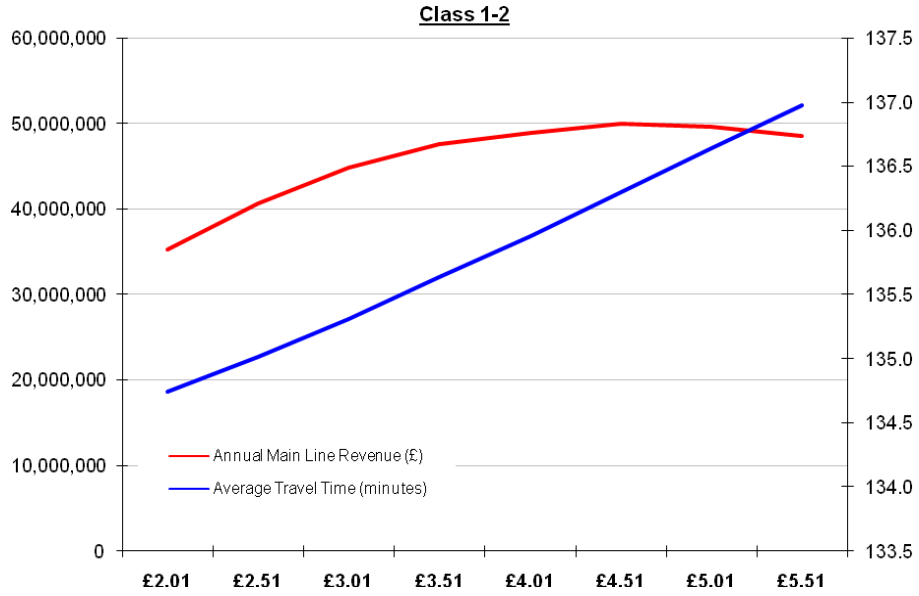


Figure 3.5 Network Model, Flow Changes with Increasing Tolls, Classes 3-6

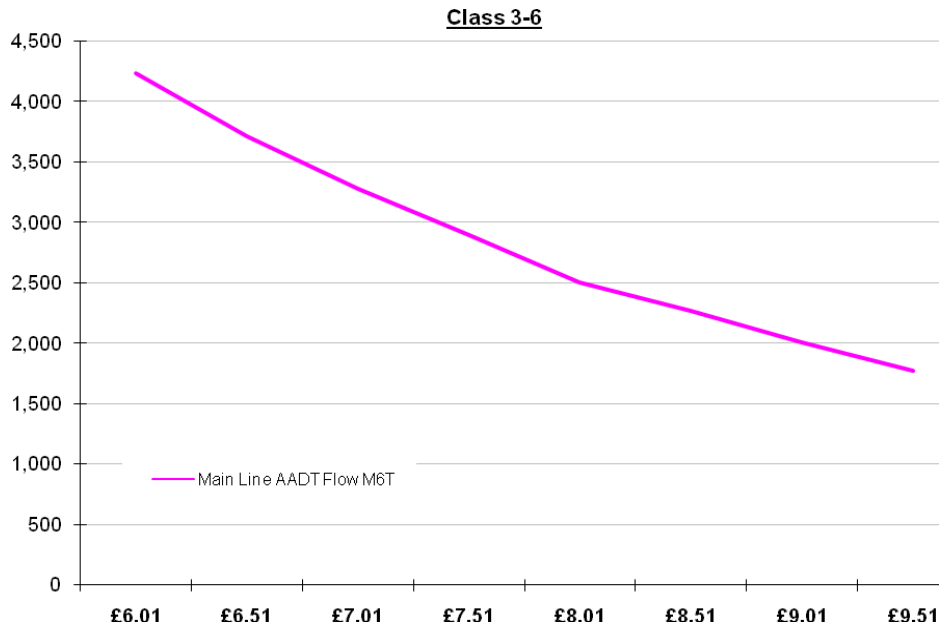
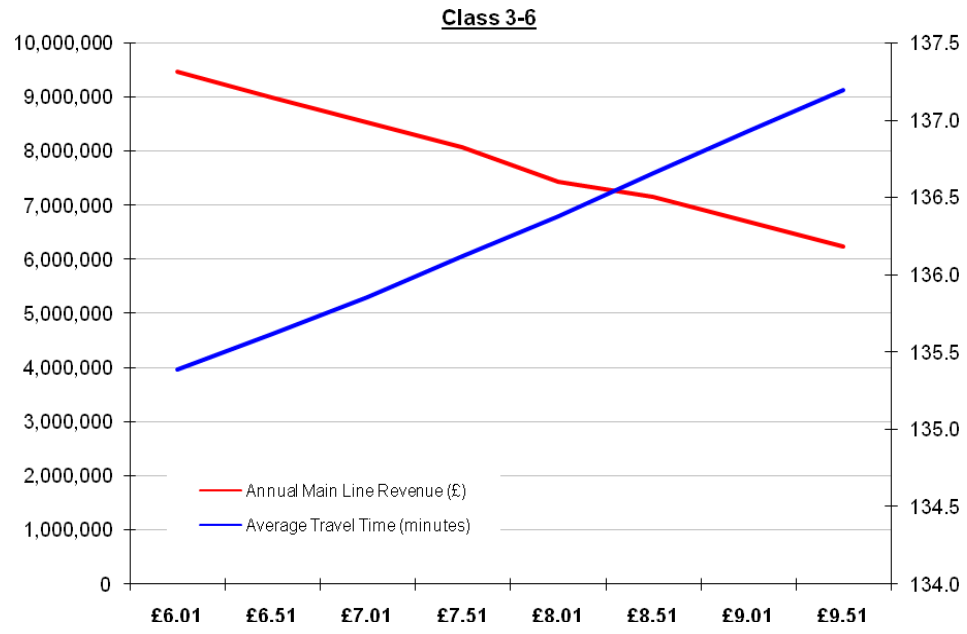



Figure 3.5 Network Model, Revenue Changes with Increasing Tolls, Classes 3-6