Department for Transport

CONGESTION DEPENDENT VALUES OF TIME IN TRANSPORT MODELLING
FURTHER PRISM TESTING

70082346
JANUARY 2022

PUBLIC

Department for Transport

CONGESTION DEPENDENT VALUES OF TIME IN TRANSPORT MODELLING FURTHER PRISM TESTING

TYPE OF DOCUMENT (VERSION) PUBLIC

PROJECT NO. T0059 / TSTR300

OUR REF. NO. 70082346

DATE: JANUARY 2022

WSP

Unit 9, The Chase
John Tate Road, Foxholes Business Park
Hertford
SG13 7NN

Phone: +44 1992 526 000

Fax: +44 1992 526 001

WSP.com

Quality control

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks	First Draft	Second Draft following DfT comment		
Date	10/12/2021	13/01/2022		
Prepared by	Andrew Gordon	Andrew Gordon		
Signature				
Checked by	John Collins James Fox	John Collins		
Signature				
Authorised by	John Collins	John Collins		
Signature				
Project number	T0059	T0059		
Report number	1	1		
File reference	70082346	70082346		

Contents

1. PROJECT BACKGROUND

1.1. INTRODUCTION

1.1.1. The 2015 report 'Provision of market research for value of time savings and reliability' commissioned by the Department for Transport (DfT), provided the results of primary research into the value of travel time savings (VTTS). Since publication of that report, DfT has made significant progress in implementing the findings of the research through both updating the values of travel time used in transport analysis guidance (TAG) and implementing the relationships found between travel distance and values of time for employer's business travellers, in some contexts.

1.1.2. The research covered a number of other aspects of travellers' values of time, making recommendations for further investigation into a number of areas. In particular, the research recommended the application of multipliers to VTTS to account for traffic conditions (congestion). This was based on evidence which seemingly indicated that people tend to assign a higher value to time savings in congested conditions relative to free flow conditions.

1.1.3. In 2017/18, a combined team of WSP, Mott MacDonald, and RAND Europe carried out a research project for DfT to investigate the application of multipliers to VTTS to account for differences in traffic conditions (congestion multipliers).

1.1.4. The research project made very good progress in understanding the modelling and appraisal implementation issues on a conceptual basis. The project also included some modelling work using GPS data to test the realism of behavioural responses implied by a range of plausible congested value of travel time (CVTT) multipliers, as well as a test using the West Midlands Combined Authority PRISM model to provide a 'proof of concept', giving an indication of what modelling results using CVTT may look like in practice.

1.1.5. Further work by the same team, reported in 2019, investigated the use of CVTT in model forecasting and scheme appraisal, again using the PRISM model as a test bed. This showed that the use of CVTT was technically possible and could have a significant impact on modelled route choice, forecast traffic flows and scheme appraisal.

1.1.6. In 2020 DfT commissioned a CVTT Forward Look Report from ITS Leeds which reviewed the research so far into CVTT. The report provided advice on further steps in implementation of CVTT in modelling and appraisal and the further research required to support that. While the ITS report stated there is a robust mandate for change it concluded that further research is needed before CVTT can be implemented in TAG.

1.1.7. The work described in the current report forms part of that further research and is based on the recommendations for further work in the 2019 report. The main objectives are to:

- Examine the impact of using CVTT during matrix building,
- Examine the impact of CVTT on model elasticities, and

- Examine the impact of the level of congestion on the use of CVTT in modelling and appraisal.

1.2. OVERVIEW OF STUDY METHODOLOGY

1.2.1. The project was divided into four main stages:

- Stage 1: Base matrix development review: investigate the influence of VTT on the development of the PRISM prior matrices which feed into the matrix estimation process.
- Stage 2: Carry out matrix estimation incorporating CVTT. Compare the validation of the estimated matrix to the 'TAG standard VTT' base. Calculate base year model elasticities.
- Stage 3: Carry out a series of forecast model runs using TAG standard VTT and different CVTT multipliers.
- Stage 4: Carry out economic appraisal using the model outputs from Stage 3.

1.2.2. Each of these stages is described in more detail later in this report.

1.3. REPORT STRUCTURE

1.3.1. The bulk of this report covers the four stages of the study, plus a final summary, conclusions, and recommendations section:

- Chapter 2 summarises those parts of the methodology used in the 2019 report which are relevant to the current study.
- Chapter 3 describes Stage 1.
- Chapter 4 describes the first part of Stage 2 (matrix estimation with CVTT).
- Chapter 5 describes the second part of Stage 2 (base year model elasticities).
- Chapter 6 describes Stage 3 (forecasting).
- Chapter 7 describes Stage 4 (appraisal).
- Chapter 8 summarises the key findings from each stage, provides an overarching conclusion to the work, and makes recommendations for further research that will be needed before CVTT can be included in TAG.

1.3.2. In some places the reader is referred to the 2019 report for further technical details of how the model and economic appraisal were set up. This can be found here: 2019 Congestion Dependent Values of Travel Time Follow-on Report.

2. SUMMARY OF 2019 METHODOLOGY

2.1. OVERVIEW

2.1.1. The work described in the current report builds on earlier work described in the 2019 WSP and Mott MacDonald report 'Congestion-dependent values of time in transport modelling'. That describes the use of CVTT in an existing large-scale model (the PRISM model of the West Midlands) in forecasting and economic appraisal. The tests comprised:

- Adding CVTT to base year highway assignment models to determine the impact on model validation, run times and convergence.
- Using CVTT in the future year model runs (including full variable demand modelling (VDM)) for 2036, with and without a test road scheme, to determine the impact on forecast flows, run times and convergence.
- Using the results of the future year model runs in DfT's TUBA economic appraisal software to determine the impact of CVTT on user benefits.

2.1.2. The 2019 report includes technical details of how the modelling and appraisal were set up to accommodate CVTT. The rest of this chapter provides a brief summary. It does not cover the results from the 2019 tests; these are discussed in subsequent chapters where relevant.

2.2. THE MODEL

2.2.1. The 2019 and current project used the PRISM 5 model of the West Midlands. PRISM stands for Policy Responsive Integrated Strategy Model. It has a 2016 base year and comprises:

- A highway assignment model in the Visum software.
- A public transport assignment model, also in Visum.
- A disaggregate tour-based demand model, now coded in Python (previously in ALOGIT).

2.2.2. Reports describing the development and application of PRISM can be found on the Transport for West Midlands and RAND Europe websites (TfWM PRISM Reports , RAND PRISM Reports including 'Related Products' at the bottom of that page).

2.2.3. PRISM was chosen because it (a) includes a variable demand model, and (b) is one of the few models in the UK to use Visum for the highway assignment. It was necessary to use Visum in preference to SATURN (which is the most commonly used highway assignment software in the UK), because it allows CVTT to be modelled without any software modifications.

2.2.4. The highway assignment and demand models were both modified to accommodate CVTT, as described in the following sections.

2.3. HIGHWAY ASSIGNMENT MODIFICATIONS

2.3.1. An earlier 2018 report from WSP, RAND Europe and Mott MacDonald (found here: 2018 Congestion Dependent Values of Travel Time Report) looked at the theoretical conditions for representing CVTT in highway assignment models and concluded that the following representation of time costs in the generalised cost function met these requirements and had the added benefit of being available in commercial software (Visum):

$$VTT_{FreeFlow} \times T_{FreeFlow} + VTT_{Delay} \times T_{Delay}$$

where

$T_{FreeFlow}$	is the free flow travel time (minutes)
T_{Delay}	is the delay time (minutes)
$VTT_{FreeFlow}$	is the value of free-flow time (p/min)
VTT_{Delay}	is the value of delay (p/min)

2.3.2. Other components of generalised cost (toll and distance) are unaffected by CVTT and included in the model in the usual way.

2.3.3. This leads to the definition of the delay multiplier, *M*, as the ratio of VTT_{Delay} to $VTT_{FreeFlow}$. For example *M*=2 implies that one minute of delay time has twice the value of one minute of free-flow time.

2.3.4. In addition to a benchmark test using the standard TAG VTT, we have tested *M* values of 3 and 5, referred to as Medium and High multipliers respectively.

2.3.5. $VTT_{FreeFlow}$ was estimated from TAG VTT by applying the following factors taken from the 2014/2015 UK Value of Travel Time report (found here: 2015 Values of Travel Time Savings and Reliability Final Reports):

Table 1: Free-flow VTT factors

Car journey purpose	Factor *r*
Commute	0.6968
Employer's business	0.5718
Other	0.5008

2.3.6. Free-flow VTTs therefore varied by purpose. The same values were used for the Medium and High tests.

2.3.7. The 2020 ITS Leeds Forward Look report noted that it would have been better to use a different set of factors from the 2014/15 report, which tended to be lower. The above values have been retained in the current study for consistency with the 2019 work.

2.3.8. It should be emphasised that the above modification to the generalised cost function was a pragmatic choice based on a combination of meeting the theoretical requirements and being available in commercial software. As discussed in the 2018 report, there may be other functions that also meet the theoretical requirements but which may provide a better fit to observed data.

2.3.9. Similarly, the true value of the multiplier *M* is unknown, so we have chosen a plausible range of values to test.

2.3.10. Visum requires separate coefficients for free-flow time (*t0*) and total time (*tCur*). Delay time can be calculated as *tCur-t0.* We can therefore write:

$$VTT_{FreeFlow} \times T_{FreeFlow} + VTT_{Delay} \times T_{Delay}$$
$$= VTT_{FreeFlow} \times t0 + VTT_{Delay} \times (tCur - t0)$$
$$= (VTT_{FreeFlow} - VTT_{Delay}) \times t0 + VTT_{Delay} \times tCur$$

2.3.11. So the coefficient on *t0* is $(VTT_{FreeFlow} - VTT_{Delay})$ and the coefficient on *tCur* is VTT_{Delay} (with appropriate adjustments to be consistent with the units currently used in PRISM for time and generalised cost).

2.3.12. Since $VTT_{FreeFlow} \leq VTT_{Delay}$ the coefficient on *t0* will be negative for some tests. However, the total generalised cost of time will always be positive so this does not cause any problems in the modelling.

2.3.13. VTTs used for the AM peak base year model runs are shown in Table 2 (using *r* values from Table 1 for the Medium and High multiplier tests). These are based on version 1.8.2 (October 2017) of the TAG Data Book, which was the current version when the PRISM 5.1 base year model was validated. We have continued to use this version for consistency

Table 2: VTT (p/min) - AM – per vehicle

CVTT	Commute $VTT_{FreeFlow}$	Commute VTT_{Delay}	Employer's business $VTT_{FreeFlow}$	Employer's business VTT_{Delay}	Other $VTT_{FreeFlow}$	Other VTT_{Delay}
TAG	20.18	20.18	30.10	30.10	13.92	13.92
Medium	14.06	42.18	17.21	51.63	6.97	20.91
High	14.06	70.31	17.21	86.06	6.97	34.86

2.4. DEMAND MODEL MODIFICATIONS

2.4.1. Section 3.2 of the 2019 report describes the modifications made to the PRISM demand model to enable the testing of CVTT multipliers.

In summary, the travel time and cost components of the utility function (ignoring attraction variables, mode constants and socio-demographic constants) for car driver trips in the

PRISM demand model can, in most cases, be simplified as:

$$U = \beta_{time} T + \beta_{cost} f(cost)$$

where:

U	is the utility in utils
β_{time} and β_{cost}	are estimated parameters
T	is the travel time in minutes
$cost$	is the monetary cost in pence (vehicle operating cost plus toll)
$f()$	is a function of cost that varies by trip purpose and may include linear and log(cost) terms

2.4.2. For the purposes of testing the impact of CVTT multipliers, the input travel time T was replaced by a modified travel time:

$$r(T_{FreeFlow} + M \times T_{Delay})$$

where:

r	is the ratio of free-flow VTT to average VTT (i.e. the factor we applied to the TAG VTT value to estimate the free-flow VTT, see Table 1).
M	is the delay multiplier (i.e. the ratio of delay VTT to free-flow VTT
$T_{FreeFlow}$	is the free-flow travel time (minutes)
T_{Delay}	is the delay travel time (minutes, total travel time is simply $T = T_{FreeFlow} + T_{Delay}$)

3. STAGE 1: BASE MATRIX DEVELOPMENT REVIEW

3.1.1. Stage 1 of the project comprised a review of the development of PRISM prior matrices (i.e. the matrices which are used as the basis for matrix estimation from counts). The focus of this was to understand the extent to which the prior matrices depend on values of travel time (VTT), and therefore assess whether the use of congested values of travel time (CVTT) throughout the matrix development process would have resulted in a significantly different set of prior matrices.

3.1.2. In the 2019 work, all the tests carried out, whether base year assignments or future year forecasts, were founded on the same PRISM 5.0 base year matrix. PRISM is an 'absolute model applied incrementally' which, in the simplest case, means that forecast growth from synthetic models is applied to a validated base year matrix; hence the forecasts are dependent on the base year matrix.

3.1.3. In common with most models in the UK, this matrix was produced by applying a matrix estimation process which makes use of count data, a set of prior matrices, and route choice information from an assignment.

3.1.4. Chapter 4 describes the use of CVTT multipliers in matrix estimation and how they affect the base year matrix. In this section we explore whether the prior matrices could be affected by VTT, and therefore might have been different if CVTT had been incorporated from the outset of the PRISM matrix development process, including the development of data and matrices produced by third parties.

3.1.5. Full details of the development of the prior matrices are given in the PRISM 5.0 Model Validation Report. Here, we do not describe the process in full, focusing only on those elements where VTT could have an effect.

3.1.6. The focus is on the development of the car prior matrices, as car is the only vehicle type or mode in our tests to which the CVTT multipliers are applied.

Source matrices

3.1.7. Table 3 below summarises how the source matrices used in the development of PRISM were derived and whether they are affected by VTT.

Table 3: Source matrices used in PRISM 5.0

Source	Description	Impact of VTT
MRTM	Prior matrices from Highways England's Midlands Regional Traffic Model. Most cells are from mobile phone data (MPD), but shorter trips	The synthetic matrix was calibrated using cost skims from an assignment using TAG VTT.

Source	Description	Impact of VTT
	come from a synthetic matrix. Each cell is either 100% MPD or 100% synthetic. In urban areas cells <4km are synthetic; in rural areas the threshold is 10km.	However, only cells derived from MPD were used for PRISM. MPD is less dependent on VTT than the synthetic matrix. The original MPD was subject to a number of adjustments during the development of MRTM, including some which are VTT-dependent: (1) the synthetic matrix was used to disaggregate MPD by journey purpose; (2) rail trips were removed from the MPD using trip data from the PLANET Midlands rail model which may have some dependency on VTT.
GPS	Matrices from INRIX and Trafficmaster derived from GPS devices.	None
Census JTW	2011 Census journey to work matrices. (Used for commuting trips only.)	None
Synthetic	Matrices generated by the PRISM 4.8 demand model, using 2016 planning data and cost skims from a 2011 assignment.	The PRISM 4.8 demand model was estimated using cost skims from a 2011 assignment which used 2011 VTT from the Nov 2016 TAG Data Book. The same skims were used to apply the model with 2016 planning data to generate the 2016 base matrix.

3.1.8. Two of the source matrices, MRTM and synthetic, have some dependency on VTT. The impact on the synthetic matrix is likely to be more significant than on the MRTM matrices, with VTT mainly affecting the purpose split applied to the latter.

Processing of Source matrices

3.1.9. The source matrices listed above were subject to subsequent processing to produce the prior matrices used in matrix estimation. The processing comprised further adjustments to the matrices, followed by merging the different sources.

3.1.10. Factors were applied to the GPS matrices to ensure that the trip length distribution (TLD) was a good match to National Travel Survey (NTS) data. The matrix TLD was derived from distance skims from a 2011 inter-peak assignment model, which therefore depends on the VTT used.

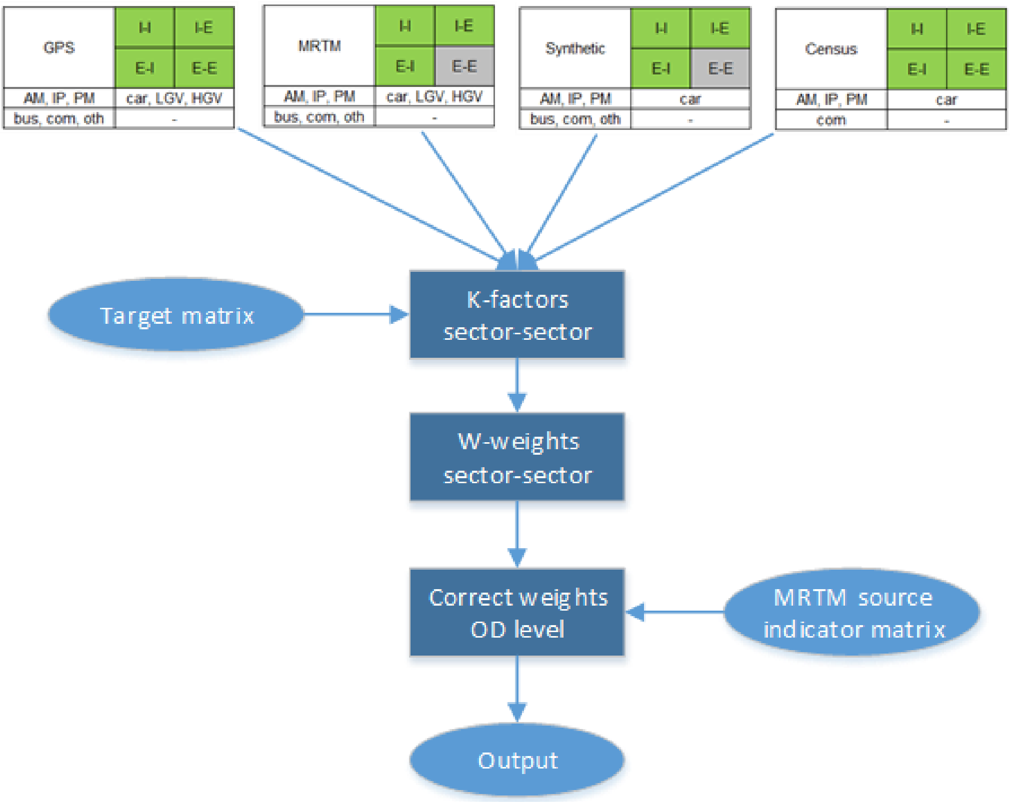
3.1.11. The four source matrices were then merged. Figure 1, taken from the PRISM MVR, shows the process. This makes use of a 'target matrix', with the weight given to each matrix in the merge process dependent on how close it is to the target matrix at the sector to sector level.

3.1.12. The target matrix was derived by combining the synthetic (for internal-internal trips) and GPS matrices (for other movements), then applying matrix estimation using screenline counts. Only the sector-sector flows from the target matrix affect the matrix merging process (where sectors are defined by the count screenlines).

3.1.13. The production of the target matrix is therefore affected by VTT in two ways:

- The production of the synthetic matrix used for internal-internal trips (see Table 3).
- The assignment used to derive route choice for the matrix estimation step. The use of screenline rather than link counts reduces, but does not eliminate, the dependency on the precise route choice produced by the assignment.

Figure 1: PRISM 5.0 matrix merging process



Summary of impact of VTT on prior matrices

3.1.14. It is clear from the above description that VTT affects the development of the PRISM 5 prior matrices, as follows:

- Estimation of the PRISM 4.8 demand model used to produce a synthetic matrix. The synthetic matrix is used in the prior matrix development as (a) one of the matrices used in the merge, and (b) to derive the target matrix, which in turn determines the merge weights given to each matrix.
- Development of the MRTM prior matrices.
- Calculation of modelled TLDs, used as the basis for adjusting the GPS matrices.

3.1.15. The first impact listed above, on the synthetic matrix, is likely to be the most significant, with less impact on the MRTM prior matrices and the TLD adjustment of the GPS matrices.

3.1.16. In terms of the overall impact on the prior matrices it is therefore likely that VTT (and CVTT multipliers, if they were to be applied) has more impact on shorter trips (for which the synthetic matrix is likely to have a higher weight in merging) than longer trips (where MPD and GPS data, which are less VTT-dependent, are likely to have more weight).

3.1.17. It is not possible to quantify the impact of VTT on the prior matrices without going back and repeating the processing with different VTT (with or without congestion multipliers). In particular, we would need to repeat the estimation of the demand model and its application to produce a synthetic matrix.

3.1.18. To summarise:

- Using CVTT multipliers during production of the prior matrices would have altered the result, but there is no evidence for the scale or direction of the change.
- To try to quantify the impact would be a significant amount of work, limiting what other investigations could be carried out within budget and programme constraints.
- We therefore made the pragmatic assumption that we would proceed using the existing prior matrices for the remaining tests, while bearing in mind that some of the differences observed in the results may have been greater or smaller if CVTT had been used in the production of the prior matrices.

4. STAGE 2A: MATRIX ESTIMATION WITH CVTT

4.1. INTRODUCTION

4.1.1. This chapter describes the results of the first part of Stage 2 of the project, which involved incorporating CVTT multipliers into the matrix estimation (ME) process.

4.1.2. The original intention for Stage 2 matrix estimation was to repeat the existing ME process described in chapter 3, but with the inclusion of CVTT multipliers in the assignment(s) used to produce route choices for use in ME. However, various technical difficulties meant that a more fundamental change in the approach to ME was required. This is described in the next section.

4.2. MATRIX ESTIMATION TECHNICAL ISSUES

4.2.1. A series of verification tests were carried out to confirm that ME was correctly set up for PRISM 5.1.18 in the base case of using TAG values of travel time (VTTs), without congestion multipliers. Having completed these tests, the expectation was that ME would simply be repeated with medium and high CVTT multipliers in the assignment (these tests are referred to as ME2 and ME3 respectively). However, each of the ME2 and ME3 runs failed in at least one time period. Upgrading to the latest version of Visum (either the latest service pack for Visum 18, or the very latest Visum 21 release) did not solve the problem.

4.2.2. PRISM 5 uses the TFlowFuzzy matrix estimation method in Visum. PTV were contacted for technical support and advised that this method is sensitive to small changes in the assignment and can fail to find a solution. This can either be because there is no solution, or the solution algorithm is not robust enough to find the solution (for more details see: TFlowFuzzy Algorithm).

4.2.3. A second matrix estimation method, least squares, is also available in Visum. PTV's advice was to use this instead. Details of both ME methods are available online:

- TFlowFuzzy: TFlowFuzzy Method
- Least squares: Least Squares Method

4.2.4. After a certain amount of trial and error with ME parameters and implementing a workaround to deal with a software bug, ME2 and ME3 ran to completion for all time periods using the least squares method.

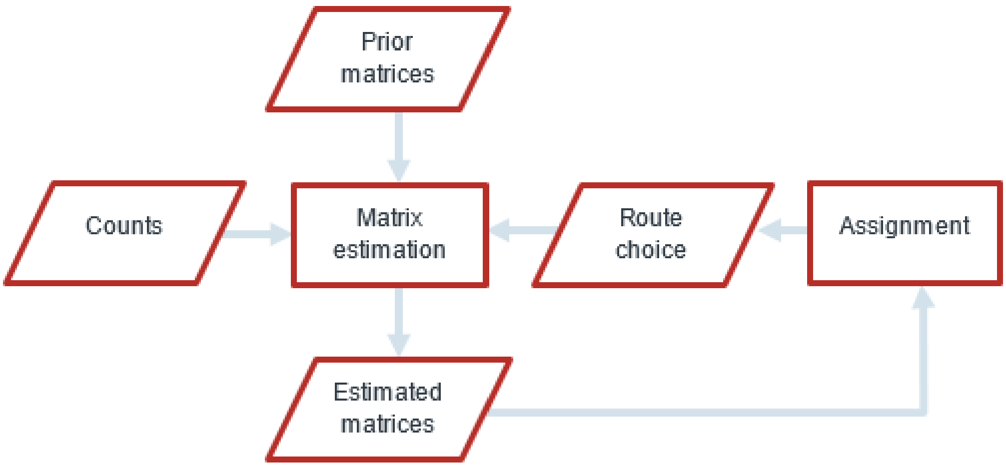
4.2.5. The main parameters tweaked were the weights applied to the traffic counts and prior matrix cells. These determine the importance given to matching observed counts compared to staying close to the prior matrix. Full details can be found in the above links to the Visum documentation.

4.2.6. The final weights used were:

- Count weights equal to 1 divided by the square root of the count. This was based on advice from PTV and is broadly equivalent to minimising the GEH statistic for modelled and observed counts.
- A matrix weight of 0.5. This approximates to the relative importance of staying close to the prior matrix compared to matching observed counts. A range of weights from 0.25 to 2.0 was tested, with little apparent impact on the result.

4.2.7. Figure 2 is a simplified representation of the overall ME process. It shows an iterative loop between the assignment and the matrix estimation. This is necessary because as the matrices change, so will the route choice in the assignment that feeds into the main ME calculations.

Figure 2: Simplified matrix estimation process



4.2.8. Investigation of the results revealed a further problem for some time periods, with the assignment failing to converge, particularly in later iterations of the assignment-ME loop. This appeared to be the result of the ME process continually increasing demand for some OD pairs until the network became too congested for the assignment to converge. This seemed to be a result of capacity constraints in the network meaning that the modelled flow on certain links could never reach the observed value, but on each run of ME (in the assignment-ME loop), more and more demand was added to the matrix for the OD pairs using those links. Unlike TFLowFuzzy, the least squares method does not have a parameter limiting the scale of changes that ME can make, so this is a problem that only arose with the switch to the new ME method.

4.2.9. This behaviour means that, in this case, the ME-assignment loop can never fully converge. In a real-life application further work would be required to either check and correct the observed flow or modify the network capacity. However, for the purposes of this research a more pragmatic approach was adopted, to take the estimated matrix from an earlier loop, with consideration of the following requirements:

- Minimising matrix distortion (i.e. differences between the prior and estimated matrices). Distortion tends to get worse as the loops progress.
- Maximising the proportion of the calibration links (i.e. those with an observed flow used in ME) that meet TAG link flow targets. This tends to increase as the loops progress.
- Recognising the need for the assignment to converge, noting that the risk of non-convergence will be higher when it comes to forecasting. Assignment convergence problems increase as the loops progress, due to the increases in demand.

4.2.10. Taking all this into consideration, the decision was made to take estimated matrices from the second iteration of the ME-assignment loop. This decision was based on the tables in Appendix A, which show calibration, matrix distortion, and convergence statistics for each loop.

4.2.11. The estimated matrices have therefore not been taken from the end of a converged ME-assignment loop (as noted above, this loop does not currently converge). Caution is therefore needed when interpreting the differences between the estimated matrices as some of the differences may be due to convergence noise. Similarly, comparison with results from the 2019 study is complicated by the change in the matrix estimation method underpinning the base matrices.

4.2.12. While the first attempts to estimate matrices using CVTT multipliers failed, this was due to the nature of the TFlowFuzzy method and does not indicate that the use of CVTT multipliers introduces additional technical difficulties. In the original PRISM 5 matrix estimation work there was a lot of trial and error involved before a successful run of TFlowFuzzy was finally achieved.

4.3. ANALYSIS OF ESTIMATED MATRICES

4.3.1. Table 4 below sets out the completed matrix estimation runs analysed in the rest of this note. The ME run with TAG VTT is referred to as ME1B, to distinguish it from the ME1 run presented in chapter 3 (the difference being that ME1B uses the least squares ME method, for consistency with ME2 and ME3).

Table 4: Matrix estimation runs

Run ID	CVTT multiplier or TAG	Output matrix
ME1B	TAG	MAT1
ME2	Medium	MAT2
ME3	High	MAT3

Matrix deformation

4.3.2. Paragraphs 8.3.14-8.3.17 of TAG Unit M3.1 set out a series of 'matrix deformation' tests intended to monitor the changes to the prior matrix brought about by matrix estimation. These include:

- Regression statistics (R^2, slope, and intercept) and scatterplots for matrix cells and trip ends (estimated vs prior matrix).
- Comparison of trip length distributions, including means and standard deviations.
- Absolute and percentage changes in sector to sector matrix cells.

4.3.3. For the current research project we have focused on a more limited range of analyses compared to the full TAG requirements.

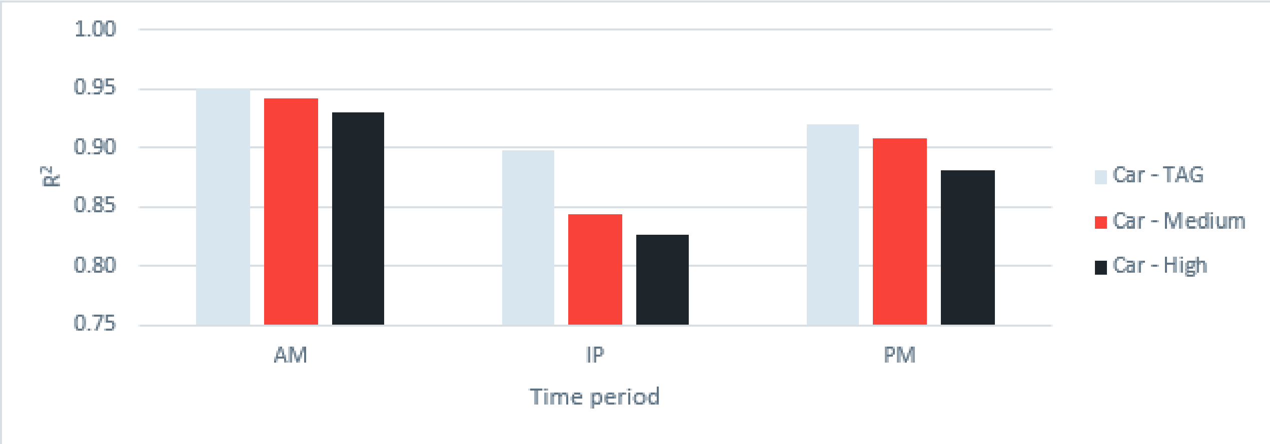
4.3.4. Table 5 shows regression statistics for each multiplier value (TAG, Medium, High) and time period, for all vehicles and car only. (CVTT multipliers are only applied to cars. Any impact on LGV and HGV matrices is only secondary, caused by these vehicles changing their routes in response to cars changing their routes.) As noted above, these are for the estimated matrices from the second iteration of the ME-assignment loop.

Table 5: Matrix deformation: OD regression statistics

Statistic	Time period	Car TAG	Car Medium	Car High	All vehicles TAG	All vehicles Medium	All vehicles High
Intercept	AM	0.031	0.040	0.045	0.035	0.044	0.049
Intercept	IP	0.024	0.031	0.037	0.028	0.035	0.041
Intercept	PM	0.034	0.042	0.049	0.037	0.046	0.052
Slope	AM	1.001	1.001	1.002	1.001	1.001	1.002
Slope	IP	0.999	1.001	1.003	1.000	1.001	1.003
Slope	PM	1.001	1.003	1.003	1.001	1.002	1.003
R^2	AM	0.950	0.941	0.930	0.951	0.944	0.935
R^2	IP	0.898	0.843	0.827	0.900	0.856	0.842
R^2	PM	0.920	0.908	0.881	0.925	0.915	0.891

4.3.5. There is a consistent pattern with TAG VTT having the least deformation (intercept closest to zero, slope closest to 1, R^2 closest to 1), followed by the Medium CVTT multiplier, followed by the High multiplier. This is illustrated in Figure 3 which shows the R^2 values for the car matrices.

Figure 3: Matrix deformation R^2 statistics, car matrices

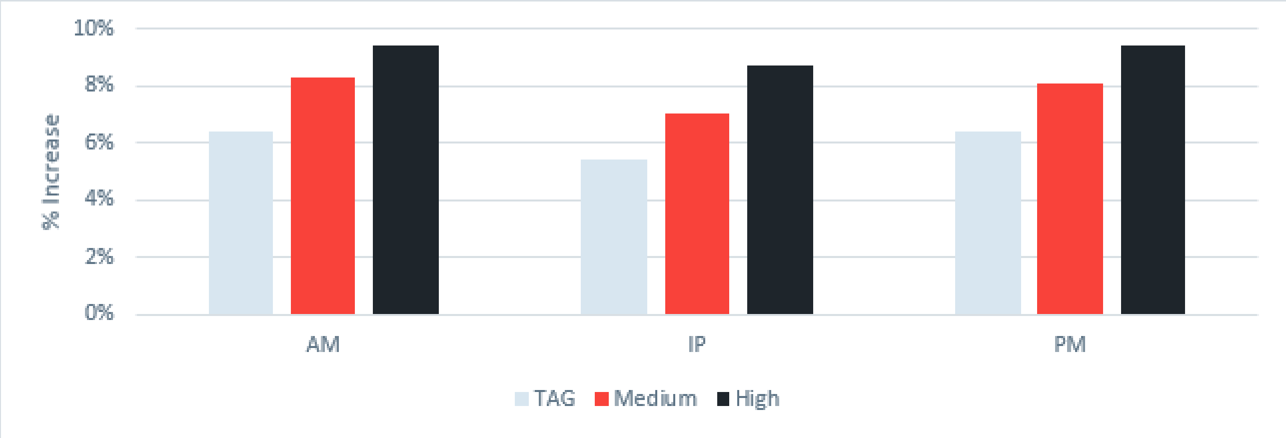


4.3.6. A similar pattern is apparent if we compare the change in total trips in the matrices, as shown in Table 6 and Figure 4. TAG VTT shows the smallest increases, followed by the Medium and then the High multiplier.

Table 6: Matrix totals and changes from prior

Metric	Matrix	Car AM	Car IP	Car PM	All vehicles AM	All vehicles IP	All vehicles PM
Total trips	Prior	483,032	435,925	536,079	549,764	502,585	589,861
Total trips	TAG	513,793	459,546	570,493	584,832	529,997	627,534
Total trips	Medium	523,029	466,698	579,356	594,307	537,350	636,355
Total trips	High	528,677	474,002	586,483	599,788	544,532	643,452
% change from prior	TAG	6.4%	5.4%	6.4%	6.4%	5.5%	6.4%
% change from prior	Medium	8.3%	7.1%	8.1%	8.1%	6.9%	7.9%
% change from prior	High	9.4%	8.7%	9.4%	9.1%	8.3%	9.1%

Figure 4: **Increases in total trips due to ME**



4.3.7. Figure 5 to Figure 13 are scatterplots comparing the prior and estimated matrices at the OD matrix level, for each time period, cars only, for each multiplier value. In each case the largest changes tend to occur in cells with relatively small trip numbers. In particular, there is a cluster of points close to the *y* axis, indicating a large increase between the prior and estimated matrices. This may relate to the behaviour noted in section 4.2 with some matrix cells being increased by large amounts to try to increase flows on a link, or links, where capacity constraints prevent the observed flow being matched.

Figure 5: Estimated vs prior matrix, OD cells, AM peak, TAG VTT

Figure 6: Estimated vs prior matrix, OD cells, inter-peak, TAG VTT

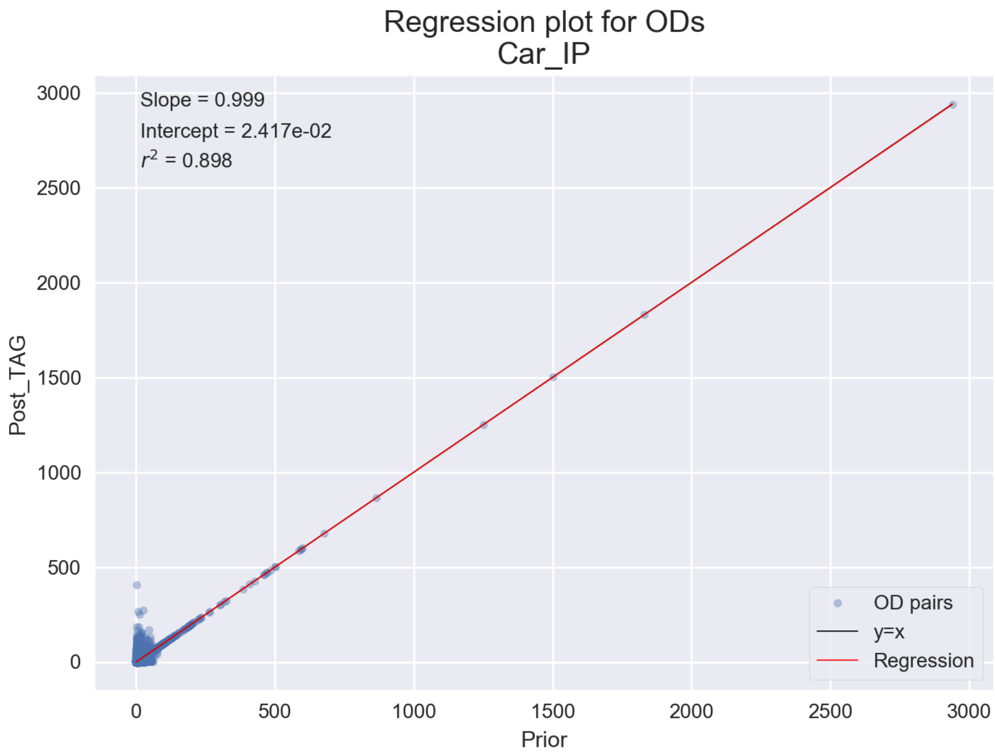


Figure 7: Estimated vs prior matrix, OD cells, PM peak, TAG VTT

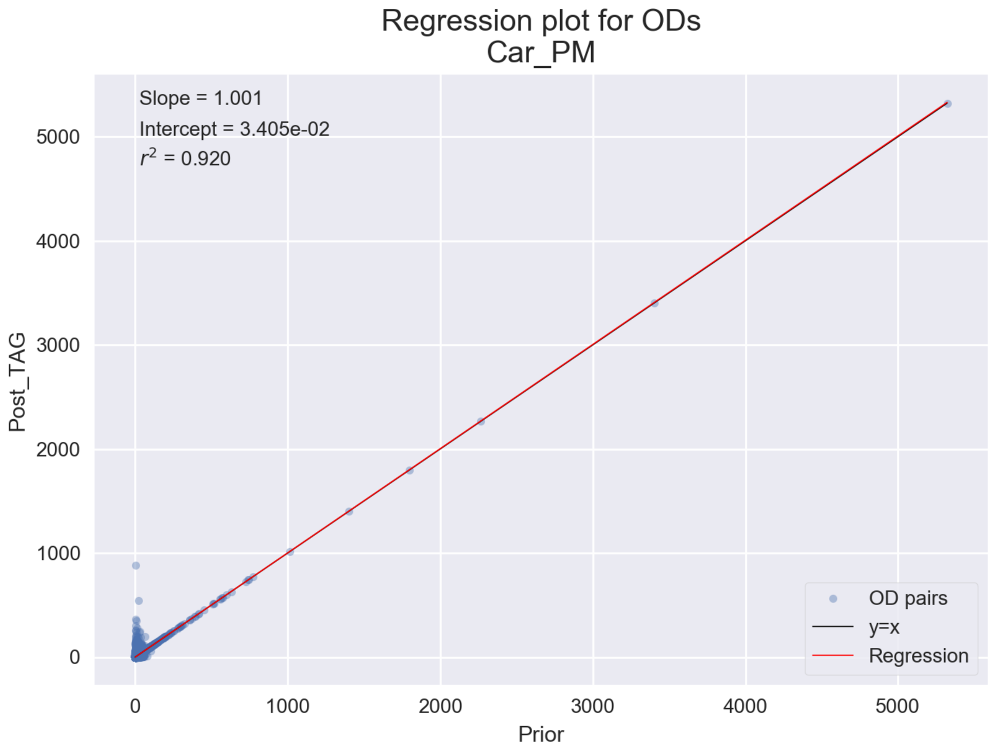


Figure 8: Estimated vs prior matrix, OD cells, AM peak, Medium CVTT

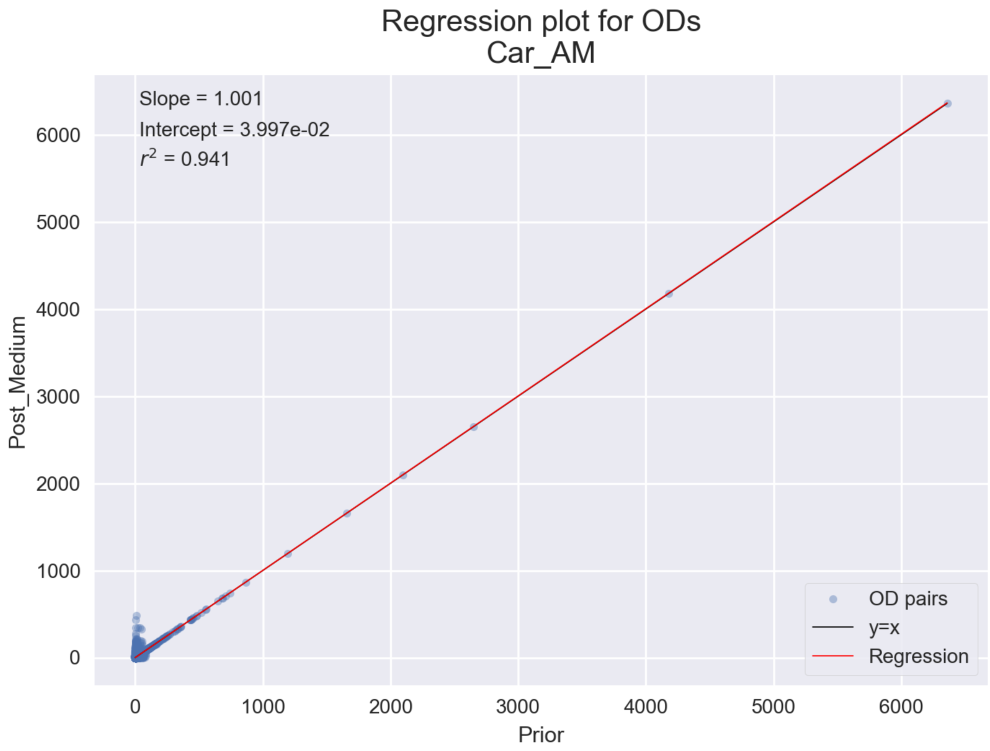


Figure 9: Estimated vs prior matrix, OD cells, inter-peak, Medium CVTT

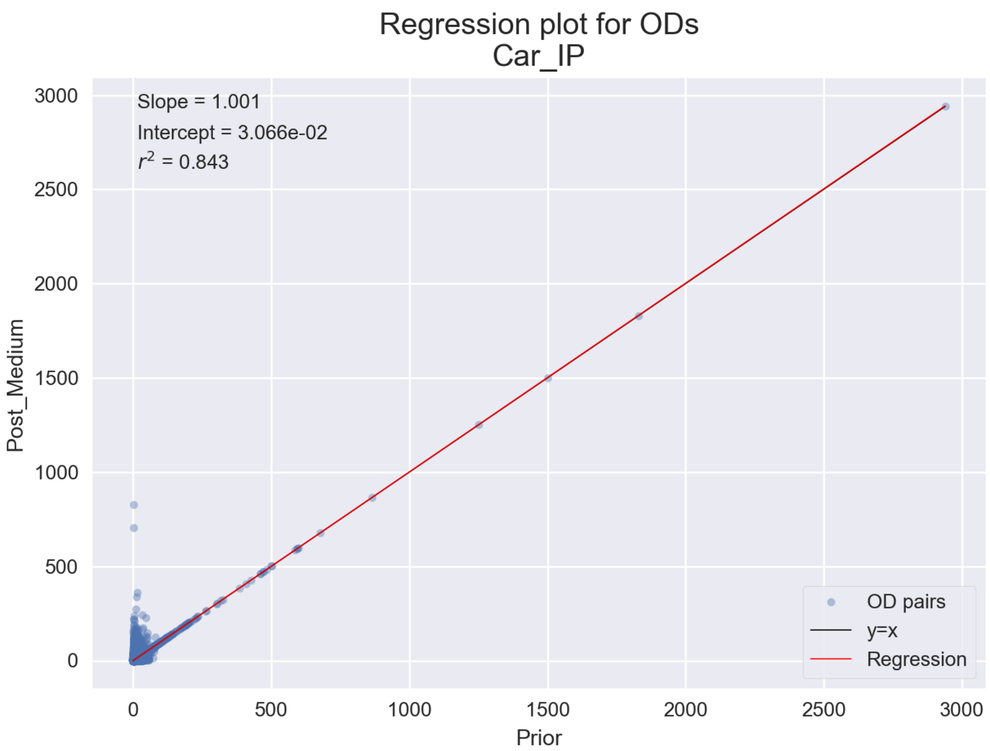
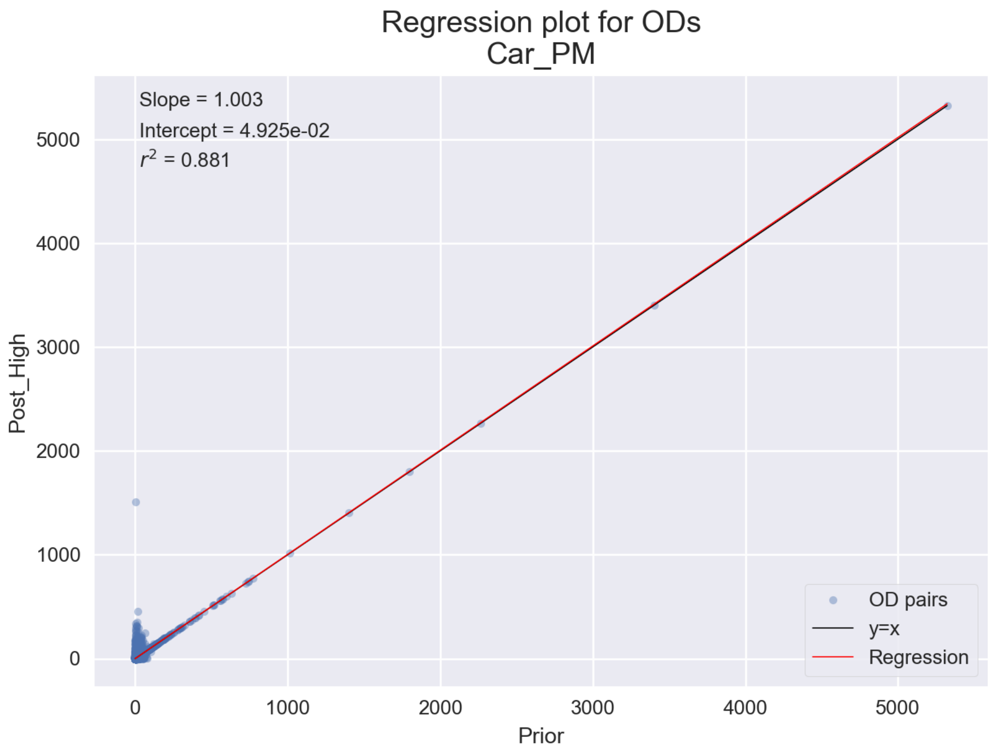


Figure 10: Estimated vs prior matrix, OD cells, PM peak, Medium CVTT

Figure 11: Estimated vs prior matrix, OD cells, AM peak, High CVTT

Figure 12: Estimated vs prior matrix, OD cells, inter-peak, High CVTT

Figure 13: Estimated vs prior matrix, OD cells, PM peak, High CVTT



4.3.8. Table 7 compares means and standard deviations of trip lengths for the matrices. The trip lengths are based on the assigned routes, meaning that the distance for a given OD pair will vary between the matrices, i.e. these results are a function of the assignment as well as the structure of the matrix.

4.3.9. Although all the estimated matrices tend to reduce the mean trip length compared to the prior, there is otherwise no clear pattern here, with no significant differences between any of the estimated matrices.

Table 7: Means and standard deviations (SD) of trip lengths (km)

Time period	Veh type	Mean Prior	Mean TAG	Mean Med CVTT	Mean High CVTT	SD Prior	SD TAG	SD Med CVTT	SD High CVTT
AM	Car	16.4	16.0	16.1	16.1	35.2	35.2	34.3	34.2
AM	LGV	28.6	27.5	27.3	27.5	54.2	53.3	53.4	53.6
AM	HGV	66.3	61.5	61.3	61.6	92.2	88.8	88.9	88.7
IP	Car	15.3	15.0	15.1	15.2	35.9	35.8	34.9	35.7
IP	LGV	26.3	25.7	25.6	25.5	53.0	52.5	52.6	52.5
IP	HGV	78.0	71.6	71.8	71.6	97.5	93.8	94.5	94.1
PM	Car	16.0	15.6	15.6	15.5	31.9	32.1	31.2	31.1
PM	LGV	24.7	24.0	24.0	24.1	51.4	50.4	50.5	50.8
PM	HGV	70.7	64.6	65.4	65.4	94.5	90.7	91.6	91.4

Comparison of Estimated Matrices

4.3.10. As well as looking at changes from the prior matrices it is instructive to look at differences between the three estimated matrices.

4.3.11. When comparing the estimated matrices, it is important to note that in a real life application more emphasis would be placed on reducing the extent of matrix deformation, which would in turn reduce the differences between the estimated matrices.

4.3.12. Table 8 shows the regression statistics from pairwise comparisons of Medium CVTT vs TAG, and High CVTT vs TAG. Intercept values are lower than those in Table 5 and R^2 values are closer to 1, suggesting that the estimated matrices are more similar to each other than they are to the prior matrix. However, slopes tend to be further from 1, suggesting the opposite.

Table 8: Comparison of estimated matrices: regression statistics

Models	Time period	Car R^2	Car Slope	Car Intercept	All vehs R^2	All vehs Slope	All vehs Intercept
Medium vs TAG	AM	0.965	0.987	0.016	0.969	0.988	0.016
Medium vs TAG	IP	0.883	0.971	0.021	0.899	0.974	0.021
Medium vs TAG	PM	0.952	0.984	0.018	0.958	0.985	0.019
High vs TAG	AM	0.950	0.986	0.022	0.956	0.987	0.023
High vs TAG	IP	0.861	0.971	0.028	0.878	0.973	0.029
High vs TAG	PM	0.933	0.989	0.022	0.941	0.990	0.023

4.3.13. Figure 14 to Figure 16 compare the matrix estimated with Medium CVTT with that using TAG VTT. Figure 17 to Figure 19 compare High CVTT to TAG.

4.3.14. Despite the relatively high R^2 values there are some considerable differences between the matrices, particularly for smaller cell values. They are reasonably evenly spread around the diagonal.

Figure 14: Comparison of estimated matrices, OD cells, AM peak, Medium CVTT vs TAG

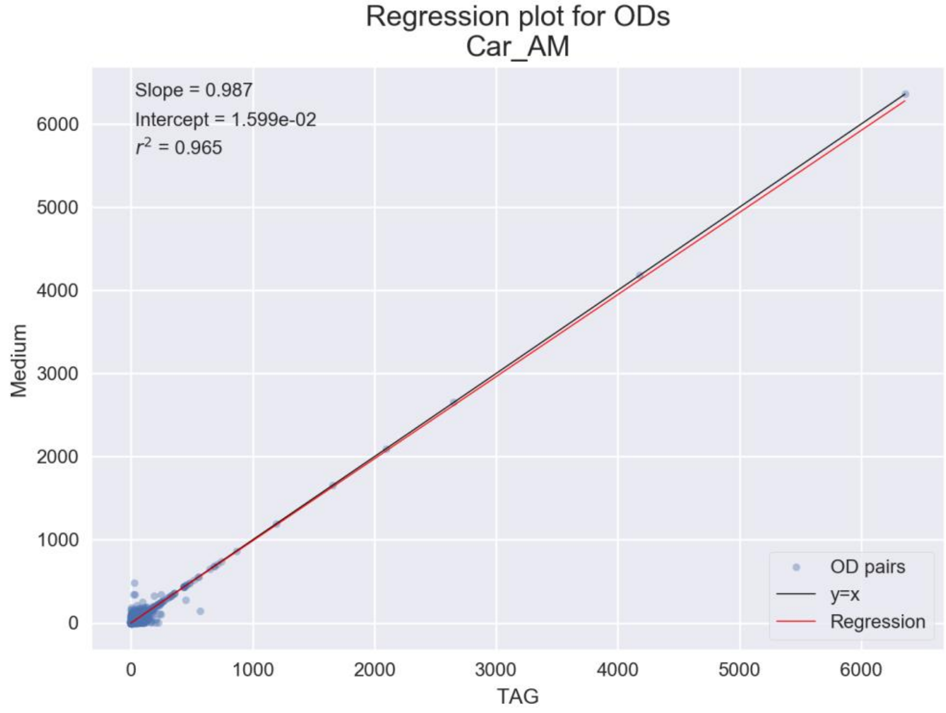


Figure 15: Comparison of estimated matrices, OD cells, inter-peak, Medium CVTT vs TAG

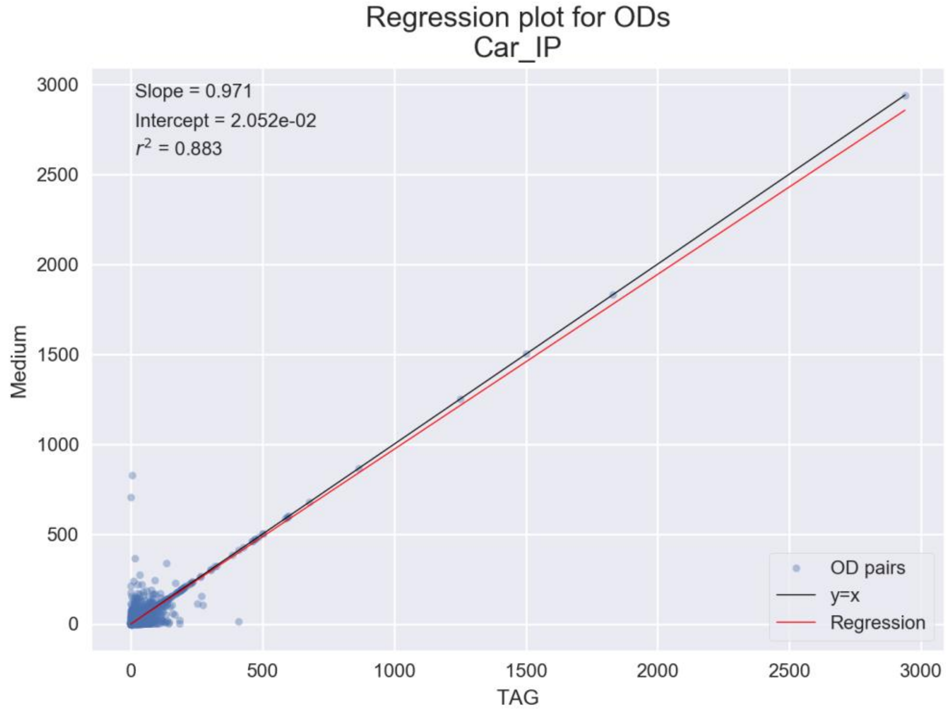


Figure 16: Comparison of estimated matrices, OD cells, PM peak, Medium CVTT vs TAG

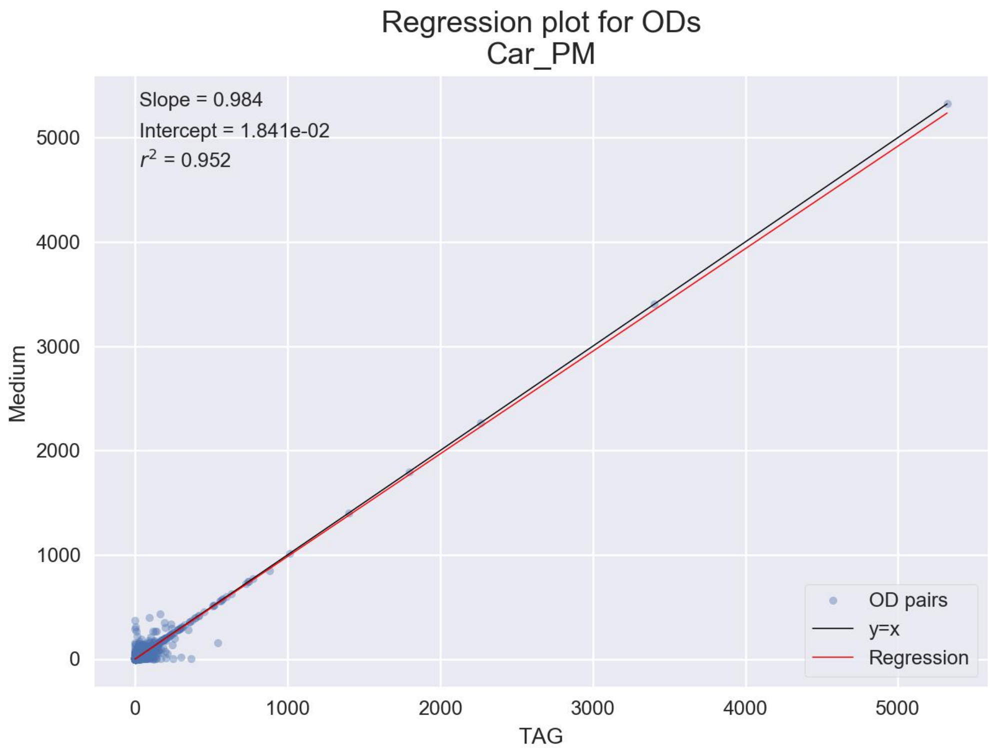


Figure 17: Comparison of estimated matrices, OD cells, AM peak, High CVTT vs TAG

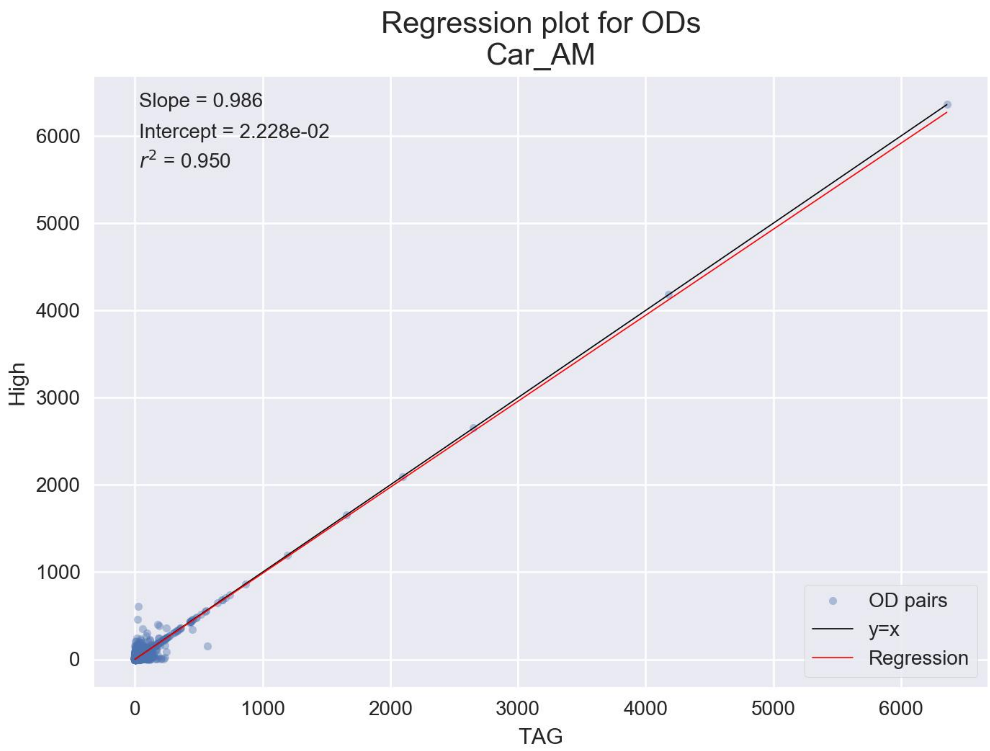


Figure 18: Comparison of estimated matrices, OD cells, inter-peak, High CVTT vs TAG

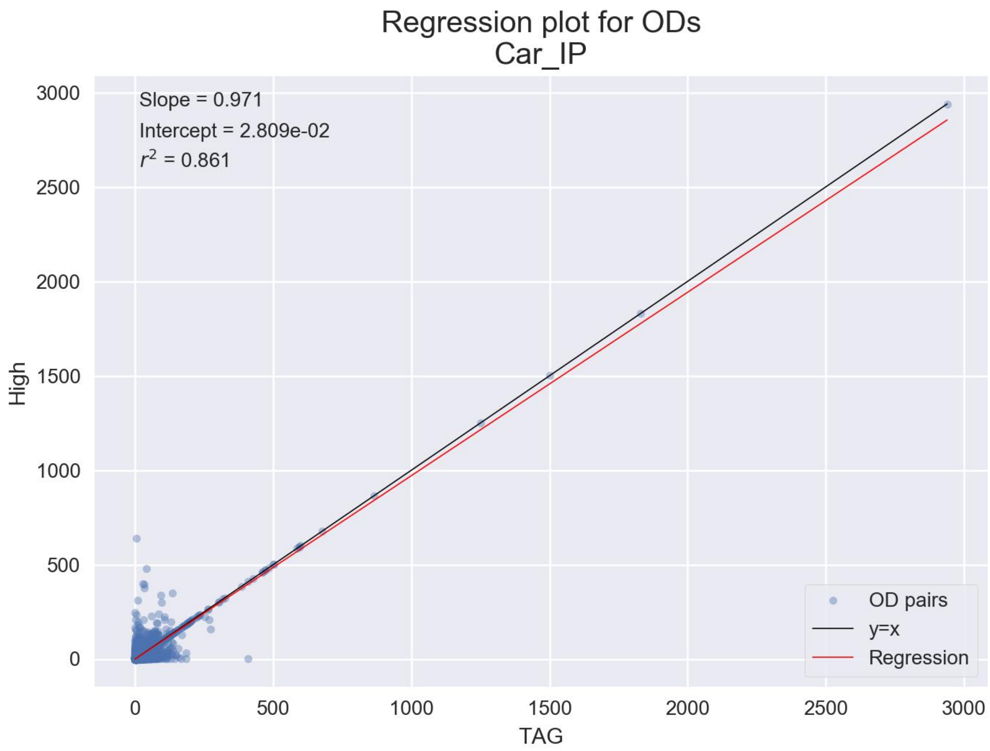
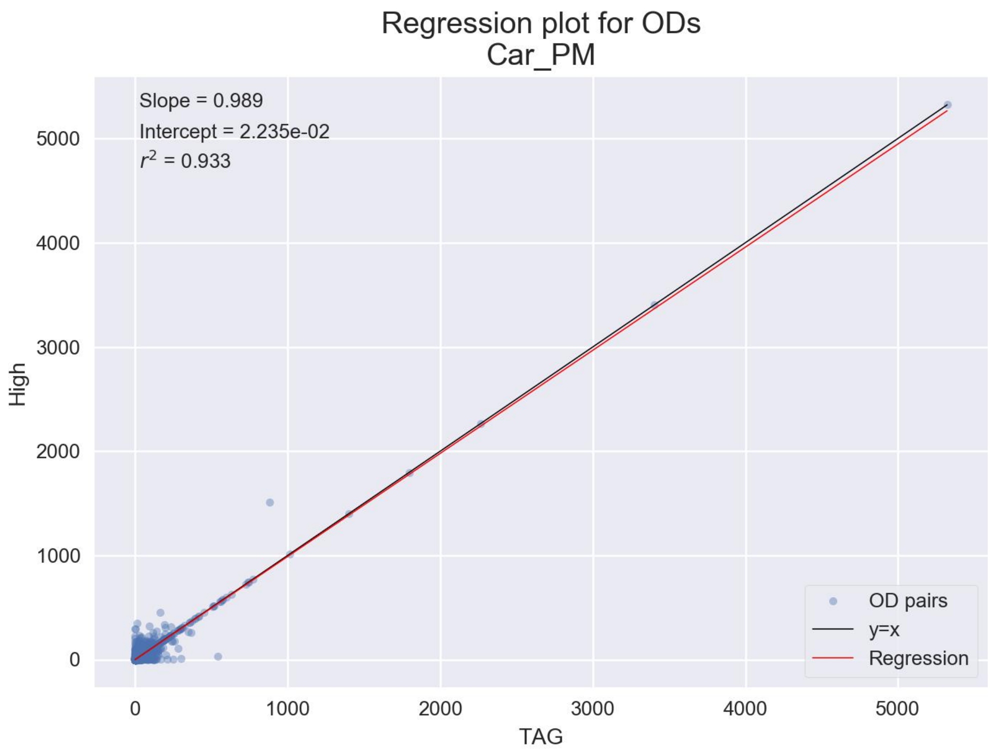


Figure 19: Comparison of estimated matrices, OD cells, PM peak, High CVTT vs TAG



4.4. ASSIGNMENT RESULTS

Screenline flow validation

4.4.1. Table 9 shows screenline flow validation statistics from the assignment of the estimated matrices, for those screenlines used in calibration and those held back for validation. This shows the proportion of screenlines that meet the PRISM target of modelled and observed flows within 5%, or a GEH less than 4 (noting that the latter is no longer part of TAG).

4.4.2. Overall there is relatively little difference in performance between the different matrices and assignments. There is nothing to choose between TAG and Medium CVTT for the calibration screenlines, with High CVTT slightly worse. TAG is marginally the best for the validation screenlines.

4.4.3. For comparison Table 10 shows the same statistics from the assignment of the prior matrices, from the 2019 study, which are only available for the AM peak.

Table 9: Screenline validation, post-ME matrices

Time period	VTT	Calibration Car	Calibration LGV	Calibration HGV	Calibration All vehs	Validation Car	Validation LGV	Validation HGV	Validation All vehs
AM	TAG	90%	100%	94%	89%	52%	83%	74%	52%
AM	Med	87%	99%	98%	89%	54%	85%	74%	54%
AM	High	79%	99%	98%	80%	52%	85%	74%	54%
IP	TAG	91%	99%	96%	89%	57%	85%	63%	48%
IP	Med	91%	100%	96%	91%	48%	85%	65%	43%
IP	High	85%	100%	97%	86%	54%	85%	70%	43%
PM	TAG	91%	100%	99%	90%	52%	89%	74%	48%
PM	Med	91%	99%	99%	93%	41%	83%	76%	46%
PM	High	83%	100%	99%	87%	46%	85%	76%	46%

Table 10: Screenline validation, prior matrices, AM peak only (from 2019 study)

Time period	VTT	Calibration Car	Calibration LGV	Calibration HGV	Calibration All vehs	Validation Car	Validation LGV	Validation HGV	Validation All vehs
AM	TAG	44%	92%	64%	46%	46%	89%	57%	41%
AM	Med	40%	91%	64%	42%	41%	83%	59%	48%
AM	High	37%	93%	66%	40%	30%	80%	57%	43%

Link Flow Validation

4.4.4. Table 11 shows the proportion of links that meet the TAG link flow validation criteria, split between calibration and validation sites.

4.4.5. There is a clearer pattern here than for screenline flows. TAG VTT gives the best fit in all cases, followed by medium CVTT and then high CVTT. Possible reasons for this are discussed in section 8.3.4.

Table 11: Link flow validation, post-ME matrices

Time period	VTT	Calibration Car	Calibration All vehs	Validation Car	Validation All vehs	All Car	All All vehs
AM	TAG	85%	85%	60%	58%	81%	81%
AM	Med	78%	79%	57%	58%	75%	75%
AM	High	74%	75%	54%	54%	71%	71%
IP	TAG	91%	89%	63%	61%	86%	85%
IP	Med	84%	84%	61%	57%	81%	79%
IP	High	80%	80%	58%	57%	76%	76%
PM	TAG	85%	85%	59%	59%	81%	81%
PM	Med	78%	78%	58%	58%	75%	75%
PM	High	73%	73%	57%	55%	70%	70%

4.4.6. For comparison, Table 12 shows the corresponding statistics from the assignment of the prior matrices from the 2019 study, for the AM peak only. This shows a similar pattern.

Table 12: Link flow validation, prior matrices AM peak only, from 2019 study

Time period	VTT	Calibration Car	Calibration All vehs	Validation Car	Validation All vehs	All Car	All All vehs
AM	TAG	51%	49%	63%	64%	53%	51%
AM	Med	46%	46%	56%	59%	48%	48%
AM	High	35%	41%	43%	51%	36%	43%

Journey Time Validation

4.4.7. Table 13 shows journey time validation statistics, as the proportion of routes that achieve the target PRISM validation standards. These are disaggregated into different route types. Tier 1 are the most important routes, and the target is the TAG standard of 85% of modelled times within 15% of observed. Tiers 2 and 3 are less strategically important, and tolerances of 25% and 35% respectively are used. The full rationale behind this, with maps showing the different tiers, can be found in section 5.5 of the PRISM 5.0 Model Validation Report.

4.4.8. The pattern here is quite different from the link flow validation statistics. The high CVTT multiplier generally performs best, followed by medium CVTT, and then TAG.

Table 13: Journey time validation, estimated matrices

Time period	VTT	Tier 1	Tier 2, non-motorway	Tier 2, motorway	Tier 3
AM	TAG	79%	88%	88%	93%
AM	Med	79%	89%	88%	93%
AM	High	83%	95%	88%	93%
IP	TAG	76%	95%	100%	93%
IP	Med	79%	96%	100%	96%
IP	High	81%	98%	100%	96%
PM	TAG	79%	84%	82%	91%
PM	Med	81%	93%	85%	95%
PM	High	78%	95%	85%	96%

OD routing

4.4.9. Figure 20 shows the modelled route choice in the AM peak between Coventry and Stafford for the three estimated matrices. There is little difference between the TAG and Medium CVTT matrices, with most traffic using the M6 to go around the northern edge of Birmingham. With High CVTT this switches to the M6 Toll; the high CVTT multiplier increases the generalised cost of the M6 relative to the M6 Toll and makes the latter a more attractive option. It is worth noting that the M6/M6 Toll route choice has always been a difficult part of the PRISM calibration, with the value of the toll having to be factored down to get sufficient traffic on the M6 Toll. The results shown here suggest that the use of CVTT multipliers could be an alternative way to get modelled traffic to use the toll route.

4.4.10. Figure 21 shows the modelled route choice between Studley and Birmingham City Centre. With TAG VTT the most direct route is used. With Medium and High CVTT most traffic uses the M42 to reduce the amount of time in congested urban areas.

4.4.11. Other routes used in the 2019 study have also been examined, i.e. Kings' Heath to Smethwick, and Stafford to Worcester (maps are not included in this report). In each case the same route is used in all three assignments.

Figure 20: Modelled route choice, Coventry-Stafford, AM peak: TAG (top), Medium CVTT (middle), High CVTT (bottom)

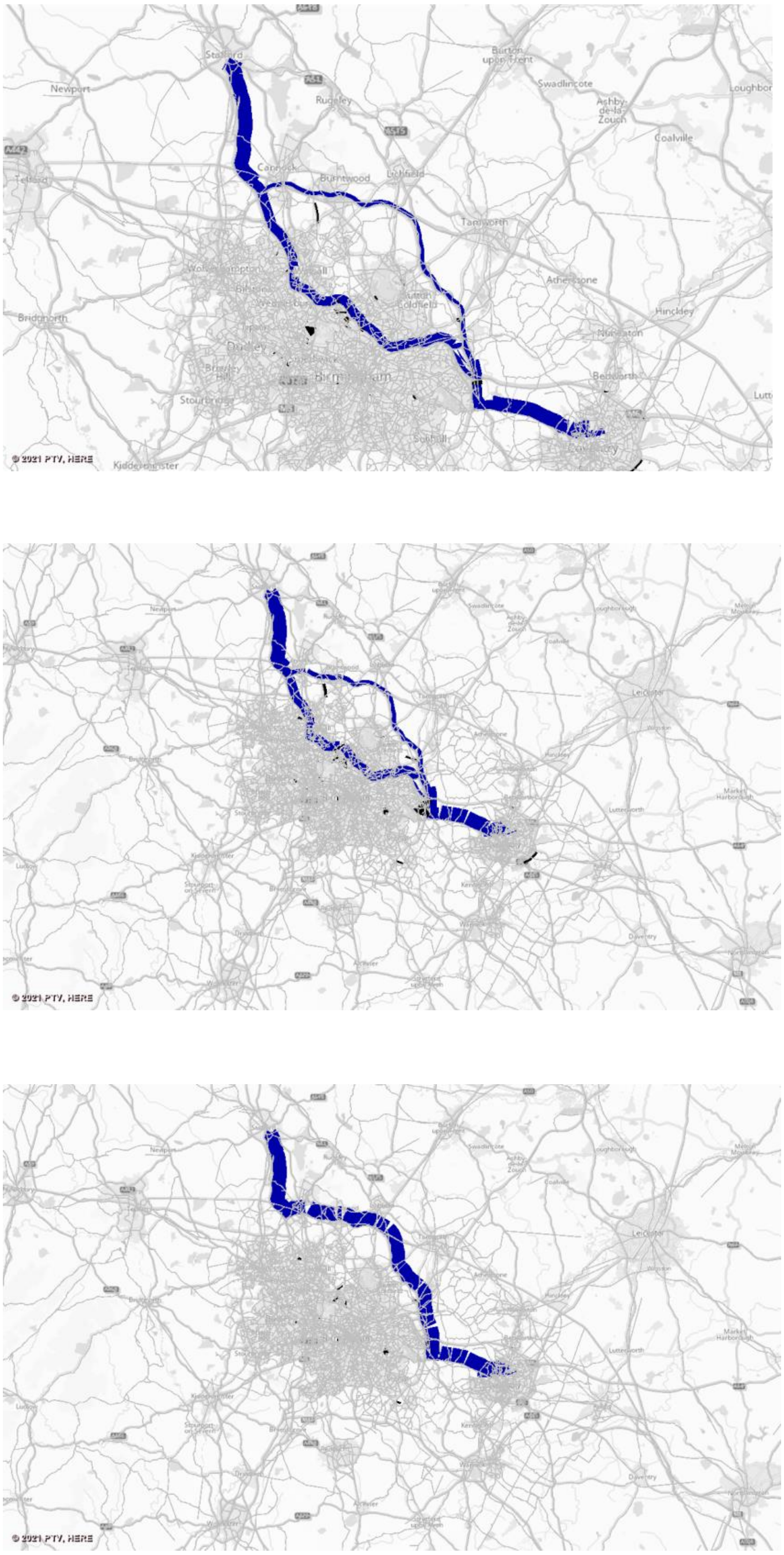
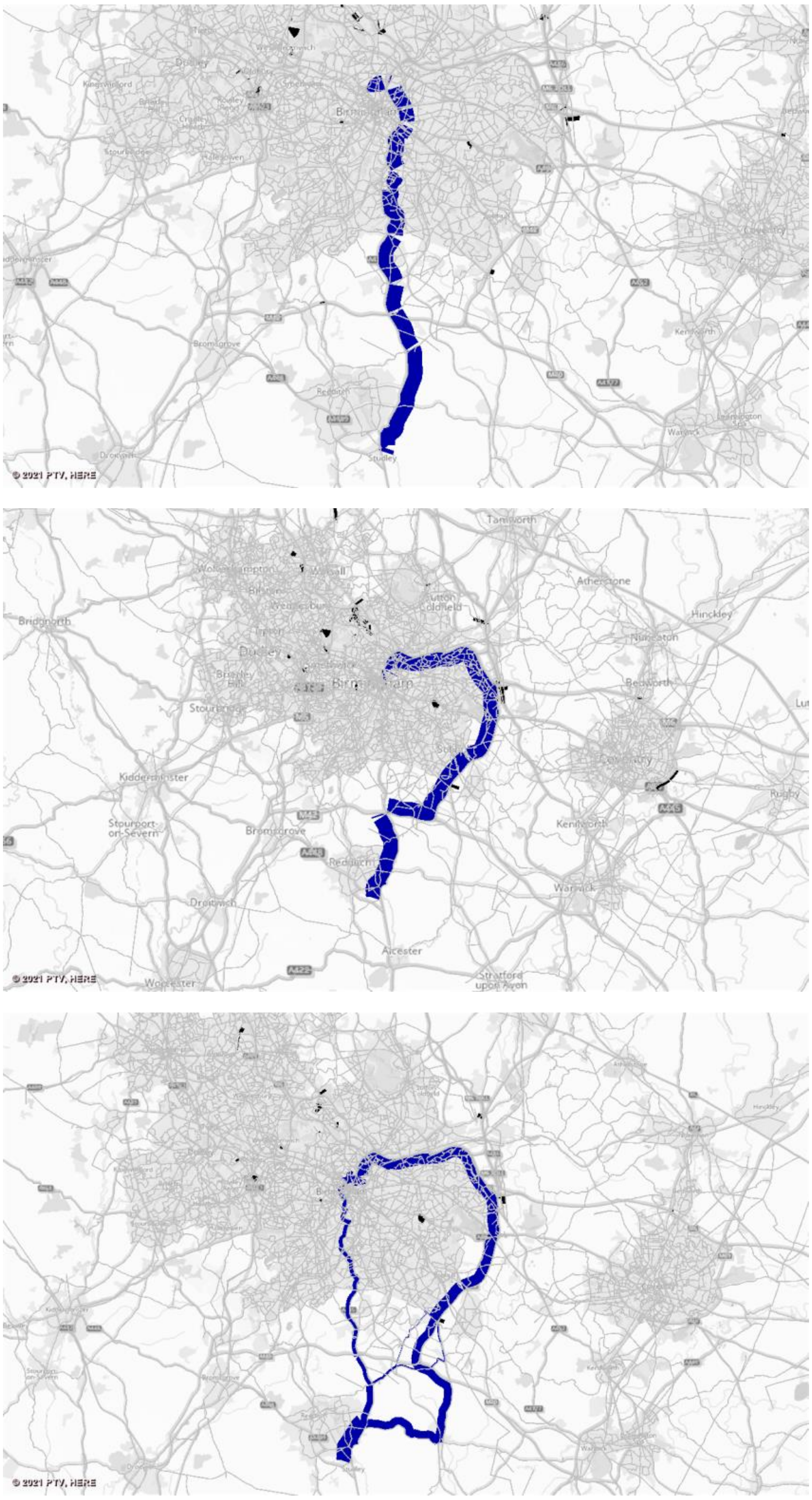


Figure 21: Modelled route choice, Studley-Birmingham City Centre, AM peak: TAG (top), Medium CVTT (middle), High CVTT (bottom)



Run Times and Convergence

4.4.12. Table 14 shows convergence statistics and run times by time period. The high CVTT multiplier assignments converge in the fewest iterations in the peaks, but not necessarily in less time. Conversely, TAG VTT takes the most iterations, but is actually the quickest to converge in the IP and PM.

4.4.13. High CVTT has the highest gap value (i.e. worst proximity convergence), but often outperforms the others in terms of stability (changes in flows and costs).

4.4.14. To a large extent these results are governed by the convergence stopping parameters defined in the assignment. Adjusting these could well lead to improved convergence in all these runs, albeit at the expense of increased run time. The key point here is that all assignments with CVTT converge to acceptable levels without undue increases in run time.

Table 14: Run time and convergence statistics

Time period	VTT	Iterations	% gap	% of links with flow change <1%	% of links with cost change <1%	Run time
AM	TAG	59	0.067%	96.7%	99.0%	164m 12s
AM	Med	46	0.062%	97.9%	99.0%	141m 24s
AM	High	39	0.097%	98.3%	98.8%	142m 12s
IP	TAG	28	0.056%	97.2%	99.3%	94m 20s
IP	Med	26	0.051%	98.0%	99.0%	115m 10s
IP	High	27	0.091%	98.1%	98.8%	114m 36s
PM	TAG	63	0.079%	96.5%	98.9%	181m 24s
PM	Med	57	0.093%	97.9%	98.8%	199m 59s
PM	High	50	0.093%	98.8%	99.2%	206m 48s

5. STAGE 2B: BASE YEAR ELASTICITIES

5.1. INTRODUCTION

5.1.1. This chapter describes the results of the second part of Stage 2 of the project, which involved calculating base year demand model elasticities when CVTT multipliers are used.

5.2. WHY CALCULATE ELASTICITIES?

5.2.1. Section 2.4 summarises the modifications made to the PRISM demand model to enable the testing of CVTT multipliers. For the 2019 tests the demand model was not re-estimated or re-calibrated in any way. Here we use 'estimation' to refer to a formal statistical estimation of the model; 'calibration' is a more informal/ad-hoc adjustment of parameters to achieve a desired characteristic, typically ensuring that outturn model elasticities meet the targets set out in TAG Unit M2.1.

5.2.2. The 2019 tests showed that the model outputs were significantly different when CVTT multipliers were used, particularly in terms of the behavioural response to a major road scheme. For example, modelled flows on the scheme, mode shares and trip lengths all varied, as well as the economic benefits of the scheme.

5.2.3. However, it is possible that at least some of those differences were a result of not re-calibrating the demand model when CVTT multipliers were used, which may have meant the model was significantly more or less sensitive than in the original PRISM model. Perhaps if the sensitivity of the demand model had been adjusted then there would have been smaller differences between the model outputs. It is also possible that there would have been larger differences.

5.2.4. One way to try to ascertain if this is likely to have been the case is to examine the sensitivity of the demand model when CVTT multipliers are used, i.e. to calculate outturn elasticities and see if they vary.

5.2.5. The rest of this chapter presents the results of carrying out the standard TAG realism tests for car journey time and car fuel cost elasticities. PT fare elasticities have not been calculated. The reason for this is that CVTT multipliers have only been applied to car VTTs; whilst PT fare elasticities may have changed, this will only be a second-order effect through the impact on car travel times and costs of the demand response to increased fares. Any change in the PT fare elasticity is therefore likely to be small.

5.2.6. The car journey time elasticities are for the change in car trips with respect to a 10% increase in car journey times, for a single pass of the demand model (i.e. there is no iteration with the assignment). They have been calculated for the entire trip matrix, excluding external-external movements (which are fixed demand). Since this is the elasticity of car *trips,* it is largely determined by the mode shift response to the increase in journey time, with a smaller contribution from the trip frequency response.

5.2.7. The car fuel cost elasticities are for the change in car kilometres with respect to a 20% increase in fuel costs (applied to all highway vehicles, not just cars), after iteration between the demand model and highway assignment until convergence. 20% was used instead of 10% as experience shows this is less sensitive to convergence noise in the demand-assignment loops.

5.2.8. Matrix and network fuel cost elasticities have been calculated. The former are on the same basis as the journey time elasticities (i.e. excluding external-external movements), the latter are calculated across links in the fully modelled area.

5.2.9. Like the journey time elasticities, the fuel cost elasticities are affected by the mode shift response but, since this is the elasticity of car *kilometres,* it tends to be dominated by the destination choice (distribution) response.

5.3. CAR JOURNEY TIME ELASTICITIES

5.3.1. For the car journey time elasticity tests the input modified journey time ($r(T_{FreeFlow}+M \times T_{Delay})$) was increased by 10%. No change was made to the input monetary costs.

5.3.2. Although the same percentage increase in (modified) travel time was applied to all costs, it is the absolute increase that really determines the scale of the demand response. This means that the higher the base travel time, the larger the absolute increase and the larger demand response we would expect.

5.3.3. For the test with TAG VTT the base time is just $(T_{FreeFlow}+T_{Delay})$.

5.3.4. For the CVTT tests the base time will be higher than TAG VTT (and therefore the demand response likely to be stronger) if:

$$(r(T_{FreeFlow}+M \times T_{Delay})) > (T_{FreeFlow}+T_{Delay})$$

which can be rewritten as:

$$(rM-1)T_{Delay} > (1-r)T_{FreeFlow}$$

5.3.5. This is more likely to be true if (a) delay time is high relative to free-flow time, and (b) the CVTT multiplier (*M*) is relatively high.

5.3.6. This means that other things being equal, we might expect a stronger elasticity for the high CVTT multiplier than the medium CVTT multiplier. It is less obvious where the TAG CVTT tests would sit in that range.

5.3.7. Outturn elasticities can also be affected by the structure of the base matrix, with longer trips having a higher elasticity.

5.3.8. Table 15 shows the car journey time elasticities for the PRISM 5 model, as well as the TAG VTT, Medium CVTT multiplier and High CVTT multiplier tests (the last three using VTTspecific base matrices estimated using the least squares method, as described in Chapter 4). Values are shown by time period and journey purpose.

Table 15: Elasticities of car trips with respect to car journey time

Model	Journey purpose	AM peak	IP	PM peak	12 hour total
PRISM5	Car business	-0.19	-0.17	-0.20	-0.19
PRISM5	Car commute	-0.14	-0.11	-0.14	-0.13
PRISM5	Car other	-0.24	-0.14	-0.17	-0.17
PRISM5	**Car total**	**-0.18**	**-0.14**	**-0.16**	**-0.16**
TAG VTT	Car business	-0.20	-0.17	-0.21	-0.19
TAG VTT	Car commute	-0.14	-0.11	-0.14	-0.14
TAG VTT	Car other	-0.24	-0.15	-0.17	-0.17
TAG VTT	**Car total**	**-0.18**	**-0.14**	**-0.16**	**-0.16**
Medium CVTT	Car business	-0.20	-0.17	-0.21	-0.19
Medium CVTT	Car commute	-0.12	-0.08	-0.12	-0.11
Medium CVTT	Car other	-0.21	-0.12	-0.15	-0.15
Medium CVTT	**Car total**	**-0.15**	**-0.12**	**-0.14**	**-0.14**
High CVTT	Car business	-0.23	-0.19	-0.24	-0.22
High CVTT	Car commute	-0.15	-0.10	-0.15	-0.14

Model	Journey purpose	AM peak	IP	PM peak	12 hour total
High CVTT	Car other	-0.23	-0.13	-0.16	-0.16
High CVTT	**Car total**	**-0.18**	**-0.13**	**-0.16**	**-0.16**

5.3.9. TAG Unit M2.1 has a broad target range for car journey time elasticities, stating only that the values should be between 0 and -2. This is achieved in all cases.

5.3.10. There are very slight differences between the PRISM 5 and TAG VTT tests. While both tests use the same VTTs (without CVTT multipliers), they have different estimated base matrices, which explains the difference in elasticities. The PRISM 5 results in this table differ from those published in the PRISM 5.0 Model Validation Report. This is a result of adjustments made to the demand model when the CVTT functionality was added, particularly the way 24 hour PT fares are calculated.

5.3.11. Comparing the TAG, Medium and High results shows that there is relatively little difference. Elasticities are slightly lower for the Medium test, mainly due to car commute.

5.3.12. The High CVTT multiplier test gives higher elasticities than Medium CVTT multiplier, which accords with prior expectations.

5.4. FUEL COST ELASTICITIES

5.4.1. The increase in fuel cost only affects the *f(cost)* component of the utility function. This is not directly affected by the CVTT multipliers. However, it is indirectly affected in two ways:

- Route choice will be affected by the use of multipliers in the assignment model. This could change the cost for each OD pair.
- The estimated matrix differs for each multiplier value. Hence the level of congestion, which influences cost, may vary for each OD (even if route choice is not affected).

5.4.2. It is therefore not obvious to what extent, or in which direction, the CVTT multipliers would affect the fuel cost elasticities.

5.4.3. Table 16 shows the matrix-based car fuel cost elasticities for the PRISM 5 model, as well as the TAG VTT, Medium CVTT multiplier and High CVTT multiplier tests (using the CVTT-dependent base matrices described in chapter 4). Values are shown by time period and journey purpose.

5.4.4. Table 17 shows the corresponding network-based values.

Table 16: Elasticities of car kilometres with respect to fuel cost, matrix-based calculation

Model	Journey purpose	AM peak	IP	PM peak	12 hour total
PRISM5	Car business	-0.16	-0.18	-0.18	-0.17
PRISM5	Car commute	-0.22	-0.28	-0.23	-0.24
PRISM5	Car other	-0.34	-0.33	-0.34	-0.34
PRISM5	**Car total**	**-0.23**	**-0.27**	**-0.25**	**-0.26**
TAG VTT	Car business	-0.16	-0.16	-0.17	-0.17
TAG VTT	Car commute	-0.24	-0.28	-0.26	-0.26
TAG VTT	Car other	-0.37	-0.34	-0.36	-0.35
TAG VTT	**Car total**	**-0.25**	**-0.27**	**-0.26**	**-0.26**
Medium CVTT	Car business	-0.13	-0.14	-0.15	-0.14
Medium CVTT	Car commute	-0.21	-0.28	-0.23	-0.24
Medium CVTT	Car other	-0.42	-0.32	-0.34	-0.34
Medium CVTT	**Car total**	**-0.24**	**-0.25**	**-0.24**	**-0.25**
High CVTT	Car business	-0.11	-0.13	-0.14	-0.13
High CVTT	Car commute	-0.21	-0.27	-0.23	-0.23
High CVTT	Car other	-0.39	-0.31	-0.32	-0.32
High CVTT	**Car total**	**-0.23**	**-0.24**	**-0.23**	**-0.24**

Table 17: Elasticities of car kilometres with respect to fuel cost, network-based calculation

Model	Journey purpose	AM peak	IP	PM peak	12 hour total
PRISM5	Car business	-0.07	-0.08	-0.08	-0.08
PRISM5	Car commute	-0.2	-0.22	-0.20	-0.20
PRISM5	Car other	-0.26	-0.26	-0.28	-0.27
PRISM5	**Car total**	**-0.18**	**-0.21**	**-0.20**	**-0.20**
TAG VTT	Car business	-0.07	-0.06	-0.06	-0.06
TAG VTT	Car commute	-0.22	-0.23	-0.22	-0.22
TAG VTT	Car other	-0.29	-0.28	-0.31	-0.29
TAG VTT	**Car total**	**-0.20**	**-0.22**	**-0.21**	**-0.21**
Medium CVTT	Car business	-0.04	-0.05	-0.06	-0.05
Medium CVTT	Car commute	-0.18	-0.21	-0.18	-0.19
Medium CVTT	Car other	-0.30	-0.27	-0.27	-0.27
Medium CVTT	**Car total**	**-0.18**	**-0.20**	**-0.18**	**-0.19**
High CVTT	Car business	-0.00	-0.03	-0.04	-0.03
High CVTT	Car commute	-0.18	-0.21	-0.18	-0.19
High CVTT	Car other	-0.28	-0.26	-0.26	-0.26
High CVTT	**Car total**	**-0.17**	**-0.20**	**-0.18**	**-0.18**

5.4.5. TAG Unit M2.1 requires that the annual average fuel cost elasticity should be between -0.25 and -0.35, with Business less elastic (around -0.1), Other the most elastic (around -0.4) and Commute somewhere around the average (around -0.3). TAG recognises that elasticities can be affected by income and trip length, with lower incomes and higher trip lengths leading to higher elasticities.

5.4.6. Judged against the TAG targets, the PRISM matrix-based elasticities are at the lower end of the TAG range. The pattern of variation by purpose is in line with expectations. For this project the variation by CVTT is the main point of interest, rather than the absolute values of the elasticities.

5.4.7. The network-based elasticities are smaller than the matrix-based ones. This is often the case and is because the network-based calculations include some trips (external-external) which are not subject to VDM. Otherwise the pattern is very similar for the two sets.

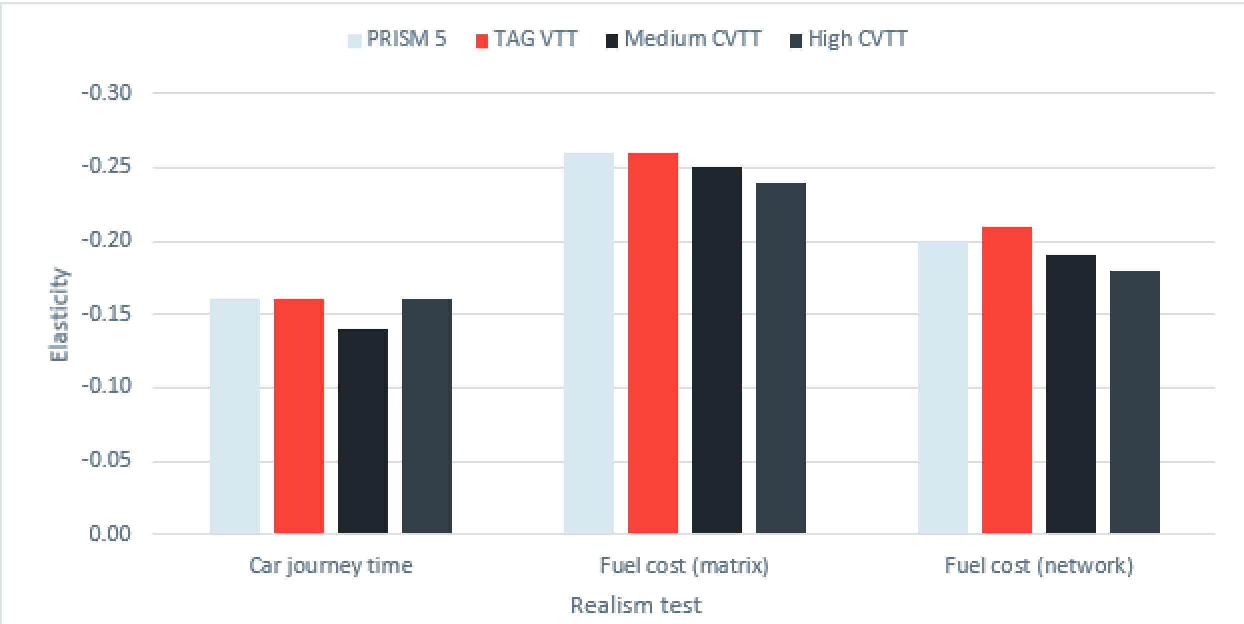
5.4.8. As with the journey time elasticities, there are small differences between the PRISM 5 and TAG VTT elasticities, which can be attributed to differences in the estimated base matrices.

5.4.9. Of the current set of model tests, TAG VTT is the most elastic, followed by the Medium multiplier and then the High multiplier.

5.5. SUMMARY OF ELASTICITIES

5.5.1. Figure 22 summarises the 12 hour elasticities (all journey purposes) for each model run for each realism test.

Figure 22: Comparison of 12 hour elasticities



6. STAGE 3: FORECASTING

6.1. INTRODUCTION

6.1.1. This chapter describes the results of Stage 3 of the project, which involves a range of forecasting tests in the modified PRISM model:

- Do-minimum (DM) and do-something (DS) forecast model runs for 2036.
- Do-minimum (DM) and do-something (DS) forecast model runs for 2026.
- Assignment of DM matrices to the DS network for 2036.
- Calculation of car journey time elasticities for 2036.

6.1.2. The rationale for, and results of, each of these tests are set out in the following sections.

6.2. 2036 FORECASTS

Description of tests

6.2.1. The 2036 forecast model runs involved running the DM and DS scenarios for each of the CVTT multipliers (TAG, Medium and High) through a full VDM run of PRISM. The runs are listed in Table 18. Note that the run IDs follow on from the 2019 report, which finished with run ID F12.

Table 18: List of 2036 model runs

Run ID	Year	Scenario	Multiplier value	Pivots off base year matrix
F13	2036	DM	TAG VTT	MAT1
F14	2036	DM	Medium	MAT2
F15	2036	DM	High	MAT3
F16	2036	DS	TAG VTT	MAT1
F17	2036	DS	Medium	MAT2
F18	2036	DS	High	MAT3

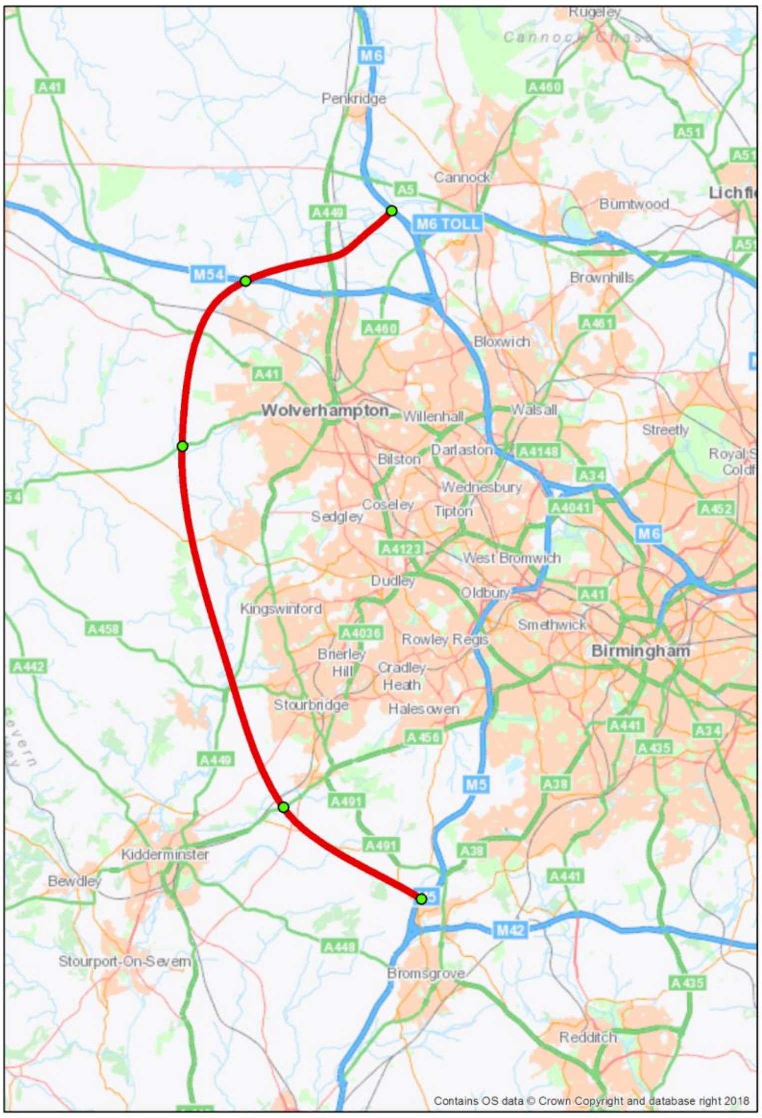
6.2.2. The main difference from the 2019 study is that the forecasts pivot off a different base matrix. In the 2019 study all the forecasts pivoted off the original PRISM 5.1 base matrix, regardless of the CVTT multiplier value. In these latest runs, each forecast pivots off a base matrix estimated using the appropriate CVTT multiplier (MAT1, MAT2, or MAT3, as described in chapter 4). As described in chapter 4, these matrices differ from the PRISM 5.1 base matrix not only in their use of the CVTT multiplier in the estimation process (for the Medium and High tests), but also in their use of a different Visum matrix estimation method (least squares, rather than TFlowFuzzy). Although the matrix estimation process is CVTT-specific, the same prior matrix was used in each case.

6.2.3. The only other difference is that the latest runs use a more recent version of Visum, Visum 2021.

6.2.4. All other inputs to the forecasting process (such as population and employment forecasts, value of time and income growth, fare, and fuel cost changes) are as per the 2019 study, to maximise consistency and enable more meaningful comparisons between the two sets of forecasts.

6.2.5. The DS scheme is a purely hypothetical new four-lane motorway to the west of the Birmingham motorway box, as shown in Figure 23.

Figure 23: Sketch map showing location of hypothetical scheme



6.2.6. The main purpose of these tests is to see if the conclusions of the 2019 report still hold true when we have a CVTT-specific base matrix, or whether the differences are significantly greater, or smaller, than previously seen.

Results

Convergence

6.2.7. Table 19 summarises the convergence statistics for the highway assignment (by time period), and the VDM-assignment loop.

Table 19: Convergence statistics, 2036

Run ID	Scenario	Multiplier	Assignment gap AM	Assignment gap IP	Assignment gap PM	VDM gap
F13	DM	TAG	0.08%	0.06%	0.09%	0.19%
F14	DM	Medium	0.05%	0.03%	0.06%	0.23%
F15	DM	High	0.05%	0.07%	0.09%	0.21%
F16	DS	TAG	0.06%	0.03%	0.06%	0.17%
F17	DS	Medium	0.04%	0.03%	0.05%	0.16%
F18	DS	High	0.07%	0.06%	0.09%	0.18%

6.2.8. While the highway assignment gap meets the TAG target of 0.1%, the VDM gap sometimes exceeds the TAG target of 0.2% and in all cases exceeds the usual stopping value of 0.15%. This contrasts with the 2019 work, in which all the corresponding runs achieved the 0.15% target.

6.2.9. This is likely to be caused by the change to the matrix estimation process used for the base year. As noted in chapter 3, the least squares method does not allow for limits to be placed on the scale of changes made to the prior matrix. This resulted in large increases in some cells, which appear to have led to increased modelled congestion in 2036, and hence worse convergence.

6.2.10. Comparison of flows between the $(n\text{-}1)^{th}$ and n^{th} loops (where *n* is the VDM-assignment loop with the lowest gap value) shows that, despite not meeting the target convergence level, the results are quite stable, with limited flow differences. Comparing scheme benefits, calculated using TUBA, between the $(n\text{-}1)^{th}$ and n^{th} loops also shows very little difference. Chapter 7 provides more details.

Aggregate Model Results

6.2.11. Table 20 to Table 23 show the aggregate results from the highway assignment, i.e. total trips (car vehicles), vehicle kms and vehicle hours (split between free-flow and delay time), and average time and distance per trip. Although these are extracted from the highway assignment, they do not just reflect routing responses, but also depend on the VDM response in both the DM and DS. These are just for cars; LGVs and HGVs do not use the CVTT multiplier and are not shown here.

Table 20: Aggregate model results: car commute, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	2,264	36,877	752.9	541.5	211.4	16.3	20.0	14.3	5.6
F14	DM	Medium	2,195	37,554	715.0	544.7	170.3	17.1	19.5	14.9	4.7
F15	DM	High	2,240	37,986	711.7	551.7	159.9	17.0	19.1	14.8	4.3
F16	DS	TAG	2,261	37,292	751.3	543.7	207.6	16.5	19.9	14.4	5.5
F17	DS	Medium	2,188	38,091	713.3	547.4	165.9	17.4	19.6	15.0	4.5
F18	DS	High	2,235	38,843	714.8	557.5	157.3	17.4	19.2	15.0	4.2

Table 21: Aggregate model results: car employer's business, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	709	40,471	540.6	451.5	89.0	57.1	45.7	38.2	7.5
F14	DM	Medium	695	40,263	523.9	452.3	71.7	57.9	45.2	39.0	6.2
F15	DM	High	699	39,750	513.4	449.3	64.1	56.9	44.1	38.6	5.5
F16	DS	TAG	708	40,816	539.8	453.2	86.6	57.7	45.8	38.4	7.3
F17	DS	Medium	692	40,770	524.5	455.1	69.3	58.9	45.5	39.4	6.0
F18	DS	High	697	40,386	515.7	452.9	62.8	58.0	44.4	39.0	5.4

Table 22: Aggregate model results: car other, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	4,164	46,992	984.5	717.7	266.8	11.3	14.2	10.3	3.8
F14	DM	Medium	4,233	47,813	980.2	741.5	238.8	11.3	13.9	10.5	3.4
F15	DM	High	4,302	48,304	973.0	748.6	224.4	11.2	13.6	10.4	3.1
F16	DS	TAG	4,164	47,313	982.7	719.8	262.9	11.4	14.2	10.4	3.8
F17	DS	Medium	4,230	48,294	978.6	744.4	234.1	11.4	13.9	10.6	3.3
F18	DS	High	4,302	48,929	974.6	752.7	222.0	11.4	13.6	10.5	3.1

Table 23: Aggregate model results: car all purposes, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	7,138	124,340	2,278	1,711	567.3	17.4	19.1	14.4	4.8
F14	DM	Medium	7,123	125,630	2,219	1,738	480.7	17.6	18.7	14.6	4.0
F15	DM	High	7,241	126,040	2,198	1,750	448.4	17.4	18.2	14.5	3.7
F16	DS	TAG	7,133	125,422	2,274	1,717	557.1	17.6	19.1	14.4	4.7
F17	DS	Medium	7,110	127,154	2,216	1,747	469.4	17.9	18.7	14.7	4.0
F18	DS	High	7,233	128,158	2,205	1,763	442.1	17.7	18.3	14.6	3.7

6.2.12. Figure 24 to Figure 27 show the average trip distances, times, free-flow times, and delays from the above tables.

Figure 24: Average trip distance (km)

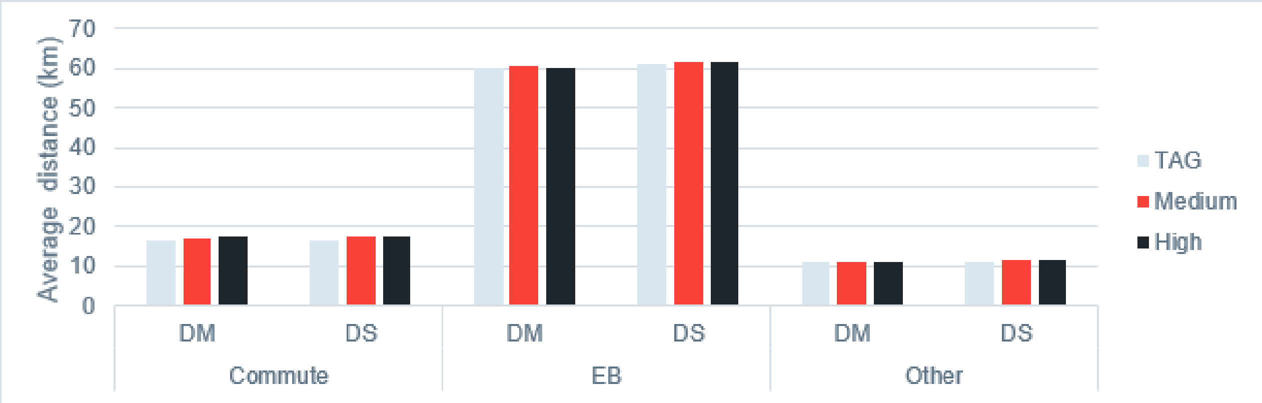


Figure 25: Average trip time (mins)

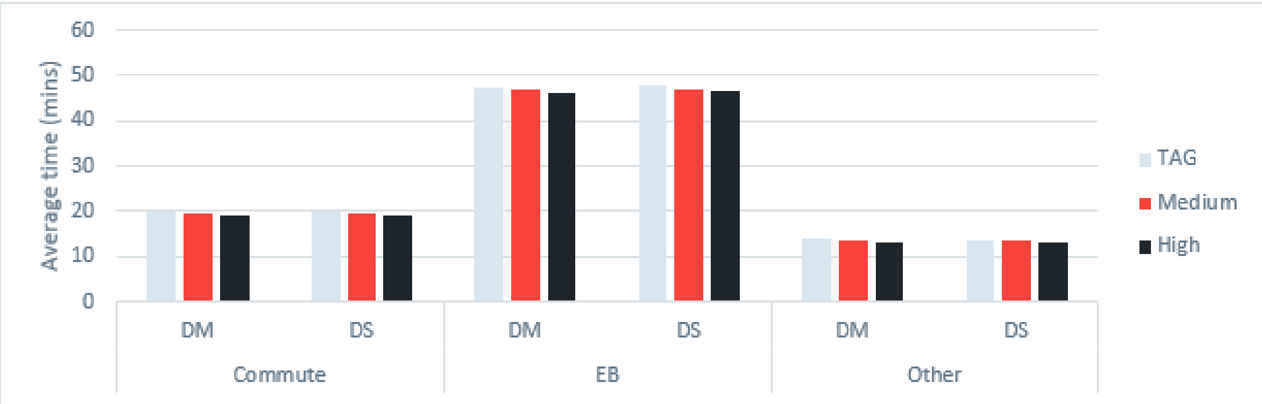


Figure 26: Average trip free-flow time (mins)

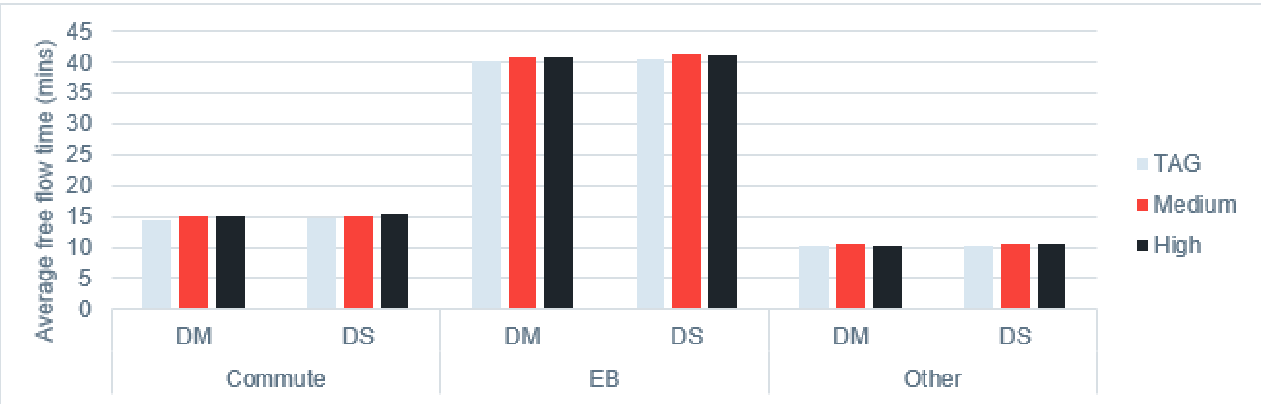
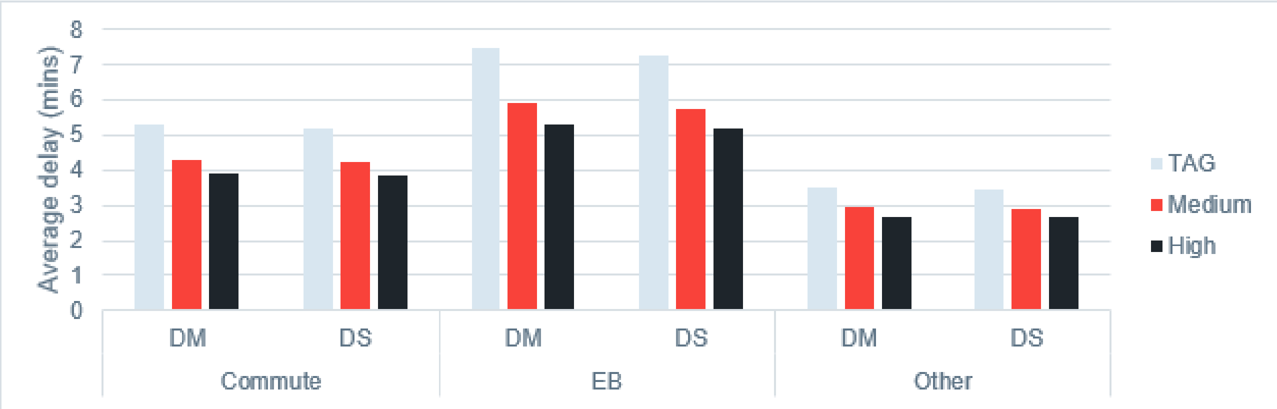


Figure 27: Average trip delay (mins)



6.2.13. Some general patterns are discernible from the tables and figures:

- The use of a CVTT multiplier decreases the total travel time in the system, with the impact greater with High than Medium. (There is one exception to this: Commute in the DS, where the total travel time is greater with High than Medium.)
- This is largely the result of significant decreases in total delay time. Changes in total free-flow time are relatively modest and, in most cases, free-flow time increases with the multiplier as traffic moves to less congested routes.
- Changes in average times per trip follow the same pattern as the changes in total vehicle hours. The biggest impact is on employer's business trips, which see a reduction in average trip time of more than a minute with the High multiplier, compared to TAG.
- There is a less clear pattern for average trip distance. Car commute sees the biggest effect, with distances increasing with the multiplier, presumably reflecting a change in routing to avoid the most congested areas. It may also reflect the fact that a larger proportion of commute trips take place in the AM and PM peaks, which are the most congested periods.
- In most cases there is a decrease in car trips between the DM and DS, which is contrary to expectation for a scheme that significantly increases highway capacity. The biggest decreases occur between Wolverhampton, and Shropshire and Telford. These are movements that are approximately east-west, perpendicular to the scheme. Therefore, for the most part, they do not benefit from the scheme itself but do experience the localised congestion caused by scheme users. It might be expected that these decreases would be outweighed by the traffic induced by the scheme, but in this application the latter is likely to be underestimated as a lot of traffic on the scheme is external-external and therefore not subject to VDM in PRISM.

- With the High multiplier (and also Medium for EB) total travel time increases between DM and DS. This may be counter-intuitive but it is consistent with the idea that travellers are willing to spend longer travelling in free-flow conditions to avoid congestion. It is important to note that the *value* of travel time decreases between DM and DS as a result of a reduction in the proportion of delay to total time.

6.2.14. These patterns are virtually identical to those in the 2019 report. Some of the numbers are slightly different (e.g. the average trip distance tends to be slightly shorter and the average delay time slightly higher in the latest results), but the direction and scale of the changes are very similar. For example, Table 20 shows that in the DM scenario, commuting trips, the average delay reduces from 5.6 minutes (TAG) to 4.3 minutes (High), a reduction of 1.3 minutes. The equivalent figures in the 2019 report are a reduction from 5.3 minutes to 3.9 minutes (a reduction of 1.4 minutes, TAG vs High).

6.2.15. Appendix A presents the same data broken down by time period. This shows a very similar pattern. Differences between the multipliers are slightly less in the less-congested inter-peak period, compared to the peaks, but are still significant.

6.2.16. The conclusion from these results is that the use of CVTT-specific base matrices does not fundamentally alter the 2019 results in terms of the direction and scale of differences due to different CVTT multipliers.

Trip totals

6.2.17. Table 24 shows all-mode 24 hour person trip totals from the demand model, before the pivoting process is applied. (All-mode totals can only be calculated from before the pivoting process, as only motorised modes have pivoting applied and it would not be meaningful to combine pivoted and non-pivoted matrices.)

6.2.18. The differences are small as they reflect the trip frequency response to changing travel costs, which is the least sensitive demand response in PRISM.

6.2.19. The table shows that the Medium multiplier has the most trips, and the High multiplier the least, in both the DM and DS scenarios. This is consistent with the Medium multiplier giving the lowest generalised cost of travel, and the High multiplier the highest. This is plausible given the way the demand model was modified to deal with CVTT multipliers, as described in section 2.4.

Table 24: All-mode 24 hour person trip totals (synthetic), 2036

Run ID	Scenario	Multiplier	Total trips
F13	DM	TAG	11,215,081
F14	DM	Medium	11,298,962
F15	DM	High	11,195,281
F16	DS	TAG	11,218,077
F17	DS	Medium	11,304,430
F18	DS	High	11,200,437

Implied Average VTT

6.2.20. Table 25 shows the outturn average VTT for each model run and car journey purpose. This is a weighted average of the input free-flow and delay VTTs (weighted by free-flow and delay vehicle hours).

Table 25: Outturn average VTTs, current study (£/hr per vehicle, 2036, 2010 prices)

Run	Scenario	Multiplier	Commute	Employer's Business	Other
F13	DM	TAG	16.82	25.25	11.96
F14	DM	Medium	17.30	18.39	8.91
F15	DM	High	22.26	21.65	11.52
F16	DS	TAG	16.82	25.25	11.96
F17	DS	Medium	17.18	18.25	8.86
F18	DS	High	22.04	21.46	11.45

6.2.21. These values are not directly comparable with those in the 2019 report, which were reported incorrectly. The corrected figures from the 2019 study are in Table 26 below.

Table 26: Outturn average VTTs, corrected figures from 2019 study (£/hr per vehicle, 2036, 2010 prices)

Run	Scenario	Multiplier	Commute	Employer's Business	Other
F7	DM	TAG	16.82	25.25	11.96
F8	DM	Medium	16.94	18.08	8.64
F9	DM	High	21.42	21.07	10.91
F10	DS	TAG	16.82	25.25	11.96
F11	DS	Medium	16.82	17.96	8.59
F12	DS	High	21.22	20.91	10.85

6.2.22. In the current study, for EB and Other, TAG has the highest average VTT. With the medium and high multipliers, the free flow VTT is 30-50% lower than the TAG value (specifically, 30% lower for commute, 43% for EB and 50% for Other). Even with the high multiplier there is not sufficient delay to bring the average VTT up to the TAG level, although it comes close for Other.

6.2.23. The pattern for commute is different, with TAG having the lowest VTT and the high multiplier the highest. This is likely to be due to two factors: (i) the commute free-flow VTT is closer to the TAG value than for EB or Other, and (ii) commute travel is more concentrated in the peaks, which have higher levels of delay.

6.2.24. DS VTTs are lower than DM for Medium and High multipliers, reflecting the lower level of delay in the DS.

6.2.25. The ITS Leeds review of the 2019 work noted that the incorrect *r* values had been taken from the 2015 UK VTT study (where *r* is the ratio of free flow VTT to average VTT) and should have been lower. While accepting the error, it was agreed that the current study should use the same *r* values as in 2019 for consistency. The values in Table 25, for the Medium and High multipliers, are therefore higher than they would have been if the correct *r* values had been used.

DM flows

6.2.26. Figure 28 and Figure 29 show the difference in link flows between TAG VTT, and the CVTT multiplier (Medium and High respectively) for the AM peak (cars only). Red indicates a reduction in flow (CVTT flow is lower than TAG), green an increase (CVTT is higher than TAG).

6.2.27. The largest changes in flow are a reduction (with CVTT) on the motorway box, and most of the motorways that connect into it, and an increase on the M1 and M6 to the east. The latter impact may be exaggerated in the model due to congestion on the M1 not being fully represented in PRISM.

Figure 28: Comparison of DM link flows, 2036 AM, Medium vs TAG

Figure 29: Comparison of DM link flows, 2036 AM, High vs TAG

OD routing

6.2.28. For each model run, a series of plots has been produced showing the routing of 2036 DM AM peak car traffic for four selected OD pairs. These were chosen for the 2019 report to represent a range of different kinds of trips in the model:

- Coventry - Stafford: an inter-urban OD pair where the main route choice is between the M6 and M6 Toll.
- Studley - Birmingham City Centre: a more local trip where the main choice is between a longer distance motorway route and shorter (but more congested) local roads.
- Kings Heath to Smethwick: a shorter trip within Birmingham where using the motorway is not a realistic option.
- Worcester to Stafford: an inter-urban OD pair likely to use the new road in the DS.

6.2.29. As with all highway assignment models, there is a need for caution when interpreting results based on the analysis of route choice. Under fairly general conditions, an equilibrium highway assignment is unique in terms of link flows, i.e. there is no alternative set of link flows that would also be an equilibrium solution. However, this uniqueness does not apply to route flows. In other words, any apparent difference in route flows between two assignments could just be chance variation and not the direct result of, say, a different multiplier.

6.2.30. The Coventry-Stafford routing shows most traffic using the M6 Toll, even with the TAG VTT. This contrasts with the base year, as presented in chapter 4, which showed most traffic using the M6 with TAG VTT, switching to most traffic using the M6 Toll with the high multiplier. This shows that the impact of CVTT on routing is not necessarily greater in more congested conditions.

6.2.31. The Studley-Birmingham City Centre routing is perhaps more in line with expectations, with traffic switching to the longer route via the motorway box as the CVTT multiplier is introduced and then increased.

6.2.32. In both above cases there is little difference in routing between the Medium and High multipliers.

6.2.33. There is little consistent variation in routing for the other OD pairs.

6.2.34. Routings are broadly consistent with those in the 2019 report, with the most noticeable difference being that for Studley-Birmingham, Medium multiplier, most traffic uses the motorway box, whereas in the earlier work it used the more direct urban route.

Figure 30: Coventry-Stafford route choice, 2036 DM AM peak cars (order of plots: TAG, Medium, High)

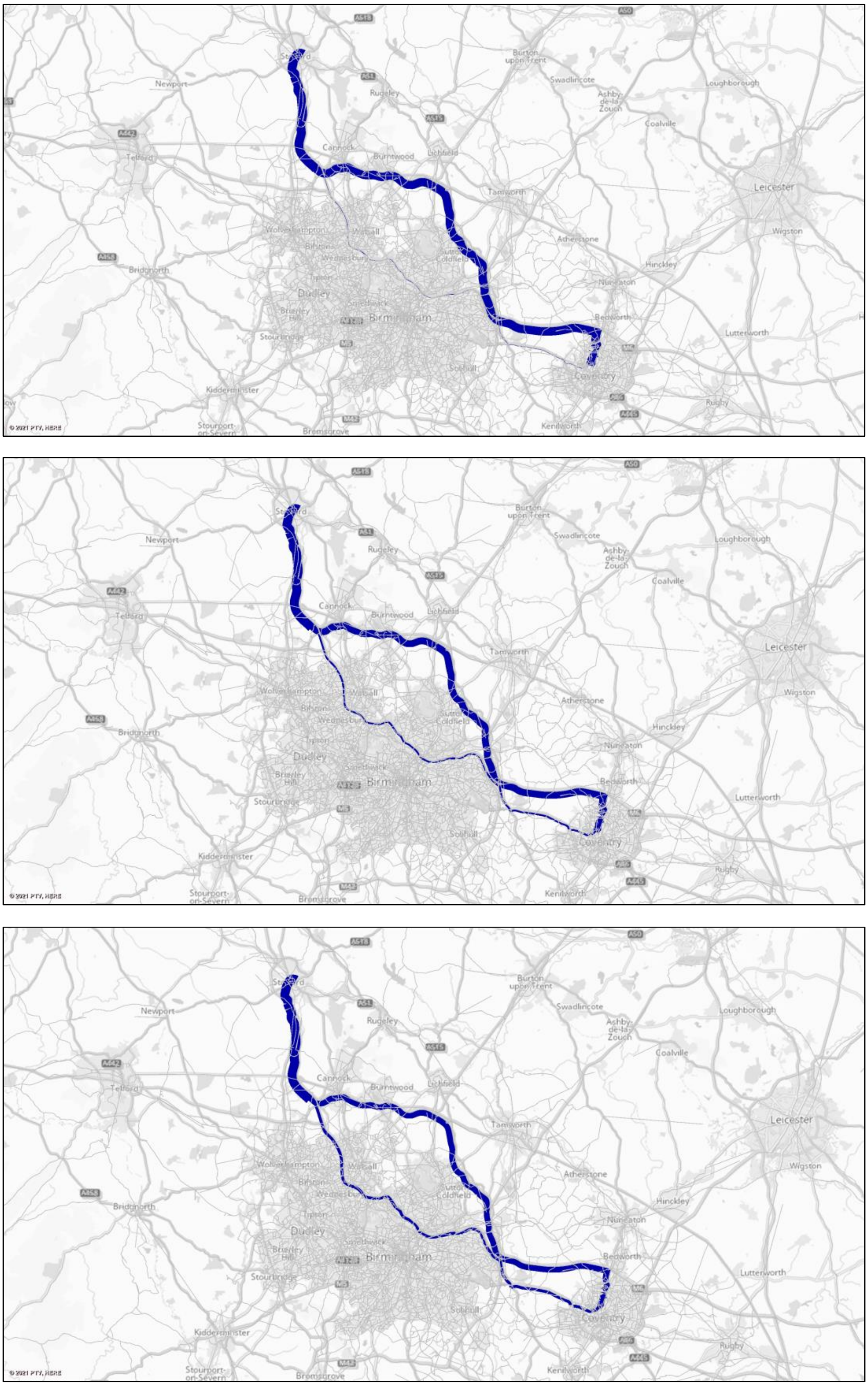


Figure 31: Studley - Birmingham City Centre route choice, 2036 DM AM peak cars (order of plots: TAG, Medium, High)

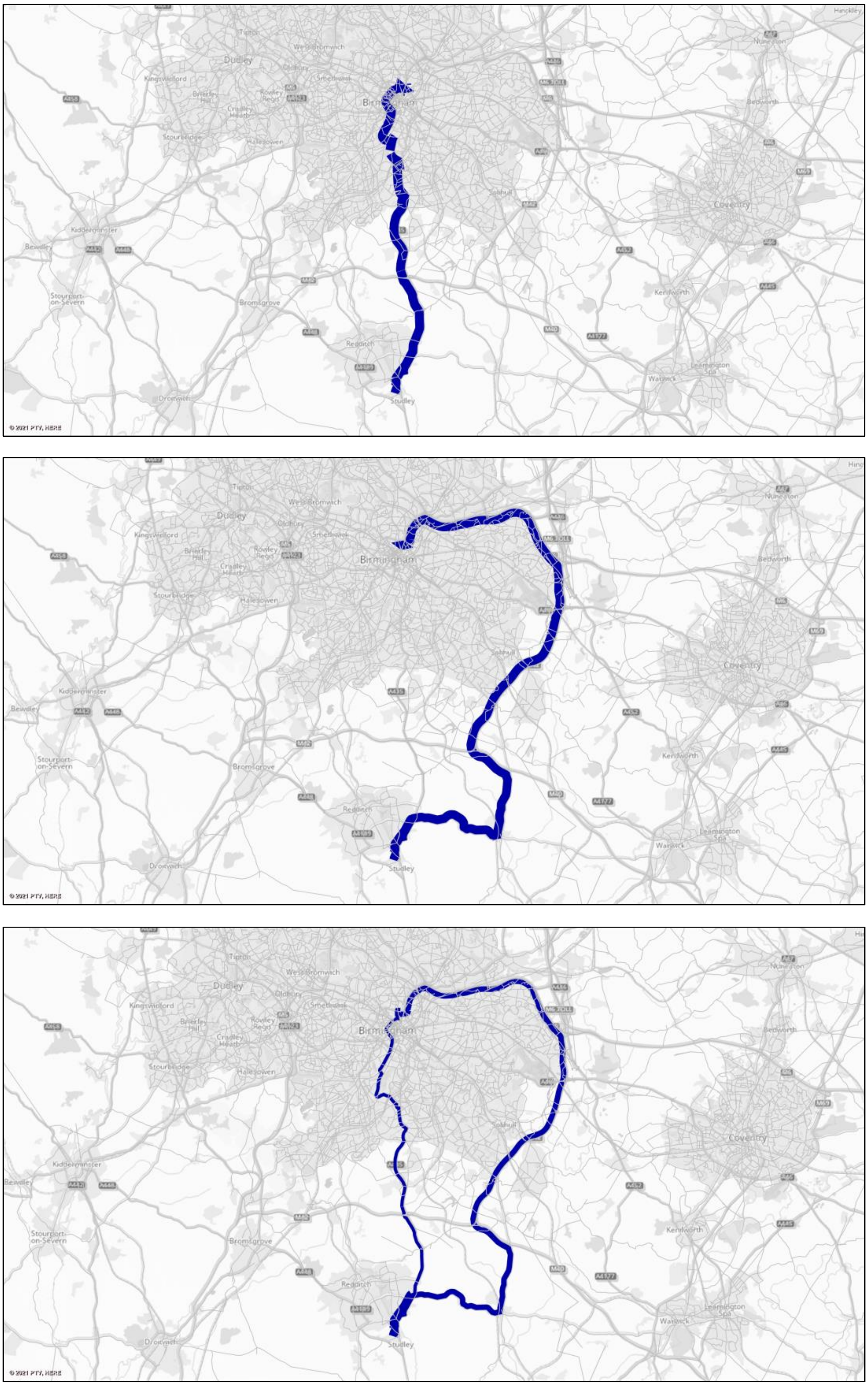


Figure 32: Kings Heath to Smethwick route choice, 2036 DM AM peak cars (order of plots: TAG, Medium, High)

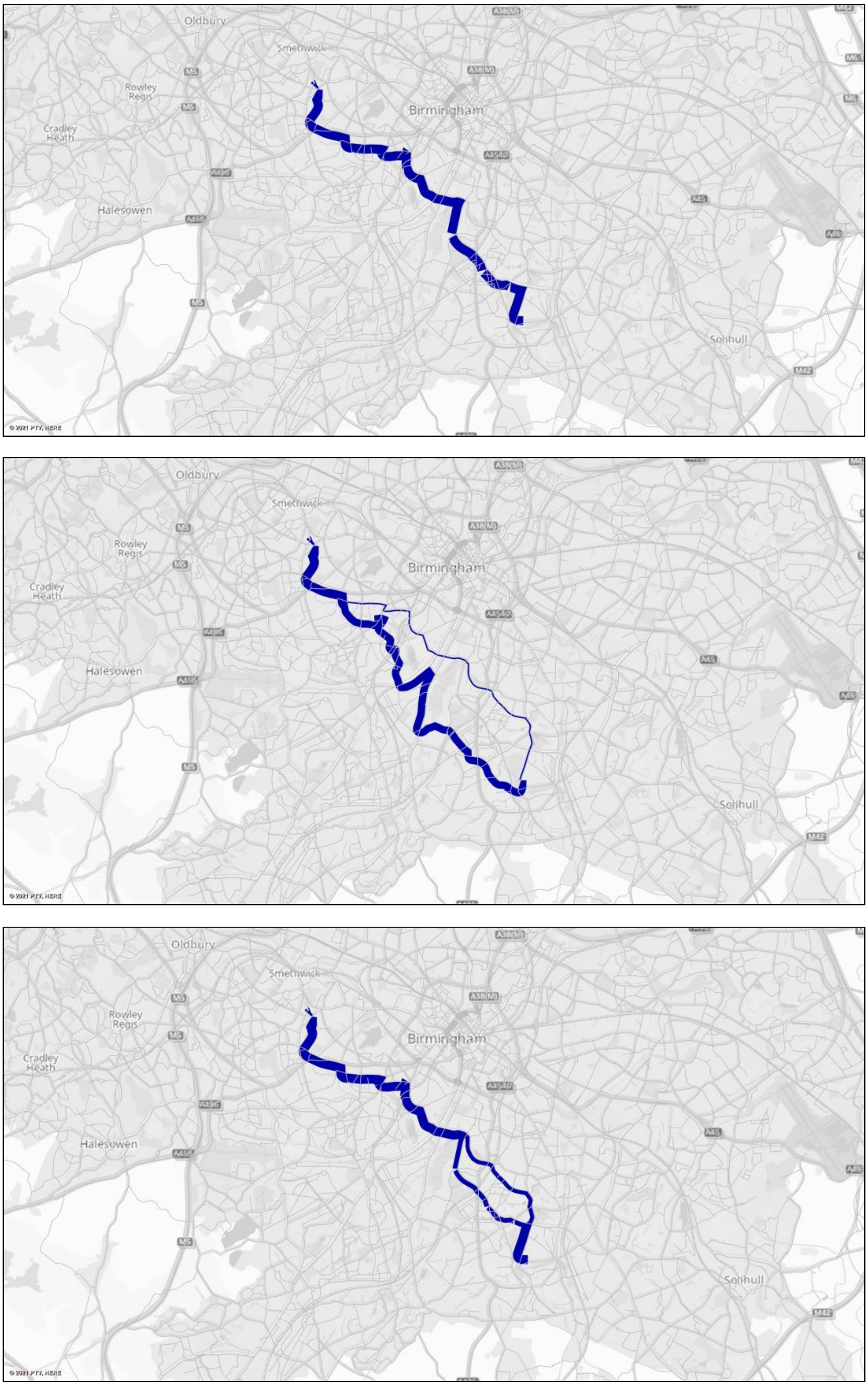
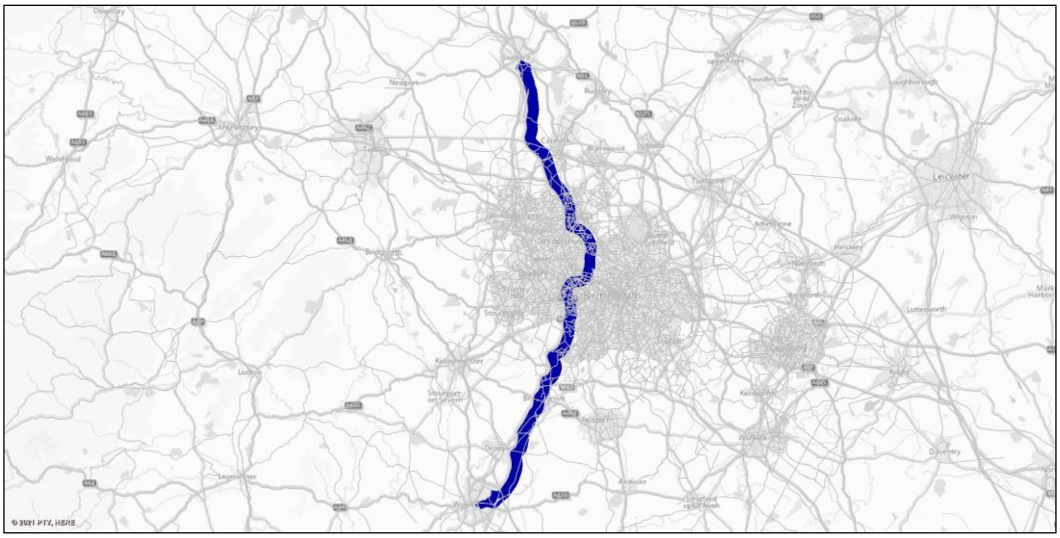
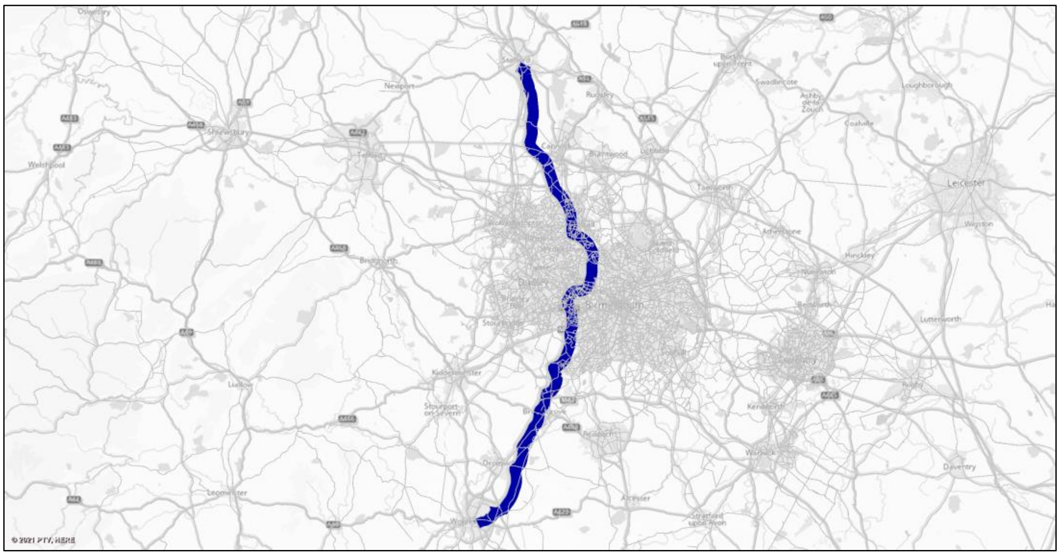
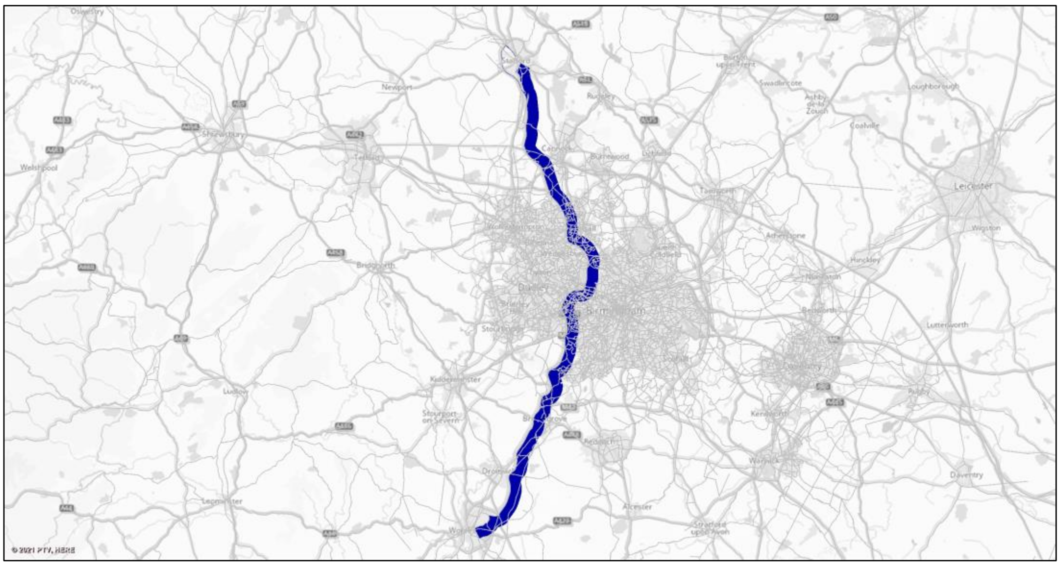


Figure 33: Worcester to Stafford route choice, 2036 DM AM peak cars (order of plots: TAG, Medium, High)







Scheme impact

6.2.35. Figure 35 to Figure 37 show the changes in flows between the DM and DS for each multiplier value, all vehicles, AM peak only. There is little difference in the pattern of changes between each model run, only the scale changes.

6.2.36. Most traffic on the scheme appears to be re-routing from the existing M5, with much smaller reductions on the M42 on the eastern side of the motorway box (only visible with the CVTT multipliers), and on routes to the west of the new road.

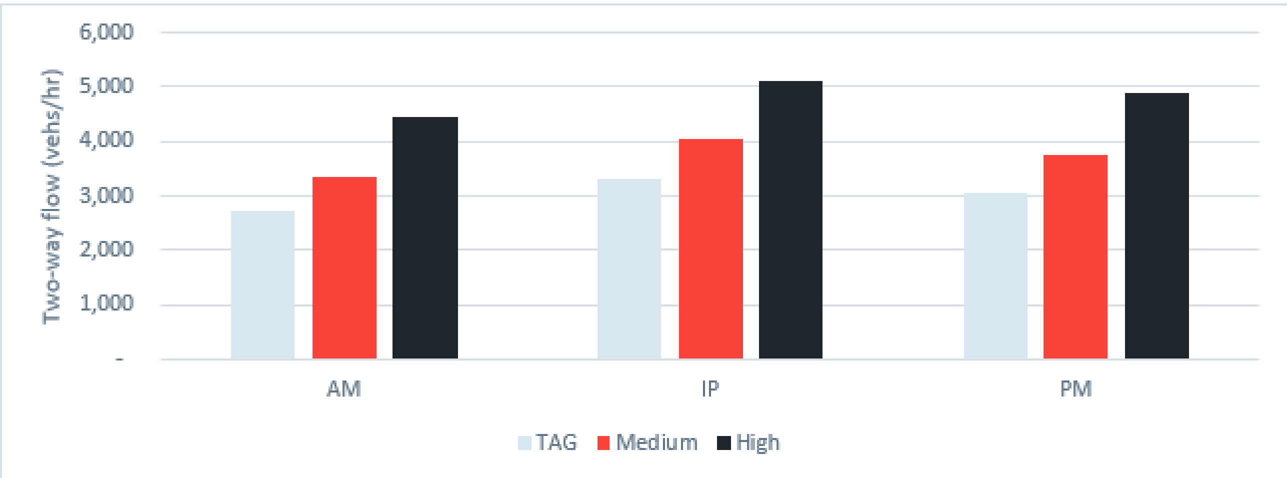
6.2.37. Table 27 shows the 2-way flows on the central section of the scheme between the A454 and A456 for the current study and the 2019 study; Figure 34 shows the flows from the current study only.

6.2.38. The flow on the scheme increases significantly with the multiplier. This is consistent with expectations: with the multiplier, drivers are more inclined to travel longer distances to avoid congestion, particularly if that is to use a route that is almost entirely operating under free-flow conditions. The difference between TAG and the High multiplier is about 2,000 vehs/hr in the PM peak – effectively an additional lane of traffic.

Table 27: Scheme flows (two-way, vehs/hr), 2036

Run ID	Multiplier value	Current study AM	Current study IP	Current study PM	2019 study AM	2019 study IP	2019 study PM
F16	TAG	3,711	4,014	4,014	3,776	3,971	3,866
F17	Medium	4,413	4,930	4,974	4,520	4,773	4,791
F18	High	5,544	5,906	6,046	5,241	5,326	5,711

Figure 34: Scheme flows, 2036



6.2.39. The variation between the multiplier values is very similar to the 2019 study, with the biggest difference between the two studies occurring with the High multiplier. This may be the result of the change in matrix estimation method, rather than specifically a CVTT-related effect.

Figure 35: Comparison of DM and DS flows, 2036 AM, TAG VTT

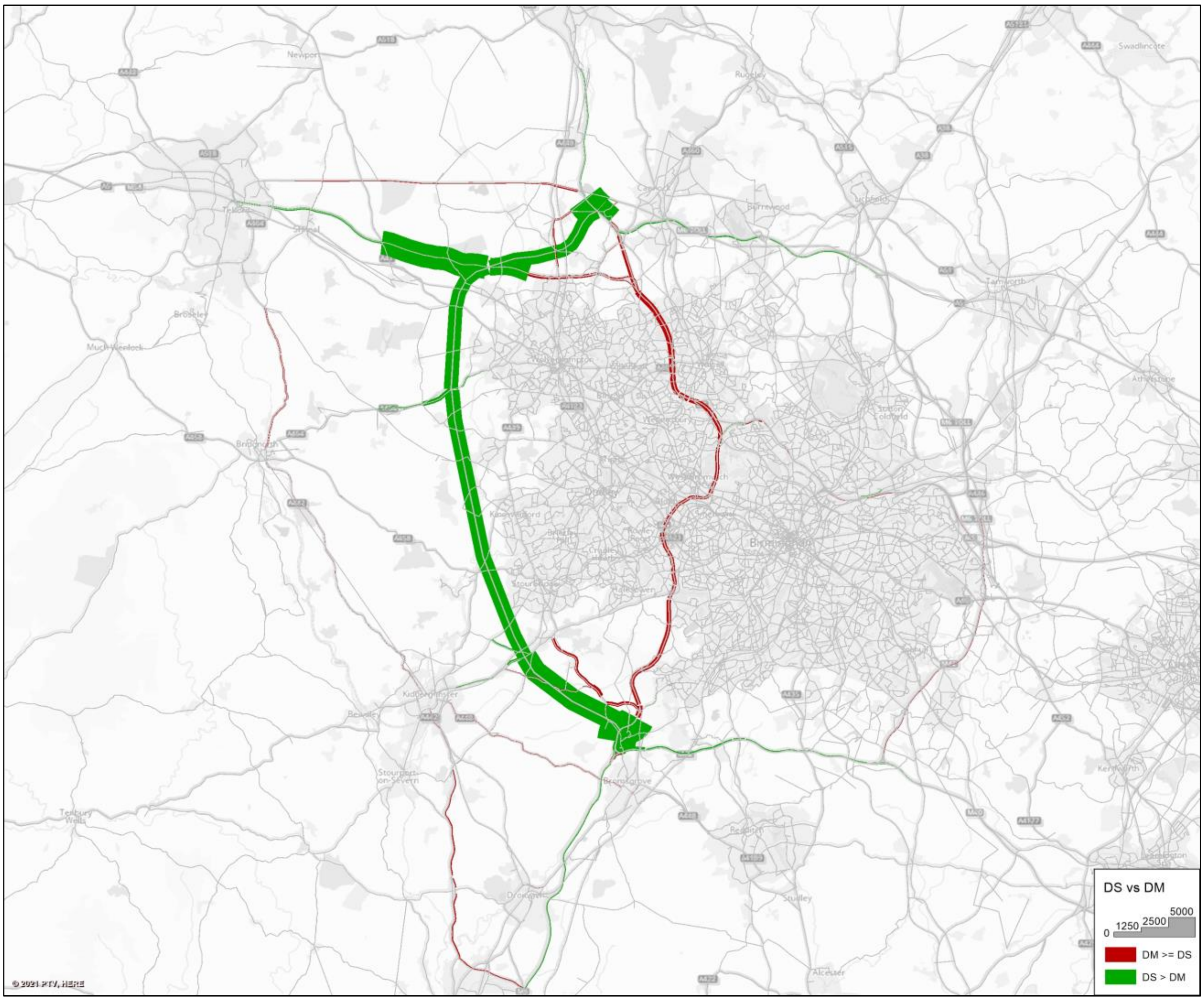


Figure 36: Comparison of DM and DS flows, 2036 AM, Medium CVTT multiplier

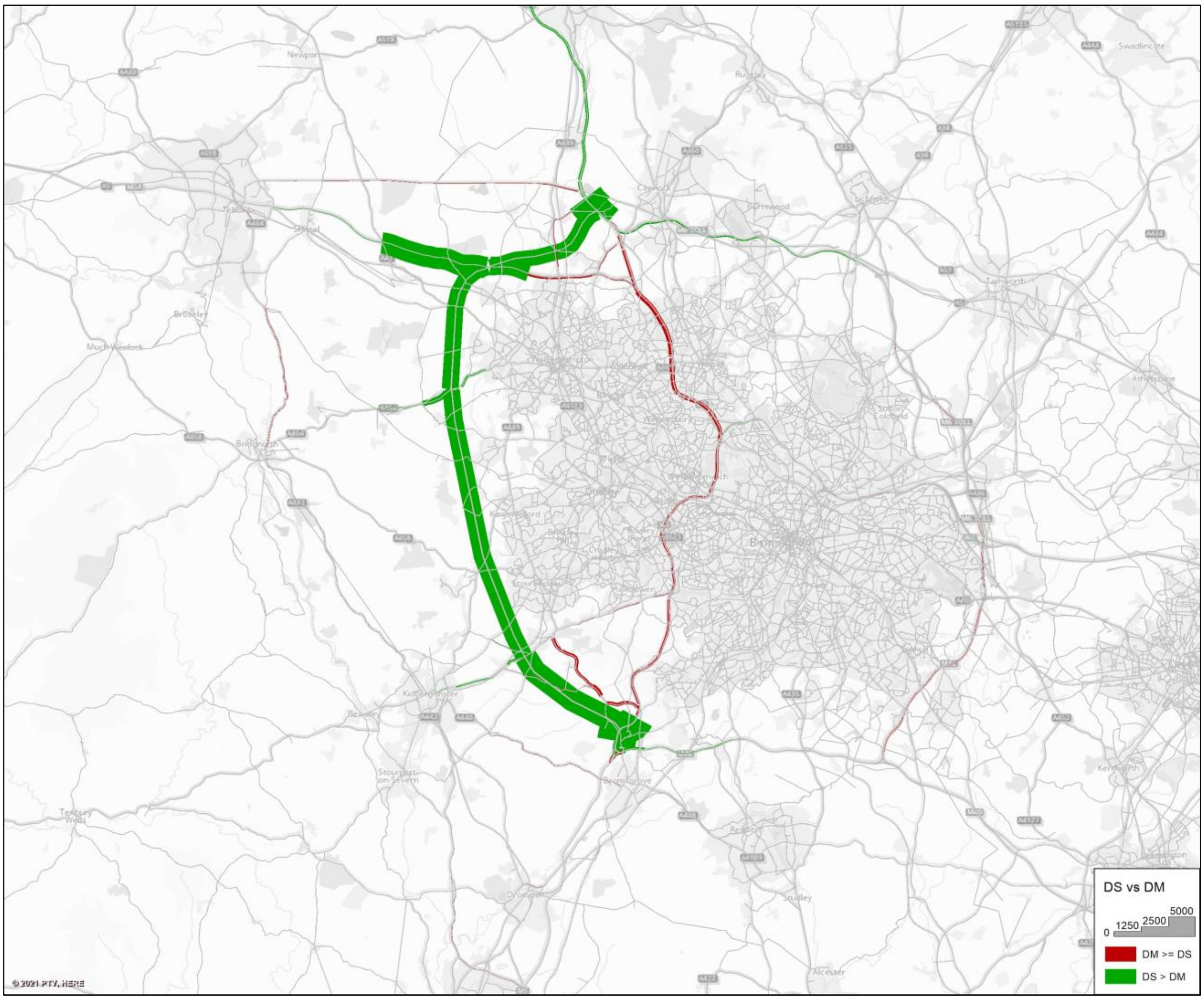


Figure 37: Comparison of DM and DS flows, 2036 AM, High CVTT multiplier

6.3. 2026 FORECASTS

Description of tests

6.3.1. The purpose of the 2026 forecasts is to examine the impact of the CVTT multipliers when there is less congestion (compared to 2036). These tests were not done in the 2019 study.

6.3.2. The runs are listed in Table 28. These repeat the 2036 runs, with only the forecast year, and all associated inputs, changed (for example: planning data, VTT growth, fuel cost growth, and PT fare growth).

Table 28: List of 2026 model runs

Run ID	Year	Scenario	Multiplier value	Pivots off base year matrix
F19	2026	DM	TAG VTT	MAT1
F20	2026	DM	Medium	MAT2
F21	2026	DM	High	MAT3
F22	2026	DS	TAG VTT	MAT1
F23	2026	DS	Medium	MAT2
F24	2026	DS	High	MAT3

Results

Convergence

6.3.3. Table 29 summarises the convergence statistics for the highway assignment (by time period) and the VDM-assignment loop.

Table 29: Convergence statistics, 2026

Run ID	Scenario	Multiplier	Assignment gap AM	Assignment gap IP	Assignment gap PM	VDM gap
F19	DM	TAG	0.07%	0.05%	0.07%	0.17%
F20	DM	Medium	0.02%	0.02%	0.07%	0.16%
F21	DM	High	0.04%	0.02%	0.06%	0.13%
F22	DS	TAG	0.07%	0.06%	0.06%	0.15%
F23	DS	Medium	0.02%	0.02%	0.10%	0.16%
F24	DS	High	0.03%	0.02%	0.07%	0.13%

6.3.4. Although convergence is better than in 2036, as would be expected, there are still two runs where the VDM gap exceeds the 0.15% stopping value. As with the 2036 results, comparison of flows and economic benefits between successive loops shows that the model outputs are stable.

Aggregate Model Results

6.3.5. Table 30 to Table 33 show the aggregate results from the highway assignment.

Table 30: Aggregate model results: car commute, 12 hr, 2026

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	2,125	31,739	642.5	476.5	165.9	14.9	18.1	13.5	4.7
F20	DM	Medium	2,097	32,577	624.1	484.1	140.0	15.5	17.9	13.8	4.0
F21	DM	High	2,128	33,096	624.6	491.7	132.9	15.6	17.6	13.9	3.7
F22	DS	TAG	2,123	32,011	641.4	477.9	163.5	15.1	18.1	13.5	4.6
F23	DS	Medium	2,093	32,970	622.8	485.9	136.9	15.8	17.9	13.9	3.9
F24	DS	High	2,124	33,762	626.6	496.0	130.6	15.9	17.7	14.0	3.7

Table 31: Aggregate model results: car employer's business, 12 hr, 2026

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	654	34,974	463.4	394.4	69.0	53.5	42.5	36.2	6.3
F20	DM	Medium	649	35,381	458.9	400.9	58.0	54.5	42.4	37.1	5.4
F21	DM	High	651	35,157	452.6	399.6	53.0	54.0	41.7	36.8	4.9
F22	DS	TAG	653	35,241	463.3	395.8	67.4	53.9	42.6	36.4	6.2
F23	DS	Medium	646	35,749	459.2	402.9	56.3	55.3	42.6	37.4	5.2
F24	DS	High	649	35,723	454.8	403.1	51.7	55.1	42.1	37.3	4.8

Table 32: Aggregate model results: car other, 12 hr, 2026

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	3,804	41,641	856.5	643.5	213.0	10.9	13.5	10.2	3.4
F20	DM	Medium	3,885	42,275	861.8	664.9	196.8	10.9	13.3	10.3	3.0
F21	DM	High	3,952	43,093	864.8	676.3	188.5	10.9	13.1	10.3	2.9
F22	DS	TAG	3,803	41,872	855.6	644.9	210.7	11.0	13.5	10.2	3.3
F23	DS	Medium	3,882	42,632	860.7	666.8	193.9	11.0	13.3	10.3	3.0
F24	DS	High	3,951	43,644	866.2	680.1	186.1	11.0	13.2	10.3	2.8

Table 33: Aggregate model results: car all purposes, 12 hr, 2026

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	6,582	108,354	1,962	1,514	447.9	16.5	17.9	13.8	4.1
F20	DM	Medium	6,631	110,233	1,945	1,550	394.8	16.6	17.6	14.0	3.6
F21	DM	High	6,731	111,347	1,942	1,568	374.4	16.5	17.3	14.0	3.3
F22	DS	TAG	6,579	109,124	1,960	1,519	441.6	16.6	17.9	13.8	4.0
F23	DS	Medium	6,621	111,351	1,943	1,556	387.1	16.8	17.6	14.1	3.5
F24	DS	High	6,724	113,129	1,948	1,579	368.4	16.8	17.4	14.1	3.3

6.3.6. Figure 38 to Figure 41 show the average trip distances, times, free-flow times, and delays from the above tables.

Figure 38: Average trip distance (km)

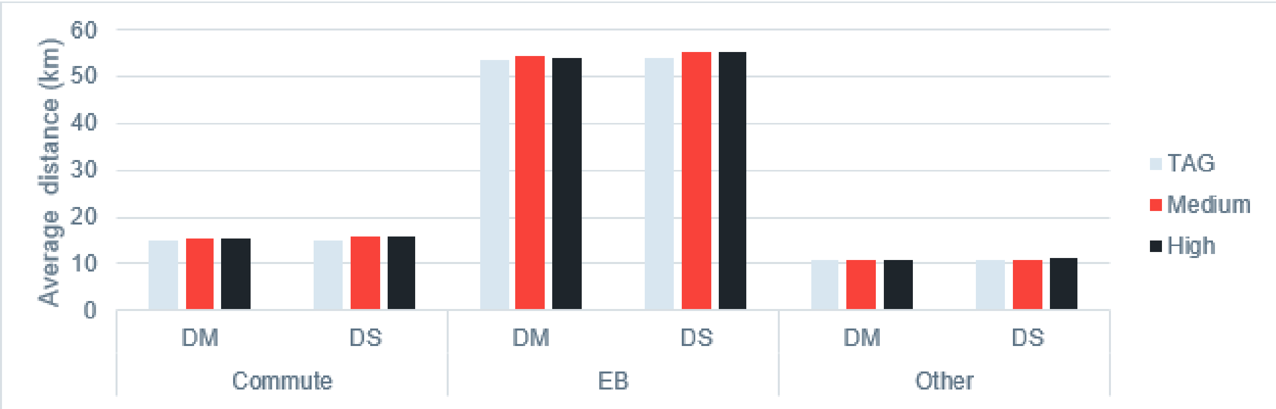


Figure 39: Average trip time (mins)

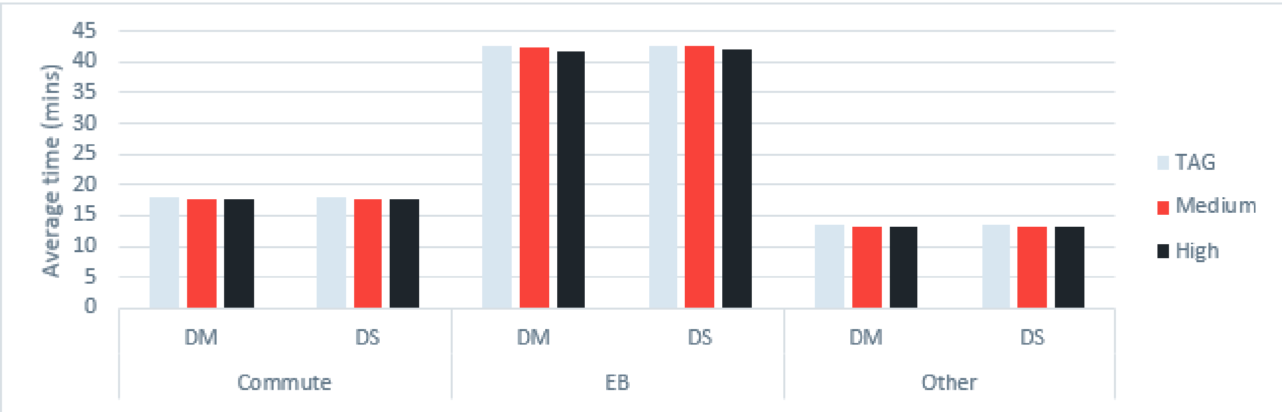


Figure 40: Average trip free-flow time (mins)

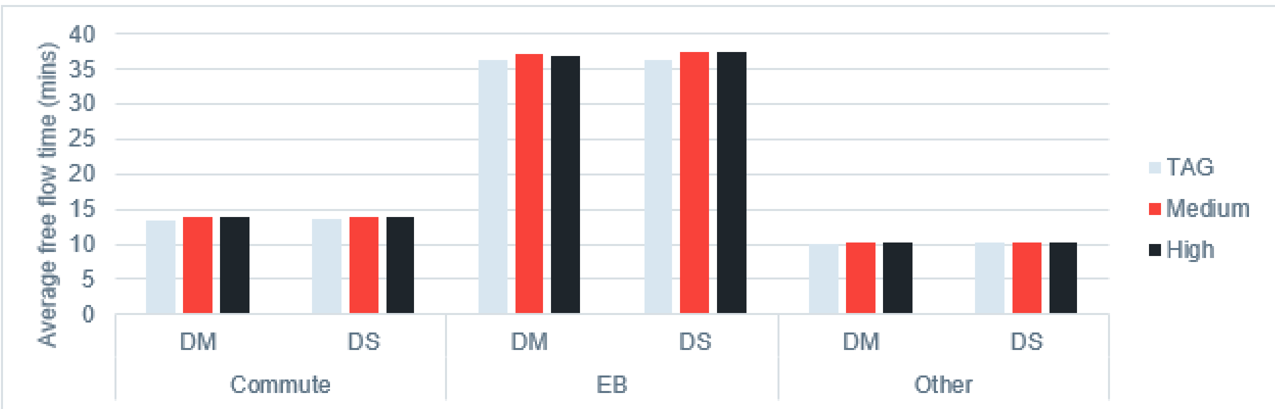
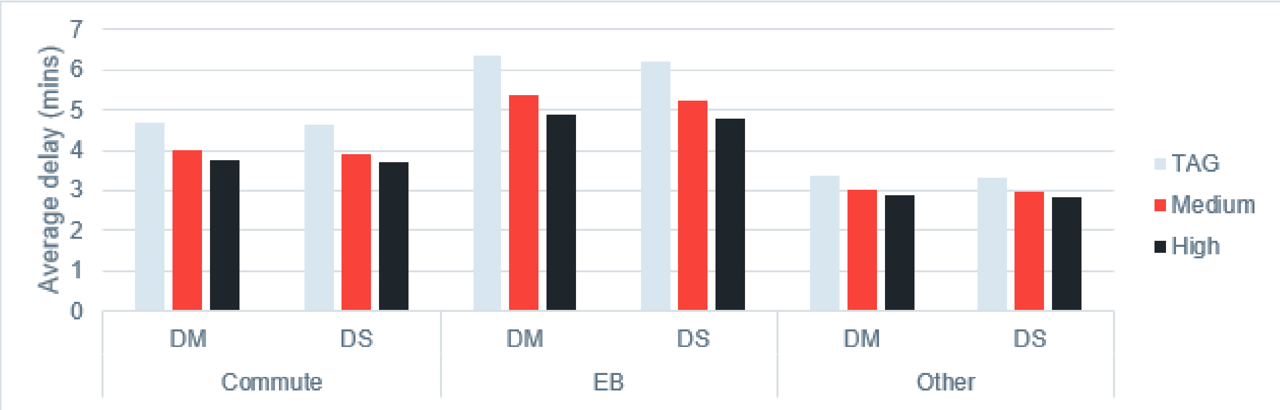


Figure 41: Average trip delay (mins)



6.3.7. The pattern of results, particularly in terms of differences with the CVTT multiplier is very similar to the 2036 results, albeit the scale of the differences is a little less. For example, the average delay per trip is highest with TAG VTT and lowest with the High multiplier (see Figure 41), but the size of that difference is lower in 2036 (0.9 second difference in the DM, compared to 1.3 second difference in the 2036 DM).

6.3.8. Overall, the impact of CVTT is slightly lower in 2026 compared to 2036, which is to be expected given the lower level of congestion. However, the difference is still significant.

Trip totals

6.3.9. Table 34 shows all-mode 24 hour person trip totals from the demand model, before the pivoting process is applied.

6.3.10. The table shows that the Medium multiplier has the most trips, and the High multiplier the least, in both the DM and DS scenarios, consistent with the 2036 results.

Table 34: All-mode 24 hour person trip totals (synthetic), 2026

Run ID	Scenario	Multiplier	Total trips
F19	DM	TAG	10,742,415
F20	DM	Medium	10,822,786
F21	DM	High	10,732,812
F22	DS	TAG	10,744,405
F23	DS	Medium	10,826,802
F24	DS	High	10,737,467

Implied Average VTT

6.3.11. Table 35 shows the outturn average VTT for each model run and car journey purpose. This is a weighted average of the input free-flow and delay VTTs (weighted by free-flow and delay vehicle hours).

Table 35: Outturn average VTTs, 2026 (£/hr per vehicle, 2010 prices)

Run	Scenario	Multiplier	Commute	Employer's Business	Other
F19	DM	TAG	14.04	21.07	9.99
F20	DM	Medium	14.17	15.10	7.29
F21	DM	High	18.11	17.70	9.36
F22	DS	TAG	14.04	21.07	9.99
F23	DS	Medium	14.09	15.01	7.25
F24	DS	High	17.94	17.53	9.30

6.3.12. The pattern of variation is virtually the same as in 2036. The percentage variation is just a little bit lower.

DM flows

6.3.13. Figure 42 and Figure 43 show the difference in link flows between TAG VTT, and the CVTT multiplier (Medium and High respectively) for the AM peak (cars only). Red indicates a reduction in flow (CVTT flow is lower than TAG), green an increase (CVTT is higher than TAG). The pattern is very similar to 2036, but on a smaller scale (in line with the other results so far), i.e. with CVTT there is shift away from the motorway box to the M1 and M6 to the east.

Figure 42: Comparison of DM link flows, 2026 AM, Medium vs TAG

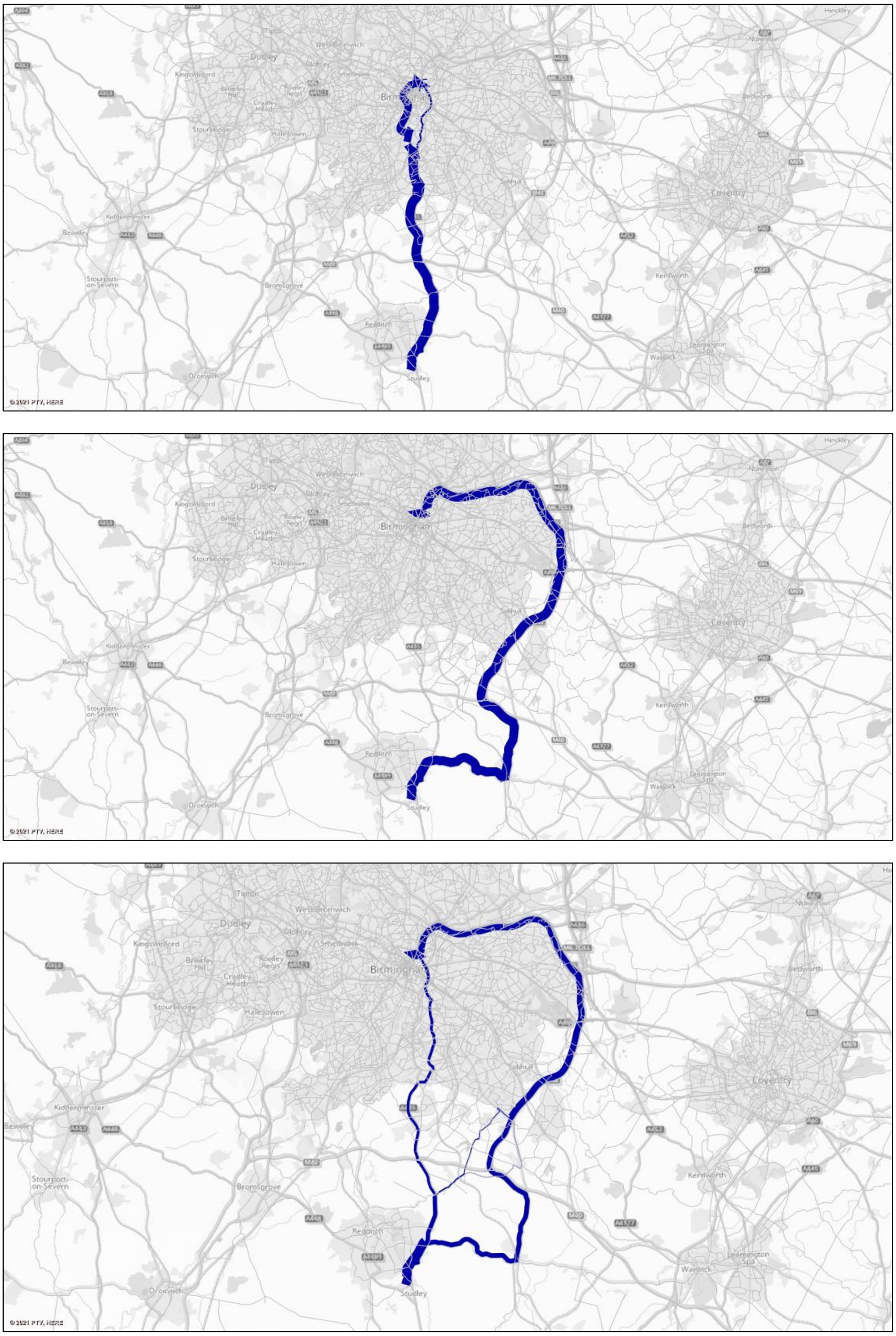
Figure 43: Comparison of DM link flows, 2026 AM, High vs TAG

OD routing

6.3.14. The earlier analysis for 2036 (particularly Figure 31) showed that the only OD pair significantly affected by the CVTT multiplier was Studley-Birmingham City Centre. Figure 44 shows the corresponding routes for 2026. This shows a similar impact to 2036, with TAG VTT putting traffic on the most direct urban route, but Medium and High multipliers putting most traffic on to the motorway box. This is to be expected as drivers become more averse to the congested urban route.

6.3.15. Other OD pairs (not shown here) either show no difference in routing between TAG VTT and CVTT or have limited variation similar to 2036 (for example King's Heath to Smethwick).

Figure 44: Studley - Birmingham City Centre route choice, 2026 DM AM peak cars (order of plots: TAG, Medium, High)



Scheme impact

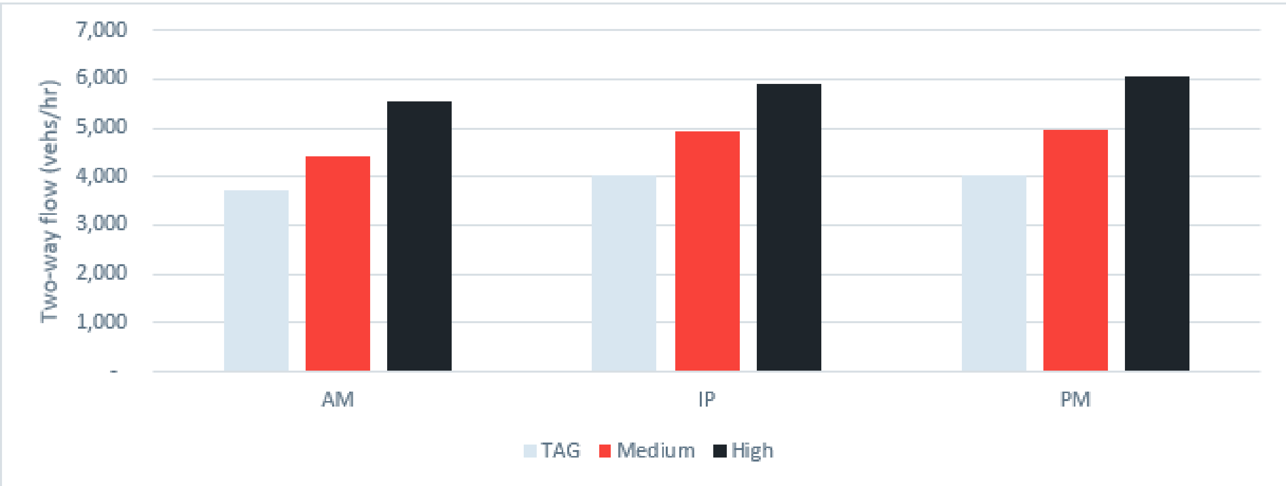
6.3.16. Figure 46 to Figure 48 show the changes in flows between the DM and DS for each multiplier value, all vehicles, AM peak only.

6.3.17. Table 36 shows the 2-way flows on the central section of the scheme; Figure 45 shows the same data.

Table 36: Scheme flows (two-way, vehs/hr), 2026

Run ID	Multiplier value	AM	IP	PM
F16	TAG	2,721	3,327	3,075
F17	Medium	3,363	4,041	3,765
F18	High	4,444	5,112	4,907

Figure 45: Scheme flows, 2026



6.3.18. The flows are much lower than in 2036, typically around 1,000 vehs/hr less in the peaks. However, there is still a large difference with the multiplier, e.g. about 1,800 vehs/hr more in the PM with the High multiplier, compared to TAG (the corresponding figure for 2036 was 2,000 vehs/hr).

Figure 46: Comparison of DM and DS flows, 2026 AM, TAG VTT

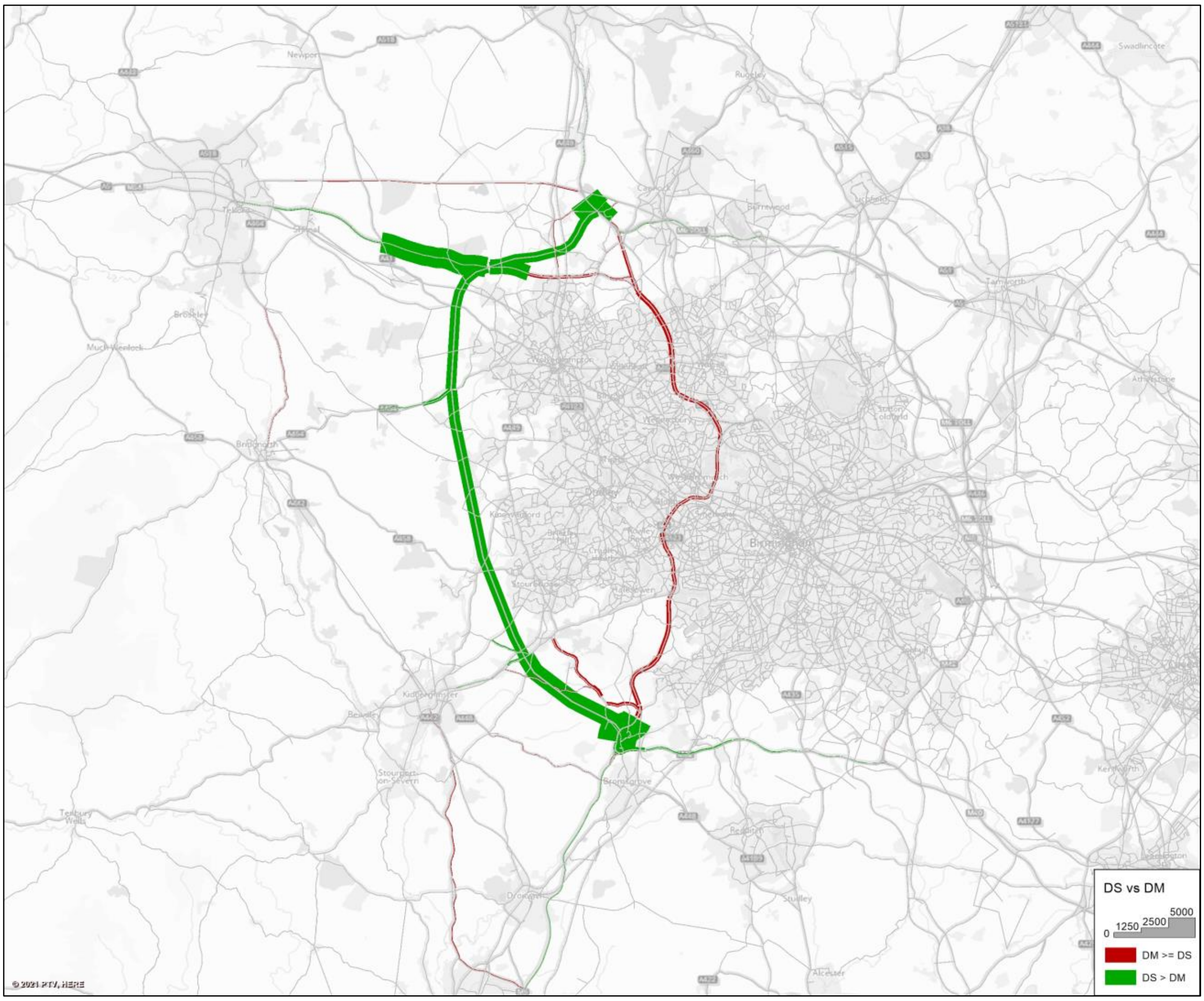


Figure 47: Comparison of DM and DS flows, 2026 AM, Medium CVTT multiplier

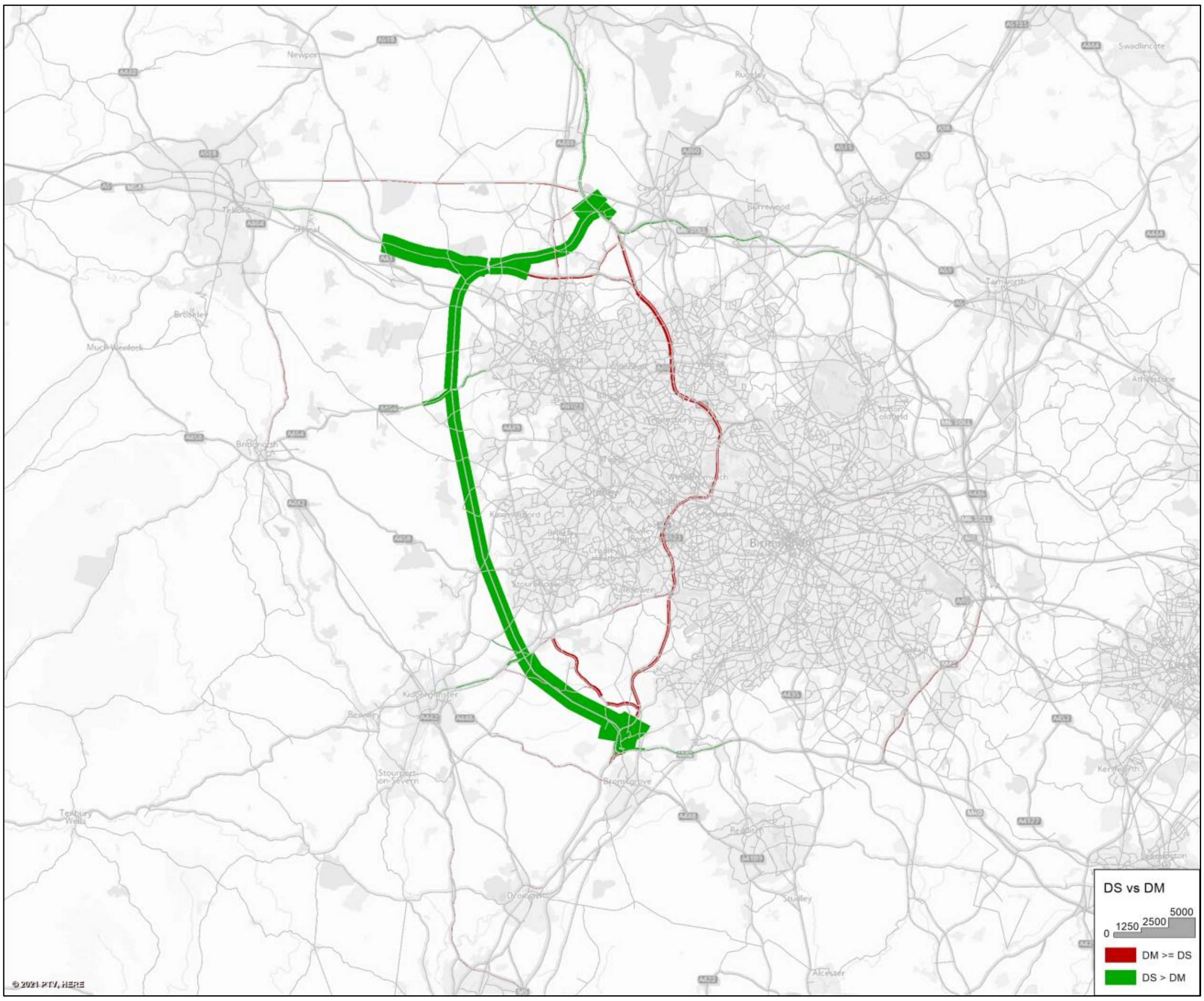


Figure 48: Comparison of DM and DS flows, 2026 AM, High CVTT multiplier

6.4. FIXED MATRIX ASSIGNMENTS

Description of tests

6.4.1. These tests involved assigning the 2036 post-VDM DM matrices to the 2036 DS network.

6.4.2. The purpose of the tests was to investigate how much of the difference between different CVTT multipliers was due to the demand model response, and how much to re-assignment in the demand model.

Table 37: List of 2036 fixed matrix assignments

Run ID	Year	Scenario (network)	Multiplier value	Assignment matrix (2036 post-VDM DM) from model run
F31	2036	DS	TAG VTT	F13
F32	2036	DS	Medium	F14
F33	2036	DS	High	F15

Results

Aggregate Model Results

6.4.3. Table 38 to Table 41 and Figure 49 to Figure 52 show the aggregate results from the highway assignment. The differences between the multipliers are very similar to those seen for the full VDM model runs in section 6.2.

6.4.4. Compared to the full VDM run using the DM network (Table 20 to Table 23) there is an increase in distance and a reduction in travel time. This is a result of trips re-routing to use the scheme to save time, at the expense of an increase in distance. A similar effect was observed in the full VDM run of the DS but with the fixed matrix assignment the total distance and time are less than with the full DS VDM as it does not include the extra traffic induced by the scheme.

Table 38: Aggregate model results: car commute, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F31	DS network DM matrix	TAG	2,264	36,981	746.7	540.5	206.1	16.3	19.8	14.3	5.5
F32	DS network DM matrix	Medium	2,195	37,744	708.9	543.9	165.0	17.2	19.4	14.9	4.5
F33	DS network DM matrix	High	2,240	38,248	706.0	551.1	154.9	17.1	18.9	14.8	4.1

Table 39: Aggregate model results: car employer's business, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F31	DS network DM matrix	TAG	709	40,545	536.5	450.8	85.7	57.2	45.4	38.1	7.2
F32	DS network DM matrix	Medium	695	40,366	520.2	451.3	68.9	58.0	44.9	38.9	5.9
F33	DS network DM matrix	High	699	39,854	509.7	447.9	61.8	57.0	43.7	38.4	5.3

Table 40: Aggregate model results: car other, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F31	DS network DM matrix	TAG	4,164	47,078	978.9	717.0	261.9	11.3	14.1	10.3	3.8
F32	DS network DM matrix	Medium	4,233	47,968	974.1	740.4	233.7	11.3	13.8	10.5	3.3
F33	DS network DM matrix	High	4,302	48,468	966.9	746.8	220.1	11.3	13.5	10.4	3.1

Table 41: Aggregate model results: car all purpose, 12 hr, 2036

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F31	DS network DM matrix	TAG	7,138	124,604	2,262	1,708	553.8	17.5	19.0	14.4	4.7
F32	DS network DM matrix	Medium	7,123	126,079	2,203	1,736	467.6	17.7	18.6	14.6	3.9
F33	DS network DM matrix	High	7,241	126,571	2,183	1,746	436.7	17.5	18.1	14.5	3.6

Figure 49: Average trip distance (km)

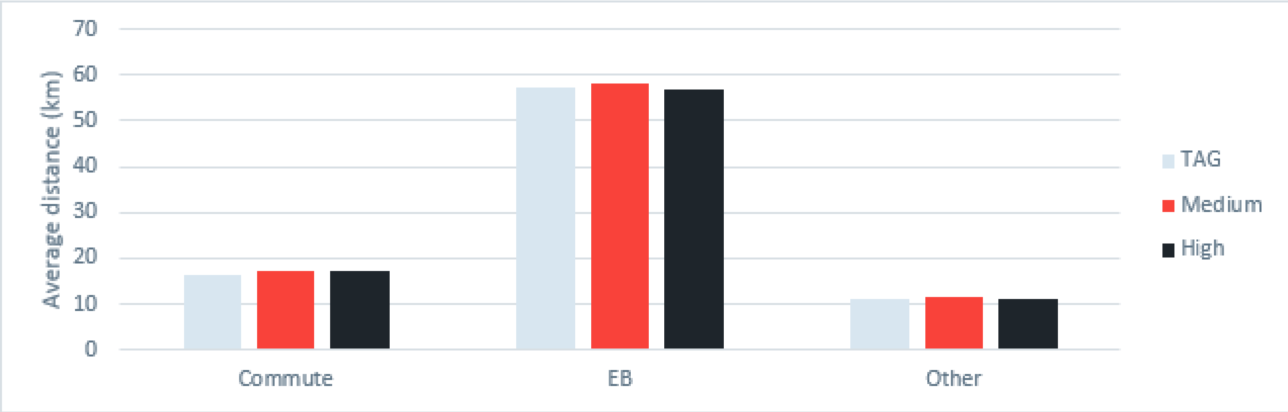


Figure 50: Average trip time (mins)

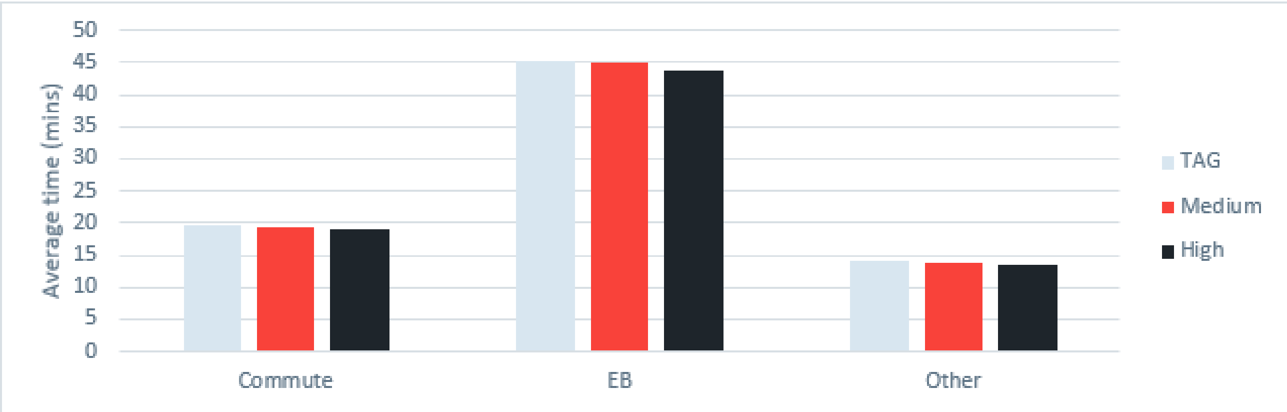


Figure 51: Average trip free-flow time (mins)

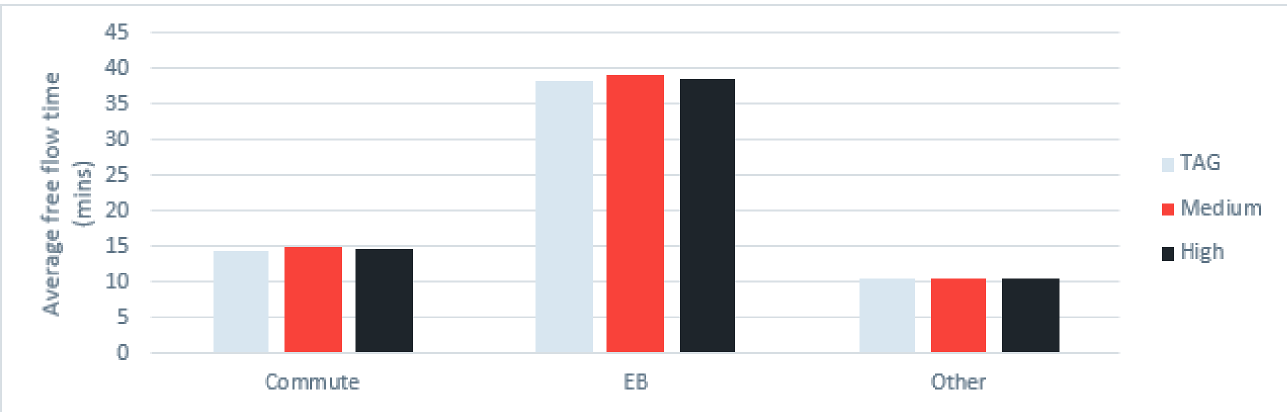
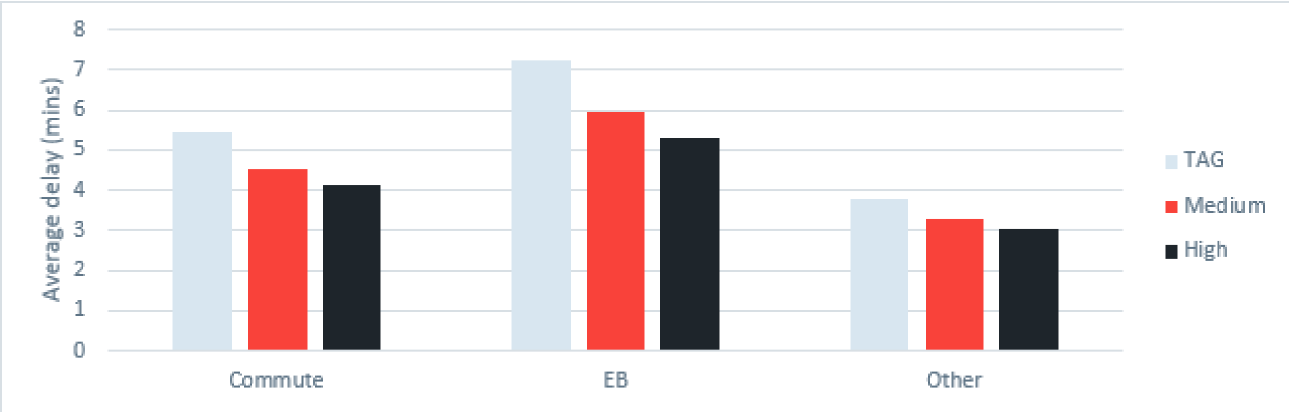


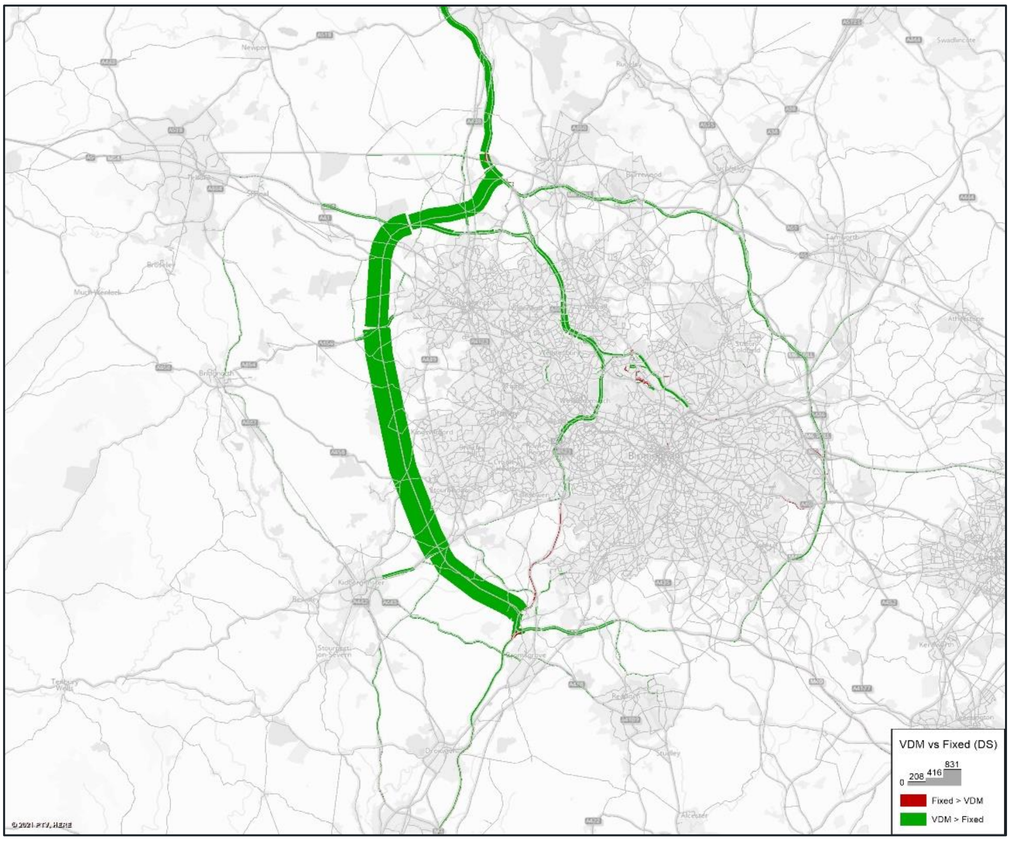
Figure 52: Average trip delay (mins)



Scheme flows

6.4.5. Figure 54 shows the increase in flows from the fixed matrix assignment to full VDM for a single example (AM peak, High multiplier). (Other model runs are very similar). As would be expected, the largest impact is on the scheme itself, with much smaller increases (and isolated decreases) elsewhere.

Figure 53: 2036 DS, AM peak, High multiplier, increase in flows from fixed assignment to VDM



6.4.6. Table 42 shows the scheme flows from the fixed matrix assignment, along with the full VDM flows, and the increase from the former to the latter.

6.4.7. Figure 54 shows the same data.

6.4.8. The fixed matrix results show a very strong effect of CVTT multipliers on the assignment-only response, with increases of 38-40% between TAG and the high multiplier.

6.4.9. VDM itself increases flows by 17-34%, other things being equal. However, the VDM response shows an even stronger effect of CVTT multipliers, with the High multiplier having nearly double the amount of induced traffic as TAG. This is likely to be mainly due to a change in destination choice (which is the most cost-sensitive choice in the demand model), with the scheme providing more options to travel to alternative destinations via a relatively uncongested road.

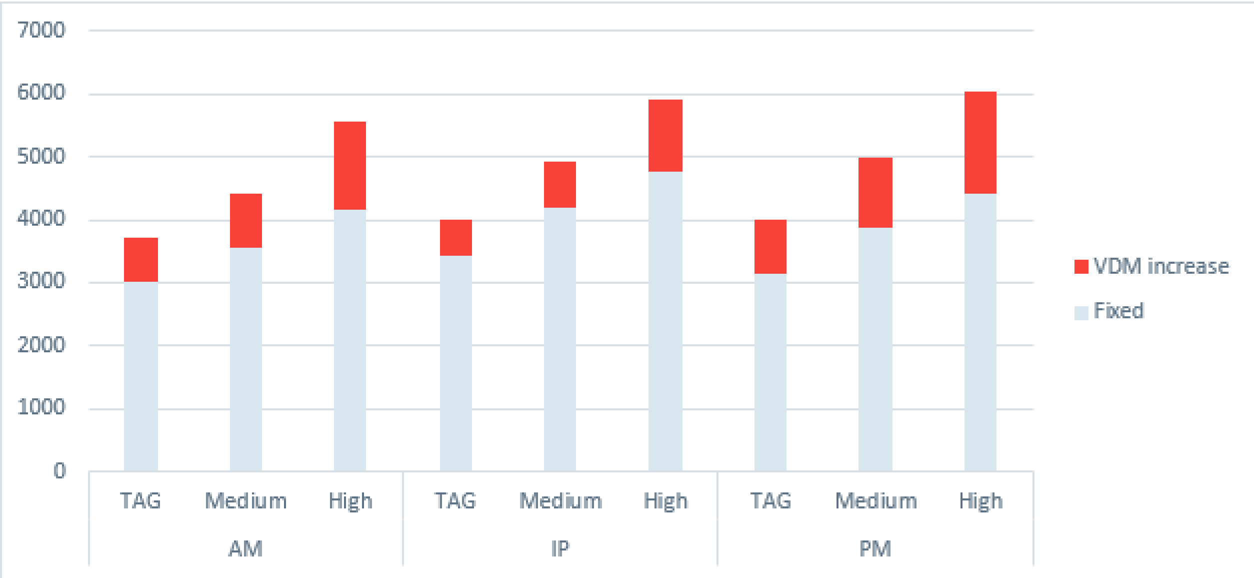
6.4.10. It should be noted that the location of the scheme means that a significant proportion of traffic using it is external-external movements. These are *not* subject to VDM in PRISM, and it is likely that a scheme in a more central location would show a proportionally larger VDM response since proportionally fewer trips would be fixed demand.

6.4.11. Overall these results show that the assignment model and VDM are both showing a significant impact from the CVTT multiplier.

Table 42: Scheme flows (two-way, vehs/hr), 2036

Run ID	Multiplier value	Fixed AM	Fixed IP	Fixed PM	VDM AM	VDM IP	VDM PM	Difference AM	Difference IP	Difference PM
F31	TAG	3,000	3,428	3,151	3,711	4,014	4,014	711	586	863
F32	Medium	3,560	4,179	3,887	4,413	4,930	4,974	853	751	1,087
F33	High	4,152	4,754	4,405	5,544	5,906	6,046	1,392	1,152	1,641

Figure 54: Scheme flows, 2036, showing increase due to VDM



6.5. 2036 CAR JOURNEY TIME ELASTICITIES

Description of tests

6.5.1. Chapter 5 reported the base year (2015) car journey time and fuel cost elasticities, with relatively small differences between CVTT multipliers. While it is not common practice to calculate outturn elasticities for future years, it was decided that it would be a useful exercise to confirm that the sensitivity of the demand model does not vary significantly between multiplier values in future years.

Results

Table 43 shows the outturn car journey time elasticities for 2036, and

6.5.2. Table 44 shows the change from 2015 (a negative value means the model is more elastic in 2036).

6.5.3. The 2036 elasticities are very similar to the base year. Some increase and some decrease but overall the differences are negligible. This may be considered surprising; however, given the way that journey times are represented in the utility function of the PRISM demand model, there is no reason to expect journey time elasticities to be directly affected by increases in VTT, or monetary costs such as fuel costs or PT fares.

6.5.4. The 2036 elasticities show little variation between TAG and CVTT multipliers (the same was true for 2015). Therefore it seems unlikely that recalibrating the demand model with the multipliers would have significantly altered the differences between TAG and CVTT results presented in the earlier part of this note.

Table 43. 2036 elasticities of car trips with respect to car journey time

Multiplier	Journey purpose	AM	IP	PM	12 hour total
TAG	Car business	-0.20	-0.16	-0.21	-0.19
TAG	Car commute	-0.12	-0.08	-0.12	-0.11
TAG	Car other	-0.24	-0.14	-0.17	-0.17
TAG	**Car total**	**-0.17**	**-0.13**	**-0.15**	**-0.15**
Medium	Car business	-0.21	-0.16	-0.22	-0.20
Medium	Car commute	-0.11	-0.05	-0.11	-0.09
Medium	Car other	-0.22	-0.12	-0.15	-0.14
Medium	**Car total**	**-0.15**	**-0.11**	**-0.14**	**-0.13**
High	Car business	-0.24	-0.19	-0.26	-0.23
High	Car commute	-0.14	-0.08	-0.14	-0.12
High	Car other	-0.24	-0.13	-0.17	-0.16
High	**Car total**	**-0.18**	**-0.13**	**-0.16**	**-0.15**

Table 44: Change in elasticities of car trips with respect to car journey time, 2015 to 2036 (negative value means the model is more elastic in 2036)

Multiplier	Journey purpose	AM	IP	PM	12 hour total
TAG	Car business	0.00	0.02	-0.01	0.00
TAG	Car commute	0.02	0.03	0.02	0.02
TAG	Car other	0.00	0.00	0.00	0.00
TAG	**Car total**	**0.01**	**0.01**	**0.01**	**0.01**
Medium	Car business	-0.01	0.01	-0.01	-0.01
Medium	Car commute	0.01	0.03	0.01	0.01
Medium	Car other	-0.01	0.00	-0.01	0.00
Medium	**Car total**	**0.00**	**0.01**	**0.00**	**0.00**
High	Car business	-0.01	0.00	-0.02	-0.01
High	Car commute	0.01	0.02	0.01	0.01
High	Car other	-0.01	0.00	0.00	0.00
High	**Car total**	**0.00**	**0.01**	**0.00**	**0.00**

7. STAGE 4: APPRAISAL

7.1. INTRODUCTION

7.1.1. This chapter describes the results of Stage 4 of the project, which involved calculating user benefits in TUBA, using model outputs described in the previous chapter.

7.1.2. TUBA has been run separately for the two forecast years, 2026 and 2036. Although it would have been possible to run TUBA for a 60 year appraisal period, benefits for other years would have been interpolated between, or extrapolated from, these two years and would not provide any additional insight into the impact of CVTT on user benefits.

7.1.3. Details of how TUBA was set up can be found in the 2019 report. Briefly, travel time skims were split between free-flow time and delay time. TUBA was run separately for each, with the VTT in the economics file set accordingly, depending on whether the run was for free-flow or delay time and, in the latter case, the value of the CVTT multiplier (or TAG). Travel time benefits from the two runs were then added together. A third TUBA run, using total travel times, was used to calculate other impacts (user charge and VOC benefits, and operator and indirect tax revenues).

7.1.4. TUBA version 1.9.11, which adopts the TAG May 2018 Data Book parameter values, was used for consistency with the 2019 study.

7.1.5. In the 2019 study, some of the TUBA runs used the CVTT multiplier only in the appraisal, in conjunction with outputs from model runs using TAG VTT (i.e. without using CVTT in the modelling). It was concluded that this would not be an acceptable way forward for practical applications as it would significantly overstate scheme benefits. Therefore those tests have not been repeated here.

7.2. 2036 TUBA OUTPUTS

7.2.1. Table 45 summarises the 2036 TUBA results, with travel time benefits split between free-flow and delay. This corresponds to Table 30 in the 2019 report. All monetary values in this chapter are in 2010 prices discounted to 2010, unless otherwise stated.

Table 45: 2036 TUBA Benefits (£000s), TAG and CVTT multipliers

Time Benefit	TAG VTT Total	TAG VTT Free-flow time	TAG VTT Delay time	Medium CVTT Total	Medium CVTT Free-flow time	Medium CVTT Delay time	High CVTT Total	High CVTT Free-flow time	High CVTT Delay time
Commuting	9,836	1,823	8,013	18,804	1,114	17,690	23,953	1,130	22,824
Other	6,911	823	6,088	11,183	602	10,581	12,608	1,036	11,572
Business (Car)	11,127	2,653	8,474	15,028	1,521	13,507	18,743	3,639	15,104
Business (Freight)	6,122	1,810	4,312	8,600	1,006	7,594	9,952	996	8,956
Total	***33,996***	***7,109***	***26,887***	***53,615***	***4,243***	***49,372***	***65,256***	***6,801***	***58,455***
Fuel VOC	-2,741	N/A	N/A	-3,723	N/A	N/A	-4,115	N/A	N/A
Non Fuel VOC	-2,360	N/A	N/A	-3,712	N/A	N/A	-5,906	N/A	N/A
User Charges	1,076	N/A	N/A	1,181	N/A	N/A	2,079	N/A	N/A
Operator Revenues	-410	N/A	N/A	-66	N/A	N/A	-392	N/A	N/A
Greenhouse Gas	-1,328	N/A	N/A	-1,775	N/A	N/A	-2,366	N/A	N/A

Time Benefit	TAG VTT Total	TAG VTT Free-flow time	TAG VTT Delay time	Medium CVTT Total	Medium CVTT Free-flow time	Medium CVTT Delay time	High CVTT Total	High CVTT Free-flow time	High CVTT Delay time
Indirect Tax Revenues	4,001	N/A	N/A	5,377	N/A	N/A	7,200	N/A	N/A
Total	**32,233**	**7,109**	**26,887**	**50,896**	**4,243**	**49,372**	**61,757**	**6,801**	**58,455**

2010 prices discounted to 2010

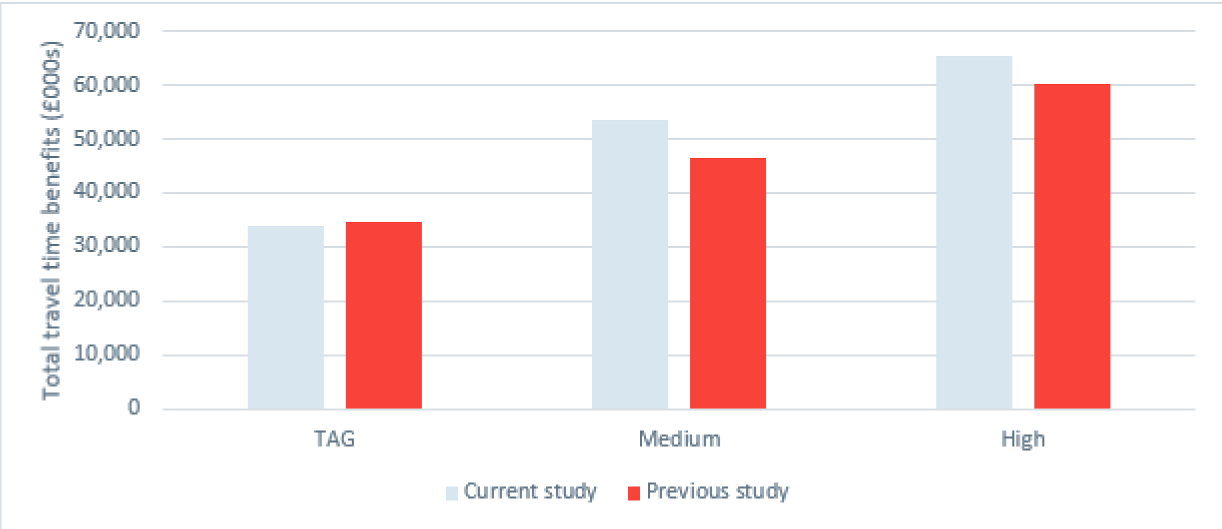
7.2.2. Benefits are significantly higher with the CVTT multipliers than TAG, with High being greater than Medium. This is almost entirely the result of differences in the travel time benefits (VOC disbenefits increase with the multiplier and user charge benefits are small).

7.2.3. For all three sets of VTT, most of the time benefits come from delay time. The value of these benefits increases with the multiplier, but not directly in proportion to the value of the multiplier. For example, with the High multiplier delays are valued 5/3 times (67%) more than with the Medium multiplier. However, the value of delay benefits is only 18% more, reflecting the different behavioural responses in the model with traffic more likely to avoid delays with the High multiplier.

7.2.4. Free-flow time benefits are modest, and highest with TAG VTT, reflecting the lower free-flow VTT with the Medium and High multipliers.

7.2.5. This pattern is similar to that observed in the 2019 report. Figure 55 compares the total travel time benefits from Table 45 with the corresponding values from the 2019 study. There is little difference with TAG VTT, but the Medium and High multiplier benefits are noticeably higher in the current study. As noted in chapter 6, these differences will partly be the result of the change in the matrix estimation method, and not entirely CVTT-related.

Figure 55: Comparison of 2036 total travel time benefits between current and previous (2019) studies



7.2.6. Figure 56 to Figure 58 show the total travel time benefits broken down by time period, purpose and trip length respectively. The pattern of differences between TAG, Medium and High is broadly similar across all the different categories. The differences between Medium and High are slightly smaller in the peaks compared to the inter-peak. Similarly, the differences between Medium and High are relatively small for Other trips, and for shorter trips less than 10km.

Figure 56: Total travel time benefits by time period, 2036

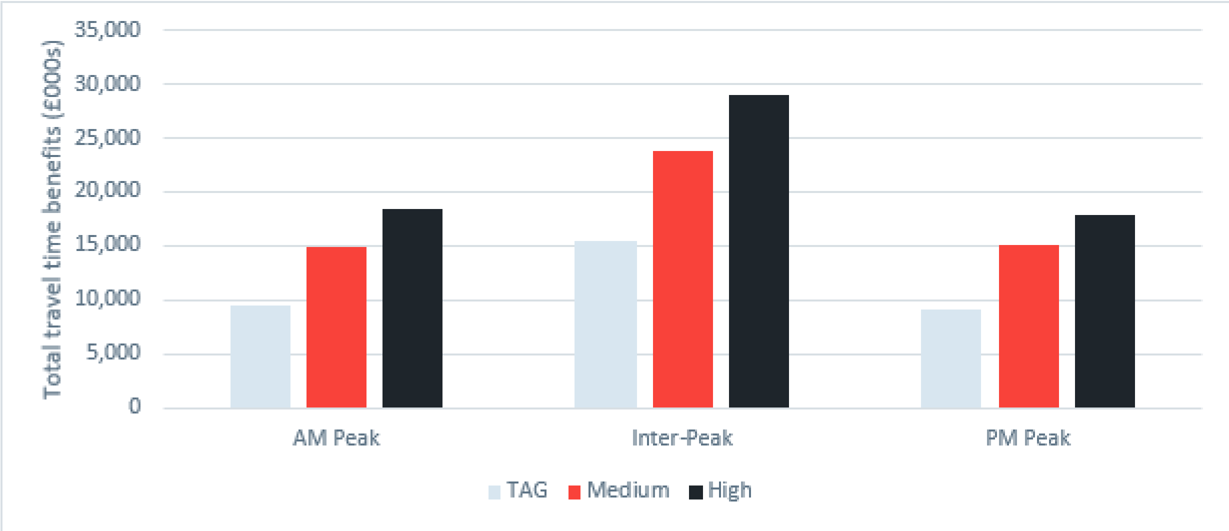


Figure 57: Total travel time benefits by purpose, 2036

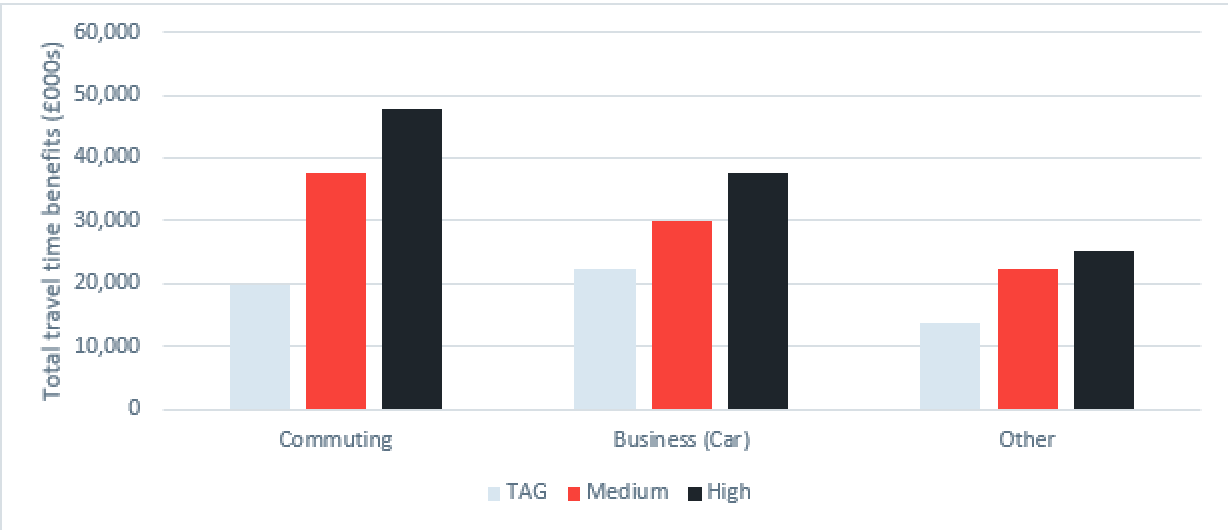
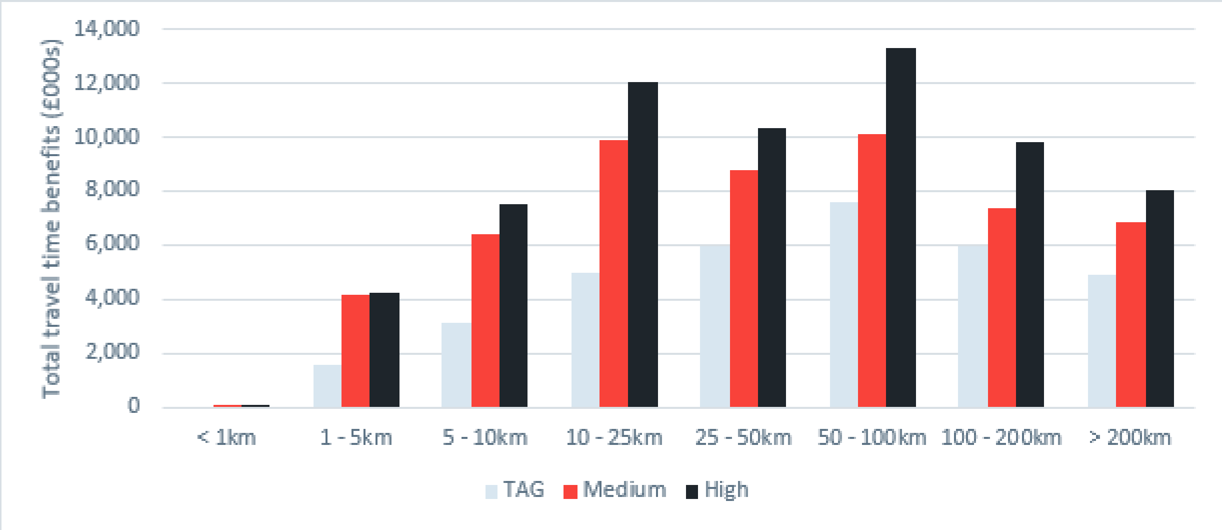


Figure 58: Total travel time benefits by trip length, 2036



7.2.7. Figure 59 and Figure 60 show the travel time benefits by origin and destination sector respectively. The sector plan is in Figure 61.

7.2.8. The sector-level benefits mostly show a similar pattern of variation by VTT to the other results. There are some sectors where benefits with the High multiplier are lower than with the Medium multiplier, e.g. Coventry and Wolverhampton, contrary to the general pattern. This suggests there may be localised increases in congestion that are offsetting the benefits of the scheme. Chapter 3 showed that scheme flows are higher with the High multiplier compared to Medium and it may be these higher flows that are increasing delays for some non-scheme traffic. This may also explain the results presented earlier where, for some categories, there is relatively little difference between Medium and High benefits.

Figure 59: Total travel time benefits by trip origin, 2036

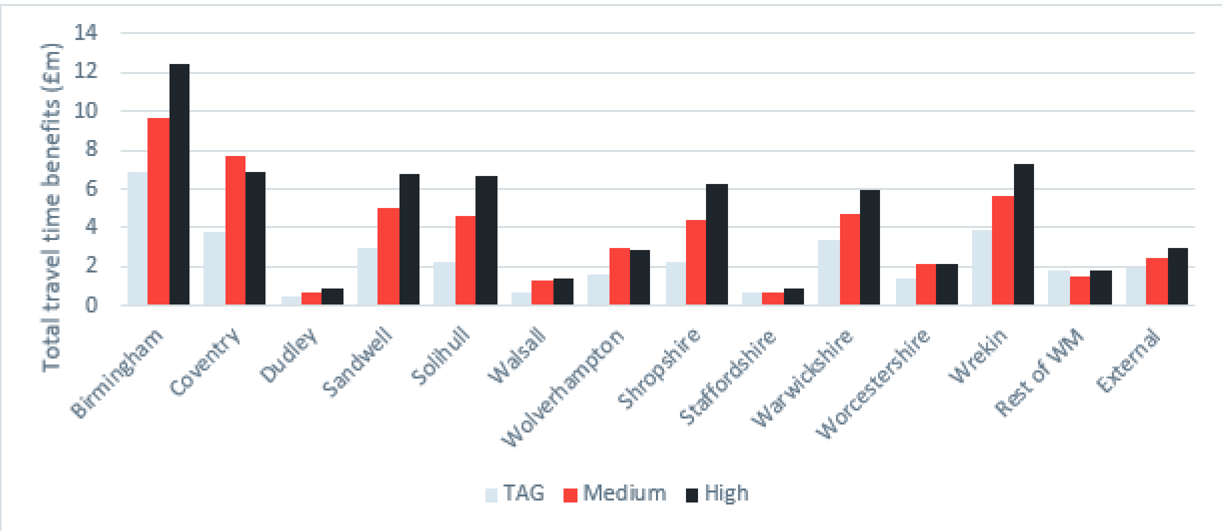


Figure 60: Total travel time benefits by trip destination, 2036

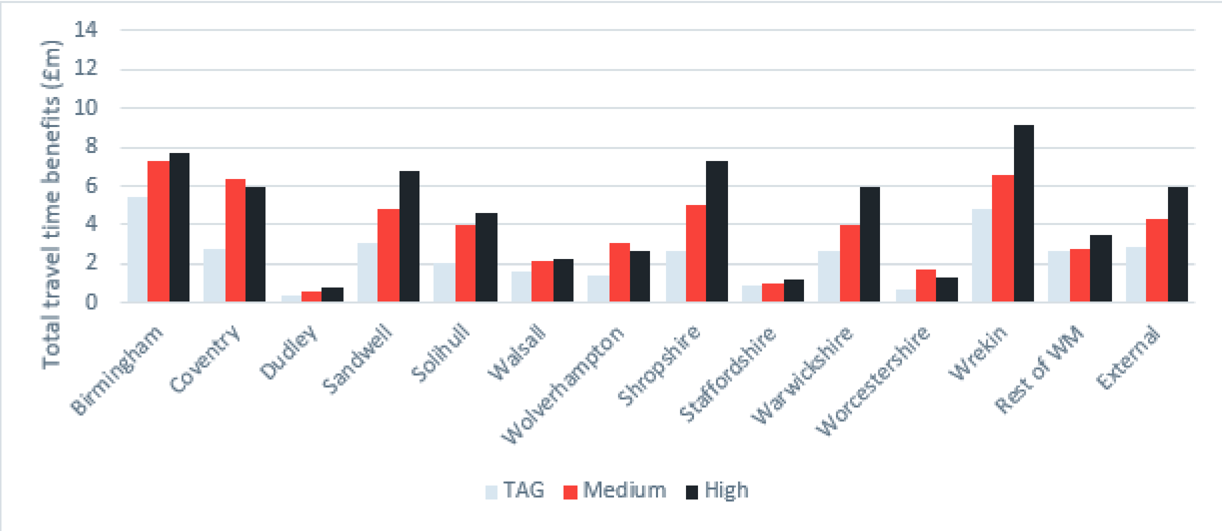
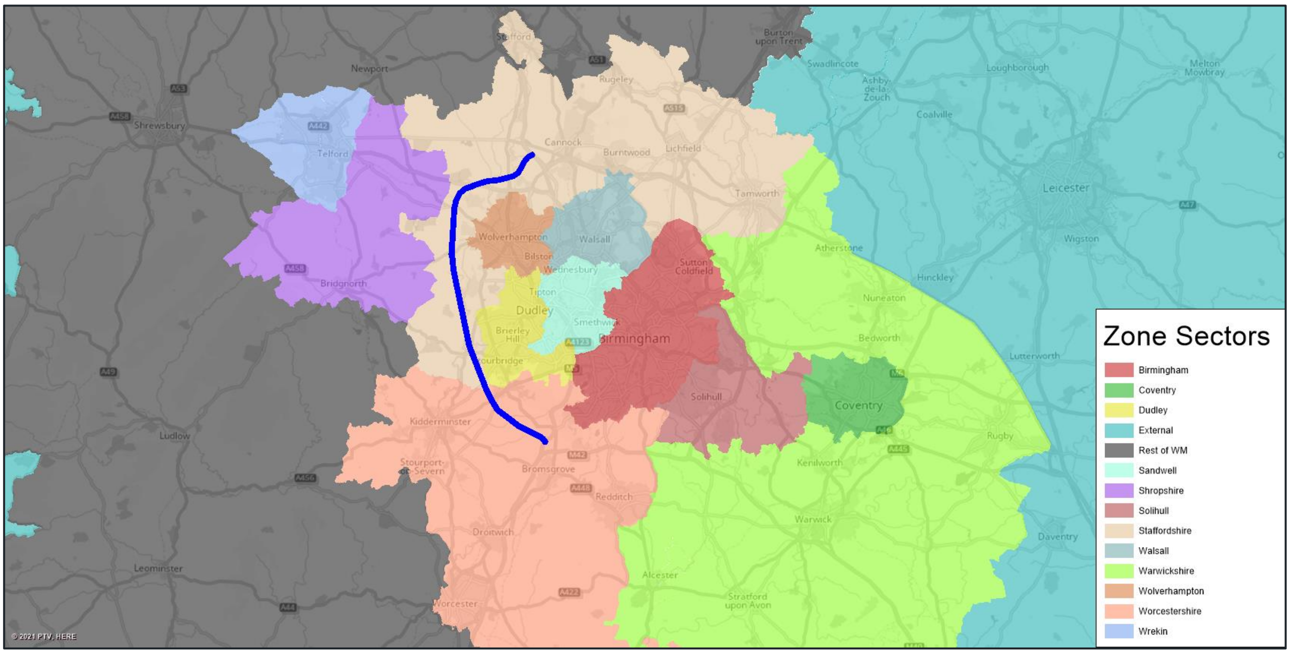


Figure 61: Sector plan



7.2.9. Table 46 summarises the TUBA warnings produced for each run. The biggest difference between the tests is in the number of warnings related to the ratio of DM/DS travel distance, i.e. where there is a large change in trip distance between DM and DS (for a given OD and user class). This reflects the fact that, with the multiplier, travellers are more inclined to choose longer distance routes to avoid congestion. This can have one of two impacts when comparing DM and DS:

- When the scheme is introduced, travellers are more inclined to make significant detours to use the scheme, avoiding congested areas. This leads to an increase in trip distance between DM and DS.

- In the DM, travellers are prepared to make significant detours to avoid congestion. If that congestion is relieved in the DS then they can revert to a more direct route. This leads to a decrease in trip distance between DM and DS. This is the only TUBA warning where a significant number are classified as 'serious'.

7.2.10. Overall, the pattern of TUBA warnings is consistent with the impact of the multipliers presented in chapter 3. The number of additional warnings is small compared to the number of OD pairs and user classes and does not suggest that the TUBA results are any less robust when a CVTT multiplier is used.

Table 46: Summary of TUBA warnings 2036

Warning type	**TAG Total**	**TAG Serious**	**Medium Total**	**Medium Serious**	**High Total**	**High Serious**
DM/DS travel time ratio lower than limit	1,661	79	948	15	654	0
DM/DS travel time ratio higher than limit	23,065	0	22,735	27	26,354	0
DM/DS travel distance ratio lower than limit	75,778	0	89,631	35	96,533	563
DM/DS travel distance ratio higher than limit	3,988	3,988	5,363	5,363	9,149	9,149
DM speeds less than limit	933	0	67	0	72	0
DM speeds greater than limit	792	0	754	0	812	0
DS speeds less than limit	940	0	72	0	72	0
DS speeds greater than limit	810	0	769	0	824	0
Total	**107,967**	**4,067**	**120,339**	**5,440**	**134,470**	**9,712**

7.3. 2026 TUBA OUTPUTS

7.3.1. Table 47 summarises the results of the 2026 TUBA runs.

7.3.2. Total user benefits are lower than in 2036, which is to be expected given fewer trips and less congestion. However, there are some slightly surprising results, including VOC disbenefits, user charge benefits, and indirect tax revenues all being higher than in 2036.

Table 47: 2026 TUBA Benefits (£000s), TAG and CVTT multipliers

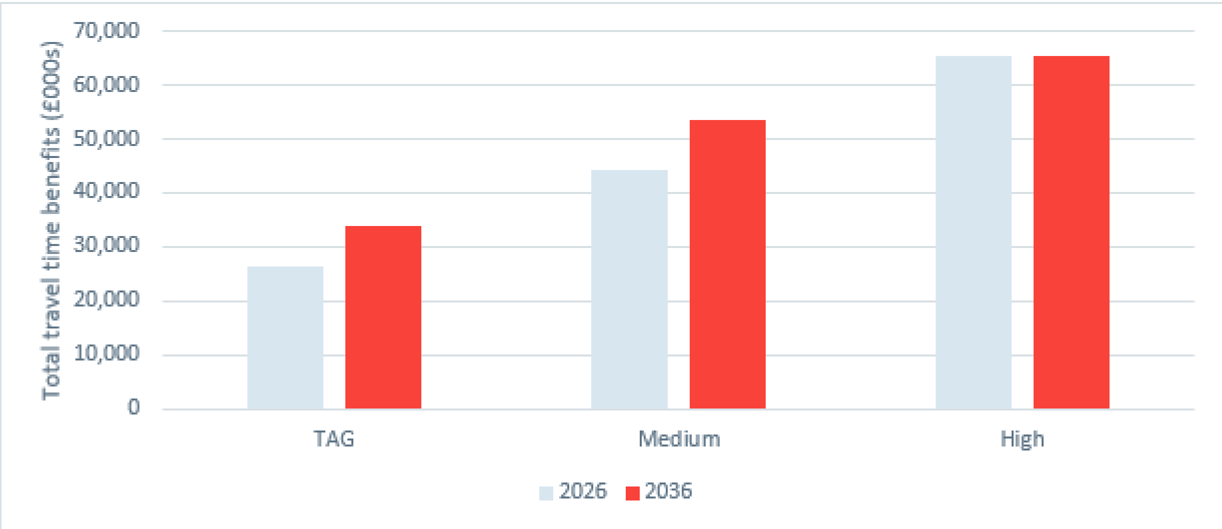
Benefit	TAG VTT Total	TAG VTT Free-flow time	TAG VTT Delay time	Medium CVTT Total	Medium CVTT Free-flow time	Medium CVTT Delay time	High CVTT Total	High CVTT Free-flow time	High CVTT Delay time
Commuting	7,479	1,725	5,754	15,599	1,138	14,461	22,756	1,007	21,749
Other	5,016	857	4,159	8,656	713	7,943	13,016	658	12,357
Business (Car)	9,015	2,448	6,567	12,729	1,423	11,307	19,269	2,827	16,441
Business (Freight)	4,742	2,022	2,720	7,350	1,107	6,243	10,295	1,145	9,150
Total	***26,252***	***7,052***	***19,200***	***44,334***	***4,380***	***39,954***	***65,335***	***5,637***	***59,698***
Fuel VOC	-2,855	N/A	N/A	-4,460	N/A	N/A	-5,382	N/A	N/A
Non Fuel VOC	-2,503	N/A	N/A	-4,099	N/A	N/A	-7,280	N/A	N/A
User Charges	2,285	N/A	N/A	1,647	N/A	N/A	3,092	N/A	N/A
Operator Revenues	-1,780	N/A	N/A	-539	N/A	N/A	-1,388	N/A	N/A
Greenhouse Gas	-972	N/A	N/A	-1,391	N/A	N/A	-2,034	N/A	N/A
Indirect Tax Revenues	4,420	N/A	N/A	6,322	N/A	N/A	9,296	N/A	N/A
Total	**24,846**	**7,052**	**19,200**	**41,815**	**4,380**	**39,954**	**61,639**	**5,637**	**59,698**

2010 prices discounted to 2010

7.3.3. Figure 62 compares total travel time benefits between 2026 and 2036. The increase in benefits between the years is highest with TAG VTT (29%), then Medium (21%). The High multiplier gives slightly lower time benefits in 2036 than 2026 (by 0.1%). This reduction is partly the result of discounting, with the discount factor in 2036 reducing benefits by about 30% more than in 2026. Even allowing for VTT growth, an hour of travel time is worth about 15% less in 2036 than 2026 (discounted). In other words, travel time benefits measured in vehicle hours still increase by about 15% between 2026 and 2036.

7.3.4. With the High multiplier it appears that something is damping down the growth in benefits between 2026 and 2036 seen with other VTTs. As discussed earlier, chapter 6 showed that scheme flows are much higher with the High multiplier. It seems likely that the induced and re-routed traffic is causing localised increases in congestion away from the scheme, generating disbenefits for some trips to an extent that counters the growth in benefits for scheme users. If so, this is likely to be a scheme-specific factor and unlikely to be a general result.

Figure 62: Comparison of 2026 and 2036 total travel time benefits



7.3.5. Figure 63 to Figure 65 show the 2026 total travel time benefits broken down by time period, purpose and trip length respectively. The impact of CVTT multipliers for each category is more consistent than it was for 2036. For example, there is a consistent difference between Medium and High in each distance band, unlike 2036 where there was relatively little difference for trips less than 10km.

Figure 63: Total travel time benefits by time period, 2026

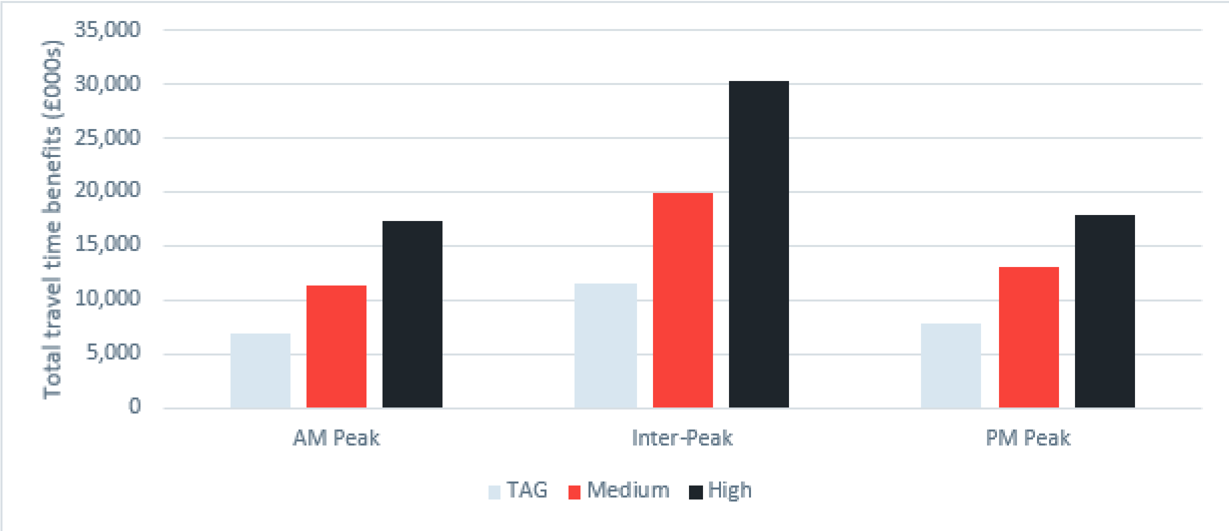


Figure 64: Total travel time benefits by purpose, 2026

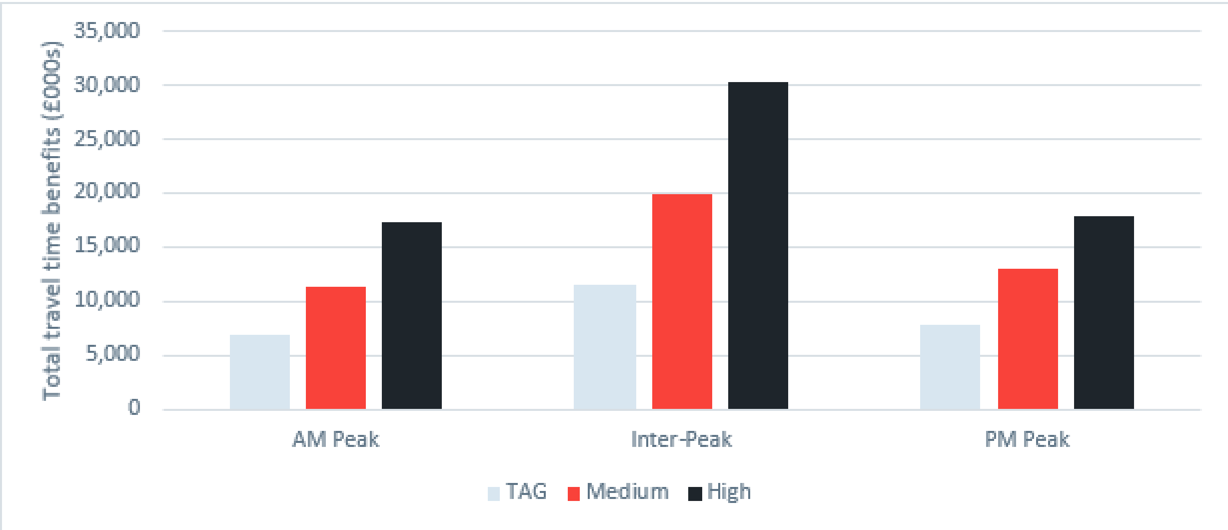
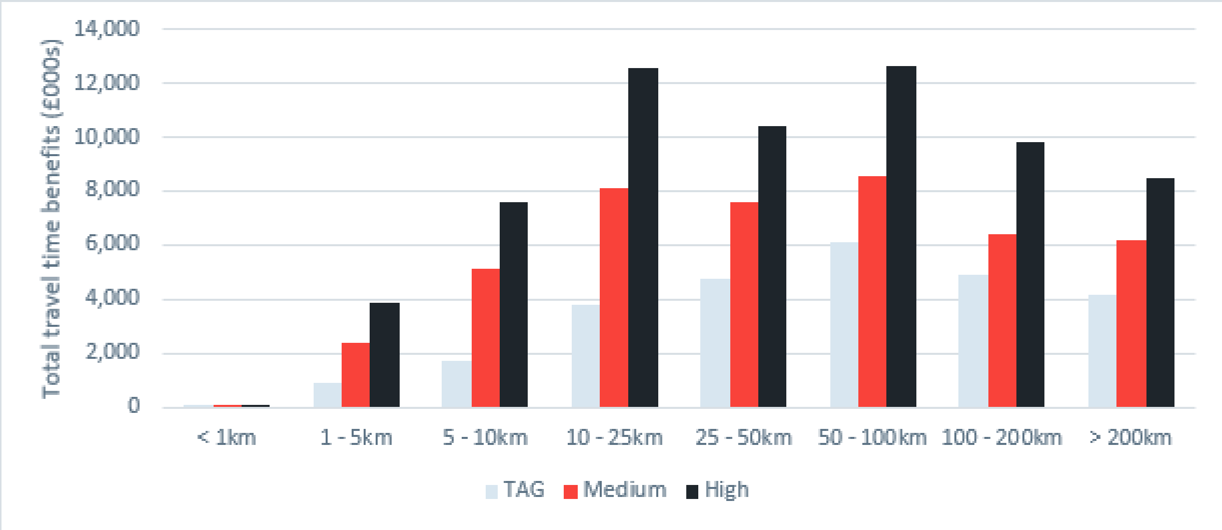


Figure 65: Total travel time benefits by trip length, 2026



7.3.6. Figure 66 and Figure 67 show total time benefits by origin and destination sector respectively. The pattern is generally consistent across sectors, more so than in 2036, with no cases where High benefits are less than Medium. This supports the argument put forward for 2036 that this was the result of localised congestion (which is presumably not present to the same degree in 2026). However, there are a couple of cases where Medium benefits are less than TAG (Staffordshire and Rest of WM, origins). It is also notable that with TAG VTT there are very small disbenefits for trips to and from Dudley, which become benefits with the CVTT multipliers.

Figure 66: Total travel time benefits by trip origin, 2026

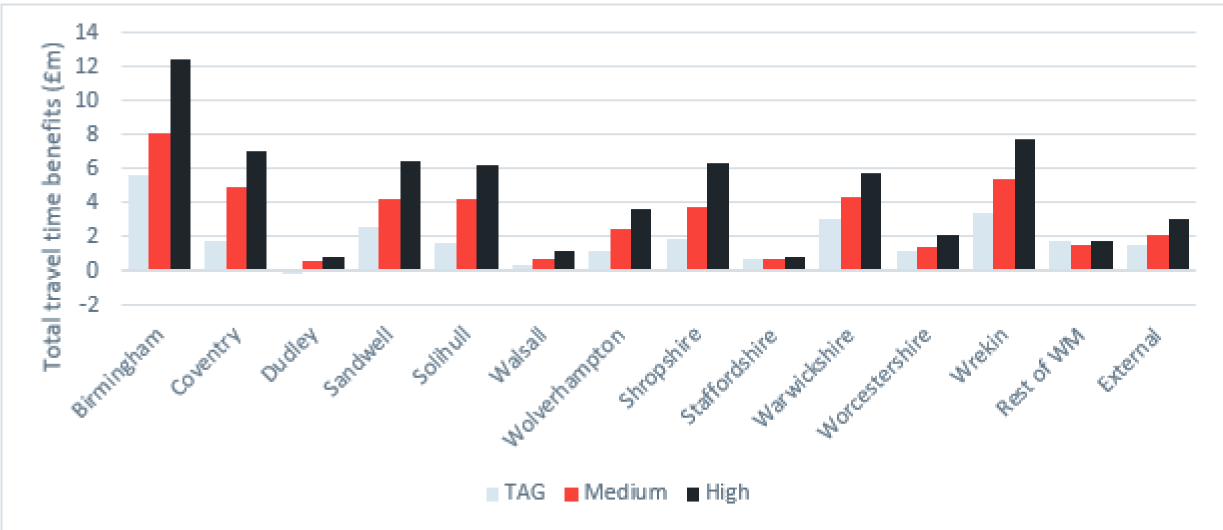
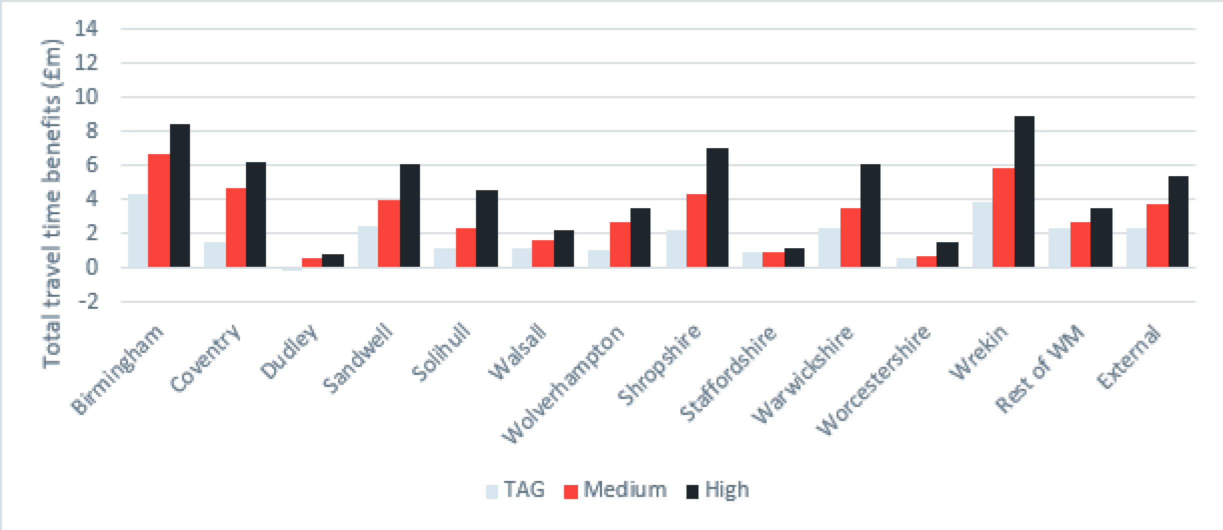


Figure 67: Total travel time benefits by trip destination, 2026



7.3.7. Table 48 summarises the TUBA warnings produced for each run. Compared to 2036 there are fewer warnings, but the impact of the multipliers on the number and type of warnings is very similar.

Table 48: Summary of TUBA warnings 2026

Warning type	TAG Total	TAG Serious	Medium CVTT Total	Medium CVTT Serious	High CVTT Total	High CVTT Serious
DM/DS travel time ratio lower than limit	1,394	36	306	0	33	0
DM/DS travel time ratio higher than limit	20,862	29	20,994	13	23,104	0
DM/DS travel distance ratio lower than limit	50,566	0	65,526	10	76,549	263
DM/DS travel distance ratio higher than limit	3,008	3,008	3,899	3,899	6,707	6,707
DM speeds less than limit	367	0	72	0	60	0
DM speeds greater than limit	1,023	0	983	0	1,018	0
DS speeds less than limit	373	0	72	0	59	0
DS speeds greater than limit	1,037	0	1,011	0	1,041	0
Total	**78,630**	**3,073**	**92,863**	**3,922**	**108,571**	**6,970**

7.4. IMPACT OF CONVERGENCE

7.4.1. It was noted in chapter 3 that some of the forecast model runs did not achieve the stopping value for the VDM-assignment gap of 0.15%, particularly for 2036. To quantify the impact of this, TUBA was run for each CVTT value using model outputs from the $(n\text{-}1)^{th}$ as well as the n^{th} loops (where *n* is the VDM-assignment loop with the lowest gap value). The results presented in the earlier sections of this note are from the n^{th} loops.

7.4.2. Figure 68 and Figure 69 show the results for the $(n\text{-}1)^{th}$ and n^{th} loops for 2026 and 2036. There is virtually no difference between the two loops for 2026. The difference for 2036 is slightly larger, as would be expected given the worse convergence, but is still proportionally very small. This gives some confidence that the results discussed earlier are unlikely to be significantly affected by convergence noise, with the caveat that this only demonstrates that the results are stable, not that they are the same as would be obtained from a fully converged model.

Figure 68: Total benefits from nth and (n-1)th loops, 2026

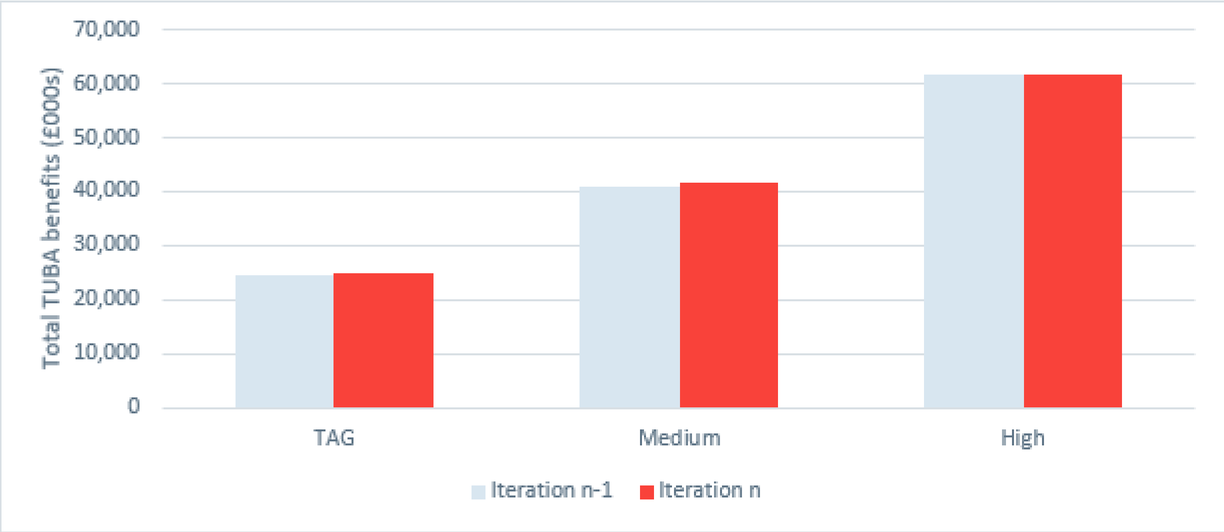
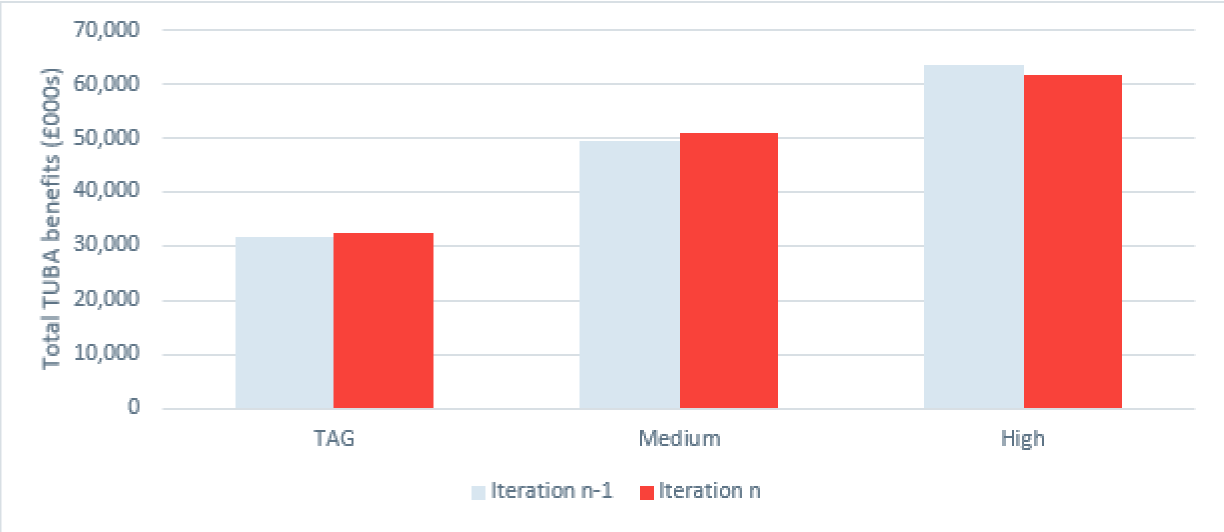


Figure 69: Total benefits from nth and (n-1)th loops, 2036



8. SUMMARY AND CONCLUSIONS

8.1.1. This report has presented the results of further work on the impact of congested values of travel time on transport modelling and appraisal. The work was divided into four stages:

- Stage 1: Base matrix development review: investigate the influence of VTT on the development of the PRISM prior matrices which feed into the matrix estimation process.
- Stage 2: Carry out matrix estimation incorporating CVTT. Compare the validation of the estimated matrix to the 'TAG standard VTT' base. Calculate base year model elasticities.
- Stage 3: Carry out a series of forecast model runs using TAG standard VTT and different CVTT multipliers.
- Stage 4: Carry out economic appraisal using the model outputs from Stage 3.

8.1.2. The key findings from each stage are as follows:

8.2. STAGE 1

8.2.1. The prior matrices used in PRISM matrix estimation are dependent on VTT and would therefore be expected to change if congestion multipliers were used throughout the matrix development process. It is not possible to quantify the scale of the impact. It is likely to be more significant for shorter distance trips which make greater use of a synthetic matrix, compared to longer trips, which make more use of GPS and mobile phone data (likely to be less sensitive to VTT than the synthetic).

8.2.2. Preliminary matrix estimation tests (without using congestion multipliers) show that there are modest differences in the estimated matrix produced in the original PRISM 5.0 work and PRISM 5.1.8 (the latter forms the basis for the remaining model tests). However, these are superseded by the change in the matrix estimation method that was required in Stage 2.

8.3. STAGE 2

8.3.1. Technical issues with the TFlowFuzzy matrix estimation process in Visum meant that it was necessary to switch to an alternative estimation method, least squares. This means that caution is required when comparing results from the current study with the previous 2019 work, which used a base matrix estimated using TFlowFuzzy.

8.3.2. Furthermore, it has been necessary to take estimated matrices from an early loop of the ME-assignment process, which has not fully converged. This means that some of the differences between the estimated matrices may be due to convergence noise, rather than the impact of the CVTT multiplier.

8.3.3. The base year model results can be summarised as follows (noting that differences are generally quite modest):

- Matrix deformation (i.e. changes between prior and estimated matrices): the level of deformation increases with the CVTT multiplier.

- Screenline flow validation: there is no distinct pattern in the results.
- Link flow validation: performance deteriorates as the CVTT multiplier increases.
- Journey time validation: high CVTT does best, followed by medium CVTT, followed by TAG VTT.
- Route choice: CVTT affects modelled route choice for some journeys, with longer (or, in the case of the M6 Toll, more expensive) routes chosen. This is plausible.

8.3.4. Overall, the base year model using TAG VTT performs best in terms of model validation and minimising distortion of the prior matrix. There are a few possible reasons for this:

- It was noted in chapter 2 that the prior matrices are VTT-dependent, though the strength of this dependency is uncertain. If the prior matrices have a strong dependency on VTT, they may well have been different if CVTT multipliers had been used in their development. This means that, with the multipliers, ME is having to work harder to correct the 'errors' in the prior matrices, caused by 'incorrect' VTT.
- Introducing CVTT multipliers may lead to less accurate routing (i.e. they differ from the routes used in real life), so ME is having to work harder to correct for errors in the assignment model. It should be emphasised that there is no evidence that this is the case.
- Network calibration in PRISM was based on prior and estimated matrices, and assignment parameters, which all use TAG VTT. Further network calibration using the relevant CVTT multiplier may well mitigate some of the apparent poor performance when using the multipliers.

8.3.5. Stage 2 has demonstrated that CVTT multipliers can be incorporated into the matrix estimation process, notwithstanding some initial technical difficulties with Visum. The matrices thus produced are demonstrably different and achieve different standards of validation. Uncertainty about the role of VTT in the development of the prior matrices means that it is not possible to say with any confidence whether the use of CVTT multipliers leads to better or worse base models.

8.3.6. There is some variation in elasticity values as the CVTT multiplier changes. This variation is modest (a maximum of 0.03, typically around 10% for the 12 hour value). It therefore seems unlikely that recalibrating the demand model so that elasticities were identical across all the tests would lead to significantly different forecast results. This increases confidence that the forecasting tests carried out in this project, including 2026 and 2036 forecasts with and without a test scheme, have produced robust results that have not be undermined by the decision not to recalibrate the demand model.

8.4. STAGE 3

2036 forecasts

8.4.1. The results of these forecasts show a very similar pattern to the 2019 study when comparing TAG VTT with Medium and High CVTT multipliers, albeit there is some difference in the absolute numbers.

8.4.2. We can therefore conclude that pivoting off different base matrices, estimated using different CVTT multipliers, does not fundamentally change the conclusions of the 2019 report (in which the same base matrix was used for all forecasts), i.e.:

- There is no significant adverse impact on either model run times or convergence. (Although convergence is slightly worse with the multipliers this is likely to be a consequence of matrix estimation rather than a CVTT-specific effect.)
- There is a reduction in the delay and total travel time experienced by car trips when CVTT multipliers are introduced. There is also a tendency for increased travel distance, but to a lesser extent.
- The use of multipliers significantly increases flows on our test scheme, due to increases in both re-routing and induced traffic (i.e. a combination of route, destination and mode choice responses, with a more modest trip frequency response).
- Multipliers increase the traffic induced by the scheme, whether that is by mode or destination choice.
- With the High multiplier in particular total travel time increases between DM and DS, though the *value* of that travel time decreases (the value of the delay reduction offsets the value of the increase in free-flow time).
- Overall, the results show that the use of multipliers can have a significant effect on car drivers' route choice, though for many OD pairs there is unlikely to be any impact.

2026 forecasts

8.4.3. When comparing TAG VTT with Medium and High CVTT multipliers the pattern of differences is very similar to those seen in the 2036 results, albeit usually on a smaller scale.

8.4.4. We can therefore conclude that CVTT multipliers still have a significant impact at lower levels of congestion, with the caveat that traffic growth between 2026 and 2036 is relatively modest (around 8%).

2036 fixed matrix assignments

8.4.5. CVTT multipliers have a significant impact on both the assignment and VDM responses. The proportional impact of the multipliers is greater on VDM.

2036 car journey time elasticities

8.4.6. There is very little change in car journey time elasticities between the 2015 base year and 2036. There remains little difference in the elasticities between the multiplier values.

8.5. STAGE 4

8.5.1. The 2036 results follow the same pattern seen in the 2019 study, with user benefits significantly higher when using a CVTT multiplier compared to TAG, by 58% for the Medium multiplier, 91% for High.

8.5.2. Breaking down the results by time period, purpose, and distance shows a broadly similar impact over all categories of trip, though there are some categories where the difference between Medium and High is relatively small (for example, trips less than 10km).

8.5.3. Similar impacts are seen for the 2026 results, with Medium multiplier user benefits 61% more than TAG, and High multiplier user benefits 140% more than TAG.

8.5.4. The proportional impacts are greater in 2026. This seems to be because there are localised disbenefits of the scheme, caused by re-routing and induced traffic which damp down benefit growth between 2026 and 2036. This damping down is greater with the multipliers (particularly High) as they have much higher flows on the scheme. This is likely to be a scheme-specific impact and should not be considered a general finding.

8.5.5. Investigation of TUBA warning messages, and the impact of model convergence on TUBA outputs, has not revealed any concerns about the robustness of the above conclusions.

8.6. CONCLUSIONS AND RECOMMENDATIONS

8.6.1. The research described in this report has confirmed the main conclusions of our 2019 work, i.e. the use of congestion-dependent values of travel time (CVTT):

- Has a significant impact on forecast flows, with implications for options appraisal and scheme design.
- Has a significant impact on the economic appraisal of road schemes, with implications for investment decisions.
- Presents no particular technical difficulties for practitioners, other than it cannot currently be done in all modelling software commonly used in the UK.

8.6.2. An important caveat is that true values of the delay (or congestion) multiplier, as defined in our modelling tests, is unknown. This means that the scale of these impacts cannot be determined. The value of free-flow travel time will also be a factor. However, there is robust evidence for appropriate values from the 2015 UK VTT study.

8.6.3. Taking all this into account, we propose that further work on CVTT should be focused on the following areas:

- Further research to quantify how CVTT should be included in modelling and appraisal. The minimum requirement would be to identify appropriate values of the delay multiplier, *M*, which we have used in our testing, and confirm free-flow values of time. Ideally it would be extended to consider alternative functional forms for representing CVTT in modelling appraisal, provided they comply with the theoretical properties set out in our 2018 report.
- Analysis of scheme evaluation reports (such as the National Highways POPE studies) to see if there is any evidence that scheme flows are consistently underestimated as a result of not including CVTT in modelling (which our test example suggests may be the case).
- Analysis of observed routing patterns, e.g. from GPS tracker data, to see if they are consistent with a higher VTT in congested areas.
- Engagement with software developers to ensure that CVTT can be represented in the most commonly used modelling platforms.
- Following completion of the above, further testing on a range of schemes to get a broader understanding of the possible implications of using CVTT.

A. STAGE 2a: Comparison of ME results by loop

Table 49: Loop by loop calibration and matrix distortion statistics (R^2), TAG VTT

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
AM	0	74.4%	73.3%	0.98	0.98	29
AM	1	83.0%	82.5%	0.97	0.97	30
AM	2	85.6%	85.2%	0.95	0.95	59
AM	3	87.7%	87.0%	0.93	0.93	87
AM	4	88.3%	88.0%	0.91	0.91	63
AM	5	89.1%	88.3%	0.87	0.88	Not converged within 100
IP	0	79.1%	76.3%	0.96	0.96	19
IP	1	87.9%	85.8%	0.93	0.93	27
IP	2	90.7%	89.2%	0.90	0.90	28
IP	3	91.7%	90.8%	0.86	0.87	32
IP	4	92.5%	91.9%	0.84	0.84	37
IP	5	92.7%	92.2%	0.80	0.81	45

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
PM	0	74.3%	73.1%	0.98	0.98	29
PM	1	81.6%	80.4%	0.95	0.96	45
PM	2	85.3%	84.9%	0.92	0.93	63
PM	3	87.5%	87.1%	0.89	0.90	59
PM	4	88.5%	87.8%	0.87	0.88	81
PM	5	89.1%	88.6%	0.84	0.85	Not converged within 100

Table 50: Loop by loop calibration and matrix distortion statistics (R^2), medium CVTT multiplier

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
AM	0	67.0%	66.6%	0.98	0.98	31
AM	1	74.9%	75.4%	0.96	0.96	35
AM	2	78.2%	78.7%	0.94	0.94	46
AM	3	81.4%	81.7%	0.91	0.92	56
AM	4	81.4%	82.1%	0.87	0.88	Not converged within 100
AM	5	83.9%	84.3%	0.85	0.86	Not converged within 100
IP	0	68.7%	67.9%	0.96	0.96	22
IP	1	78.6%	78.8%	0.90	0.91	26
IP	2	84.5%	83.7%	0.84	0.86	26
IP	3	86.3%	86.1%	0.81	0.82	25
IP	4	88.8%	88.9%	0.76	0.78	26
IP	5	89.9%	90.0%	0.72	0.74	27
PM	0	63.6%	63.8%	0.98	0.98	26

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
PM	1	73.0%	72.9%	0.95	0.95	41
PM	2	78.5%	78.1%	0.91	0.92	57
PM	3	81.4%	81.4%	0.87	0.88	45
PM	4	83.9%	83.8%	0.84	0.85	44
PM	5	84.7%	84.9%	0.80	0.82	54

Table 51: Loop by loop calibration and matrix distortion statistics (R^2), high CVTT multiplier

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
AM	0	60.7%	61.8%	0.98	0.98	39
AM	1	69.3%	70.1%	0.96	0.96	49
AM	2	73.7%	73.7%	0.93	0.94	39
AM	3	76.5%	76.9%	0.90	0.90	45
AM	4	78.4%	79.0%	0.86	0.87	52
AM	5	79.2%	80.3%	0.83	0.84	Not converged within 100
IP	0	61.9%	62.6%	0.96	0.96	28
IP	1	74.4%	74.4%	0.90	0.91	28
IP	2	79.8%	80.2%	0.83	0.84	27
IP	3	83.2%	83.7%	0.77	0.79	27
IP	4	84.7%	84.7%	0.72	0.75	28
IP	5	87.1%	87.4%	0.66	0.69	30
PM	0	59.1%	59.7%	0.97	0.98	32
PM	1	68.1%	68.5%	0.94	0.95	40

Time period	ME-assignment loop	Calibration links, pass % Car	Calibration links, pass % All vehs	R^2 Car	R^2 All vehs	Assignment iterations needed for convergence
PM	2	72.6%	73.1%	0.88	0.89	50
PM	3	77.8%	78.0%	0.86	0.87	53
PM	4	79.6%	79.9%	0.82	0.83	56
PM	5	81.5%	82.0%	0.77	0.79	70

B. STAGE 3: Aggregate model results by time period

Table 52: Aggregate model results: car commute, 2036 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	294.8	4,540	96.2	67.8	28.5	15.4	19.6	13.8	5.8
F14	DM	Medium	286.6	4,600	90.9	68.0	22.9	16.1	19.0	14.2	4.8
F15	DM	High	291.1	4,627	89.8	68.6	21.2	15.9	18.5	14.1	4.4
F16	DS	TAG	294.3	4,587	96.0	68.0	28.0	15.6	19.6	13.9	5.7
F17	DS	Medium	285.6	4,658	90.6	68.3	22.3	16.3	19.0	14.3	4.7
F18	DS	High	290.4	4,723	90.1	69.2	20.9	16.3	18.6	14.3	4.3

Table 53: Aggregate model results: car employer's business, 2036 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	63.5	3,589	48.5	40.1	8.4	56.5	45.8	37.9	7.9
F14	DM	Medium	63.7	3,552	47.1	40.2	6.9	55.8	44.3	37.9	6.5
F15	DM	High	64.2	3,494	46.0	39.8	6.1	54.4	43.0	37.2	5.7
F16	DS	TAG	63.4	3,616	48.4	40.2	8.2	57.0	45.8	38.1	7.7
F17	DS	Medium	63.3	3,589	47.0	40.4	6.7	56.7	44.6	38.2	6.3
F18	DS	High	63.9	3,538	46.1	40.1	6.0	55.4	43.3	37.6	5.6

Table 54: Aggregate model results: car other, 2036 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	244.4	2,939	60.4	43.4	17.0	12.0	14.8	10.7	4.2
F14	DM	Medium	249.8	3,084	61.0	46.0	15.0	12.3	14.6	11.0	3.6
F15	DM	High	253.7	3,066	59.4	45.7	13.7	12.1	14.1	10.8	3.2
F16	DS	TAG	244.5	2,960	60.3	43.6	16.7	12.1	14.8	10.7	4.1
F17	DS	Medium	249.6	3,112	60.9	46.2	14.7	12.5	14.6	11.1	3.5
F18	DS	High	253.6	3,102	59.6	46.0	13.6	12.2	14.1	10.9	3.2

Table 55: Aggregate model results: car commute, 2036 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	91.7	1,623	30.8	23.3	7.4	17.7	20.1	15.3	4.9
F14	DM	Medium	89.3	1,701	30.1	24.0	6.2	19.1	20.3	16.1	4.1
F15	DM	High	91.4	1,710	30.1	24.3	5.8	18.7	19.7	15.9	3.8
F16	DS	TAG	91.5	1,641	30.7	23.4	7.3	17.9	20.1	15.3	4.8
F17	DS	Medium	89.0	1,727	30.1	24.1	6.0	19.4	20.3	16.3	4.0
F18	DS	High	91.2	1,751	30.2	24.5	5.7	19.2	19.9	16.1	3.8

Table 56: Aggregate model results: car employer's business, 2036 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	51.6	3,080	40.2	34.1	6.1	59.7	46.8	39.6	7.1
F14	DM	Medium	49.9	3,093	39.4	34.4	4.9	61.9	47.3	41.4	5.9
F15	DM	High	50.5	3,094	39.1	34.7	4.4	61.3	46.5	41.2	5.3
F16	DS	TAG	51.5	3,109	40.1	34.2	5.9	60.4	46.8	39.9	6.9
F17	DS	Medium	49.7	3,137	39.4	34.7	4.7	63.1	47.5	41.8	5.7
F18	DS	High	50.3	3,152	39.3	35.0	4.3	62.6	46.9	41.7	5.2

Table 57: Aggregate model results: car other, 2036 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	405.6	4,487	92.6	69.1	23.5	11.1	13.7	10.2	3.5
F14	DM	Medium	410.2	4,507	91.8	70.7	21.1	11.0	13.4	10.3	3.1
F15	DM	High	417.3	4,605	92.0	72.0	20.0	11.0	13.2	10.4	2.9
F16	DS	TAG	405.6	4,519	92.4	69.3	23.1	11.1	13.7	10.3	3.4
F17	DS	Medium	409.9	4,556	91.6	71.0	20.7	11.1	13.4	10.4	3.0
F18	DS	High	417.2	4,667	92.1	72.4	19.8	11.2	13.2	10.4	2.8

Table 58: Aggregate model results: car commute, 2036 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	279.2	4,511	93.7	66.3	27.3	16.2	20.1	14.3	5.9
F14	DM	Medium	269.4	4,528	87.7	65.9	21.8	16.8	19.5	14.7	4.8
F15	DM	High	275.3	4,616	87.6	67.1	20.6	16.8	19.1	14.6	4.5
F16	DS	TAG	278.9	4,564	93.5	66.6	26.9	16.4	20.1	14.3	5.8
F17	DS	Medium	268.6	4,596	87.5	66.3	21.2	17.1	19.5	14.8	4.7
F18	DS	High	274.9	4,723	88.1	67.8	20.2	17.2	19.2	14.8	4.4

Table 59: Aggregate model results: car employer's business, 2036 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	68.8	3,719	50.9	42.0	8.9	54.0	44.4	36.6	7.8
F14	DM	Medium	67.6	3,665	48.6	41.5	7.1	54.2	43.1	36.8	6.3
F15	DM	High	67.4	3,558	46.9	40.5	6.3	52.8	41.7	36.1	5.6
F16	DS	TAG	68.7	3,749	50.9	42.1	8.7	54.6	44.4	36.8	7.6
F17	DS	Medium	67.3	3,708	48.7	41.8	6.9	55.1	43.4	37.2	6.2
F18	DS	High	67.1	3,609	47.1	40.8	6.2	53.8	42.1	36.5	5.6

Table 60: Aggregate model results: car other, 2036 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F13	DM	TAG	319.8	3,636	79.5	55.6	23.8	11.4	14.9	10.4	4.5
F14	DM	Medium	327.8	3,731	79.1	57.8	21.3	11.4	14.5	10.6	3.9
F15	DM	High	332.6	3,717	77.8	57.7	20.0	11.2	14.0	10.4	3.6
F16	DS	TAG	319.8	3,657	79.3	55.7	23.6	11.4	14.9	10.5	4.4
F17	DS	Medium	327.6	3,765	79.0	58.1	20.9	11.5	14.5	10.6	3.8
F18	DS	High	332.6	3,764	78.0	58.1	19.9	11.3	14.1	10.5	3.6

Table 61: Aggregate model results: car commute, 2026 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	277.4	3,929	82.1	59.9	22.2	14.2	17.8	12.9	4.8
F20	DM	Medium	274.9	4,026	79.6	60.9	18.7	14.6	17.4	13.3	4.1
F21	DM	High	277.9	4,072	79.2	61.6	17.6	14.7	17.1	13.3	3.8
F22	DS	TAG	277.2	3,960	82.0	60.0	22.0	14.3	17.7	13.0	4.8
F23	DS	Medium	274.3	4,067	79.4	61.1	18.3	14.8	17.4	13.4	4.0
F24	DS	High	277.4	4,142	79.4	62.0	17.3	14.9	17.2	13.4	3.8

Table 62: Aggregate model results: car employer's business, 2026 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	58.7	3,113	41.5	35.1	6.4	53.0	42.4	35.9	6.5
F20	DM	Medium	59.7	3,140	41.3	35.8	5.5	52.6	41.6	36.0	5.5
F21	DM	High	60.1	3,107	40.7	35.6	5.1	51.7	40.6	35.5	5.0
F22	DS	TAG	58.6	3,133	41.5	35.2	6.3	53.4	42.5	36.1	6.4
F23	DS	Medium	59.4	3,166	41.3	36.0	5.4	53.3	41.8	36.3	5.4
F24	DS	High	59.8	3,144	40.8	35.8	4.9	52.6	40.9	35.9	5.0

Table 63: Aggregate model results: car other, 2026 AM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	222.0	2,559	51.5	38.3	13.2	11.5	13.9	10.3	3.6
F20	DM	Medium	228.0	2,654	52.4	40.3	12.1	11.6	13.8	10.6	3.2
F21	DM	High	232.0	2,669	51.8	40.5	11.4	11.5	13.4	10.5	2.9
F22	DS	TAG	222.0	2,573	51.5	38.4	13.1	11.6	13.9	10.4	3.6
F23	DS	Medium	227.8	2,672	52.4	40.4	12.0	11.7	13.8	10.6	3.2
F24	DS	High	231.9	2,699	51.9	40.7	11.2	11.6	13.4	10.5	2.9

Table 64: Aggregate model results: car commute, 2026 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	85.3	1,378	26.1	20.3	5.8	16.2	18.4	14.3	4.1
F20	DM	Medium	84.4	1,444	25.9	20.9	5.0	17.1	18.4	14.9	3.5
F21	DM	High	85.7	1,457	26.0	21.2	4.8	17.0	18.2	14.8	3.3
F22	DS	TAG	85.2	1,390	26.1	20.3	5.7	16.3	18.4	14.3	4.0
F23	DS	Medium	84.2	1,466	25.9	21.0	4.9	17.4	18.5	15.0	3.5
F24	DS	High	85.6	1,492	26.1	21.4	4.7	17.4	18.3	15.0	3.3

Table 65: Aggregate model results: car employer's business, 2026 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	47.4	2,648	34.4	29.6	4.8	55.8	43.5	37.4	6.0
F20	DM	Medium	46.5	2,703	34.3	30.4	4.0	58.2	44.3	39.2	5.1
F21	DM	High	46.8	2,720	34.3	30.6	3.7	58.1	43.9	39.3	4.7
F22	DS	TAG	47.4	2,670	34.4	29.7	4.6	56.4	43.5	37.7	5.9
F23	DS	Medium	46.3	2,736	34.4	30.5	3.8	59.1	44.5	39.6	5.0
F24	DS	High	46.7	2,772	34.5	30.9	3.5	59.4	44.3	39.8	4.6

Table 66: Aggregate model results: car other, 2026 IP

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	370.8	3,994	81.0	62.2	18.9	10.8	13.1	10.1	3.1
F20	DM	Medium	376.8	4,025	81.3	63.8	17.4	10.7	12.9	10.2	2.8
F21	DM	High	383.5	4,139	82.2	65.4	16.8	10.8	12.9	10.2	2.6
F22	DS	TAG	370.8	4,017	80.9	62.3	18.6	10.8	13.1	10.1	3.0
F23	DS	Medium	376.6	4,063	81.2	64.0	17.1	10.8	12.9	10.2	2.7
F24	DS	High	383.5	4,194	82.3	65.8	16.6	10.9	12.9	10.3	2.6

Table 67: Aggregate model results: car commute, 2026 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	262.6	3,899	80.1	58.6	21.5	14.8	18.3	13.4	4.9
F20	DM	Medium	258.2	3,956	77.1	59.0	18.1	15.3	17.9	13.7	4.2
F21	DM	High	262.4	4,050	77.4	60.1	17.2	15.4	17.7	13.8	3.9
F22	DS	TAG	262.5	3,934	80.0	58.8	21.2	15.0	18.3	13.4	4.9
F23	DS	Medium	257.7	4,002	76.8	59.2	17.7	15.5	17.9	13.8	4.1
F24	DS	High	262.1	4,131	77.6	60.7	16.9	15.8	17.8	13.9	3.9

Table 68: Aggregate model results: car employer's business, 2026 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	63.7	3,230	43.8	36.8	7.0	50.7	41.3	34.7	6.6
F20	DM	Medium	63.1	3,232	42.7	36.9	5.8	51.2	40.6	35.1	5.5
F21	DM	High	62.8	3,163	41.5	36.2	5.3	50.3	39.6	34.6	5.0
F22	DS	TAG	63.6	3,254	43.8	37.0	6.8	51.2	41.3	34.9	6.4
F23	DS	Medium	62.9	3,262	42.8	37.1	5.7	51.9	40.8	35.4	5.4
F24	DS	High	62.6	3,209	41.7	36.5	5.2	51.3	40.0	35.0	4.9

Table 69: Aggregate model results: car other, 2026 PM

Run ID	Scenario	Multiplier	Total trips (1000 vehs)	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Ave. free flow (min)	Ave. delay time (min)
F19	DM	TAG	292.5	3,223	69.0	49.9	19.1	11.0	14.2	10.2	3.9
F20	DM	Medium	301.1	3,283	69.5	51.8	17.7	10.9	13.8	10.3	3.5
F21	DM	High	305.9	3,310	69.1	52.2	16.9	10.8	13.6	10.2	3.3
F22	DS	TAG	292.5	3,240	68.9	50.0	18.9	11.1	14.1	10.3	3.9
F23	DS	Medium	300.9	3,307	69.4	51.9	17.5	11.0	13.8	10.3	3.5
F24	DS	High	305.8	3,351	69.3	52.5	16.7	11.0	13.6	10.3	3.3

Unit 9, The Chase
John Tate Road, Foxholes Business Park
Hertford
SG13 7NN

wsp.com