Department for Transport

CONGESTION DEPENDENT VALUES OF TIME IN TRANSPORT MODELLING

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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) which covered employer's business and non-work travellers' willingness-to-pay for journey time savings. Since publication of that report, the DfT has made significant progress in the implementation of the findings of the research through both updating the values of time used in transport appraisal guidance (WebTAG) 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 more heavily congested conditions relative to free flow i.e. that the VTTS are an average value, which represents a combination of VTTS varying in accordance to the level of congestion of the road.

1.1.3. In 2017/18, WSP/Mott Macdonald/RAND Europe carried out a research project for DfT to take forward an investigation into 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. This project is a follow-on from that previous work to test, in a currently active model, the implementation of CVTT together with an understanding of the appraisal impacts through a case study approach. This will significantly contribute to moving towards a position where DfT will have sufficient confidence to apply CVTT multipliers in practice.

OBJECTIVES

1.1.6. The overarching objectives of this project are to:

- Provide a fully defined 'proof of concept' for applying CVTT in a transport model with an appropriate level of geographical coverage, that consists of both assignment and demand modelling.
- Improve the Department's understanding of the potential impact of including CVTT in the modelling and appraisal of highway schemes.
- Highlight any barriers to robust implementation of CVTT in extant models, and identify what additional work could be undertaken to overcome such barriers.

1.2. OVERVIEW OF STUDY METHODOLOGY

1.2.1. An initial scoping stage was carried out to (a) identify a suitable model for testing, and (b) define a range of model tests and analyses that would help meet the above objectives.

1.2.2. The main part project of the project consisted of three broad stages:

- Testing CVTT in the base year highway assignment, to investigate how it affects the model validation;
- Testing CVTT in a future year forecast, with CVTT represented in the highway assignment model and the demand model. These tests included do minimum (DM) and do something (DS) scenarios, with the latter including a hypothetical major road scheme;
- Using the results of (2) in DfT's TUBA economic appraisal software, to understand how the use of CVTT in modelling and/or appraisal affects the estimation of user benefits.

1.3. REPORT STRUCTURE

1.3.1. Chapter 2 of this report sets out the results of the initial scoping stage.

1.3.2. Chapter 3 explains how the model was set up to carry out the required testing.

1.3.3. Chapters 4 to 6 present the results from the base year model, future year model, and TUBA analysis respectively.

1.3.4. Chapter 7 summarises the results and recommends the way forward.

2. SCOPING

2.1. TEST MODEL

2.1.1. It was established in the 2017/18 WSP/Mott MacDonald/RAND Europe study that Visum is the only commercially available highway assignment software that (a) is commonly used in the UK, and (b) allows CVTT to be included in the model using the standard commercially available version. It was therefore a requirement that the test model should use Visum for highway assignment.

2.1.2. A second requirement was that the test model should have a variable demand modelling component that broadly follows WebTAG guidance.

2.1.3. Four candidate models were identified that met these requirements, and had been developed by either Mott MacDonald or WSP:

- PRISM (West Midlands);
- South East Wales Transport Model (SEWTM);
- Coventry;
- Wokingham.

2.1.4. PRISM was chosen as the preferred model. The rationale for this is as follows:

- A cordoned version of the model had been used successfully in the 2017/18 work, which reduced the risk to the current project;
- The un-cordoned version provides extensive geographical coverage, with significant numbers of both urban and inter-urban trips with numerous alternative routes available.

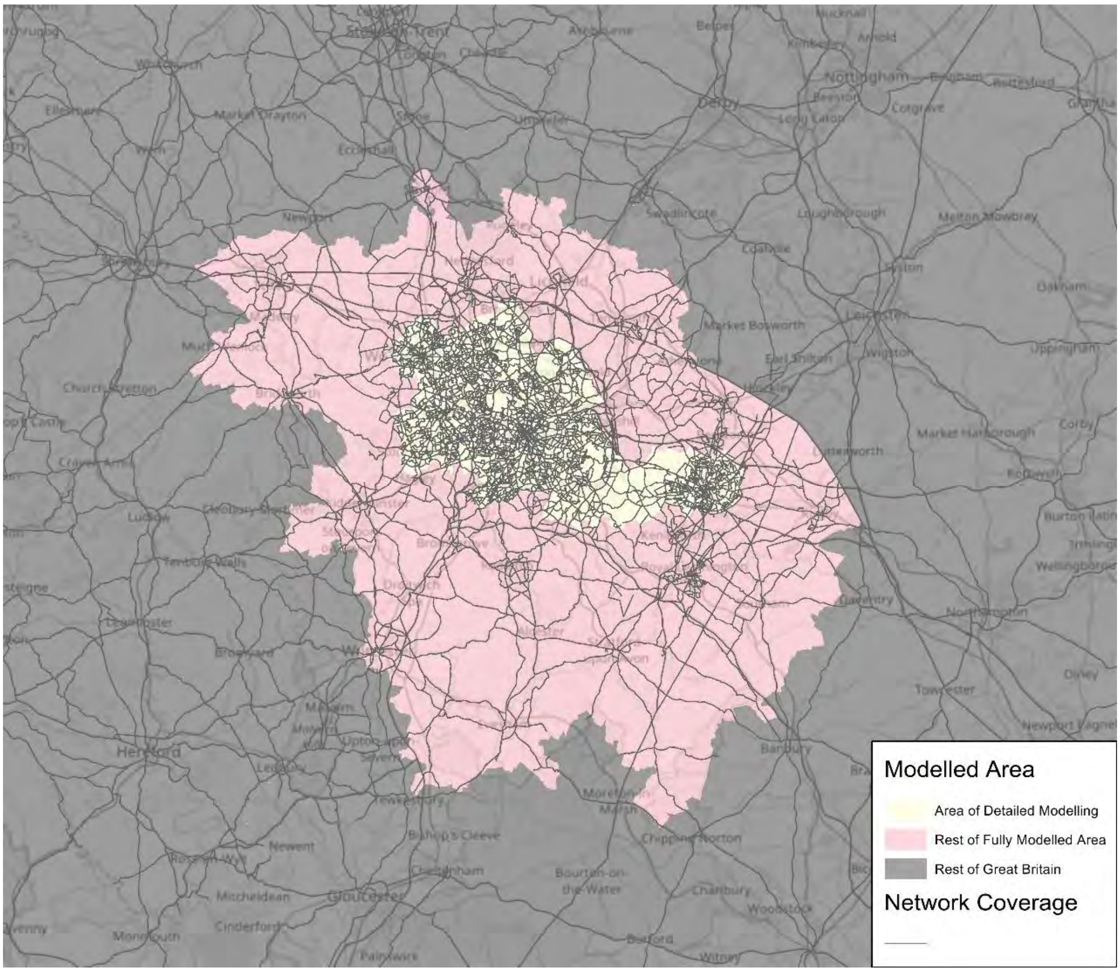
2.1.5. Full details of the PRISM model can be found on the Transport for West Midlands (TfWM) website[1]. Briefly, it comprises:

- A highway assignment model in Visum;
- A public transport assignment model in Visum;
- A disaggregate tour-based demand model.

2.1.6. The model covers the whole of the West Midlands conurbation, as shown in Figure 1. The Area of Detailed Modelling covers the seven metropolitan districts, with the Rest of the Fully Modelled Area extending into the surrounding West Midlands Region.

[1] https://www.tfwm.org.uk/strategy/data-insight/transport-modelling/about-prism/

Figure 1 PRISM Modelled Area



2.1.7. The PRISM Project Management Group (PMG, comprising the West Midlands Combined Authority (WMCA), the WMCA's seven constituent authorities, Transport for West Midlands, and Highways England) kindly gave permission to use PRISM 5.1 for the current study.

2.2. MODEL TEST SCHEDULE

2.2.1. This section sets out the broad outline of the testing undertaken. Further details of how these tests were implemented in the models can be found in chapter 3.

CONGESTION MULTIPLIER VALUES

2.2.2. As described in the 2017/18 project report, CVTT is represented in the model by using separate values of VTT for free-flow time and delay-time. This method was chosen as being one that (a) has the theoretical properties necessary for the demand and highway assignment models to work, and (b) can be tested in commercially available software (in this case Visum).

2.2.3. This results in the time component of generalised cost having the following form:

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

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)

2.2.4. Other components of generalised cost (toll and distance) are unaffected by CVTT.

2.2.5. The delay multiplier (*M*) is defined as the ratio of VTT_{Delay} to $VTT_{FreeFlow}$.

2.2.6. This cost function uses 'delay' as the definition of congestion. This differs from previous stated preference (SP) studies (including the 2015 UK work), which typically used categorical definitions of congestion (e.g. free-flowing, light traffic, heavy traffic). Our previous report discussed in detail why a categorical definition of congestion was not suitable for use in modelling, hence the need to develop a more model-friendly definition.

2.2.7. One of the consequences of this is that the 'congestion multipliers' from the SP studies do not, directly, provide evidence for appropriate values of *M.* Therefore, we had to test a wide range of values, as set out in the following table:

Table 1 Delay Multipliers

Multiplier description	Multiplier value
Low	1
Medium	3
High	5

(NB: the Low multiplier value was only used for the base year validation tests, not for the forecast tests.)

2.2.8. In model application, the free-flow VTT ($VTT_{FreeFlow}$) was calculated by applying appropriate factors to the WebTAG VTT (see paragraph 3.1.3 et seq. below for further details). The delay VTT (VTT_{Delay}) was then calculated by applying the appropriate multiplier, *M,* from the above table.

2.2.9. The nearest we can get to the congestion multipliers in the SP studies is the ratio of average VTT in the model to the free-flow VTT. This is an output from, rather than input to, the model and is reported in section 5.2.

BASE YEAR TESTS

2.2.10. Like most highway assignment models, PRISM went through a process of matrix estimation from counts as part of its base year matrix calibration[2]. This involved taking a prior matrix, built up from a variety of data sources, assigning it to the network, and then using routeing information from that

[2] Further details of the matrix development and calibration process can be found in the PRISM 5.0 Model Validation Report: https://www.tfwm.org.uk/strategy/data-insight/transport-modelling/about-prism/prism-reports/

assignment to update the matrix to give a better fit to observed count data. The routeing information from the model depends on a number of factors, including the form of, and coefficients used in, the generalised cost function. The final estimated and validated matrix is therefore a function of the VTT used in the assignment.

2.2.11. This means that if CVTT multipliers[3] were used in the assignment (and therefore affect routeing) they would also affect the final matrix. To simply assign this matrix with different CVTT multipliers would therefore not be a fair test of the impact on CVTT on model validation. Ideally, the matrix estimation process would have been repeated with CVTT multipliers in the assignment. However, this is a time consuming process which would have left little time for other model tests. As a compromise it was decided to test the impact of the CVTT multipliers on the assignment of the prior matrix, since this is less dependent on the assignment routeing than the final matrix (post matrix estimation).

2.2.12. In the case of PRISM 5, the prior matrices are not completely independent of VTT. This is because some of the data used in the development of the prior matrix, is VTT-dependent. Specifically, synthetic matrices (i.e. those produced by a demand model) and matrices from Highways England's Midlands Regional Traffic Model.

2.2.13. The base year tests comprised four assignments of the 2016 base year prior matrix, for the AM peak only. One assignment used WebTAG VTT as per the existing model (with no distinction between free flow and delay time), with three further assignments with different values of the CVTT multiplier:

Table 2 Base Year Model Runs

Run ID	Multiplier
B1	WebTAG VTT
B2	Low
B3	Medium
B4	High

FUTURE YEAR TESTS

2.2.14. Time and budget constraints limited the number of forecast year tests that could be undertaken. It was decided to focus on a single forecast year, 2036. This is one of two standard forecast years in PRISM, the other being 2026. 2036 is more congested and therefore more likely to show significant impacts from introducing CVTT multipliers.

[3] In this report 'CVTT multipliers' or 'congestion multipliers' mean the multipliers set out in Table 1. As discussed earlier, these represent a different definition of congestion multiplier compared to previous SP studies.

2.2.15. After reviewing the base year results it was concluded that there was little value in testing a Low CVTT multiplier. The following schedule of tests was therefore agreed:

Table 3 List of Model Runs

Run ID	Year	Scenario	Multiplier value
F7	2036	DM	WebTAG VTT
F8	2036	DM	Medium
F9	2036	DM	High
F10	2036	DS	WebTAG VTT
F11	2036	DS	Medium
F12	2036	DS	High

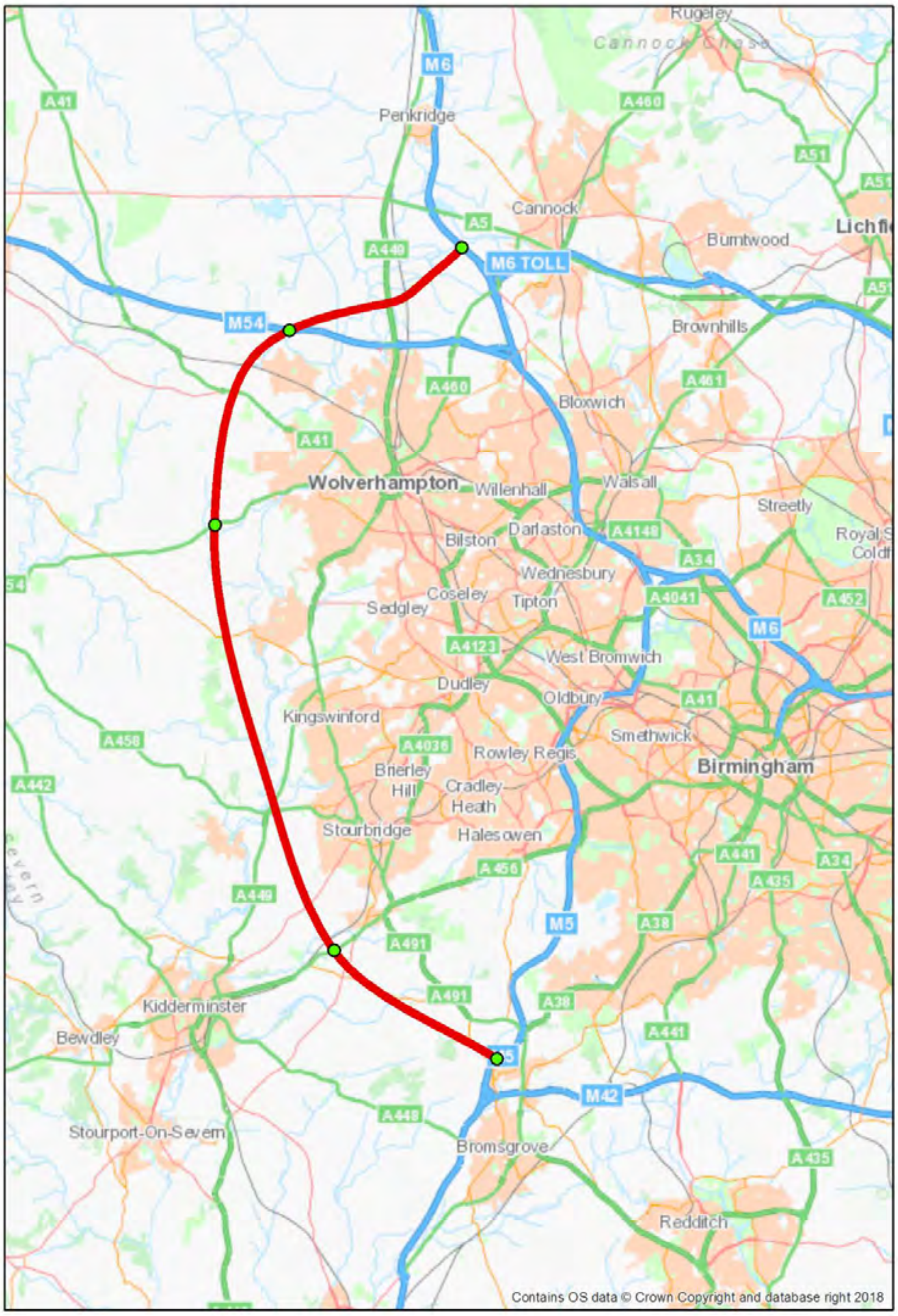
TEST SCHEME

2.2.16. One of the areas of interest for the current project is to see how CVTT might affect scheme appraisal. It was therefore necessary to test a hypothetical scheme in the model. The scheme is shown in Figure 2. Its main features are:

- A new D4M motorway to the west of the West Midlands conurbation, providing an alternative route to the existing M5;
- A new junction with the M6 at the northern end between M6 J11a and J12;
- A new junction with the M5 at the southern end between M5 J4 and J5a;
- Intermediate junctions with the A456, A454, and M54;
- All new junctions coded as free-flow (unlimited capacity) for all movements, to eliminate delays.

2.2.17. To reiterate, this is a purely hypothetical scheme designed to maximise user benefits, with no consideration given to cost, topographical or other environmental constraints.

Figure 2 Sketch map showing location of hypothetical scheme.



2.3. TUBA TESTS

2.3.1. The DfT's Transport Users Benefits Appraisal (TUBA) software has been used to assess the scheme impacts using different model test results. TUBA undertakes a matrix-based appraisal by taking trip, time, distance and charge matrices from a transport model. TUBA calculates the user benefits in time, fuel vehicle operating costs (VOC), non-fuel VOC and charges, discounted to the present value year.

2.3.2. Six TUBA tests were carried out for this research project as summarised in Table 4 below.

Table 4 CVTT TUBA Tests

No.	CVTT Multiplier (modelled)	Scheme	VDM	VTT (WebTAG or CVTT in TUBA)
T1	No	DM + DS scheme #1	Yes	WebTAG
T2	No	DM + DS scheme #1	Yes	CVTT (High Multiplier)
T3	Medium	DM + DS scheme #1	Yes	WebTAG
T4	Medium	DM + DS scheme #1	Yes	CVTT
T5	High	DM + DS scheme #1	Yes	WebTAG
T6	High	DM + DS scheme #1	Yes	CVTT

2.3.3. Tests T1 and T2 produce TUBA results with the no multiplier applied in the model but with alternative VTTs used in the appraisal. Tests T3 to T6 provide TUBA results for the Medium and High Multiplier model runs.

2.3.4. For the tests T2, T4 and T6, two separate TUBA runs were undertaken, as below:

- TUBA run with free-flow travel time with the adjusted economics file to calculate free-flow time benefits (a);
- TUBA run with multiplied delay time with the adjusted economics file to calculate delay time benefits (b);
- Total CVTT time saving benefits were calculated = (a) + (b);
- Other elements such as vehicle operating costs (VOC), user charges, operator revenues and indirect tax revenues were obtained from the equivalent TUBA runs T1, T3 and T5 with WebTAG values of travel time (VTT) as these elements are based on total travel time and distance.

2.3.5. To assist checking of the TUBA benefits for the tests T1 and T2, two additional tests were also undertaken: a) with Low Multiplier and b) with Medium Multiplier of CVTT in TUBA. These tests were used to provide assurance of the level of change in benefits in response to different CVTT multiplier values and not for detailed analysis.

3. MODEL SET UP

3.1. CHANGES TO THE HIGHWAY ASSIGNMENT

3.1.1. The only change made to the highway assignment was to use a revised generalised cost function that has separate VTT for free-flow and delay, as per paragraph 2.2.3.

3.1.2. This change was applied to car trips only. The cost function, and coefficients, for LGVs and HGVs remained unchanged.

FREE FLOW VTT

3.1.3. $VTT_{FreeFlow}$ was obtained by multiplying the WebTAG VTT[4] currently used in PRISM by a factor *r*.

3.1.4. The table below sets out the values of *r* used. These are the "SP3 free-flow" multipliers from Table 6 of the March 2018 project report, which in turn come from the 2015 UK VTT study. These values mean that, for example, free-flow VTT for 'Other' trip purpose is about half the WebTAG value currently used in the model.

Table 5 Free-flow VTT Factors

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

TRANSLATING INTO VISUM COEFFICIENTS

3.1.5. Visum requires separate coefficients for free-flow time (*t0*) and total time (*tCur*). Delay time can be calculated as *tCur-t0.* As established in the first phase of work:

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

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

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

3.1.6. 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).

3.1.7. VTTs used for the four base year model runs were therefore as follows:

[4] This is 'average' in the sense that it is, implicitly, an average over free-flow and congested travel times

Table 6 VTT (p/min) - AM – per vehicle[5]

		Commute		Employer's business		Other	
Run ID	**Description**	$VTT_{FreeFlow}$	VTT_{Delay}	$VTT_{FreeFlow}$	VTT_{Delay}	$VTT_{FreeFlow}$	VTT_{Delay}
B1	WebTAG	20.18	20.18	30.10	30.10	13.92	13.92
B2	Low multiplier (=1)	14.06	14.06	17.21	17.21	6.97	6.97
B3	Med. multiplier (=3)	14.06	42.18	17.21	51.63	6.97	20.91
B4	High multiplier (=5)	14.06	70.31	17.21	86.06	6.97	34.86

3.1.8. In runs B1 and B2, delay VTT is the same as free-flow VTT. The difference is that B1 uses WebTAG VTT implicitly based on average levels of congestion; B2 uses free-flow VTT for both free-flow and delay conditions.

3.1.9. As noted above, Visum requires coefficients for total travel time (*tCur*) and free-flow travel time (*t0*[6]). The following coefficients were therefore specified:

Table 7 Visum Time Coefficients (p/100 seconds[7]**) - AM**

		Commute		Employer's business		Other	
Run ID	**Description**	***tCur***	***t0***	***tCur***	***t0***	***tCur***	***t0***
B1	WebTAG	33.64	0	50.16	0	23.21	0
B2	Low multiplier (=1)	23.44	0	28.68	0	11.62	0
B3	Med. multiplier (=3)	70.32	-46.88	86.04	-57.36	34.87	-23.25
B4	High multiplier (=5)	117.20	-93.76	143.41	-114.73	58.11	-46.49

3.1.10. For reference, the distance coefficients used are shown in Table 8 below (unchanged from the original model, with the same value used for each run).

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[5] Based on version 1.8.2 (October 2017) of the WebTAG databook, which was the current version when the PRISM 5.1 base year model was validated.

[6] In Visum, *t0* for turns is not strictly the free-flow time for movements that give way to other traffic (since it is calculated by fixing the opposing flow at the current assigned value). It was therefore necessary to replace this with the true free-flow time calculated separately (with zero opposing flow), as a user-defined attribute. The *t0* coefficients apply to this revised *t0.*

[7] In Visum time coefficients are defined assuming times in seconds. Impedances/generalised costs are only calculated to the nearest integer. These unusual units (p/second, multiplied by 100) are therefore used to increase the precision of the calculation.

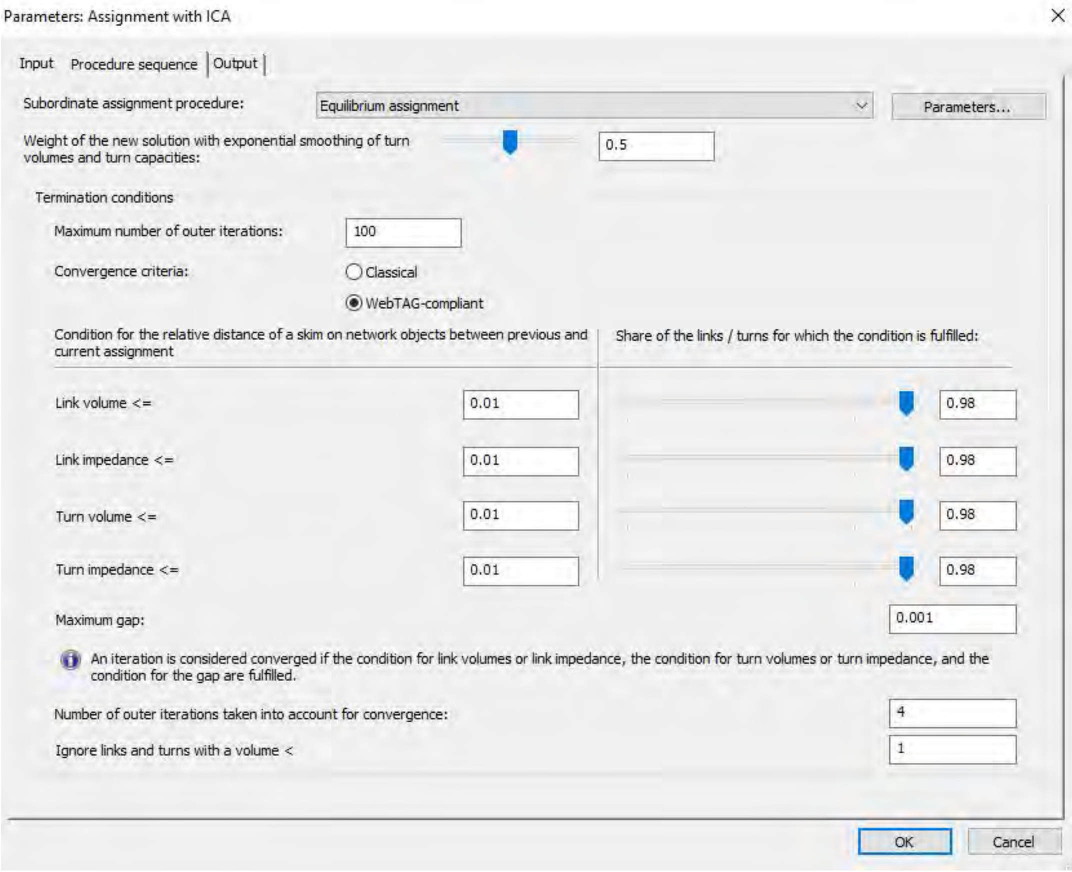
Table 8 Distance Coefficients

Car journey purpose	p/100m
Commute	0.5957
Employer's business	1.2624
Other	0.5957

CONVERGENCE CRITERIA

3.1.11. The following screenshot shows the convergence stopping criteria used in Visum:

Figure 3 Visum Highway Assignment Stopping Criteria



3.1.12. The above is based on PTV's interpretation[8] of Table 4 in WebTAG unit M3-1. This is also taking into account that, while in SATURN a 'link' includes standard network links and turn-links, PTV have always explicitly monitored links and turns separately and continue to do that, but bring them together for reporting of convergence.

Table 4 Summary of Convergence Measures and Base Model Acceptable Values

Measure of Convergence	Base Model Acceptable Values
Delta and %GAP	Less than 0.1% or at least stable with convergence fully documented and all other criteria met
Percentage of links with flow change (P)<1%	Four consecutive iterations greater than 98%
Percentage of links with cost change (P2)<1%	Four consecutive iterations greater than 98%

3.1.13. The PTV interpretation of WebTAG is that it is considered sufficient if *either* of the flow (volume) (P) *or* cost (impedance) (P2) criteria is met. While many practitioners will aim to achieve the criteria for P *and* P2, para 3.3.6 of TAG Unit M3.1 states "*iterations should continue until at least four successive values of 'P'* ***or*** *'P2' in excess of 98% have been obtained."*

3.1.14. For these model runs Visum 18.02-07 was used.

3.2. CHANGES TO THE DEMAND MODEL

CURRENT UTILITY FUNCTION

3.2.1. The existing PRISM 5 utility function for car driver travel (excluding socio-demographic terms and destination attraction variables) is:

$$U=\beta_{time}T+\beta_{cost}\left\{\gamma.cost+(1-\gamma)\log(cost)\frac{E(cost)}{E(\log(cost))}\right\}$$

Where:

U is the utility in utils

[8] PTV documentation on convergence criteria is available here: https://cgi.ptvgroup.com/vision-help/VISUM_18_ENG/#cshid=29103

And here:

https://cgi.ptvgroup.com/vision-help/VISUM_18_ENG/index.htm#1_Benutzermodell_IV/1_5_Konvergenzkriterien_ICA.htm%3FTocPath%3DVisum%2520%25E2%2580%2593%2520Fundamentals%7CUser%2520model%2520PrT%7CAssignment%2520with%2520ICA%7C_____5

β and γ	are estimated parameters[9]
T	is time in minutes
cost	is the total monetary cost in pence (vehicle operating cost plus toll)
$E(X)$	is the expected (mean) value of X
$log(X)$	is the natural logarithm of X

3.2.2. The parameters β and γ vary by journey purpose and, for some purposes, β_{cost} varies by income[10]. For some purposes, γ is 1 and the above formula then reduces to the more familiar linear combination of time and cost.

3.2.3. The value of travel time (VTT) is then given by:

$$VTT = \frac{\beta_{time}}{\beta_{cost}\left\{\gamma + \frac{(1-\gamma)}{cost}\frac{E(cost)}{E(log(cost))}\right\}}$$

3.2.4. Modelled VTT does not vary between free-flow and congested conditions. It can therefore be considered an average over the two, specifically a weighted average given the free-flow/congested split in the model base year.

3.2.5. Home-based employer's business is treated slightly differently. Money costs are converted into generalised time equivalent units using WebTAG distance-dependent VTTs. Consequently, the cost component of the above utility function does not apply, as the costs have already been accounted for in generalised time. In PRISM this different formulation was used due to the low sample size of employer's business travellers making it difficult to estimate local VTTs, and hence it was more robust to use the default WebTAG formulation.

3.2.6. In particular the utility for HBEB is given by:

3.2.7. $U = \beta_{time}\, GT$, and $GT = T + \frac{cost}{VTT(d)}$

where:

U	is the utility in utils
β_{time}	is an estimated parameter
GT	is generalised time in minutes
T	is time in minutes
cost	is the total monetary cost in pence (vehicle operating cost plus toll)

[9] Initially these were statistically estimated to give the best fit to data. γ was subsequently adjusted for some purposes to give VTT and elasticities more in line with expectations.

[10] i.e. the demand model includes income segmentation for some purposes.

3.2.8. The value of travel time (VTT) used by HBEB is:

$$VTT(d) = VOT_0 \left(\frac{d}{d_0}\right)^{\eta}$$

where:

VOT_0	is the average Value of Time imported from the WebTAG databook
d_0	is the distance underpinning the national average values of time
d	is the trip length
η	is the distance elasticity parameter imported from WebTAG

ADAPTING THE UTILITY FUNCTION

3.2.9. In the absence of any evidence to the contrary, it seemed reasonable to assume that we only need to concern ourselves with the time component of the utility function and that the utility of the cost component is unaffected by the use of the delay multiplier[11,12].

3.2.10. A naïve approach would be to replace T in the utility function with a weighted version using the delay multiplier:

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

where M is the value of the delay multiplier[13].

3.2.11. The problem with this is that $VTT_{FreeFlow}$ in the modified model would be the same as $VTT_{average}$ in the existing model (in effect, the total time input into the demand model $T_{FreeFlow} + M \times T_{Delay}$ would be in units of 'free flow time minutes'). The overall average VTT in the model would therefore increase, possibly by a significant amount (depending on the value of M and the amount of delay).

3.2.12. We therefore needed to make a further adjustment to the time component of the utility function. This was done by factoring it by the desired ratio of $\frac{VTT_{FreeFlow}}{VTT_{Average}}$, i.e. the factor r as defined in Table 5 .

3.2.13. In other words, the current time component of utilit $(\beta_{time} T)$ was replaced with:

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

[11] There will in an indirect impact in that the use of the delay multiplier in the assignment would affect the routes used and therefore the value of the cost skim that is passed to the demand model. It is also likely that the use of delay multipliers would result in different values of β_{cost} in a formal model estimation.

[12] This applies to HBEB as well. Currently money costs are converted to generalised time using WebTAG distance-dependent VTT. This should continue, with the utility of the monetary costs not affected by the processes set out in the rest of this note.

[13] Remembering that $M = \frac{VTT_{Delay}}{VTT_{FreeFlow}}$

3.2.14. To minimise the need to modify the demand model itself, this was achieved by manipulating the time skims from the assignment before they were passed to the demand model. The existing time skims passed to the demand model were replaced with:

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

3.2.15. This ensured that $VTT_{FreeFlow}$ and VTT_{Delay} in the demand model are broadly consistent with the values used in the (modified) assignment, insofar as:

$$VTT_{FreeFlow}=r\times VTT$$

and

$$VTT_{Delay}=M\times VTT_{FreeFlow}$$

3.2.16. The inclusion of the factor, *r,* means that instead of using time skims with units of free-flow time, we used skims with units of average time.

3.2.17. In full, this means that the utility function for trip purposes other than HBEB was:

$$U=r\times\beta_{time}(T_{FreeFlow}+M\times T_{Delay})+\beta_{cost}\left\{\gamma.cost+\boldsymbol{(}1\text{-}\gamma\boldsymbol{)}\log\boldsymbol{(}cost\boldsymbol{)}\frac{E\boldsymbol{(}cost\boldsymbol{)}}{E\boldsymbol{(}\log\boldsymbol{(}cost\boldsymbol{))}}\right\}$$

3.2.18. And for HBEB it was:

$$U= r\times\beta_{time}(T_{FreeFlow}+M\times T_{Delay})+\beta_{time}\frac{cost}{VTT}$$

3.2.19. Note that for all trip purposes the modification to deal with CVTT only affected the pure time component of the utility function. The utility of the monetary cost remained unchanged.

IMPLICATIONS

3.2.20. The PRISM demand model uses the same time skims in the mode choice model for car driver and car passenger mode shares. Using the above modified time skims means that the car passenger utility function also uses the CVTT multiplier. This seems reasonable, and avoids an unintended shift between car driver and car passenger modes[14].

3.2.21. Similarly, the modified car time skims are used to predict car access mode shares to PT modes (e.g. whether to walk or drive to a rail station). Again, this seems reasonable.

3.2.22. It should also be noted that walk and cycle utilities in the demand model are based on car distance skims from the assignment. The above changes do not directly affect these utilities, but the use of CVTT in the assignment model will affect the routes chosen and therefore the skims.

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[14] The model treats car driver and car passenger utilities slightly differently. The former mode has a time period choice model and utilities by time period are used in the demand model; the latter does not have a time period choice model and uses all-day average utilities.

3.3. FORECASTING ASSUMPTIONS

DEMAND MODEL

3.3.1. In standard PRISM forecasting, the parameters β_{time} and γ remain constant, while β_{cost} is divided by the VTT growth factor (e.g. if VTT increases by 10% then β_{cost} is divided by 1.1). This is consistent with most demand modelling in the UK, in which, when forecasting VTT growth, the marginal utility of time remains constant while the marginal utility of money costs reduces.

3.3.2. The time modification process above was assumed to apply equally to the base year and future year demand model runs. This is equivalent to assuming:

- The ratios of free-flow VTT to WebTAG VTTs in Table 5 apply in the base year and all future years; and therefore
- Free-flow VTT, delay VTT and WebTAG VTT all grow at the same rate, i.e. in line with forecast GDP per capita growth.

3.3.3. While it would have been possible to make a different set of assumptions about the relative growth rates, these are transparent and easiest to implement.

PIVOTING

3.3.4. In the terminology of WebTAG Unit M2, PRISM is an 'absolute model applied incrementally'. This means that the demand model is run for the base year and forecast scenarios to produce synthetic trip matrices, and these are then used to adjust the validated base matrix to produce a forecast matrix.

3.3.5. In the simplest case the two synthetic matrices are used to calculate a growth factor to apply to the validated base matrix. The pivoted matrix, *P,* is then given by:

$$P=B\frac{Sf}{Sb}$$

Where

B	is the validated base matrix
Sb	is the synthetic base matrix produced by the demand model
Sf	is the synthetic forecast matrix produced by the demand model

3.3.6. This is the most common of eight different pivoting cases used in PRISM. The other cases exist to deal with situations where one or more of the matrices has a zero cell value, or where 'extreme' growth is forecast (e.g. because of a major development in a zone). Further details can be found in section 10.2 of the PRISM 5 LMVR.

3.3.7. In the CVTT multiplier tests, *Sb* and *Sf* are both obtained from a run of the demand model that includes the multiplier.

3.3.8. However, *B* is always the same matrix, i.e. the original PRISM 5.1 validated base matrix. As noted earlier, this matrix is a function of the VTT used in the base year assignment model (in this case just WebTAG VTT). Ideally, new base matrices would have been produced for each value of the CVTT multiplier, repeating the matrix calibration process in each case. The use of the same matrix for *B* for all of the future year testing is therefore an approximation, which should be borne in mind when interpreting the results.

HIGHWAY ASSIGNMENT

3.3.9. The base year time and distance cost coefficients set out above were adjusted to 2036 using VTT and vehicle operating cost (VOC) growth figures from the October 2017 version 1.8.2 of the WebTAG data book[15]. As per the demand model assumptions, the same VTT growth rate was applied to the free-flow and delay VTTs.

GENERAL

3.3.10. Other forecasting assumptions were consistent with the standard PRISM 5.1 do minimum model runs, in terms of, for example, planning data (population, housing, employment) and transport supply (committed transport schemes).

3.4. TUBA SET UP

TUBA version 1.9.11, which adopts the WebTAG May 2018 data book parameter values, was used for the analysis of benefits in this research.

TUBA ECONOMICS FILE

3.4.1. The standard TUBA economics file was used for tests 1, 3 and 5. Tests 2, 4 and 6 however require free-flow VTT for the appraisal.

3.4.2. The free-flow VTTs were derived by applying an adjustment by trip purpose to the WebTAG VTT, as shown in Table 9 below.

Table 9 Adjustment Factor to Derive Free-Flow Values of Time

No.	Car Journey Purpose	Adjustment Factor
1	Commute	0.6968
2	Employer's Business	0.5718
3	Other	0.5008

3.4.3. A modified TUBA economics file was created by applying the adjustment factors to each of the car journey purposes prior to carrying out the TUBA assessments.

MODELLED YEARS

3.4.4. Only a single forecast model year (2036) was used to produce the TUBA benefits.

[15] Although now superseded, this was the current version at the time the original PRISM 5.1 forecast model runs were set up. Differences from the current version should be small and will not materially affect the conclusions of this work.

TIME SLICES

3.4.5. The modelling outputs consist of three modelled periods: AM peak, Inter-peak and PM peak hours. These periods were included in the TUBA runs, and provide an understanding of the impacts of CVTT on the scheme appraisal in response to the different congestion levels in each time period.

3.4.6. For simplification, standard values of annualisation factors of 759 for the AM and PM peaks and 1,518 for the Inter-peak were adopted for the TUBA runs.

USER CLASSES

3.4.7. Five highway user classes were modelled in the PRISM assignments: Car commute, Car employer's business, Car other, LGV and HGV. These user classes were subsequently converted to the standard journey purposes as defined by TUBA with the proportional splits shown in Table 10 below.

Table 10 Conversion from Assignment User Class to TUBA Purpose

No.	TUBA Purpose	Assignment User Class	Splitting Factor
1	Car - Employer's business	Car - Employer's business	1.00
2	Car – Commute	Car - Commute	1.00
3	Car - Other	Car - Other	1.00
4	LGV Personal	LGV(1)	0.12
5	LGV Freight	LGV	0.88
6	OGV1	HGV(2)	0.60
7	OGV2	HGV	0.40

3.4.8. It should be noted that: (1) LGV Personal/Freight proportional split is based on WebTAG data book values; and (2) OGV1/OGV2 proportional split adopts a simplified average proportion from NTM data.

MODEL SKIM DATA

3.4.9. Table 11 below summarises the skim data used in the TUBA runs.

Table 11 Skim Data

No.	Skim Type	Unit	Detail
1	Demand	Vehicle	By scenarios, time periods, and user classes
2	Distance	Kilometre	By scenarios, time periods, and user classes
3	Total travel time	Hour	By scenarios, time periods, and user classes
4	Free-flow travel time	Hour	By scenarios, time periods, and user classes
5	Delay time	Hour	By scenarios, time periods, and user classes
6	Toll/charges	Pence	By scenarios, time periods, and user classes

3.4.10. The skim data were checked to ensure:

- Number of zones were consistent across the input data;
- Unit of skim data (time, distance, demand, toll) were consistent across the input data.

3.4.11. Delay time skim data were then adjusted by multiplying by relevant multiplier value as specified for each test to represent either Low, Medium or High Multiplier prior to carrying out TUBA runs.

4. BASE YEAR RESULTS

4.1.1. Analysis of the base year highway assignment results focuses on the impact on model validation. This is of interest because one hypothesis floated in our earlier work is that, if the use of congestion multipliers leads to more realistic route choice in models, then the prior matrices should validate better if those multipliers are used in the assignment.

4.2. CONVERGENCE

4.2.1. Table 12 sets out the convergence statistics for the last four iterations of each assignment. As noted above, the standard PRISM5 stopping criteria have been used. No attempt has been made to improve the level of convergence above that achieved with the standard criteria.

Table 12 Model Convergence Statistics

Run ID	Iteration number	Delta – inner assignment	%GAP	Percentage of links with flow change <1%	Percentage of links with cost change <1%
B1 (WebTAG)	16	0.01%	0.04%	94.6%	98.7%
	17	0.02%	0.04%	95.5%	98.9%
	18	0.01%	0.03%	96.1%	99.0%
	19	0.01%	0.02%	96.3%	99.1%
B2 (Low)	15	0.01%	0.04%	94.7%	98.6%
	16	0.01%	0.03%	95.1%	98.8%
	17	0.01%	0.03%	95.8%	99.0%
	18	0.01%	0.02%	96.7%	99.3%
B3 (Med.)	15	0.02%	0.07%	96.0%	98.7%
	16	0.02%	0.05%	95.9%	98.8%
	17	0.02%	0.05%	96.3%	99.0%
	18	0.01%	0.04%	97.0%	99.2%
B4 (High)	15	0.02%	0.07%	96.0%	98.7%
	16	0.02%	0.05%	95.9%	98.8%
	17	0.02%	0.05%	96.3%	99.0%
	18	0.01%	0.04%	97.0%	99.2%
WebTAG Target		**0.1%**	**0.1%**	**98%**	**98%**

(WebTAG Targets for flow change and cost change should be achieved for 4 successive iterations)

4.2.2. The WebTAG % gap and delta targets are achieved for each model run, albeit the final gap is slightly higher for the Medium and higher congestion multipliers (B3 and B4) than the other model runs.

4.2.3. The WebTAG target for the percentage of link[16] costs changing by less than 1% is also achieved for each model run.

4.2.4. The WebTAG target for the percentage of link flows changing by less than 1% is not achieved for any model run. This is partly a consequence of Visum requiring either the flow stability or cost stability targets to be met, but not both (as discussed above). The level of link flow stability varies little between the runs.

4.2.5. B1 achieves the Visum convergence targets in 19 iterations. B2 to B4 each take 18 iterations.

4.2.6. In our initial project report we speculated on various reasons why convergence could be better, or worse, with congestion multipliers. The early indication from the above results is that there is little impact on convergence.

4.3. RUN TIMES

4.3.1. Table 13 shows the model run times. For the runs with the multiplier, run times increase with the value of the multiplier, but all are quicker than WebTAG VTT.

Table 13 Model Run Times

Run ID	Run time (mins)
B1 (WebTAG)	227
B2 (Low)	153
B3 (Med.)	186
B4 (High)	209

4.4. FLOW DIFFERENCES

4.4.1. Figure 4 to Figure 12 show the differences in flows when CVTT multipliers are used. In each case the plot shows the flows with the multiplier (Low, Medium or High) minus the flows with WebTAG VTT. Green indicates a decrease in flow when the multiplier is used, red an increase. Results are presented for each car journey purpose separately as they each show different responses to the multiplier. To avoid cluttering the plots only flow changes greater than 100 vehicles/hour are shown.

4.4.2. Results are not shown for LGVs and HGVs. These show very modest changes in routeing, in response to small changes in travel times caused by the re-routeing of cars.

4.4.3. For car Employer's Business the effect of the multipliers is quite clear. For the Low multiplier (effectively a reduction in VTT of 43%) there is a significant shift from the M6 Toll to the M6, which is entirely consistent with the lower VTT. There is also a small shift away from motorways elsewhere. When the multiplier is increased (Medium or High value), and congested time is valued more highly than free-flow time, there is still a reduction in flow on the M6 Toll, but the reduction is smaller and

[16] Here, 'link' includes turns, i.e. each turning movement is effectively a separate link.

rather than switching to the highly congested M6, long distance traffic switches to a more easterly route via the M1, avoiding the Birmingham motorway box altogether. The extent of this re-routeing may be overestimated as a result of the level of congestion on the M1 route is not being fully represented in the model as it is mostly outside the core model area[17].

4.4.4. The pattern is essentially the same for Medium and High multiplier values, albeit the volume of re-routeing is slightly larger for the latter.

4.4.5. For car commute with the Low multiplier value the most significant impact is a reduction on the M6 Toll but instead of switching to other motorways (as Employer's Business does) traffic uses more local roads. For Medium and High multipliers there is an increase in flow on the M6 Toll (unlike Employer's Business) and an increase in flow on the motorway box.

4.4.6. For car other there is little impact on M6 Toll, partly because very few other trips are using it to start with (the Low VTT in WebTAG means that few other trips are willing to pay the toll). There is a general diversion away from the motorway box, and the M6 to the east of the box. The difference between the model runs is quite modest, though, in common with other purposes, there is greater use of the M6 Toll with the Medium and High multipliers compared to the Low multiplier

4.4.7. Differences between the trip purposes can be explained in terms of different base levels of VTT (free-flow or WebTAG), and the different distribution of trips (long versus short distance). For example, Employer's Business trips tend to be longer distance and more likely to have the M1 as an alternative route, compared to commute.

4.4.8. Across all purposes, the pattern of flow changes is quite similar for the Medium and High multipliers, with only the scale of the changes differing between multiplier values. Flow changes tend to be quite different for the Low multiplier. It is worth repeating that the 'Low multiplier' assignment uses the same VTT for delay and free-flow time and is not really a test of the congestion multiplier at all.

[17] This supports the suggestion made in our original report that model extents may need to be increased if CVTT multipliers are used.

Figure 4 Car Employer's Business, differences between Low multiplier and WebTAG VTT

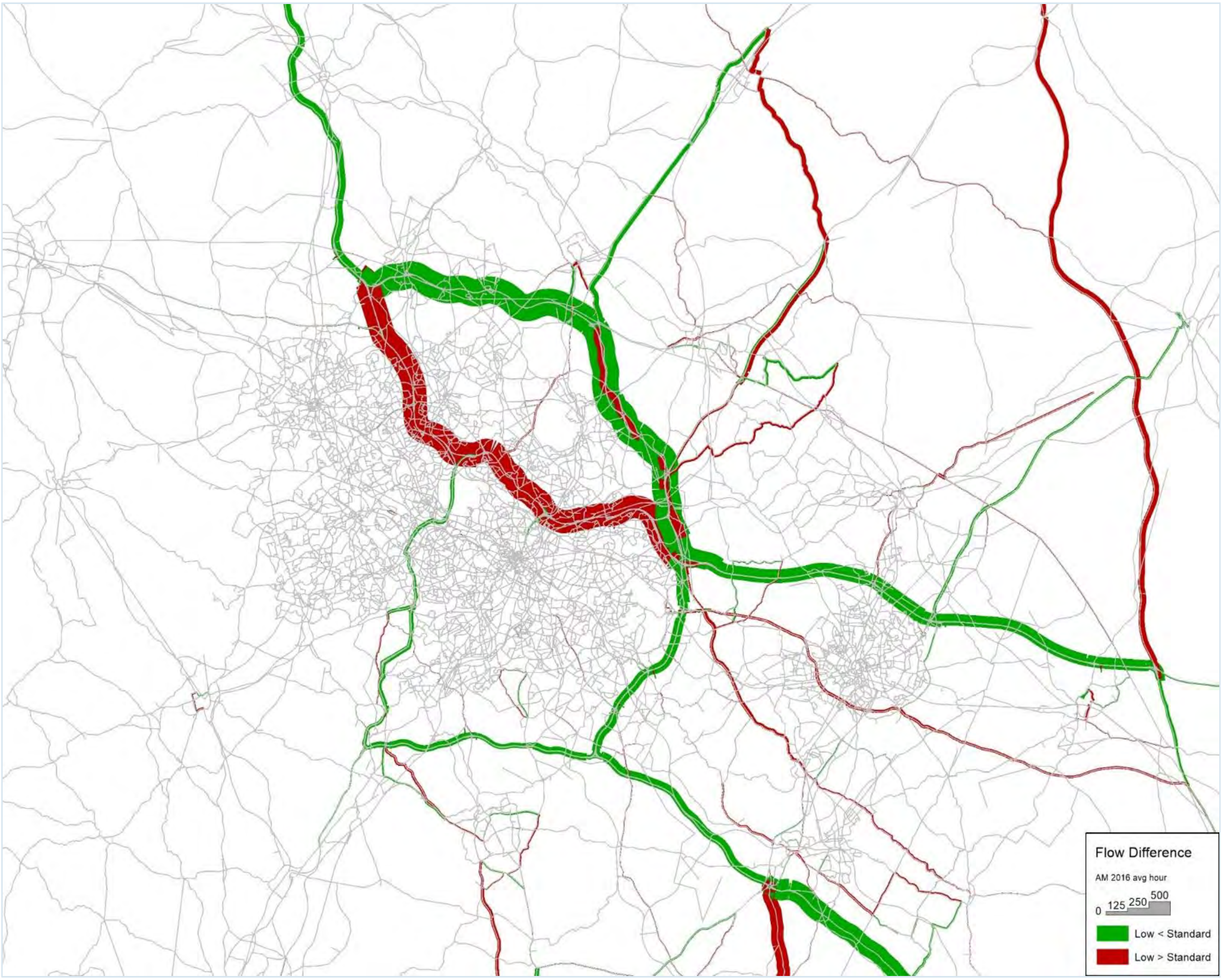


Figure 5 Car Employer's Business, differences between Medium multiplier and WebTAG VTT

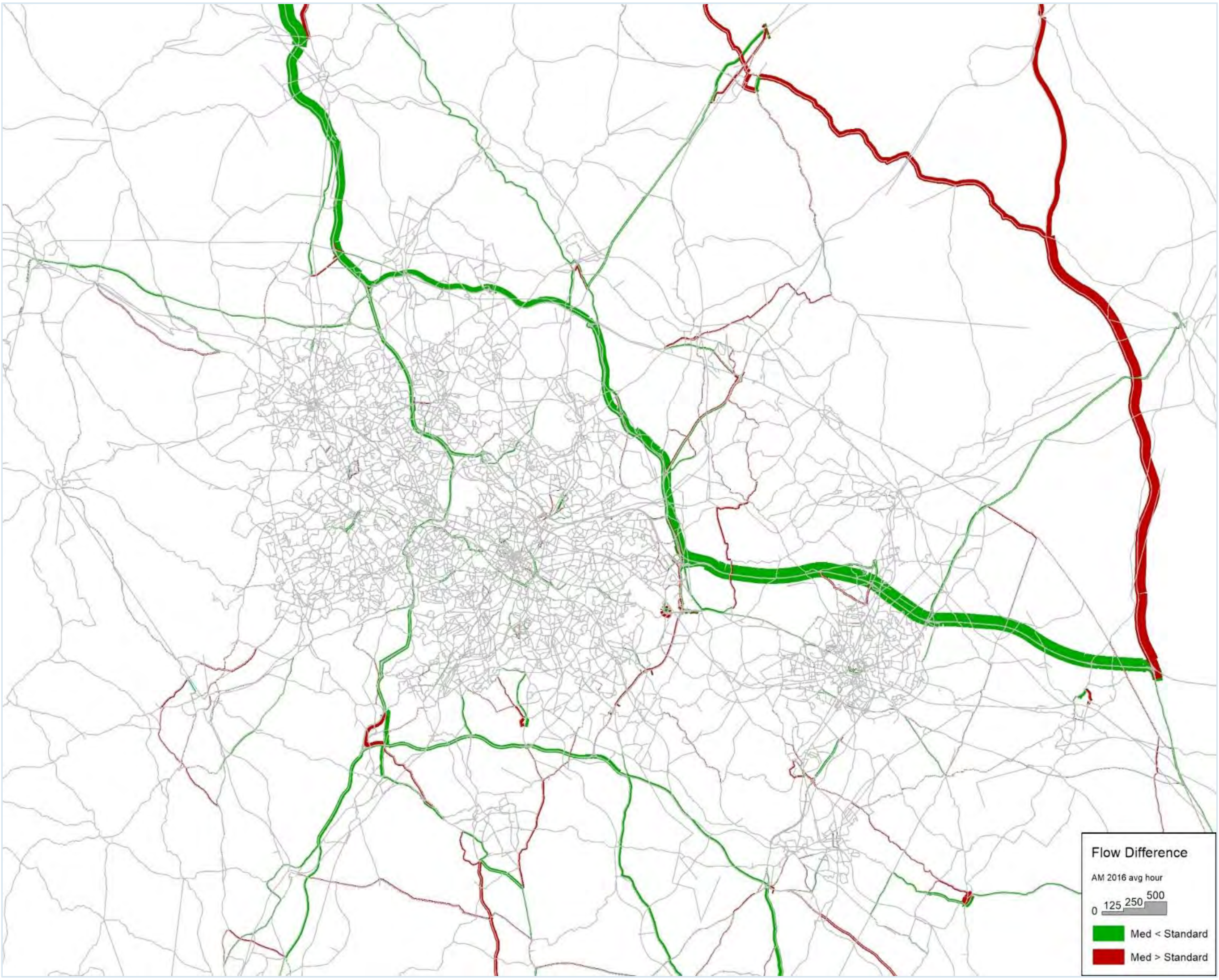


Figure 6 Car Employer's Business, differences between High multiplier and WebTAG VTT

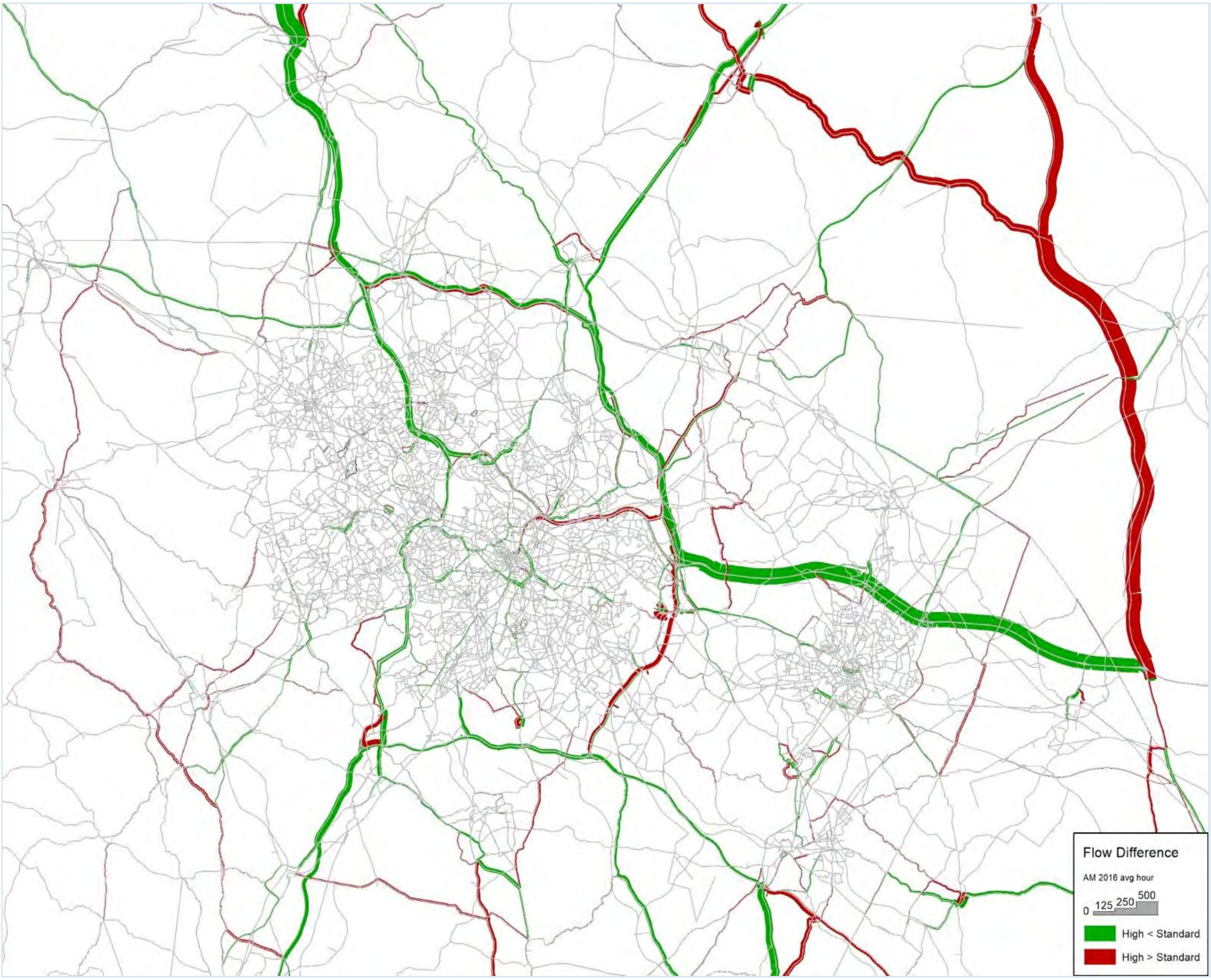


Figure 7 Car Commute, differences between Low multiplier and WebTAG VTT

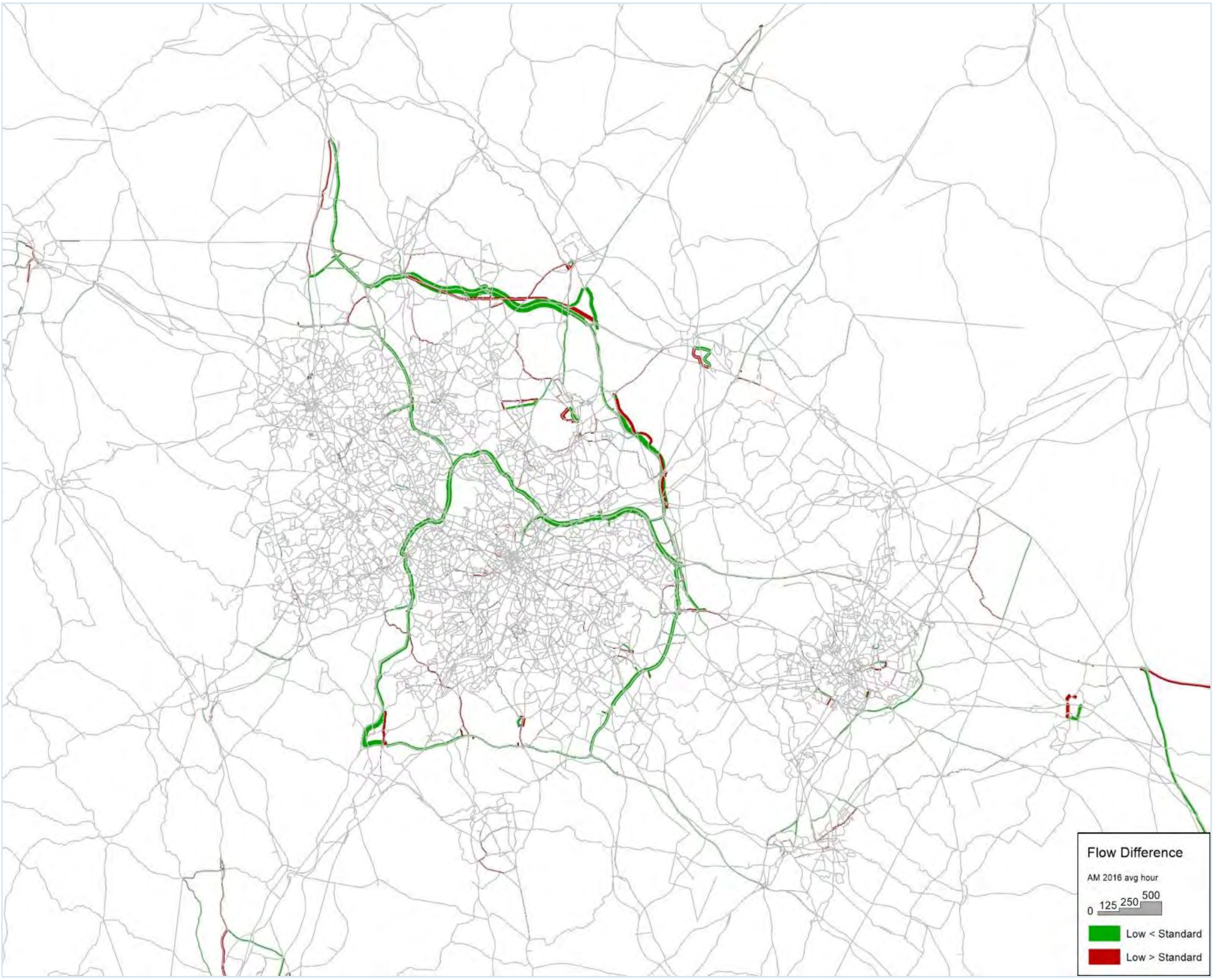


Figure 8 Car Commute B, differences between Medium multiplier and WebTAG VTT

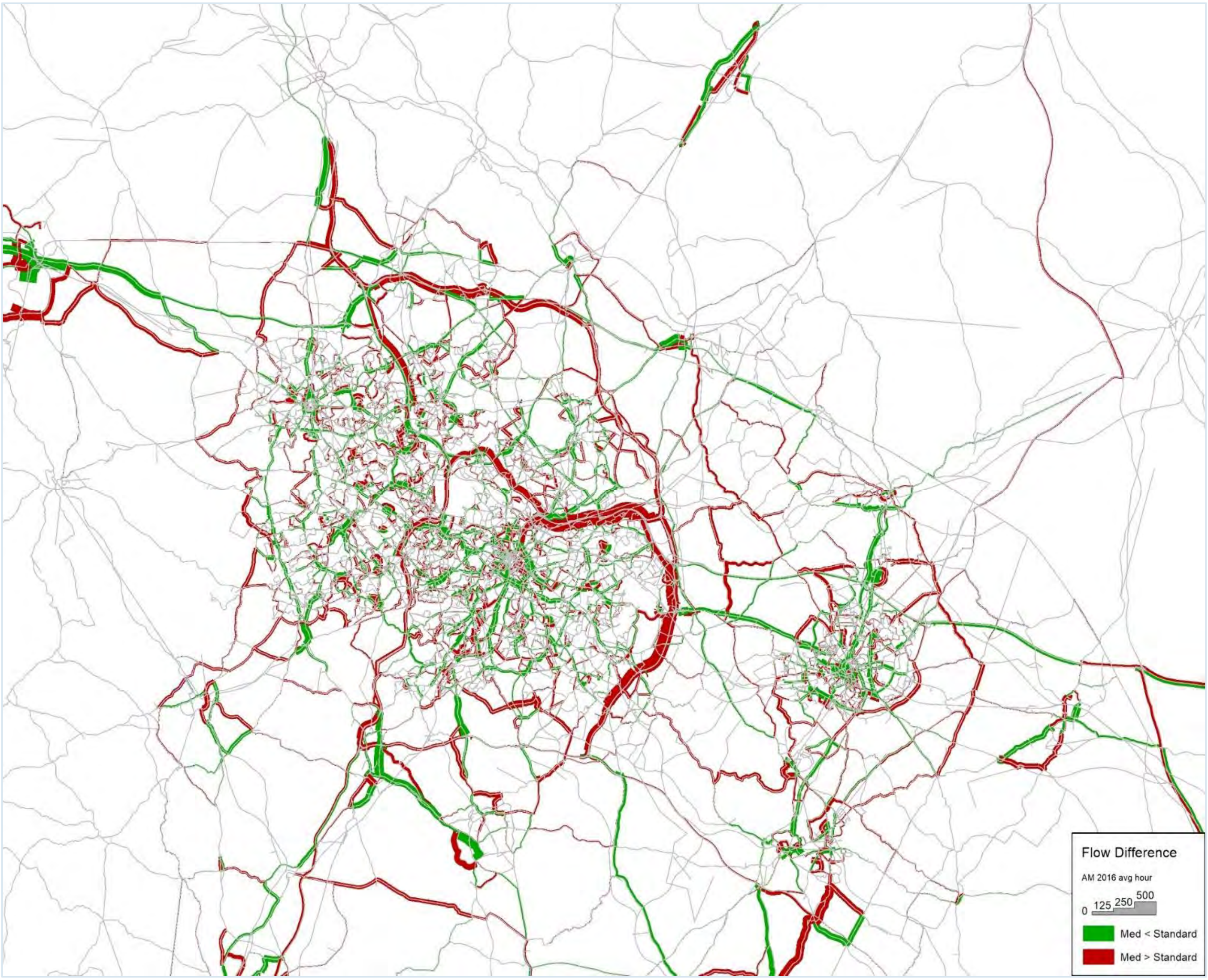


Figure 9 Car Commute, differences between High multiplier and WebTAG VTT

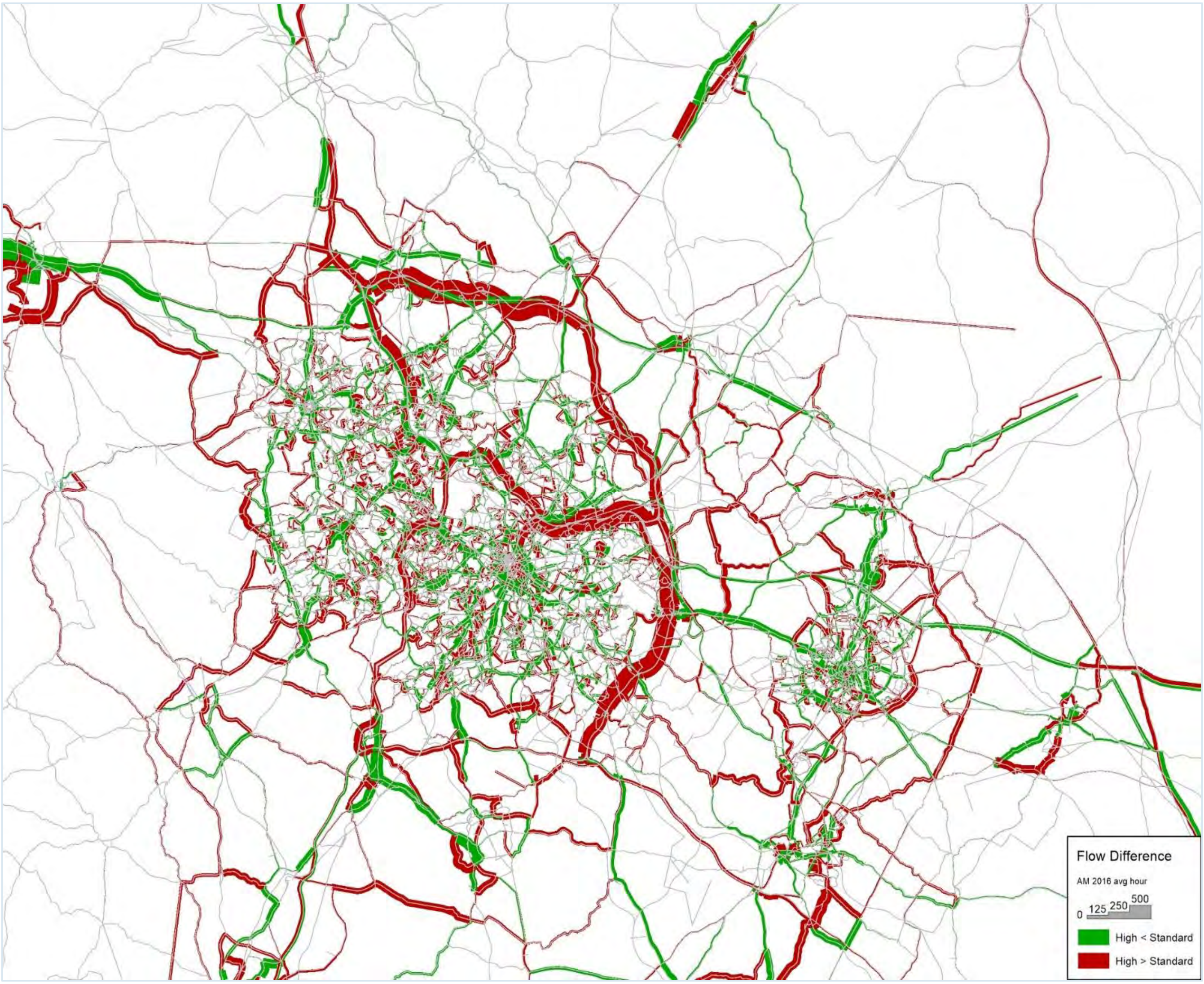


Figure 10 Car Other, differences between Low multiplier and WebTAG VTT

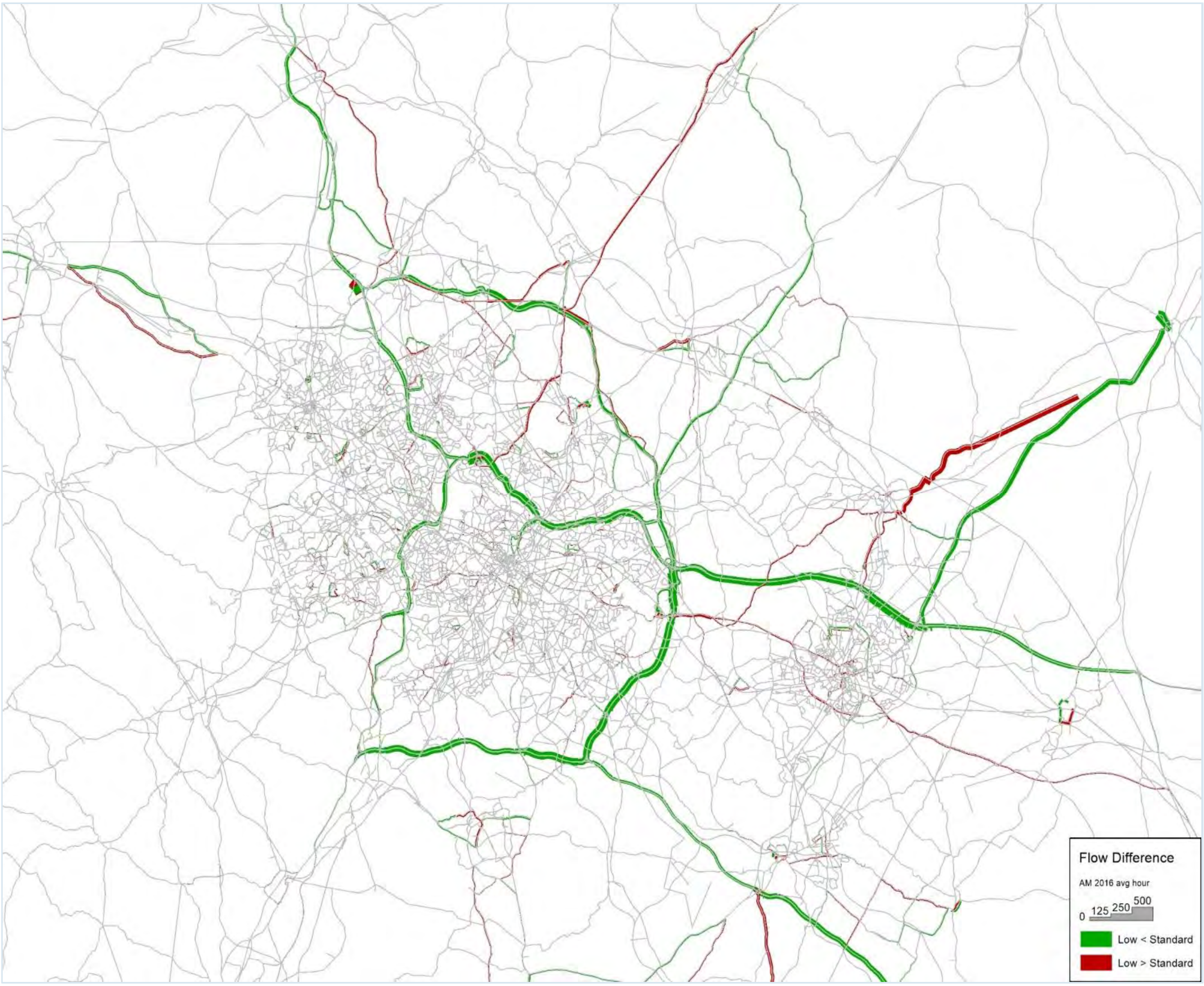


Figure 11 Car Other, differences between Medium multiplier and WebTAG VTT

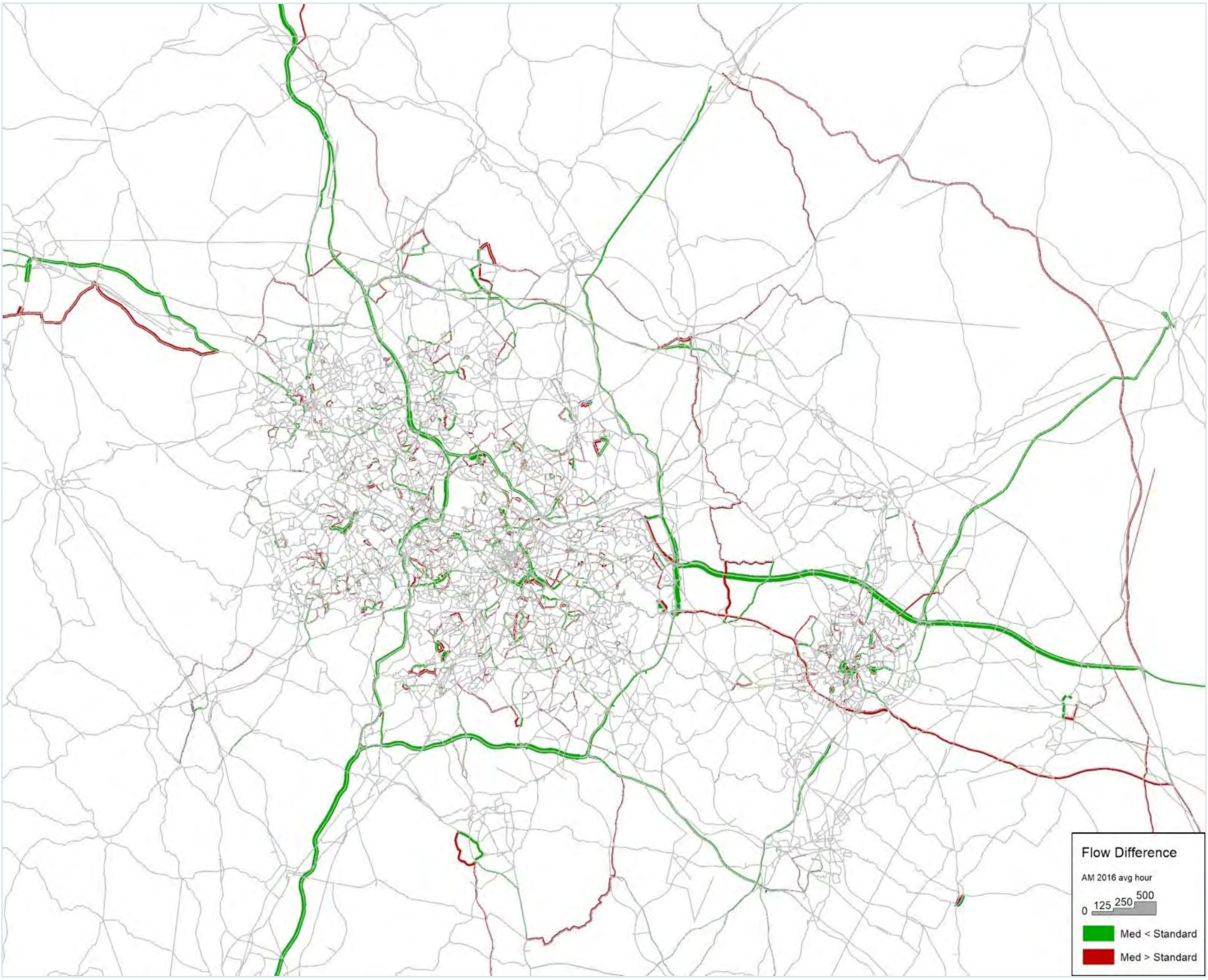
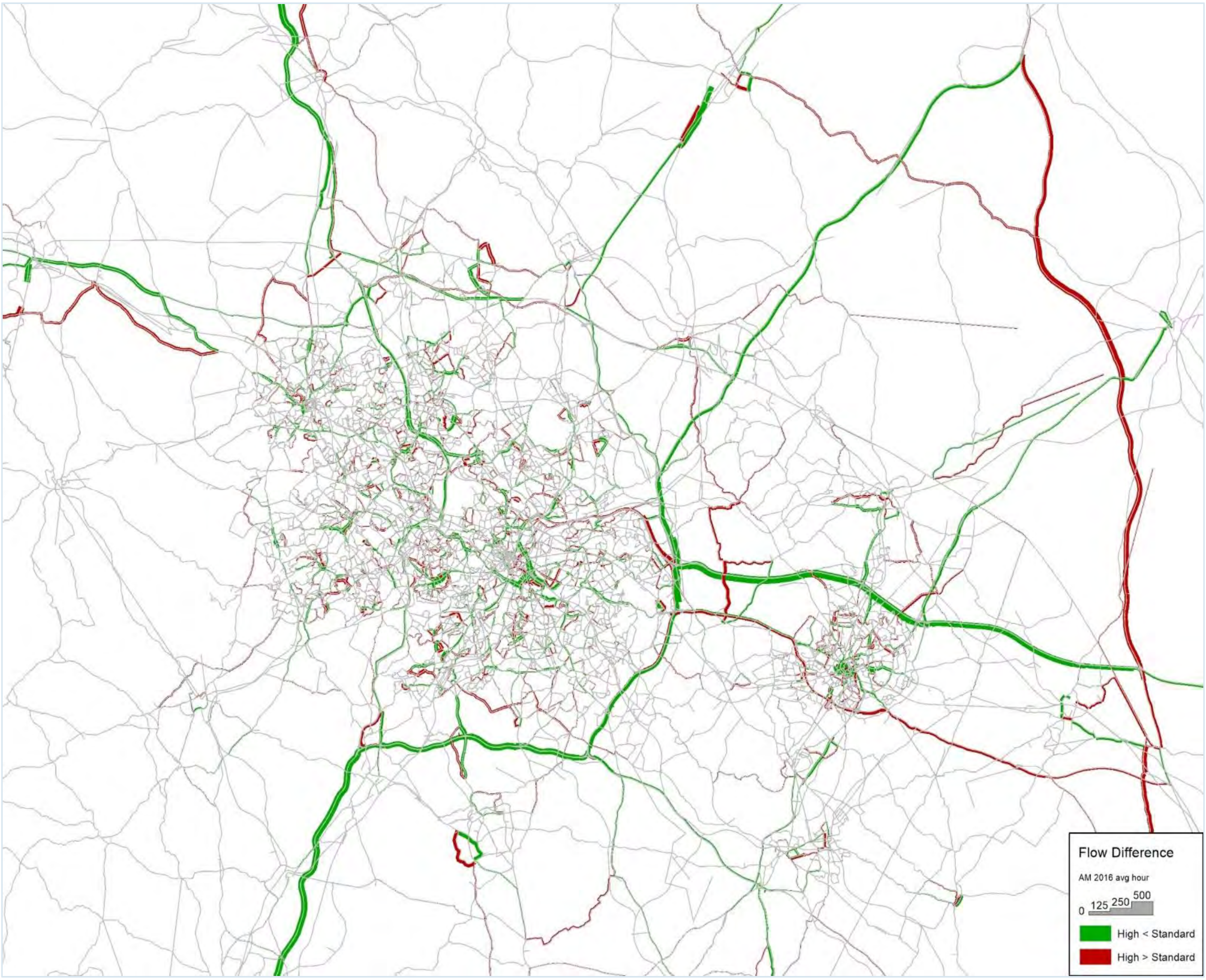


Figure 12 Car Other, differences between High multiplier and WebTAG VTT



4.5. VALIDATION – SCREENLINE FLOWS

4.5.1. Table 14 to Table 16 show the proportion of screenline flows that achieve the PRISM target validation criterion, i.e. the percentage of screenlines with a difference between modelled and observed flows of less than 5% or GEH statistic less than 4[18].

4.5.2. The results are shown for each vehicle type, and split between calibration and validation screenlines (where 'calibration' refers to the screenlines that will be used in matrix estimation, remembering that these results are from the assignment of the prior matrix *before* matrix estimation).

Table 14 Screenline Flow Calibration/Validation Statistics (calibration screenlines)

Run ID	Car	LGV	HGV	Total
B1 (WebTAG)	44%	92%	64%	46%
B2 (Low)	45%	91%	63%	45%
B3 (Med.)	40%	91%	64%	42%
B4 (High)	37%	93%	66%	40%

Table 15 Screenline Flow Calibration/Validation Statistics (validation screenlines)

Run ID	Car	LGV	HGV	Total
B1 (WebTAG)	46%	89%	57%	41%
B2 (Low)	48%	89%	61%	50%
B3 (Med.)	41%	83%	59%	48%
B4 (High)	30%	80%	57%	43%

Table 16 Screenline Flow Calibration/Validation Statistics (all screenlines)

Run ID	Car	LGV	HGV	Total
B1 (WebTAG)	44%	91%	62%	45%
B2 (Low)	45%	91%	63%	46%
B3 (Med.)	40%	89%	63%	43%
B4 (High)	35%	90%	64%	41%

[18] The GEH<4 target originates in DMRB but is no longer part of WebTAG. Nevertheless, it continues to be used in PRISM as a pragmatic way to avoid unreasonably stringent targets on screenlines with low flow.

4.5.3. The CVTT multipliers have little impact on LGV and HGV screenline flows, which is to be expected as the multipliers only apply to cars.

4.5.4. For cars, the fit between modelled and observed flows tends to deteriorate as the value of the multiplier increases. With the Low multiplier (B2) the fit is very slightly better than with WebTAG VTT (B1). The Medium (B3) and High multiplier (B4) fit is slightly worse.

4.5.5. The impact of the multipliers on the validation statistics is not as large on screenline flows as it is on individual link flows (see below). This is not a surprise. Screenline flow validation is presented in WebTAG as a validation of the trip matrix, rather than the assignment/route choice. As an aside, the fact that the generalised cost function does affect screenline flows, demonstrates that screenline flows are not just a function of the trip matrix, as implied by WebTAG.

4.6. VALIDATION – LINK FLOWS

4.6.1. Table 17 below shows a summary of the comparison between modelled and observed link flows, reported as the proportion of links which meet the WebTAG link flow validation criteria. Results are presented separately for cars and all vehicles. They are also split between calibration and validation sites, where the former are those used in matrix estimation from counts, and the latter are held back for independent validation. However, it is important to remember that these results are from the assignment of the prior matrices, i.e. before matrix estimation has been carried out.

Table 17 Link Flow Calibration/Validation Statistics

	Calibration sites		Validation sites		All sites	
Run ID	Cars	All vehs	Cars	All vehs	Cars	All vehs
B1 (WebTAG)	51%	49%	63%	64%	53%	51%
B2 (Low)	51%	49%	62%	62%	53%	51%
B3 (Med.)	46%	46%	56%	59%	48%	48%
B4 (High)	35%	41%	43%	51%	36%	43%

4.6.2. There is little difference in validation between using WebTAG VTT (B1) and using free flow VTT (B2). This is perhaps surprising given that VTT is 30% to 50% lower in the latter. Validation deteriorates with the Medium multiplier (B3), and further deteriorates with the High multiplier (B4).

4.7. VALIDATION – JOURNEY TIMES

4.7.1. Table 18 shows the journey time validation results. PRISM groups the journey time routes into three categories. Tier 1 are the most important and the target is the WebTAG 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 PRISM5 LMVR.

Table 18 Journey Time Validation Statistics

Run ID	Tier 1	Tier 2 non-motorway	Tier 2 motorway	Tier 3
B1 (WebTAG)	88%	96%	79%	95%
B2 (Low)	84%	96%	76%	93%
B3 (Med.)	93%	93%	82%	95%
B4 (High)	90%	93%	82%	96%

4.7.2. There is no clear pattern here. The biggest impact is on the tier 1 routes, but there is no correlation between the level of validation and the value of the multiplier.

4.8. DISCUSSION

4.8.1. Overall, the level of model validation tends to deteriorate as the value of the congestion multiplier increases. The impact is largest for individual link flows. There is a smaller effect on screenline flows and no clear pattern for journey times.

4.8.2. It would be unwise to draw any general conclusions from this. As noted above, the development of the prior matrices implicitly depends on WebTAG VTT. If different VTTs (i.e. with congestion multipliers) had been used to develop the prior matrices, the validation results would have been different.

4.8.3. A further caveat is that the use of the multipliers changes the average VTT in the model. This, rather than the multipliers themselves, may be responsible for some of the differences reported.

4.8.4. Nevertheless, the results do show that use of the multipliers has the potential to affect the validation results, and could make the difference between achieving WebTAG targets and not achieving them.

5. FUTURE YEAR RESULTS

5.1. MODEL RUN TIMES AND CONVERGENCE

5.1.1. Run times and convergence statistics (VDM and highway assignment gaps) for each model run are shown in Table 19. Note that the stopping value for the VDM gap is set at 0.15%; for the highway assignment the stopping criteria are to achieve a gap less than 0.1% *and* link or cost flow stability in line with WebTAG requirements (see Figure 3).

Table 19 Model Run Times and Convergence

Run ID	Scenario	Multiplier	Highway assignment gap			VDM gap	Run time
			AM	IP	PM		(hours)
F7	DM	WebTAG	0.068%	0.026%	0.099%	0.15%	43
F8	DM	Medium	0.039%	0.028%	0.057%	0.11%	38
F9	DM	High	0.049%	0.032%	0.039%	0.11%	77*
F10	DS	WebTAG	0.071%	0.024%	0.084%	0.14%	47
F11	DS	Medium	0.063%	0.029%	0.037%	0.12%	39
F12	DS	High	0.036%	0.029%	0.062%	0.14%	43

* This run was on a different, slower, computer from the others so the time can't be compared with other runs.

5.1.2. There is no significant pattern for convergence. The PM peak assignment converges the worst, being the most congested; this is consistent with other PRISM applications. For some time periods and multiplier values the DS converges better than the DM; for others the DS converges worse.

5.1.3. The specified gap stopping criteria are achieved in all cases.

5.1.4. Excluding F9 (which was run on different computer), there is relatively little variation in run times. As with the base year assignments, the Medium Multiplier run is faster than the High Multiplier, which in turn is faster than WebTAG VTT.

5.1.5. Overall, these results suggest that the use of a congestion multiplier is unlikely to have significantly adverse impacts in terms of either model convergence or run times.

5.2. AGGREGATE MODEL RESULTS

HIGHWAY ASSIGNMENT TOTAL TRAVEL TIME AND DISTANCE

5.2.1. Table 20 to Table 22 show the aggregate results from the highway assignment, i.e. total 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 routeing responses, but also depend on the VDM response in both the DM and DS.

Table 20 Aggregate Model Results: Car Commute

Run ID	Scenario	Multiplier	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)
F7	DM	WebTAG	36,368	726.3	531.8	194.5	16.5	19.8	14.5	5.3
F8	DM	Medium	36,651	684.7	532.4	152.3	17.3	19.3	15.0	4.3
F9	DM	High	37,125	679.5	539.0	140.5	17.3	19.0	15.1	3.9
F10	DS	WebTAG	36,779	724.5	533.9	190.6	16.7	19.8	14.6	5.2
F11	DS	Medium	37,115	682.8	534.2	148.6	17.5	19.4	15.1	4.2
F12	DS	High	37,836	681.6	543.5	138.2	17.7	19.1	15.2	3.9

Table 21 Aggregate Model Results: Car Employer's Business

Run ID	Scenario	Multiplier	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Free flow time (min)	Ave. delay time (min)
F7	DM	WebTAG	39,642	522.2	440.2	82.0	60.3	47.6	40.2	7.5
F8	DM	Medium	38,915	500.4	437.2	63.1	60.7	46.8	40.9	5.9
F9	DM	High	38,670	493.5	436.8	56.7	60.2	46.1	40.8	5.3
F10	DS	WebTAG	40,023	521.9	442.3	79.6	60.9	47.7	40.4	7.3
F11	DS	Medium	39,396	500.9	439.7	61.2	61.7	47.0	41.3	5.7
F12	DS	High	39,291	495.9	440.3	55.6	61.3	46.4	41.2	5.2

Table 22 Aggregate Model Results: Car Other

Run ID	Scenario	Multiplier	Total dist. (1000 vkm)	Total time (1000 vhr)	Free flow (1000 vhr)	Total delay (1000 vhr)	Ave. dist. (km)	Ave. time (min)	Free flow time (min)	Ave. delay time (min)
F7	DM	WebTAG	47,139	964.2	716.7	247.5	11.2	13.8	10.2	3.5
F8	DM	Medium	47,438	934.1	728.0	206.1	11.4	13.5	10.5	3.0
F9	DM	High	47,143	910.6	723.6	187.0	11.3	13.1	10.4	2.7
F10	DS	WebTAG	47,465	962.3	718.8	243.5	11.3	13.8	10.3	3.5
F11	DS	Medium	47,844	932.7	730.3	202.5	11.5	13.5	10.5	2.9
F12	DS	High	47,674	911.4	726.7	184.7	11.5	13.1	10.5	2.7

5.2.2. Figure 13 to Figure 15 show the average trip distances, free-flow times, and delays from the above tables.

Figure 13 Average Trip Distance (km)

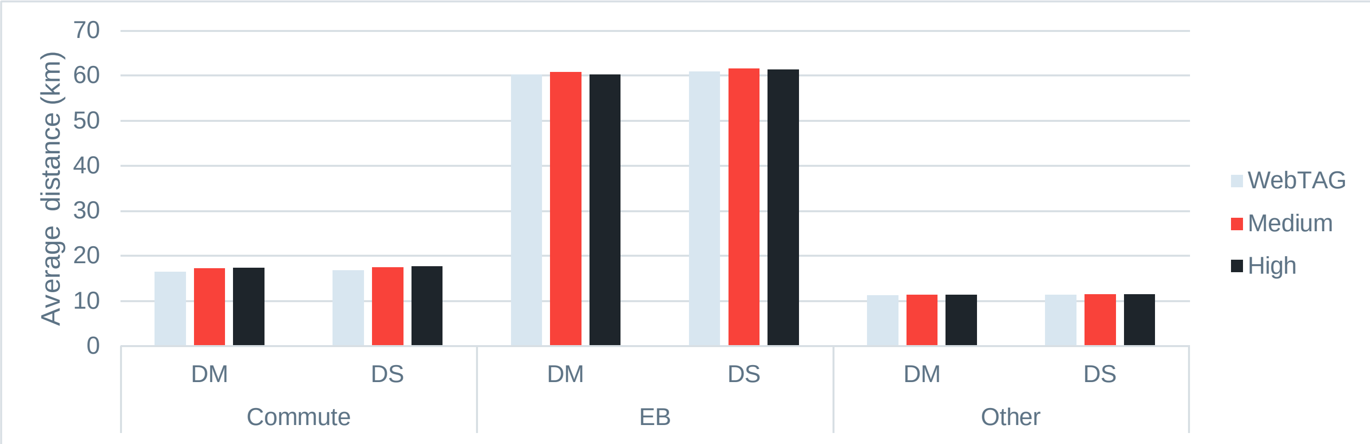


Figure 14 Average Trip Free-flow Time (mins)

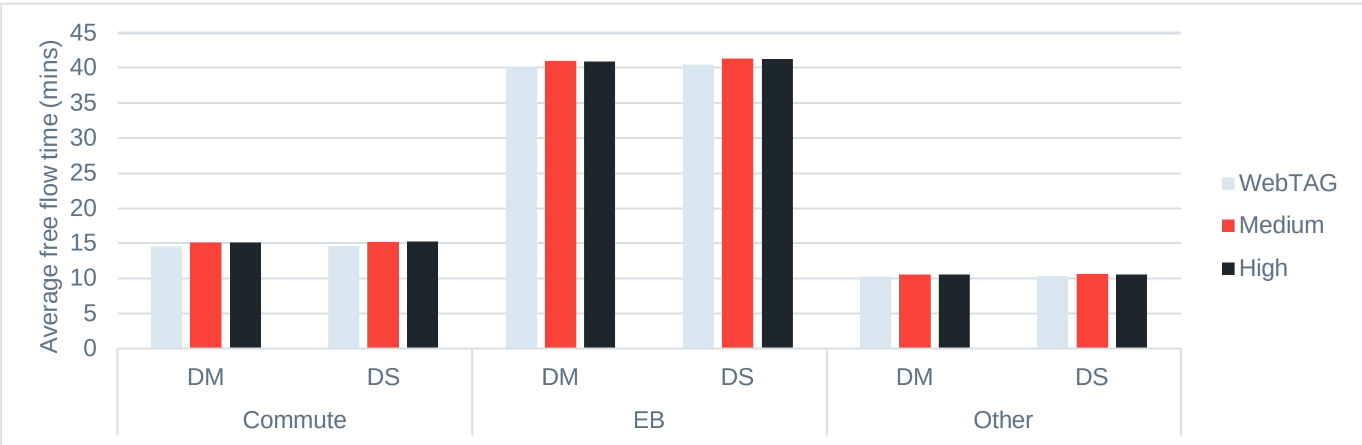
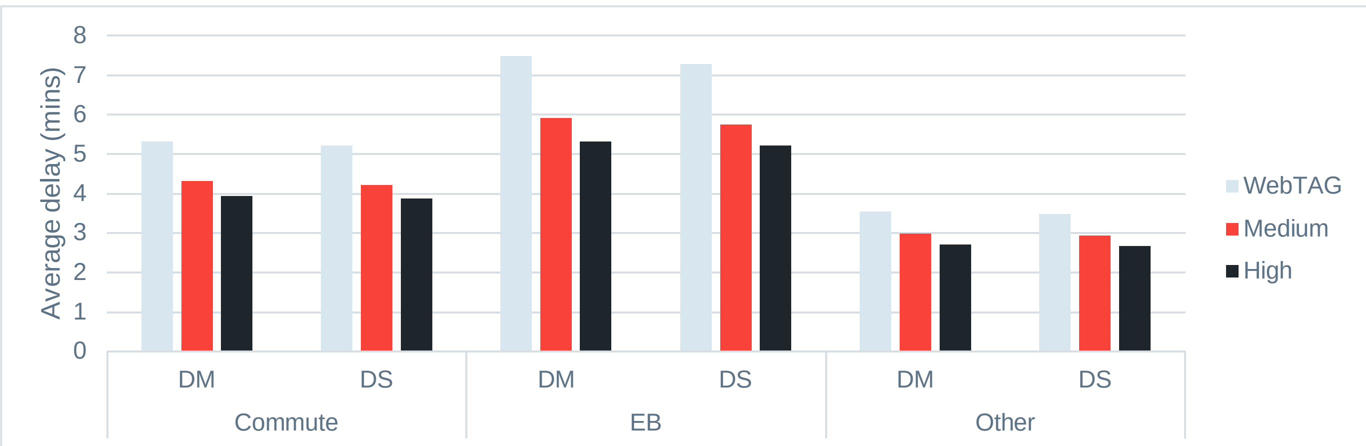


Figure 15 Average Trip Delay (mins)



5.2.3. Some general patterns are discernible from these results:

- The use of a multiplier decreases the total travel time in the system, with the impact greater with the High Multiplier than the Medium Multiplier;
- This is largely the result of significant decreases in total delay time. Changes in total free-flow time are relatively modest and, in some cases, free-flow time increases with the multiplier;
- 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 WebTAG;
- There is a less clear pattern for distance travelled. Car commute sees the biggest effect, with distances increasing with the multiplier, presumably reflecting a change in routeing 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.

IMPLIED AVERAGE VTT

5.2.4. Table 23 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 23 Outturn Average VTTs (£/hr per vehicle, 2010 prices)

Run	Scenario	Multiplier	Commute	Employer's Business	Other
F7	DM	WebTAG	16.82	25.25	11.96
F8	DM	Medium	14.68	20.86	8.64
F9	DM	High	17.11	26.38	10.91
F10	DS	WebTAG	16.82	25.25	11.96
F11	DS	Medium	14.59	20.72	8.59
F12	DS	High	16.98	26.14	10.85

5.2.5. There is a consistent pattern of the Medium Multiplier average VTT always being less than WebTAG. The High Multiplier average VTT is greater than WebTAG for commute, and Employer's Business, but not for Other.

5.2.6. As set out in Table 5, when the Medium or High Multiplier is used, the free-flow VTT is 30-50% lower than the WebTAG VTT. With the Medium Multiplier, delay is valued at 3 times the free-flow value, but it seems there is not enough delay in the model system to bring the average VTT up to WebTAG levels. With the High Multiplier the level of delay is enough to raise the average VTT just above WebTAG for commute and Employer's Business, but not for Other. This is probably a result of the free-flow VTT for Other being only 50% of WebTAG, significantly lower than for other purposes.

5.2.7. Table 24 shows the ratio of the outturn average VTT (from Table 23) to the free-flow VTT.

Table 24 Ratio of Outturn Average VTT to Free-flow VTT

Run	Scenario	Multiplier	Commute	Employer's Business	Other
F7	DM	WebTAG	1.00	1.00	1.00
F8	DM	Medium	1.44	1.25	1.44
F9	DM	High	1.83	1.46	1.82
F10	DS	WebTAG	1.00	1.00	1.00
F11	DS	Medium	1.44	1.24	1.43
F12	DS	High	1.81	1.45	1.81

5.2.8. It should be emphasised that these are averages over the entire model. The ratios will be higher in more congested locations and time periods. This makes it difficult to compare these directly with the multipliers from previous SP studies.

5.2.9. Commuting and Other ratios are similar, with Employer's Business lower. This is likely to be a consequence of the latter tending to occur in the less congested inter-peak period, and being longer distance (i.e. spending proportionally less time in the congested urban area).

5.2.10. The ratio is determined by (a) the delay multiplier *M,* and (b) the ratio of delay time to total travel time. Table 20 to Table 22 show that the latter is relatively low, and decreases as the multiplier increases as traffic chooses alternatives (routes, modes, destinations) that avoid the most congested areas.

MODE SHARES

5.2.11. Table 25 to Table 27 show the mode shares by journey purpose, with one table for each of the three main journey purposes[19].

[19] To simplify the analysis, these are 24 hour person mode shares from the synthetic demand model, i.e. before the application of the pivoting process. Out-turn mode shares after pivoting will be slightly different, but the direction of change will be the same as shown here. Only motorised modes are shown in the table, hence they do not sum to 100% (the other modes being car passenger, walk, and cycle).

Table 25 Motorised Mode Shares: Commute Trips

Run ID	Scenario	Multiplier	Car driver	Train	Metro	Bus
F7	**DM**	**WebTAG**	**70.9%**	**3.3%**	**0.4%**	**10.0%**
F8	DM	Medium	72.2%	3.1%	0.4%	9.3%
F9	**DM**	**High**	**70.8%**	**3.3%**	**0.4%**	**10.5%**
F10	DS	WebTAG	71.0%	3.3%	0.4%	10.0%
F11	**DS**	**Medium**	**72.2%**	**3.1%**	**0.4%**	**9.3%**
F12	DS	High	70.9%	3.3%	0.4%	10.5%

Table 26 Motorised Mode Shares: Employer's Business Trips

Run ID	Scenario	Multiplier	Car driver	Train	Metro	Bus
F7	**DM**	**WebTAG**	**83.2%**	**2.5%**	**0.0%**	**3.8%**
F8	DM	Medium	84.0%	2.4%	0.0%	3.7%
F9	**DM**	**High**	**83.0%**	**2.7%**	**0.1%**	**4.2%**
F10	DS	WebTAG	83.3%	2.5%	0.0%	3.8%
F11	**DS**	**Medium**	**84.0%**	**2.4%**	**0.0%**	**3.6%**
F12	DS	High	83.1%	2.7%	0.1%	4.1%

Table 27 Motorised Mode Shares: 'Other' Trips

Run ID	Scenario	Multiplier	Car driver[20]	Train	Metro	Bus
F7	DM	WebTAG	35.5%	1.5%	0.2%	11.7%
F8	DM	Medium	36.6%	1.4%	0.2%	11.1%
F9	DM	High	35.7%	1.5%	0.2%	11.6%
F10	DS	WebTAG	35.6%	1.5%	0.2%	11.6%
F11	DS	Medium	36.6%	1.4%	0.2%	11.0%
F12	DS	High	35.8%	1.5%	0.2%	11.6%

5.2.12. Looking at the DM mode shares, the multiplier has relatively little effect, though the Medium Multiplier consistently has the highest car driver mode share. This could be a result of the Medium

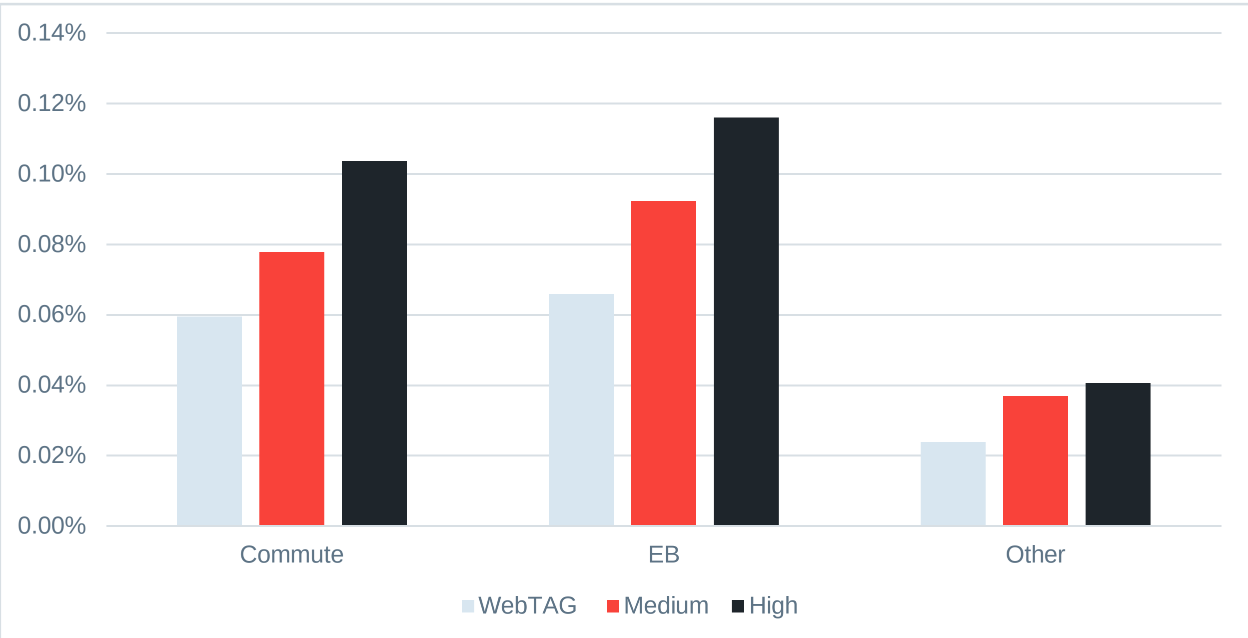
[20] Although the car driver mode share looks low, it is consistent with local household interview data (see Tables 122 and 123 of the PRISM 5.0 LMVR), and reflects a very high walking mode share for this purpose. It is also broadly consistent with NTS table 0409, which gives 40% car driver mode share for Other (https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons).

Multiplier having the lowest VTT for car drivers (remembering that VTT for public transport is the same for all the tests). The lower VTT corresponds to a lower disutility of time in the car driver utility function (see section 3.2) so, other things being equal, makes car driver travel more attractive.

5.2.13. This is probably not a result that can be generalised. To some extent it stems from the fact that the demand model parameters have not been re-estimated to account for the change in the VTT (other than changing the VTT in the demand model, as described in section 3.2). It is possible that re-calibration of the model would reduce the differences between the multiplier values in this respect. Specifically, re-estimation would test our assumption that the use of congestion multipliers only affects the time component of the utility function, not the cost component.

5.2.14. The scheme tends to increase the car driver mode share. The percentage point change in mode share increases with the multiplier value. This is shown more clearly in the following chart. Although the percentages figures are small, they amount to the level of induced traffic with the High Multiplier being about 70% higher than with WebTAG.

Figure 16 Increase in Car Driver Mode Share (percentage points increase DM to DS) by Journey Purpose and Multiplier



AVERAGE TRIP LENGTHS

5.2.15. Table 28 shows the average trip length by journey purpose. Similar to the mode shares presented above these are from the 'raw' demand model output, before the application of pivoting. They also represent all modes. They are therefore quite different from the average trip lengths presented in Table 20 to Table 22 which were based on highway assignment model outputs. They are presented here as, unlike the earlier results, they show the pure demand model impact on trip lengths, distinct from any route choice effects.

Table 28 Average Trip Length (km) by Journey Purpose

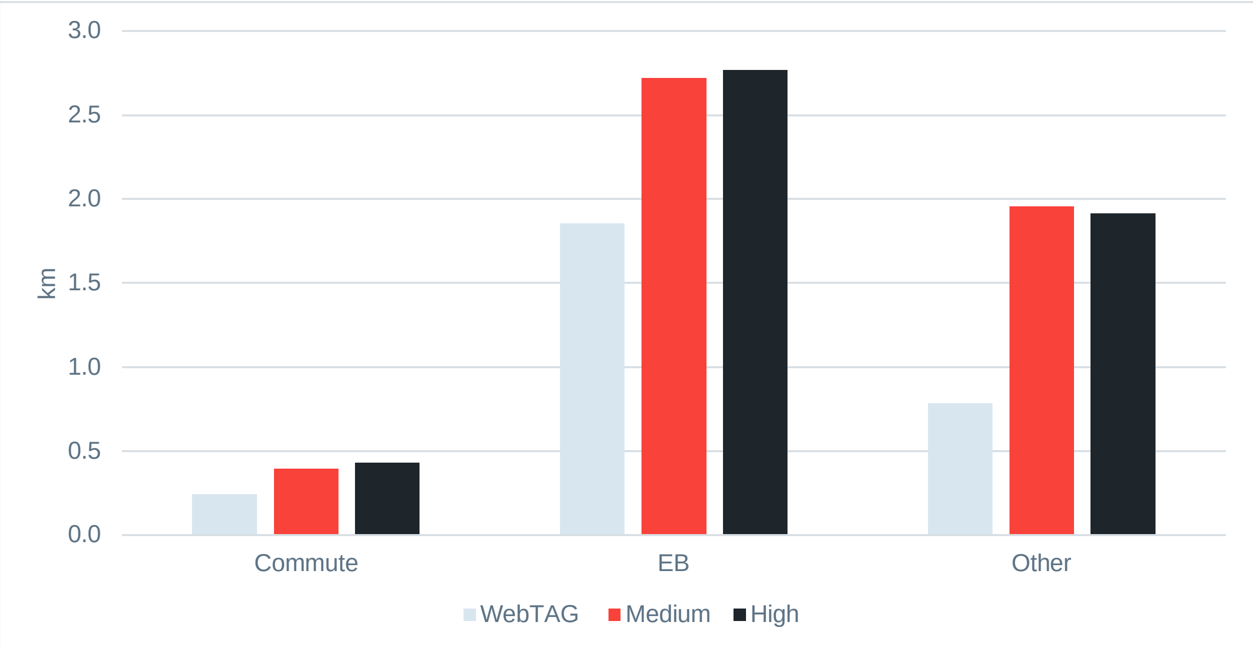
Run ID	Scenario	Multiplier	Commute	Employer's Business	Other
F7	DM	WebTAG	17.2	138.6	107.5
F8	DM	Medium	22.2	183.5	139.8
F9	DM	High	20.9	175.0	130.7
F10	DS	WebTAG	17.4	140.5	108.3
F11	DS	Medium	22.6	186.2	141.8
F12	DS	High	21.3	177.8	132.6

5.2.16. In common with most variable demand models, the destination choice (distribution) part of the model is more sensitive to travel costs than mode choice. Therefore, it is not surprising that the impact of the multiplier, and the scheme, on average trip length is more significant than the impact on mode choice.

5.2.17. Average trip lengths vary significantly with the multiplier value and are highest with the Medium Multiplier. This is consistent with the trip lengths in Table 20 to Table 22, albeit the effect is more significant here.

5.2.18. Figure 17 shows the increase in trip length by journey purpose and multiplier. The increase is generally larger as the multiplier increases, similar to the mode share impacts shown above. For this particular scheme in this particular location, this means that the volume of induced traffic increases with the multiplier value.

Figure 17 Increase in Average Trip Length (DM to DS), by Journey Purpose and Multiplier



5.3. LINK FLOWS

DO MINIMUM

5.3.1. Figure 18 to Figure 23 show the difference in DM flows between the 'with multiplier' model runs and the WebTAG VTT model, by car journey purpose for the AM peak only.

5.3.2. These plots show essentially the same information as Figure 4 to Figure 12, but for 2036 rather than the 2016 base year, and without a Low Multiplier model run. The impact of the multipliers is similar to that seen in 2016, albeit the scale of re-routeing is greater, as is its geographical extent. This is consistent with a higher level of congestion in 2036. In summary:

- Car Employer's Business trips tend to re-route away from the Birmingham motorway box to use the M1. This may be partly due to congestion on the M1 not being fully represented in the model;
- Car Commute re-routeing is more localised, reflecting the shorter trip lengths. With the Medium and High Multipliers there is an increase in flow on the M6 Toll, to avoid the more congested M6;
- For Car Other, unlike the other purposes, there is no significant change in the flow on the M6 Toll. There is a transfer of flow from the motorway box to the M1;
- The scale of re-routeing is greater with the High Multiplier than the Medium Multiplier.

Figure 18 DM, Car Commute, differences between Medium Multiplier and WebTAG VTT

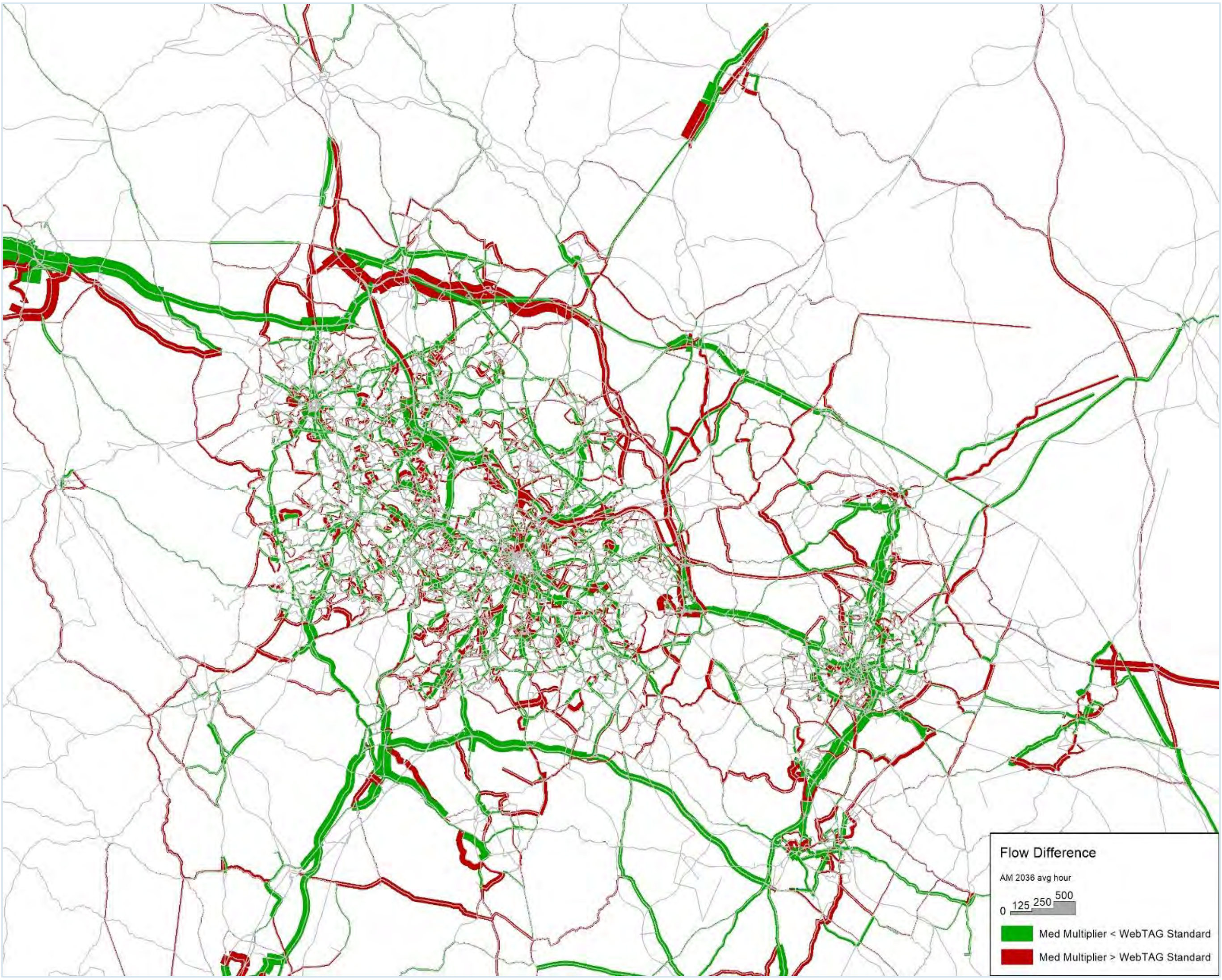


Figure 19 DM, Car Commute, differences between High Multiplier and WebTAG VTT

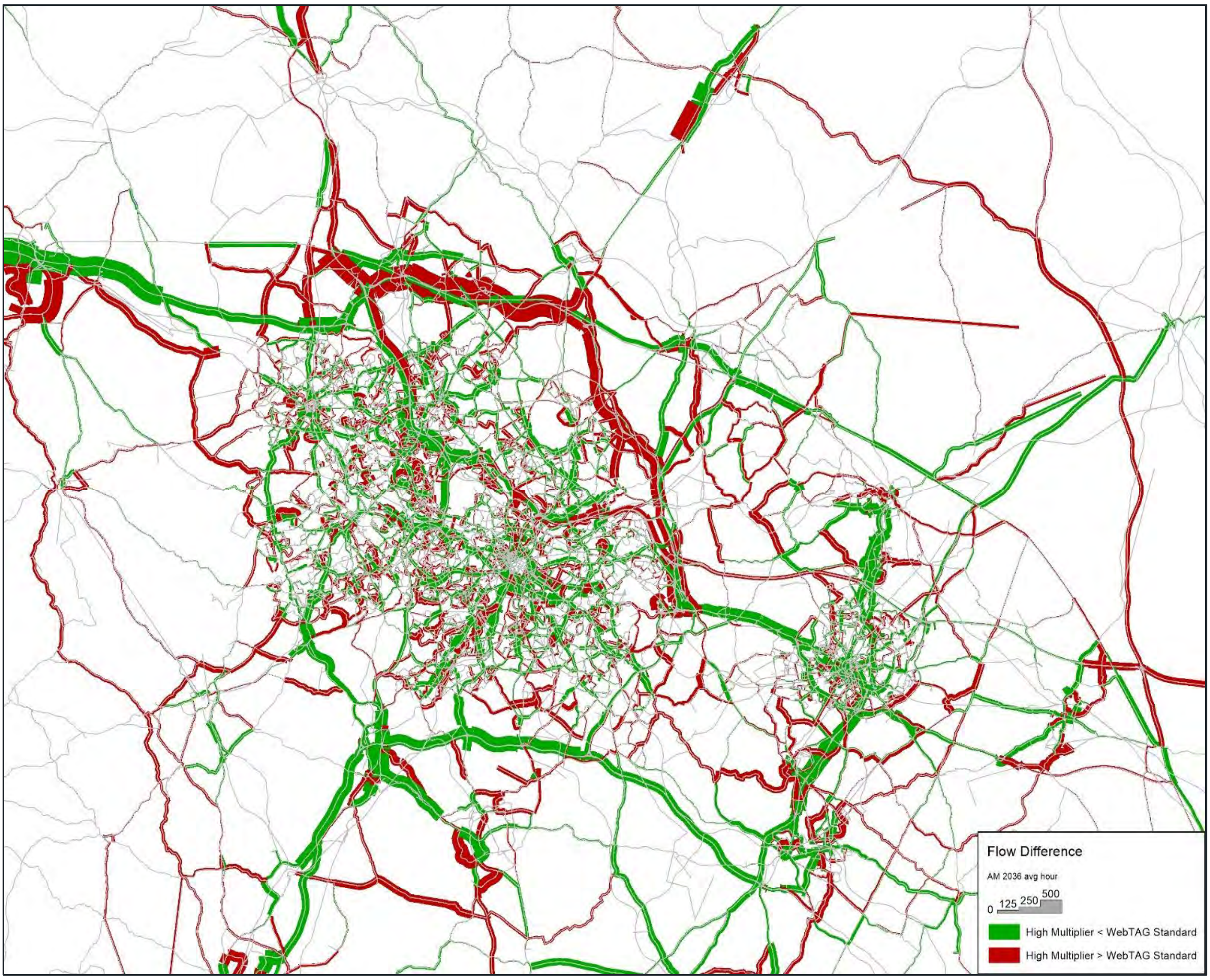


Figure 20 DM, Car Employer's Business, differences between Medium Multiplier and WebTAG VTT

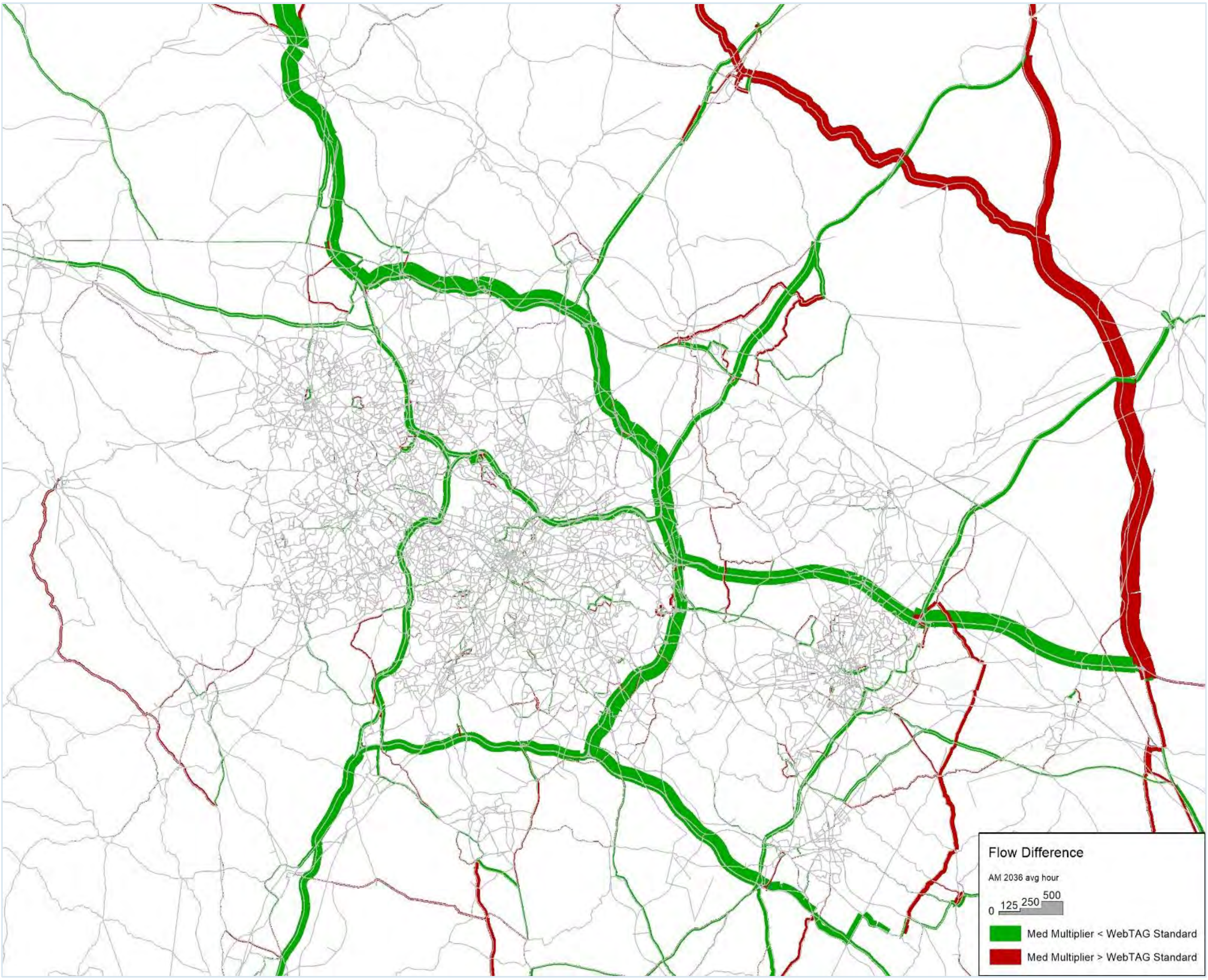


Figure 21 DM, Car Employer's Business, differences between High Multiplier and WebTAG VTT

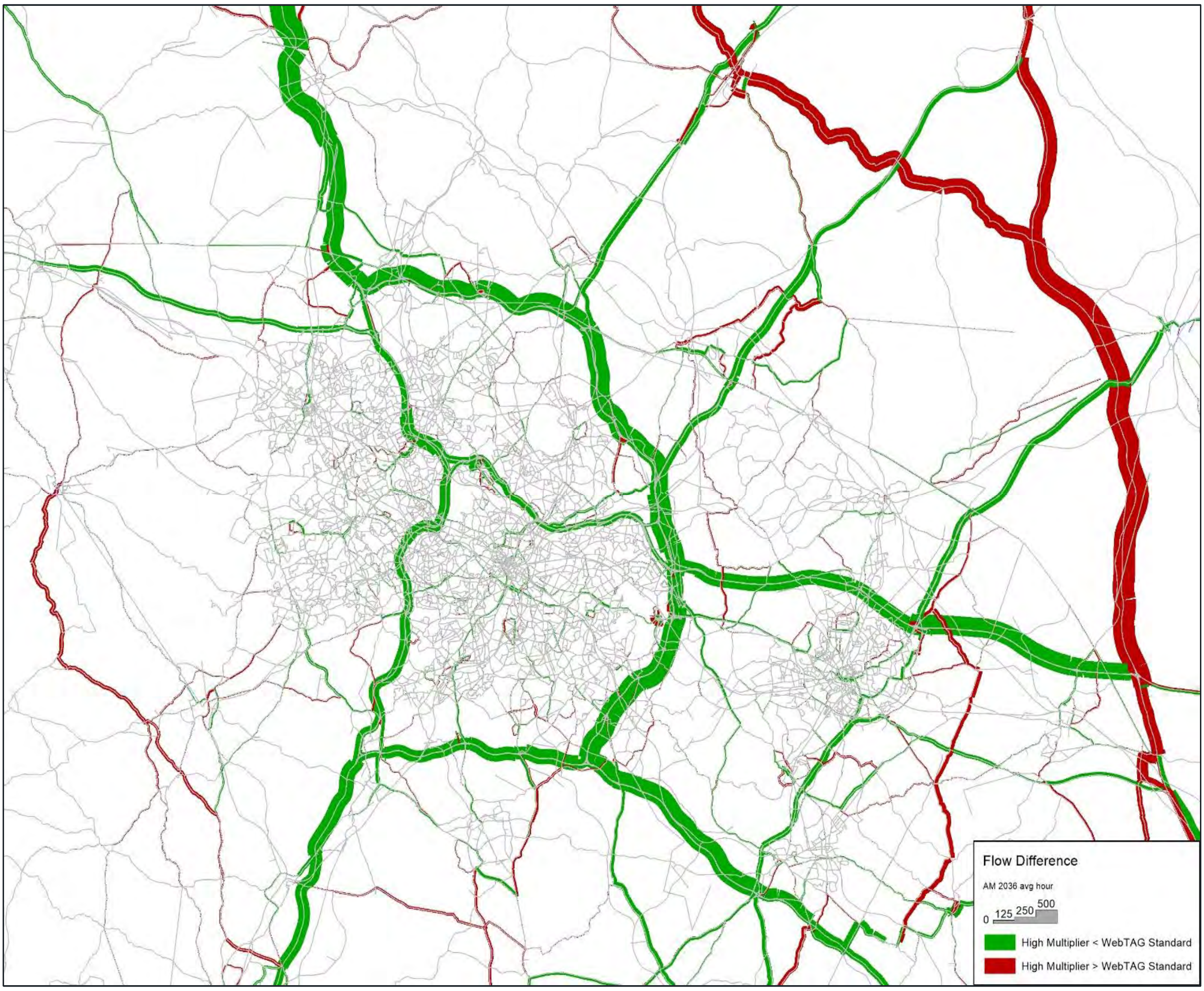


Figure 22 DM, Car Other, differences between Medium Multiplier and WebTAG VTT

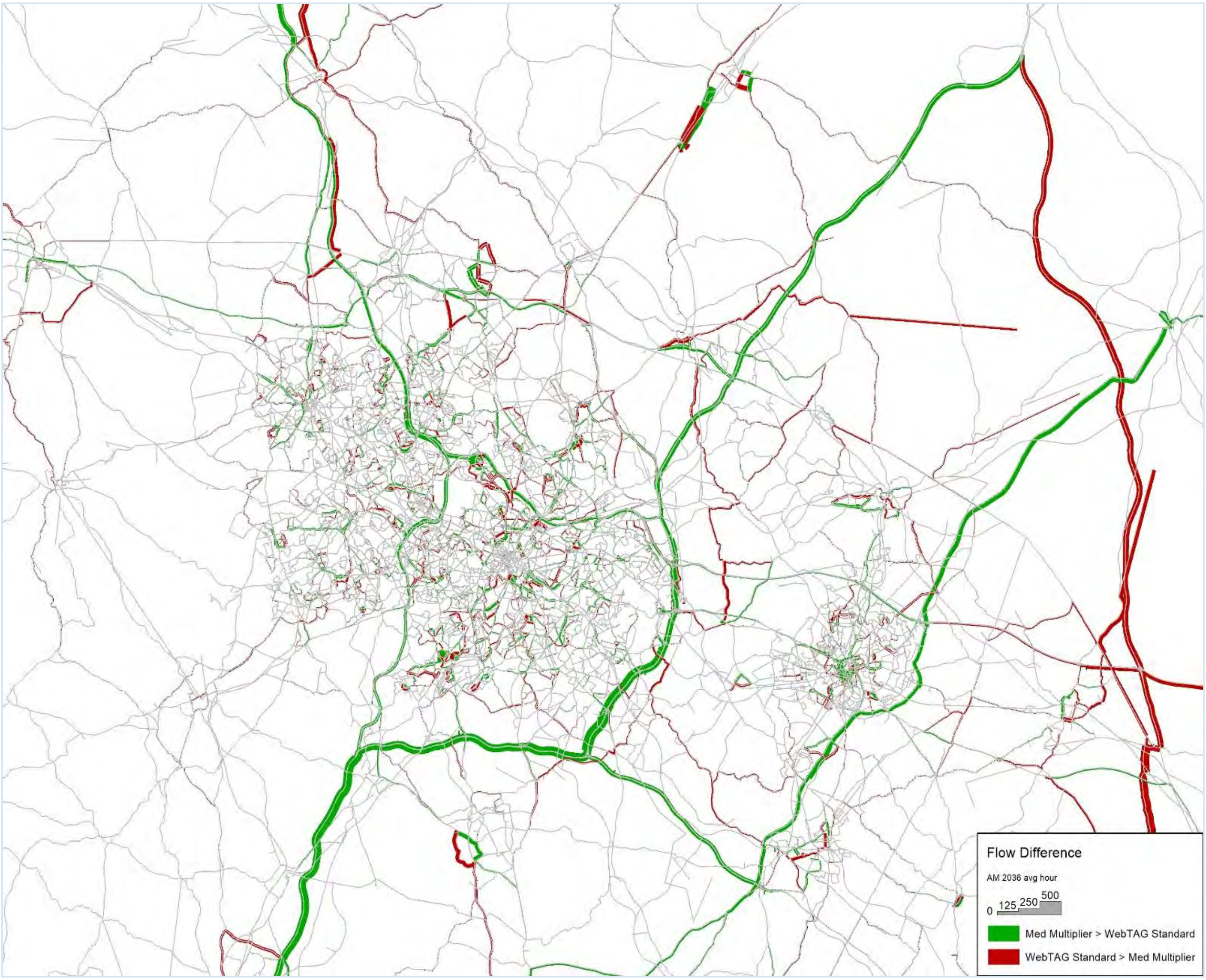
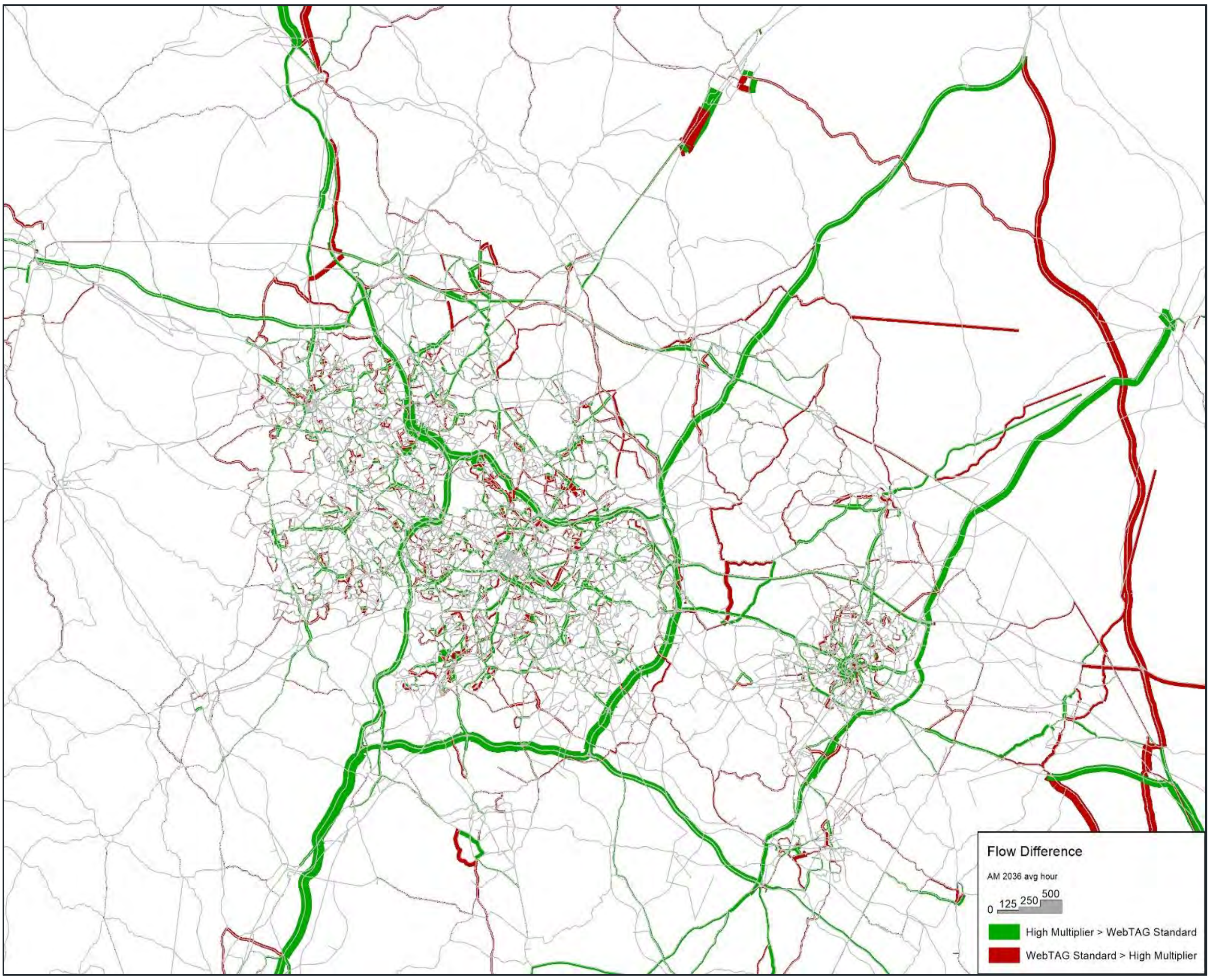


Figure 23 DM, Car Other, differences between High Multiplier and WebTAG VTT



DO SOMETHING

5.3.3. Figure 24 to Figure 26 show, for each multiplier, the difference between the DM and DS flows for the AM peak only.

5.3.4. The general pattern is consistent between multiplier values, with most traffic on the scheme re-routeing from the existing M5, with much smaller reductions on the M42 on the eastern side of the motorway box, and on routes to the west of the new road.

5.3.5. The flow on the scheme increases significantly with the multiplier. The following table shows the 2-way flows on the central section of the scheme between the A454 and A456. 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.

Table 29 Scheme Flows

Run ID	Multiplier value	Two-way Flow (vehs/hr)		
		AM	IP	PM
F10	WebTAG	3776	3971	3866
F11	Medium	4520	4773	4791
F12	High	5241	5326	5711

Figure 24 Comparison of DM and DS flows, WebTAG VTT

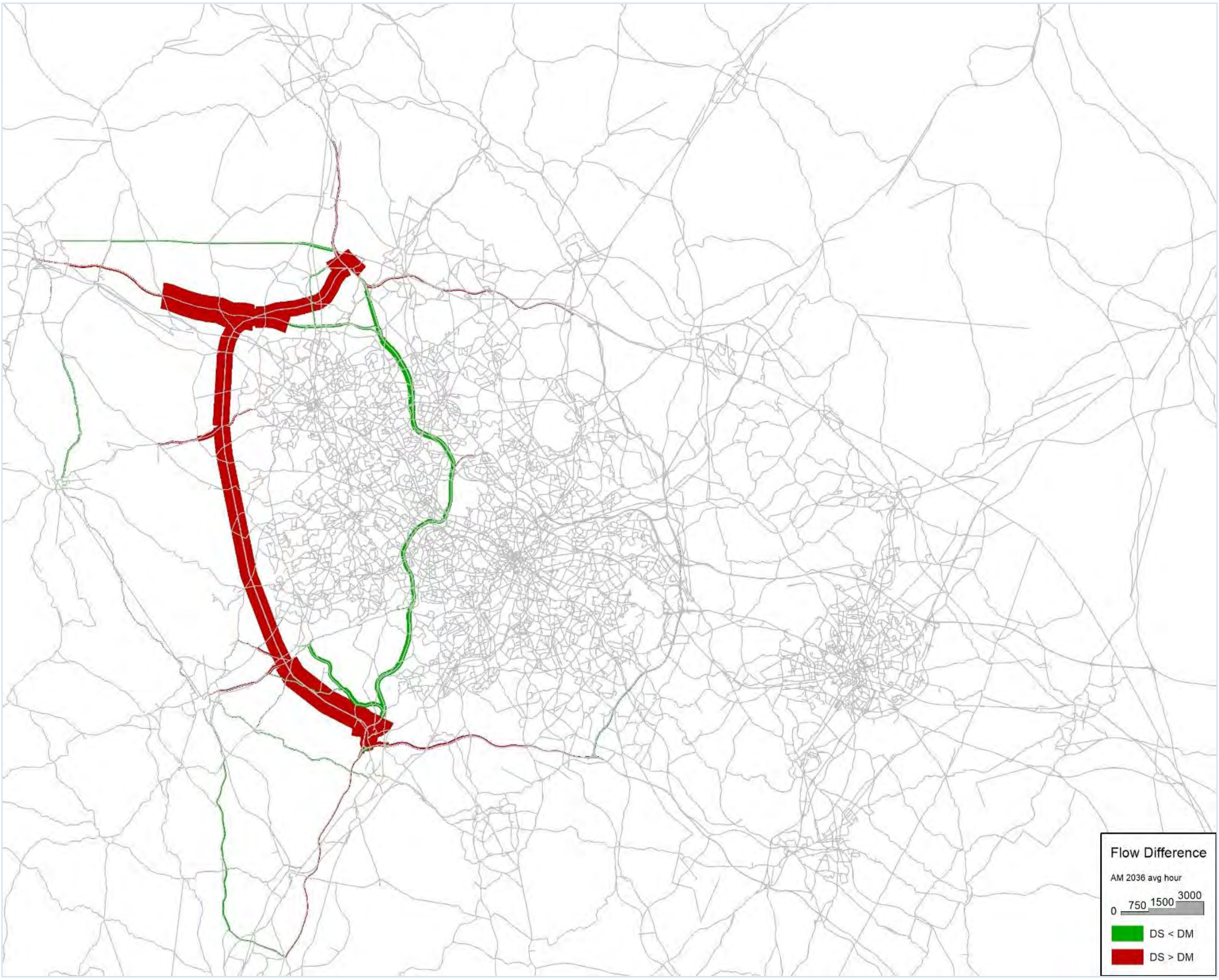


Figure 25 Comparison of DM and DS flows, Medium multiplier VTT

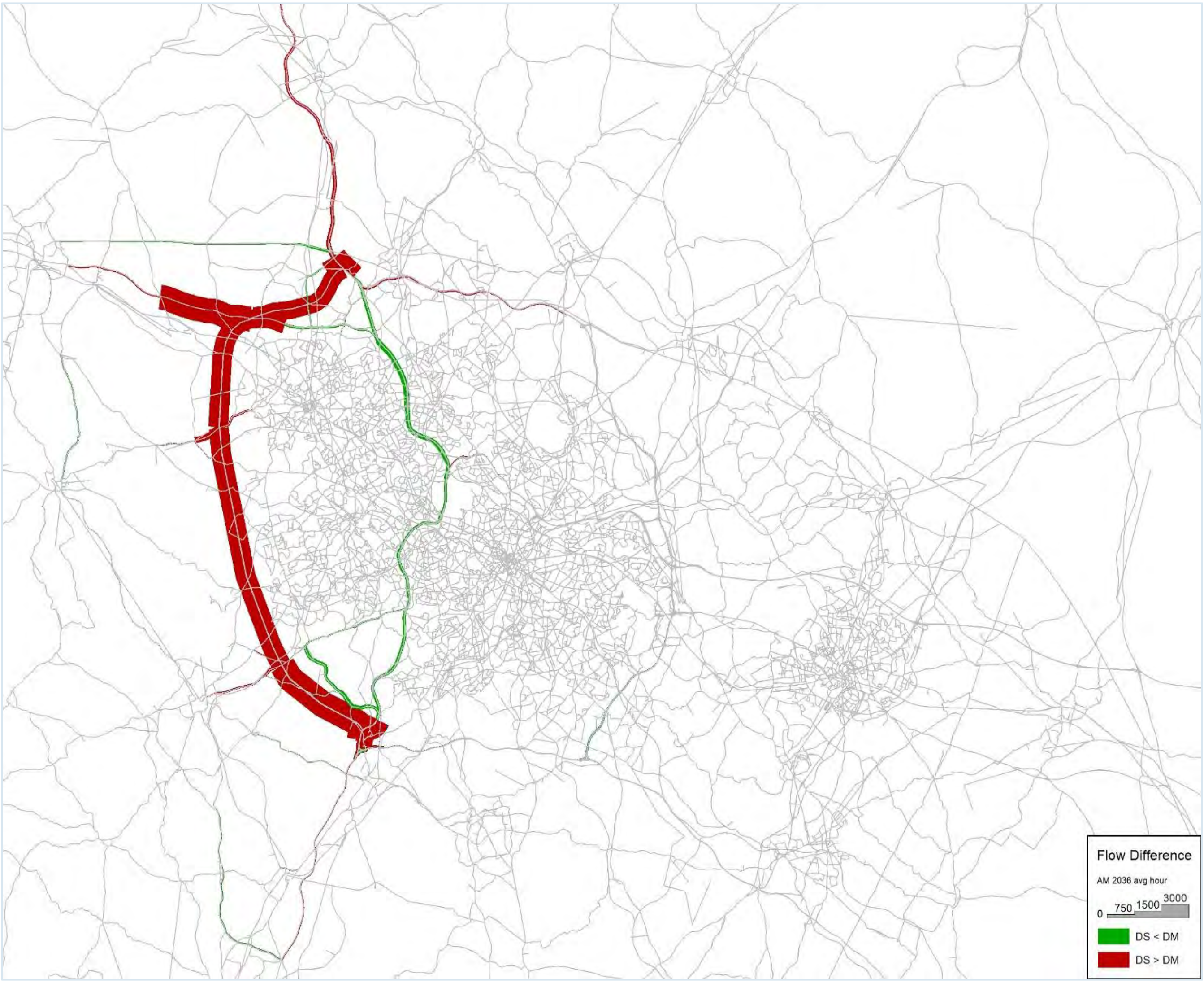
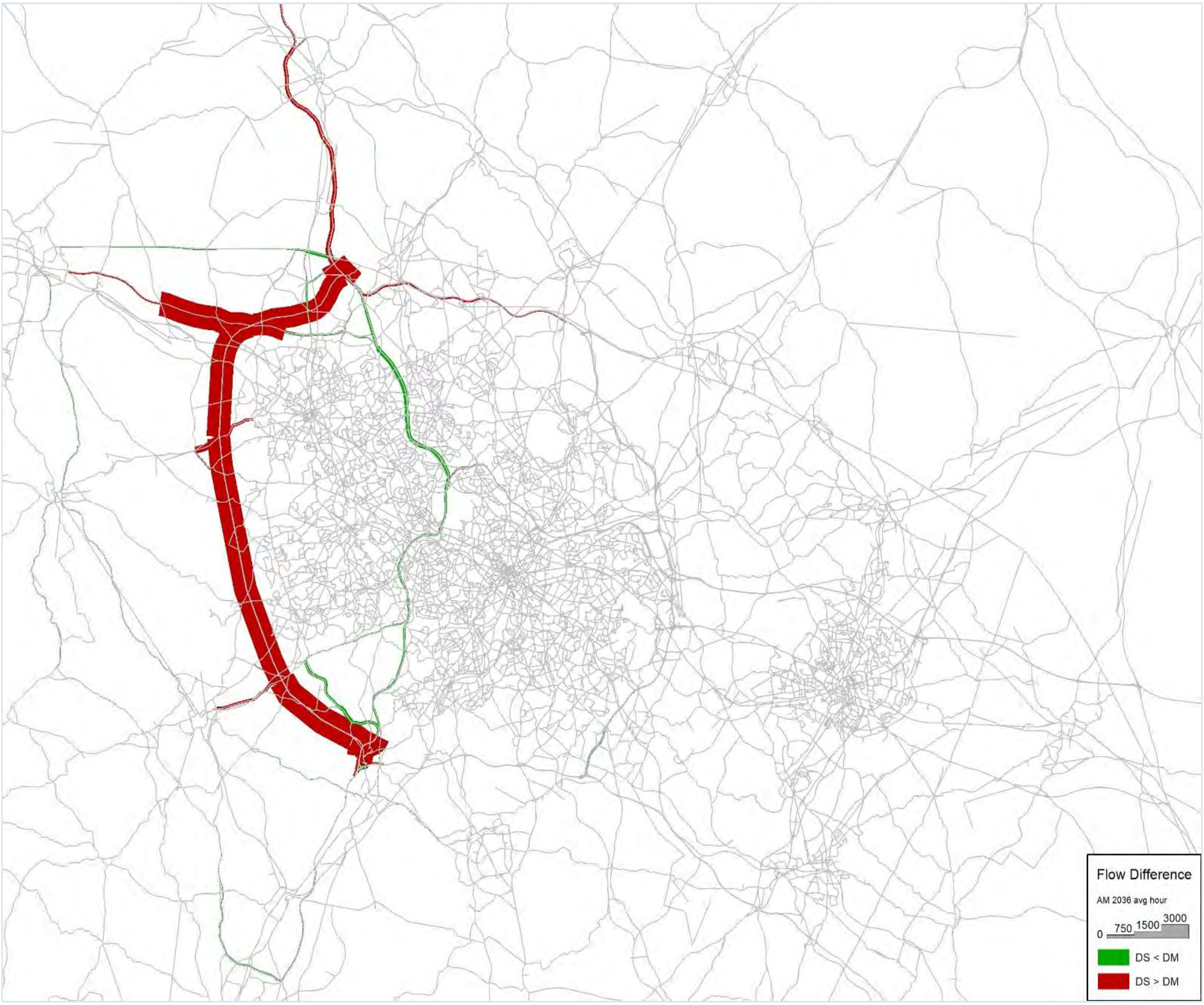


Figure 26 Comparison of DM and DS flows, High multiplier VTT



5.4. OD ROUTEING

5.4.1. For each model run, a series of plots has been produced showing the routeing of AM peak car traffic for four selected OD pairs. These have been chosen 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.

5.4.2. Except for the last OD pair, the scheme has little effect on routeing. Therefore, only DM routeing information is presented.

5.4.3. As with all highway assignment models, there is a need for caution when interpreting results based on the analysis of route choice. Under 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[21].

COVENTRY-STAFFORD

5.4.4. Routes are shown in Figure 27 to Figure 29.

5.4.5. Traffic uses the M6 Toll in all cases. The multiplier has no effect on routeing.

[21] This would be true even if the assignments were perfectly converged.

Figure 27 Coventry-Stafford OD route choice, WebTAG VTT, AM peak DM

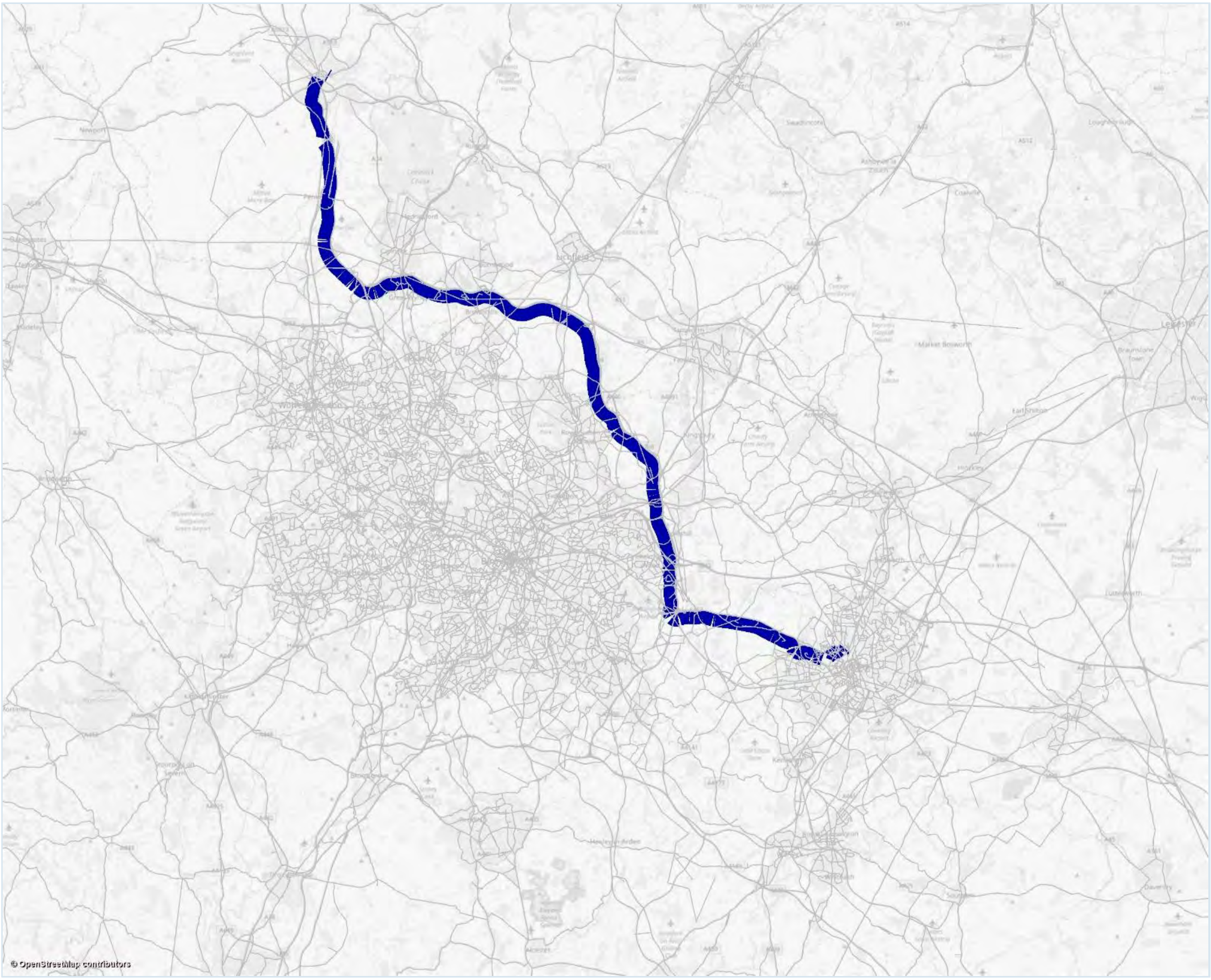


Figure 28 Coventry-Stafford OD route choice, Medium Multiplier VTT, AM peak DM

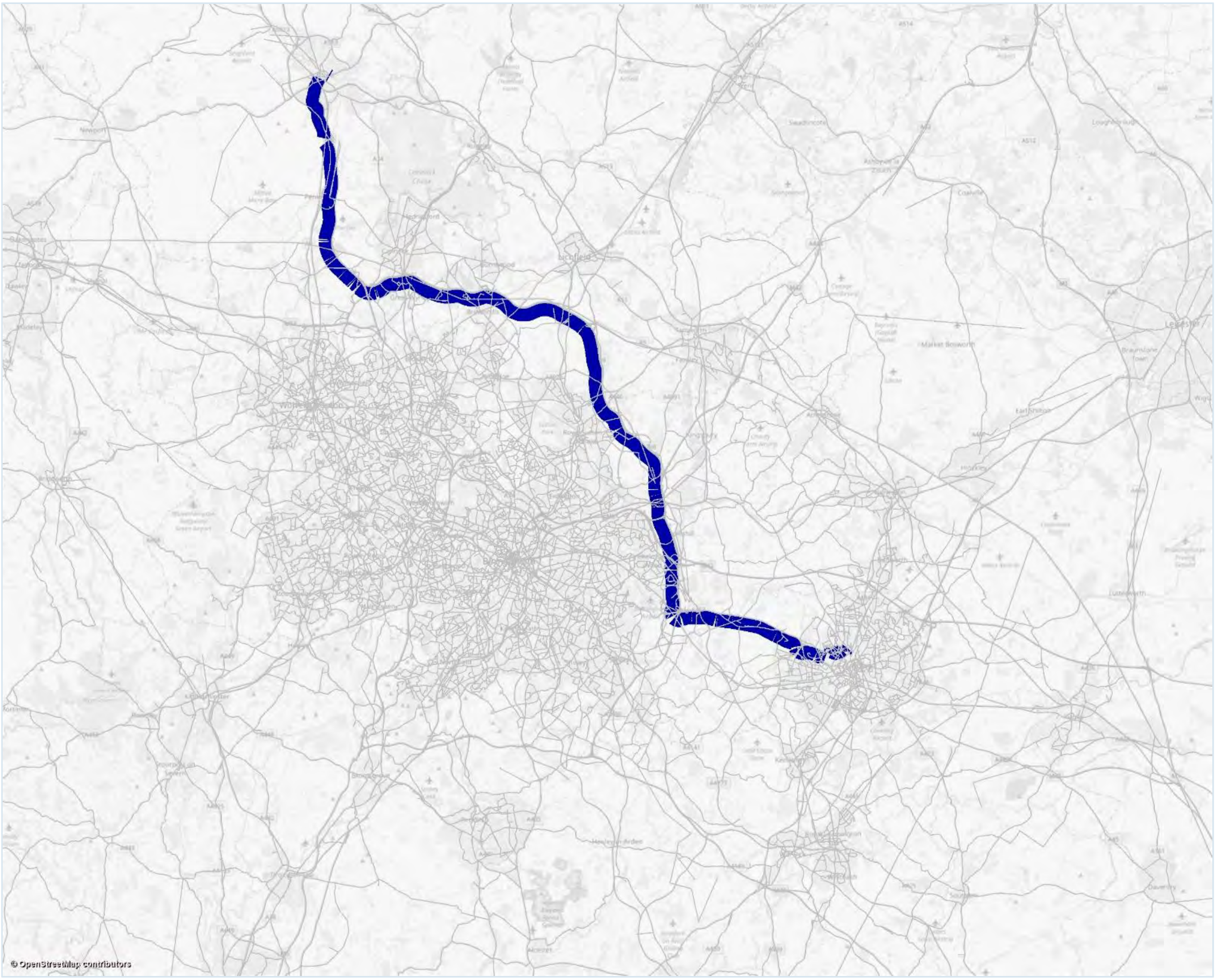
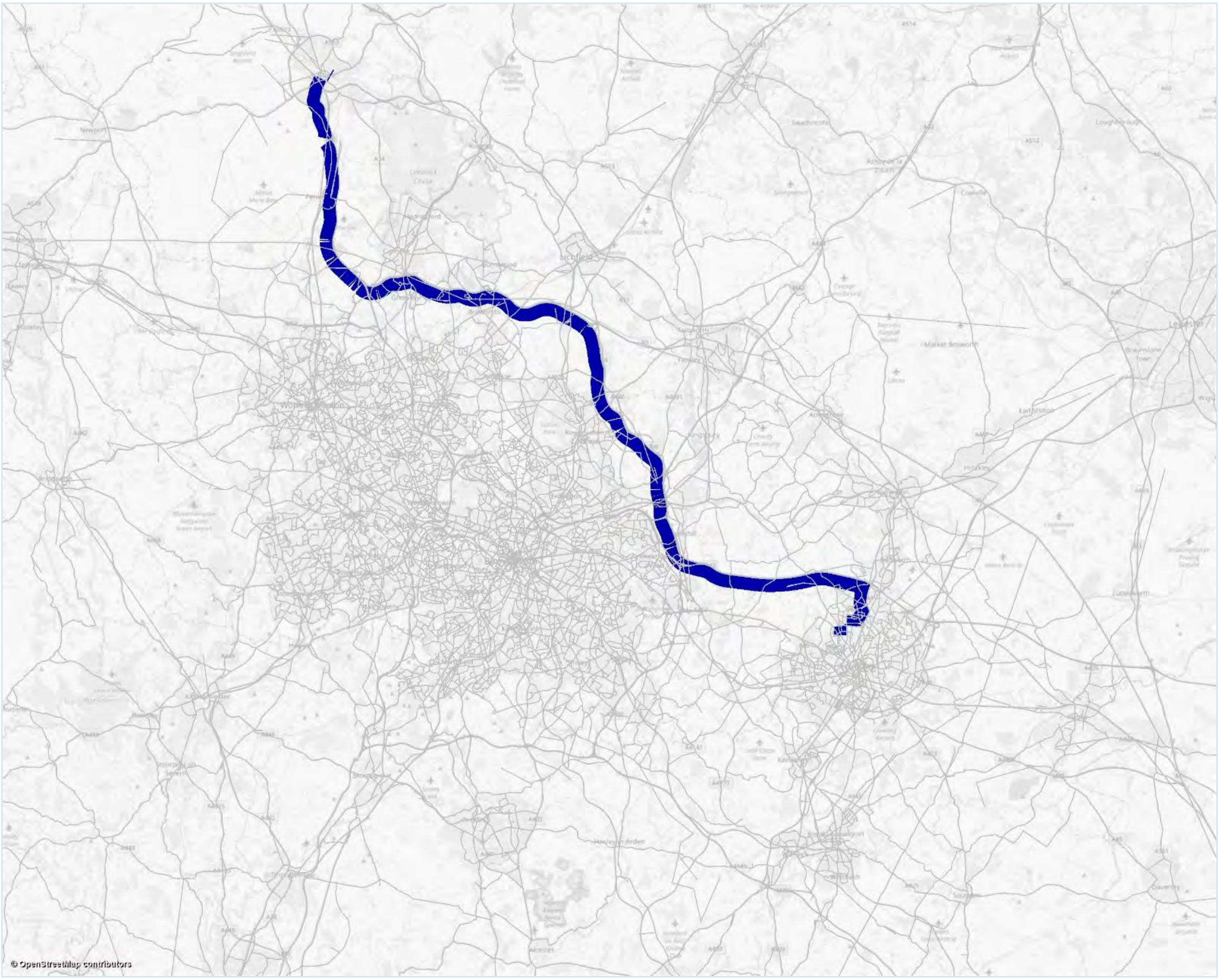


Figure 29 Coventry-Stafford OD route choice, High Multiplier VTT, AM peak DM



STUDLEY - BIRMINGHAM CITY CENTRE

5.4.6. Routes are shown in Figure 30 to Figure 32.

5.4.7. With WebTAG VTT and the Medium Multiplier traffic uses the most direct route on the A435. With the High Multiplier most traffic switches to the much longer (but less congested) route using the M42 and M6.

Figure 30 Studley-Birmingham City Centre OD route choice, WebTAG VTT, AM peak DM

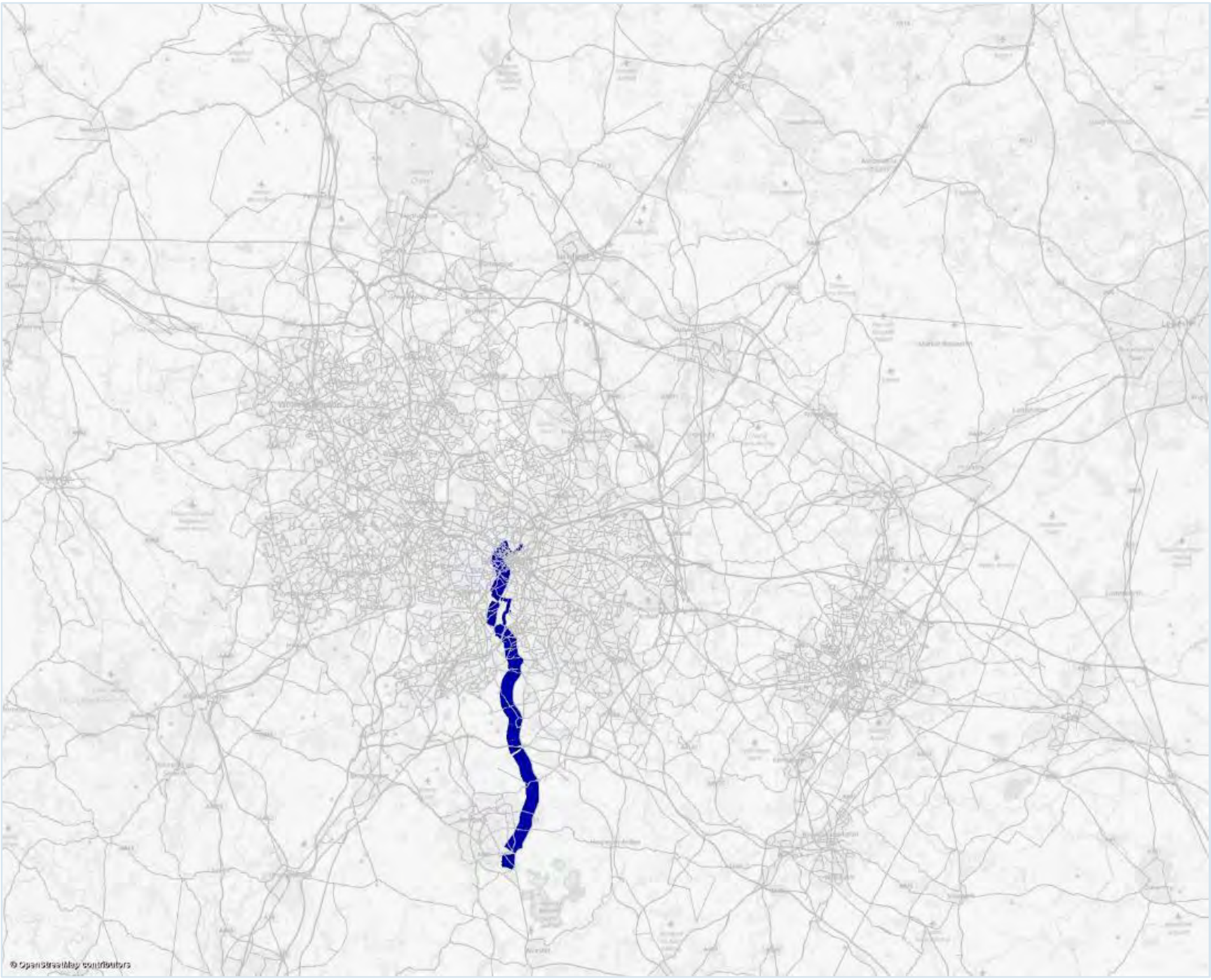


Figure 31 Studley-Birmingham City Centre OD route choice, Medium Multiplier VTT, AM peak DM

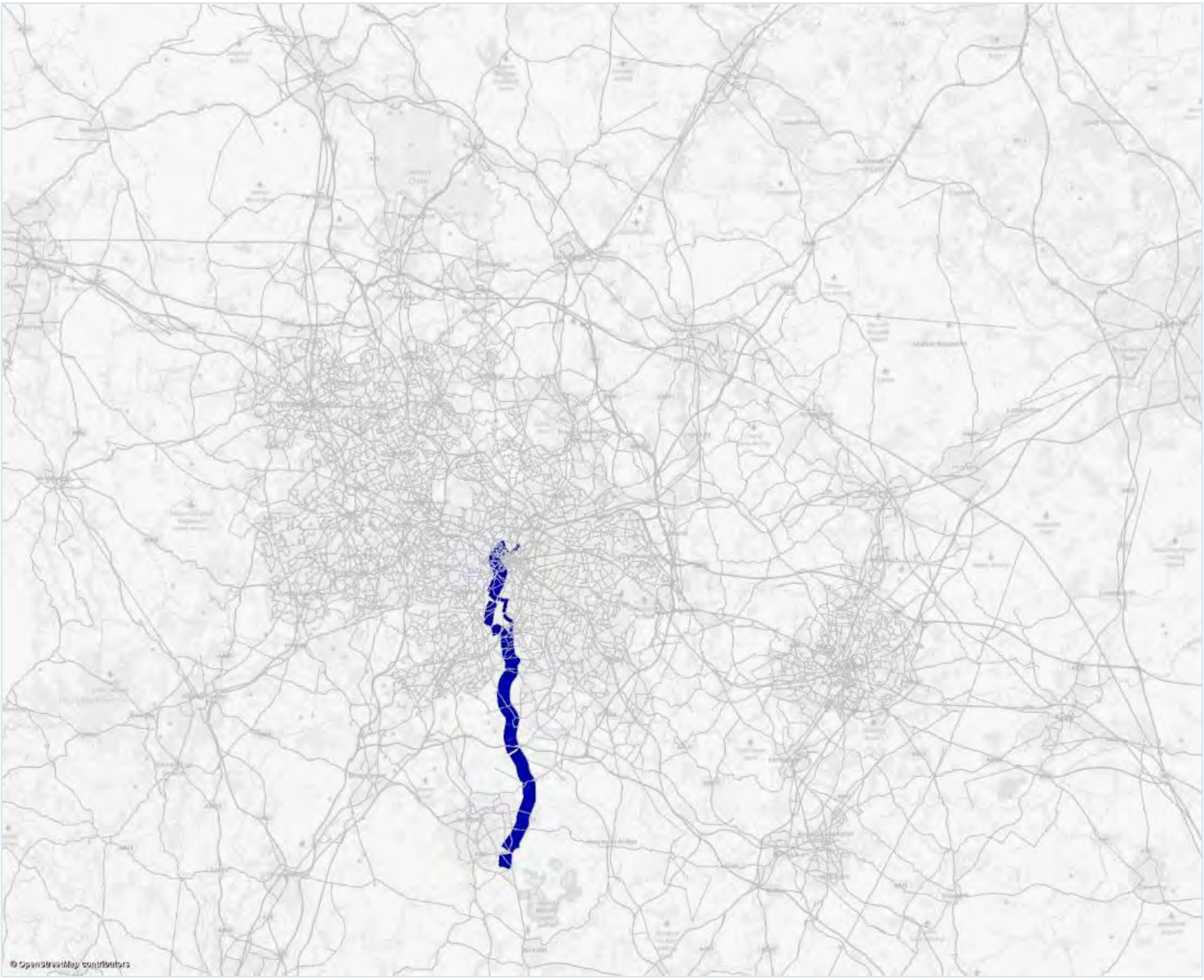
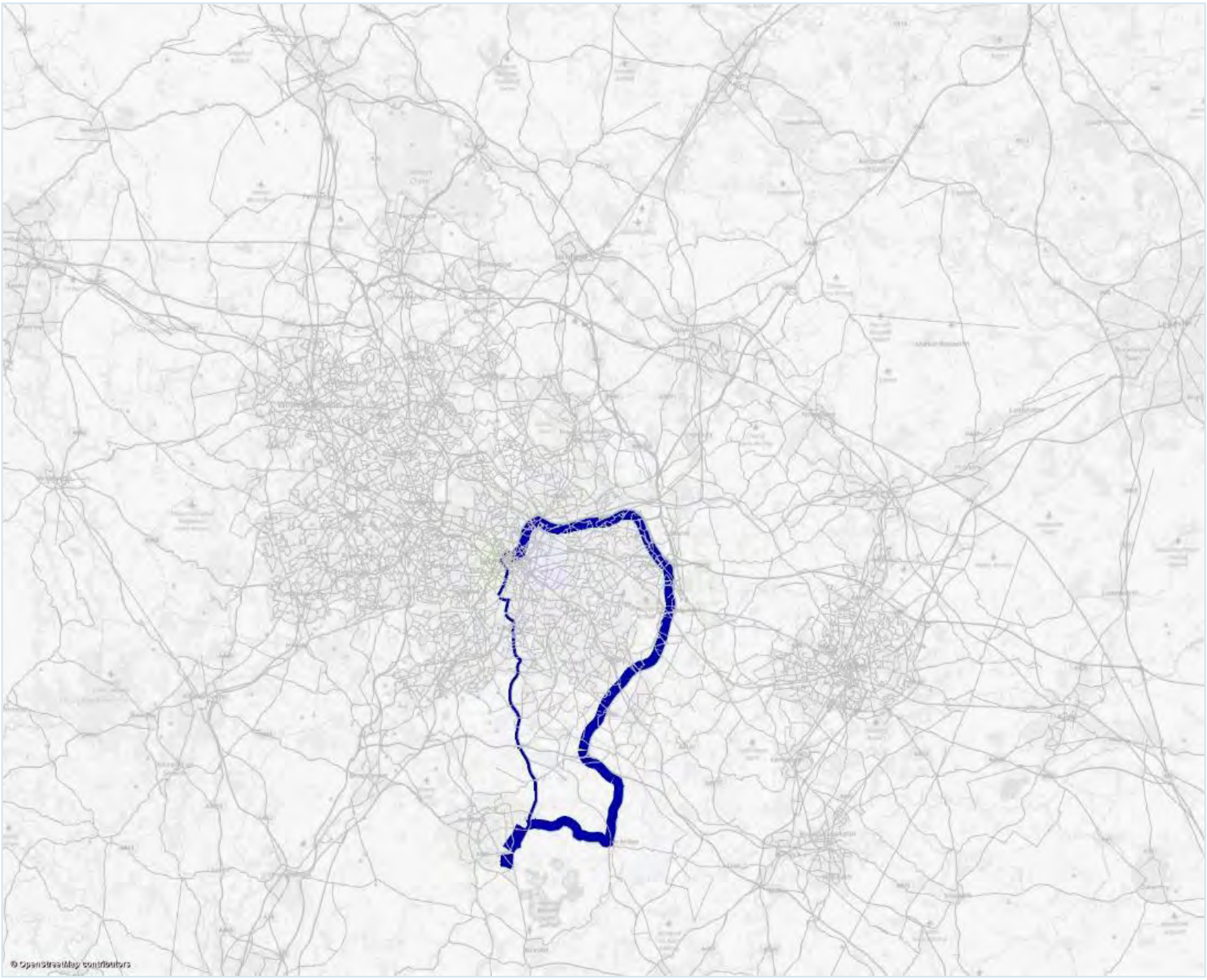


Figure 32 Studley-Birmingham City Centre OD route choice, High Multiplier VTT, AM peak DM



KINGS HEATH TO SMETHWICK

5.4.8. Routes are shown in Figure 33 to Figure 35.

5.4.9. The plots show very little variation in route choice. This reflects the absence of a feasible (i.e. not excessively long) alternative route that would avoid congestion.

Figure 33 Kings Heath-Smethwick OD route choice, WebTAG VTT, AM peak DM

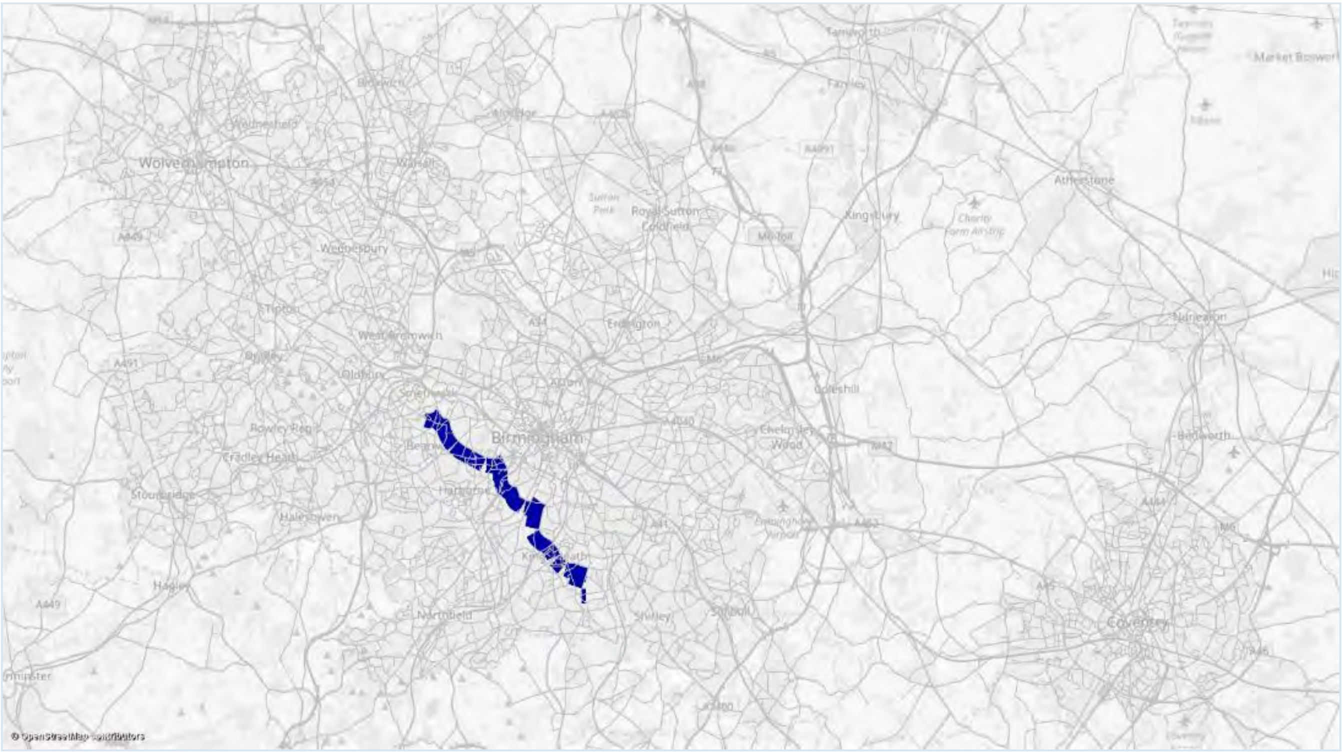


Figure 34 Kings Heath-Smethwick OD route choice, Medium Multiplier VTT, AM peak DM

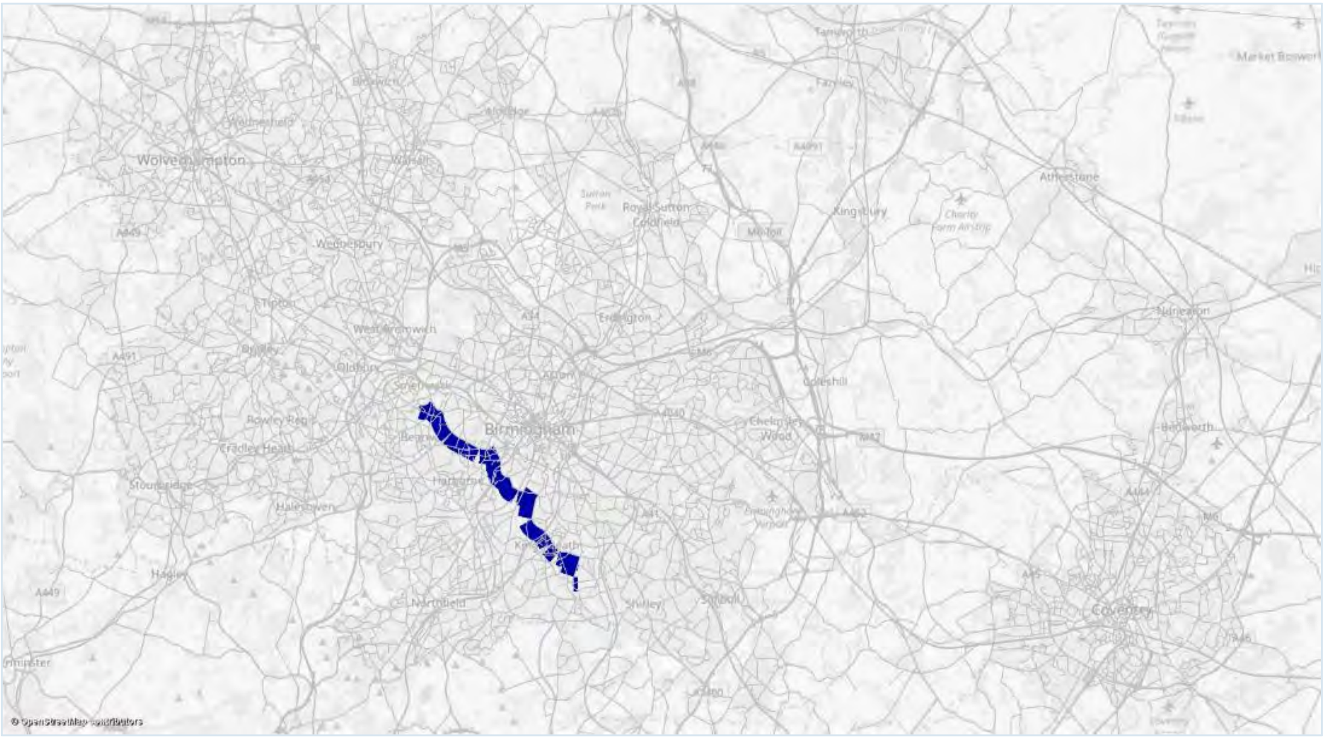
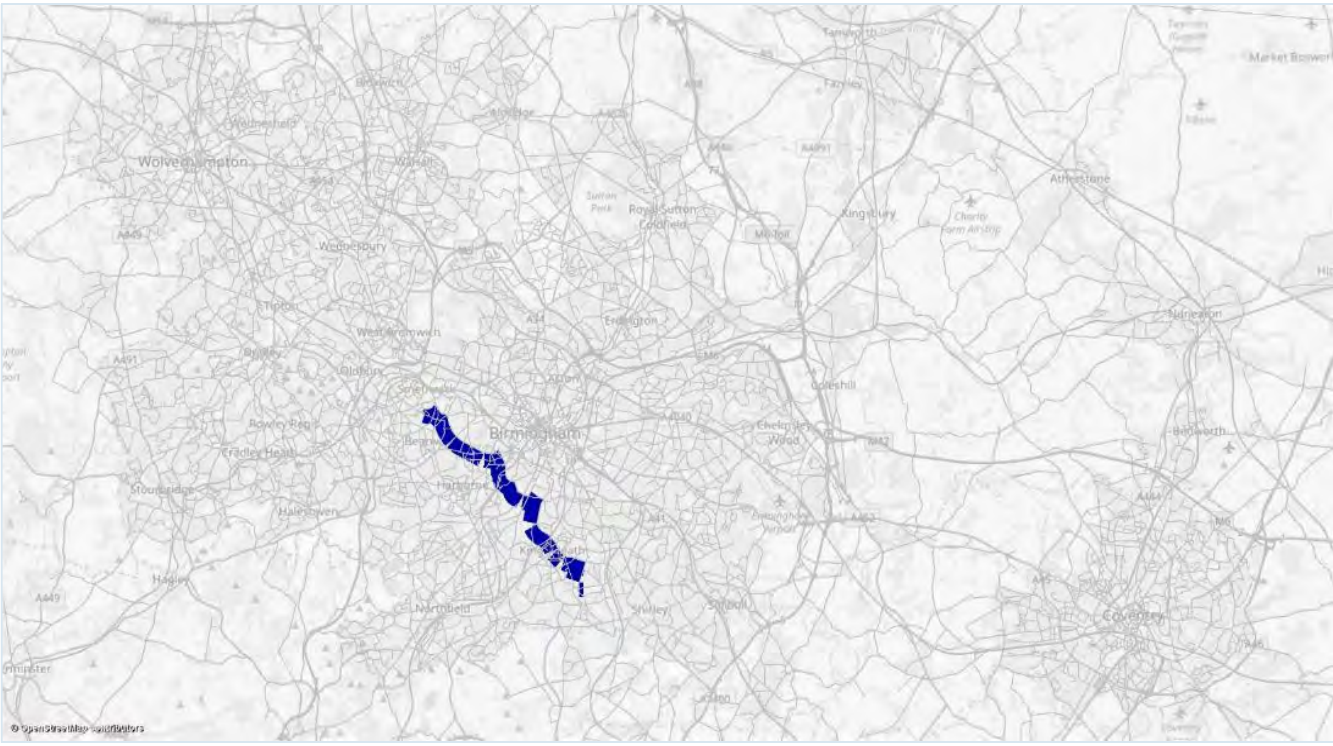


Figure 35 Kings Heath-Smethwick OD route choice, High Multiplier VTT, AM peak DM



WORCESTER TO STAFFORD

5.4.10. Routes are shown in Figure 36 to Figure 41.

5.4.11. The multiplier has very little effect on route choice, with traffic using the M5 in the DM and the new road in the DS.

Figure 36 Worcester to Stafford OD route choice, WebTAG VTT, AM peak DM

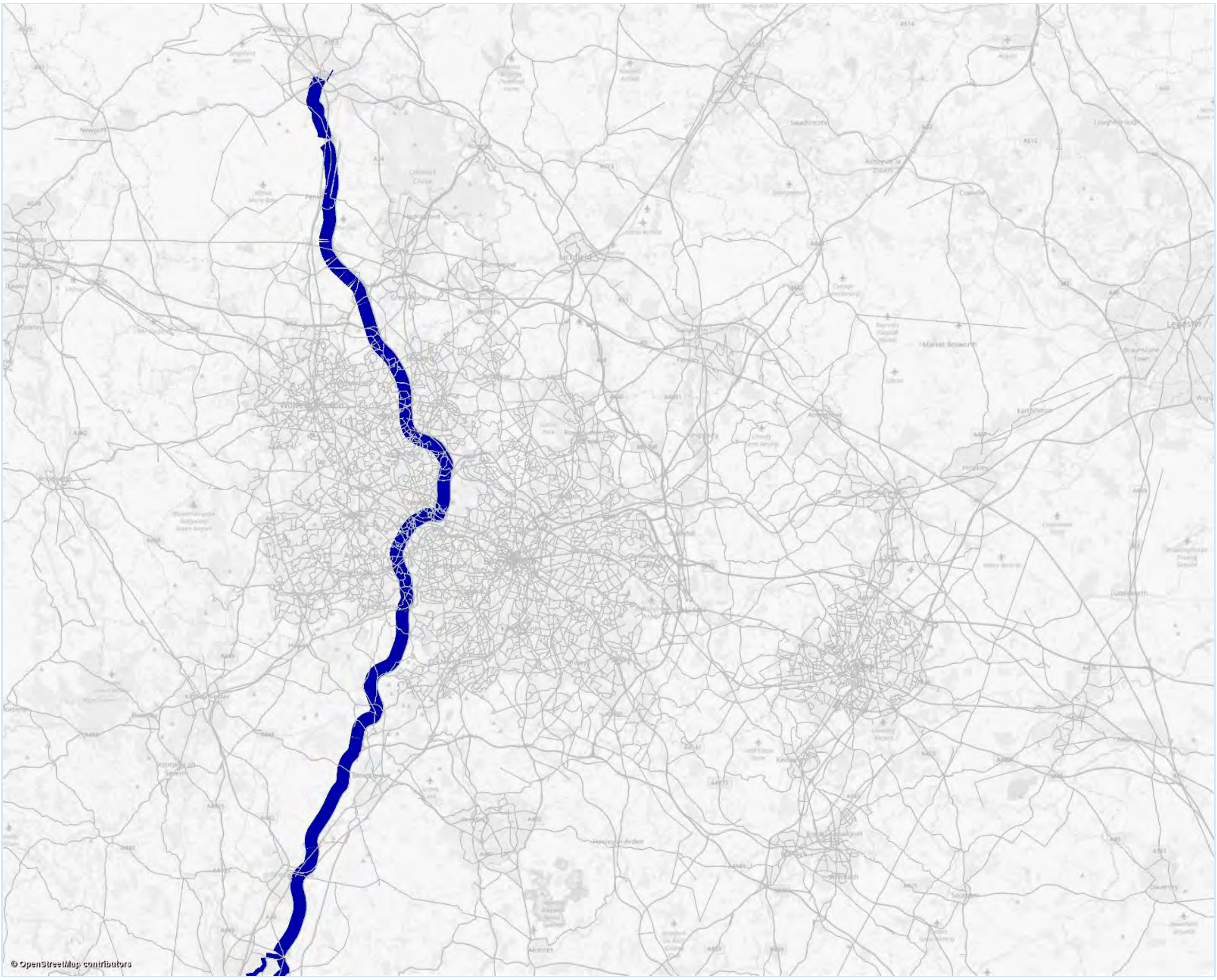


Figure 37 Worcester to Stafford OD route choice, Medium Multiplier VTT, AM peak DM

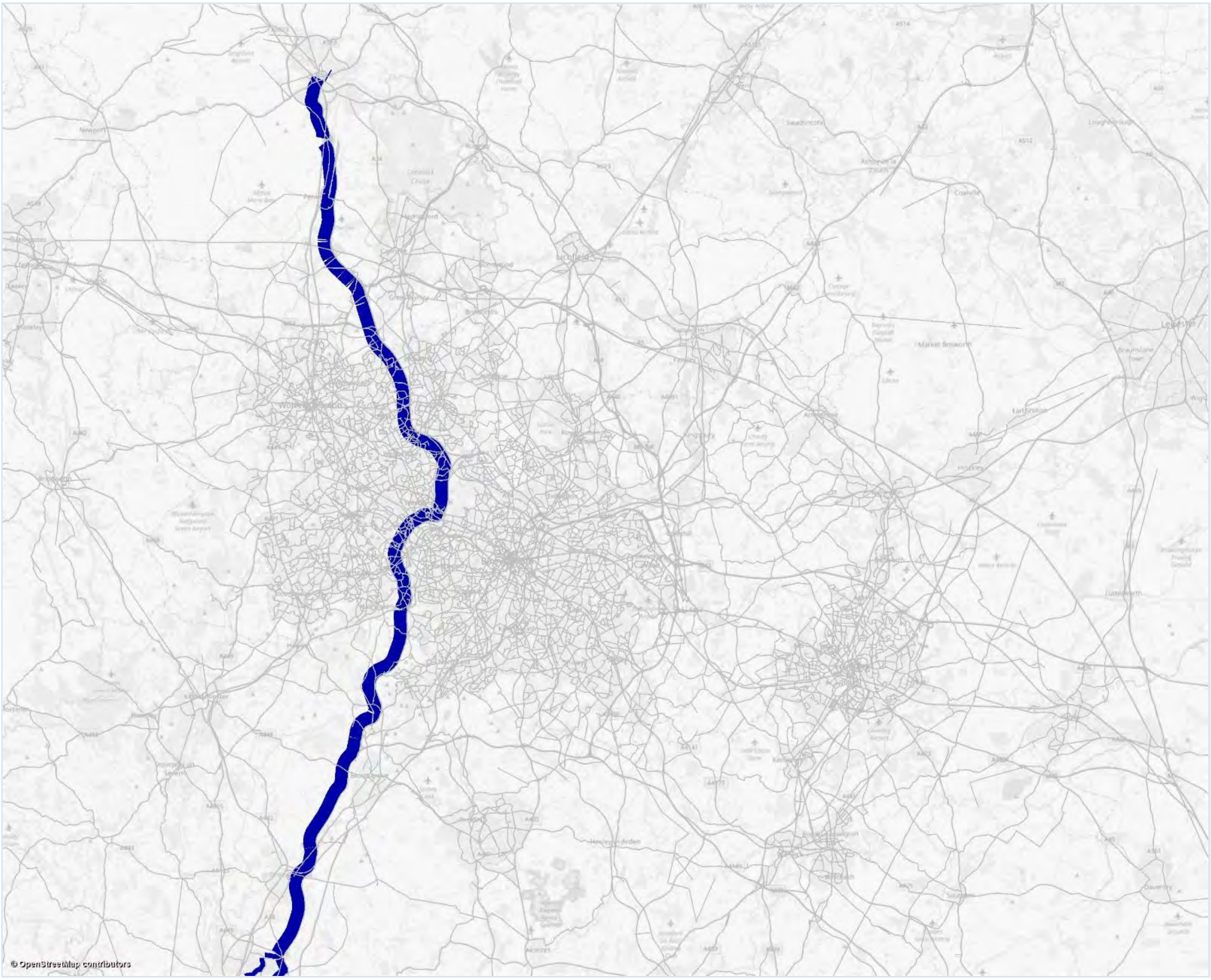


Figure 38 Worcester to Stafford OD route choice, High Multiplier VTT, AM peak DM

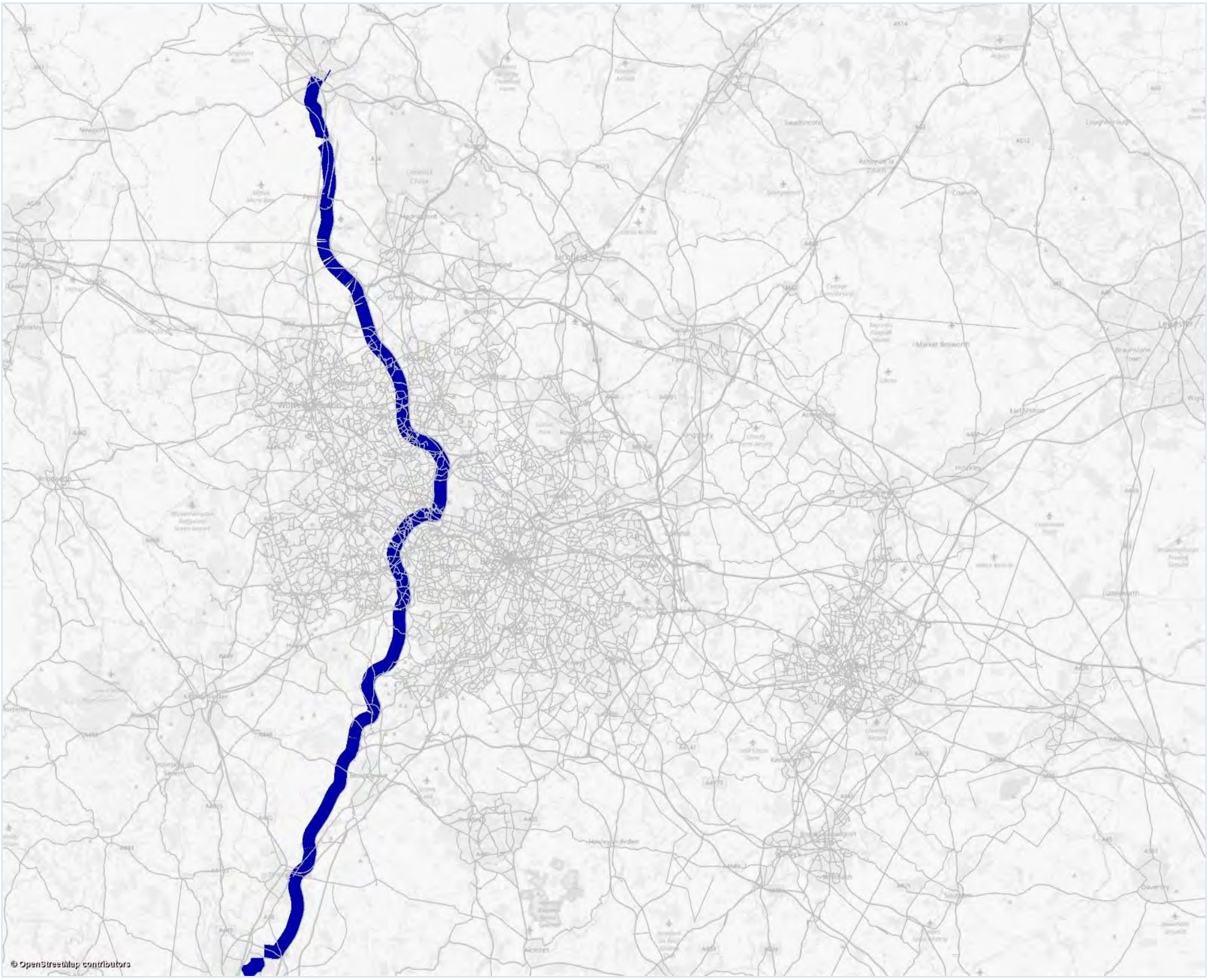


Figure 39 Worcester to Stafford OD route choice, WebTAG VTT, AM peak DS

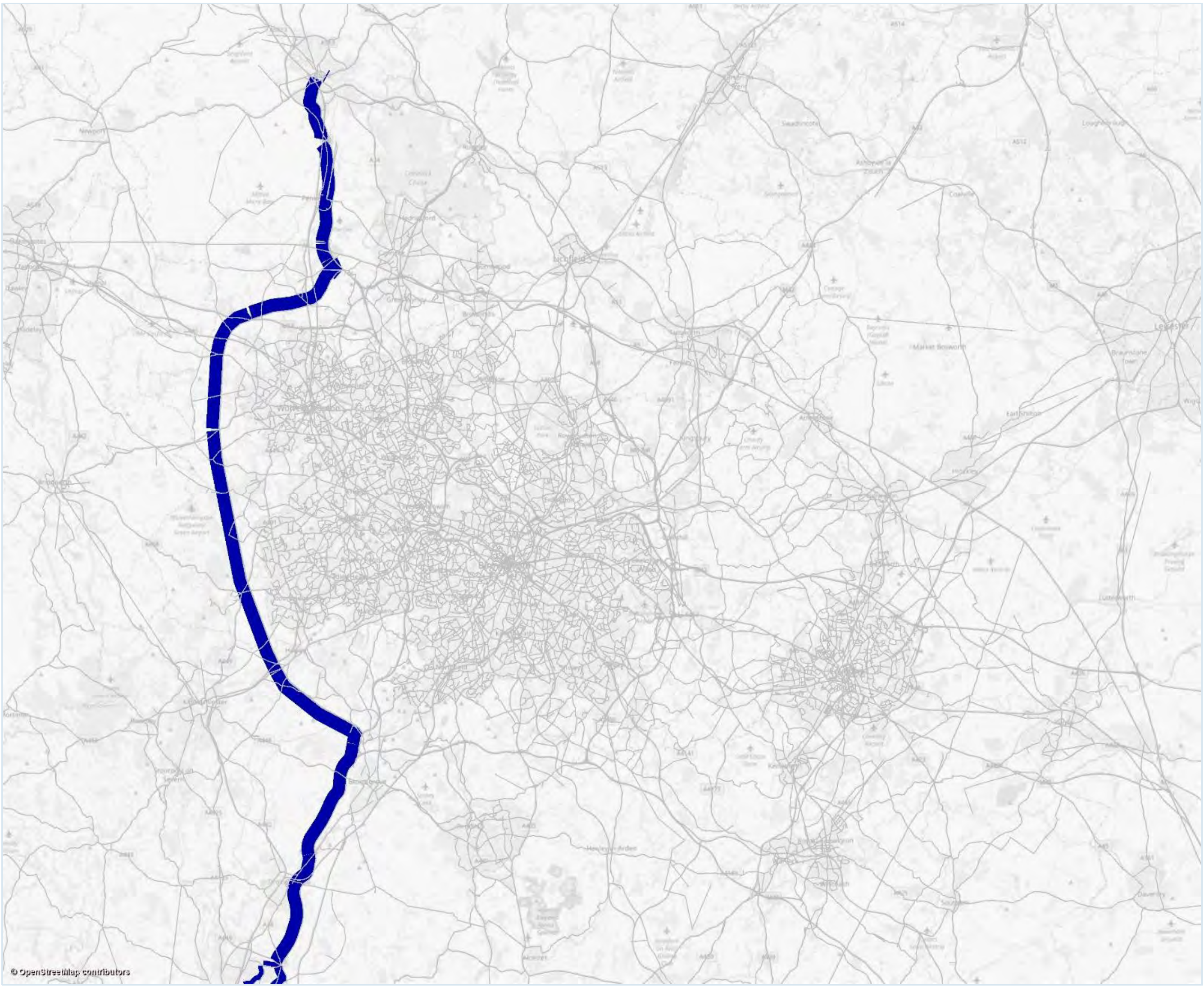


Figure 40 Worcester to Stafford OD route choice, Medium Multiplier VTT, AM peak DS

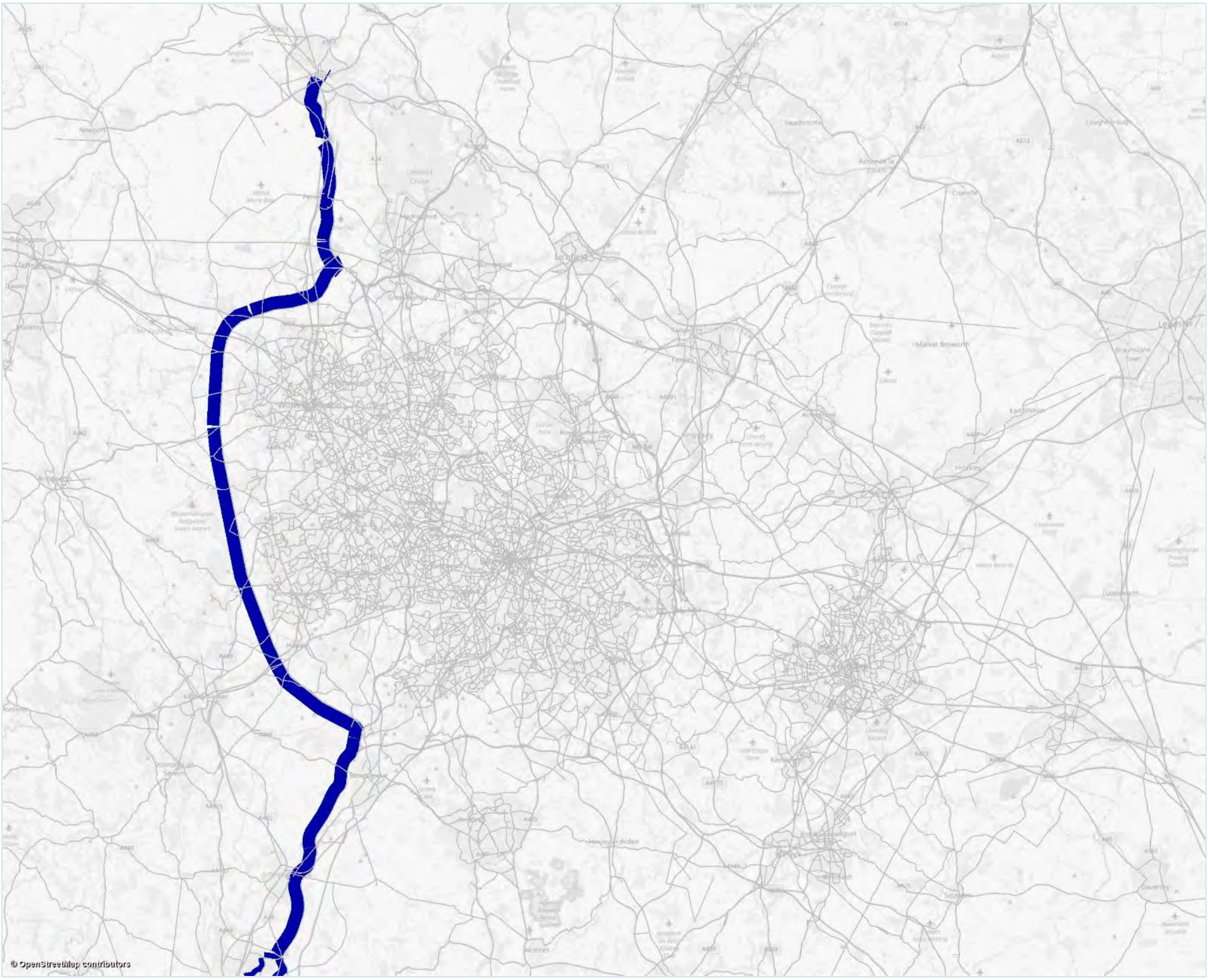
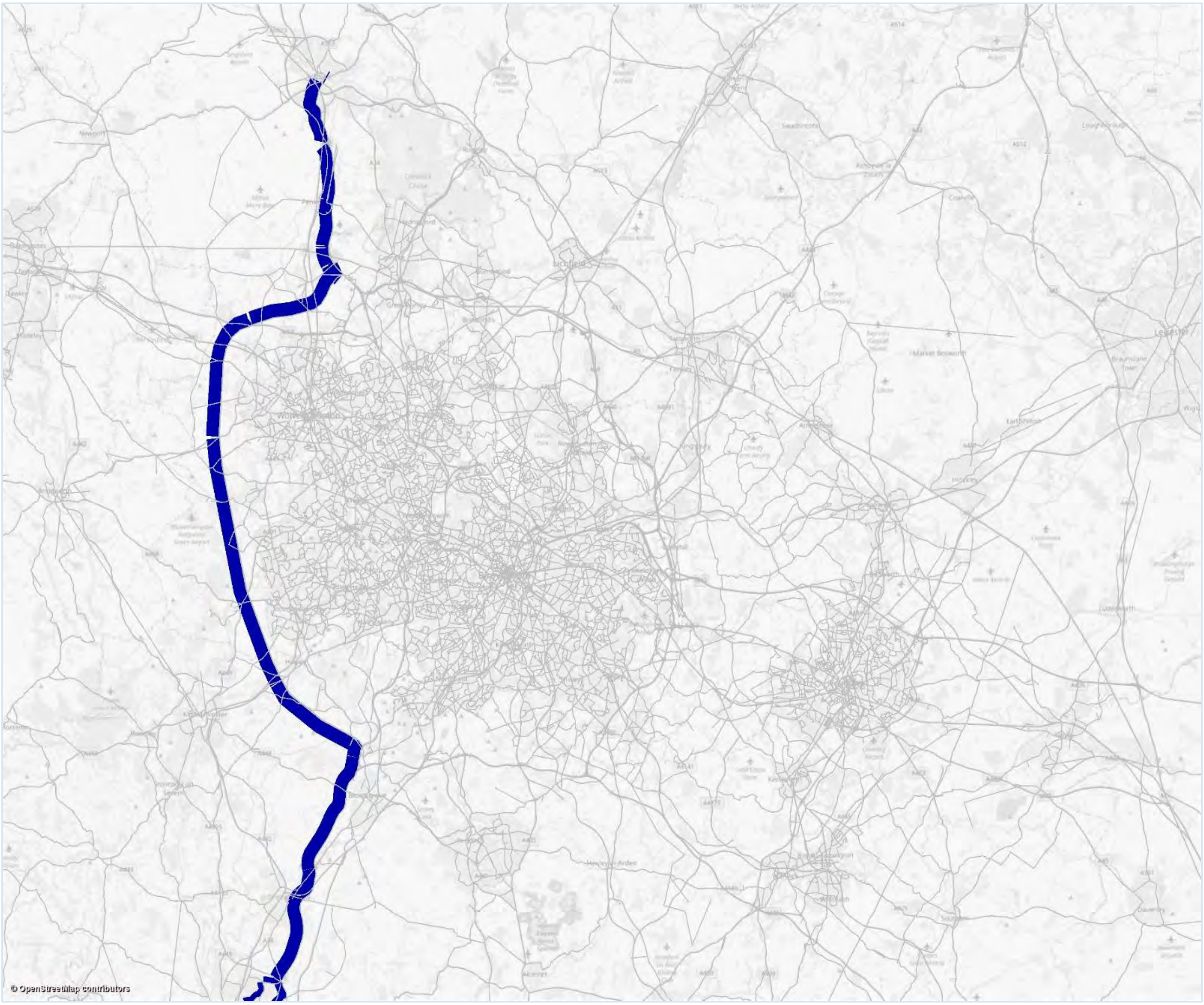


Figure 41 Worcester to Stafford OD route choice, High Multiplier VTT, AM peak DS



SUMMARY OF OD ROUTEING

5.4.12. The aggregate results presented earlier showed that total vehicle kms and average car trip lengths tend to increase with the multiplier, albeit by relatively modest amounts. Analysis of a small sample of OD pairs suggests that, in many cases, the impact on routeing in the model will be negligible and may be confined to those journeys where there is a realistic choice between a short, congested route, and a longer, less congested alternative.

6. TUBA RESULTS

6.1. OVERVIEW

6.1.1. This chapter provides a high-level summary of the TUBA results for each of the tests. This focuses on understanding whether:

- TUBA benefits produced from WebTAG VTT applied in the model would result in a plausible change in benefits using the Low, Medium and High Multiplier in appraisal;
- TUBA benefits produced from Medium and High Multiplier applied in the model would result in plausible level of benefits with WebTAG VTT and the respective CVTT multipliers in appraisal.

6.2. TESTS WITH WEBTAG VTT MODELS

6.2.1. As stated earlier, in addition to test T1 and T2 (WebTAG VTT model using WebTAG VTT and High Multiplier in TUBA), two tests (T2a and T2b) were also carried out with Low and Medium Multiplier in TUBA, primarily to ascertain whether the change in the multiplier value would result in a plausible change in TUBA benefits. For this reason, tests T2a and T2b will not be used for any detailed analysis.

6.2.2. Table 30 below provides a high-level summary of the TUBA benefits for the tests with the WebTAG VTT model with the WebTAG, Low, Medium and High Multipliers in appraisal.

Table 30 TUBA Benefits (£000s) with WebTAG VTT in Modelling

Benefit	WebTAG VTT	with Multiplier VTT						
		Free-Flow	Low CVTT		Medium CVTT		High CVTT	
			Delay	Total	Delay	Total	Delay	Total
Time Saving Benefit								
Commuting	9,966	1,308	5,635	6,944	16,906	18,215	28,177	29,486
Other	7,034	481	3,041	3,523	9,124	9,605	15,206	15,687
Business (Car)	10,991	1,385	4,899	6,285	14,698	16,083	24,497	25,882
Business (Freight)	6,674	1,200	2,615	3,816	7,846	9,047	13,077	14,278
Total	***34,664***	***4,376***	***16,191***	***20,567***	***48,574***	***52,950***	***80,957***	***85,333***
Fuel VOC	-3,183	NA	NA	-3,183	NA	-3,183	NA	-3,183
Non Fuel VOC	-2,414	NA	NA	-2,414	NA	-2,414	NA	-2,414
User Charges	1,039	NA	NA	1,039	NA	1,039	NA	1,039
Operator Revenues	-387	NA	NA	-387	NA	-387	NA	-387
Greenhouse Gas	-1,437	NA	NA	-1,437	NA	-1,437	NA	-1,437
Indirect Tax Revenues	4,325	NA	NA	4,325	NA	4,325	NA	4,325
Total	**32,608**	**4,376**	**16,191**	**18,511**	**48,574**	**50,894**	**80,957**	**83,277**
Change from WebTAG	1.00			0.59		1.53		2.46
Change from Low CVTT			1.00		3.00		5.00	

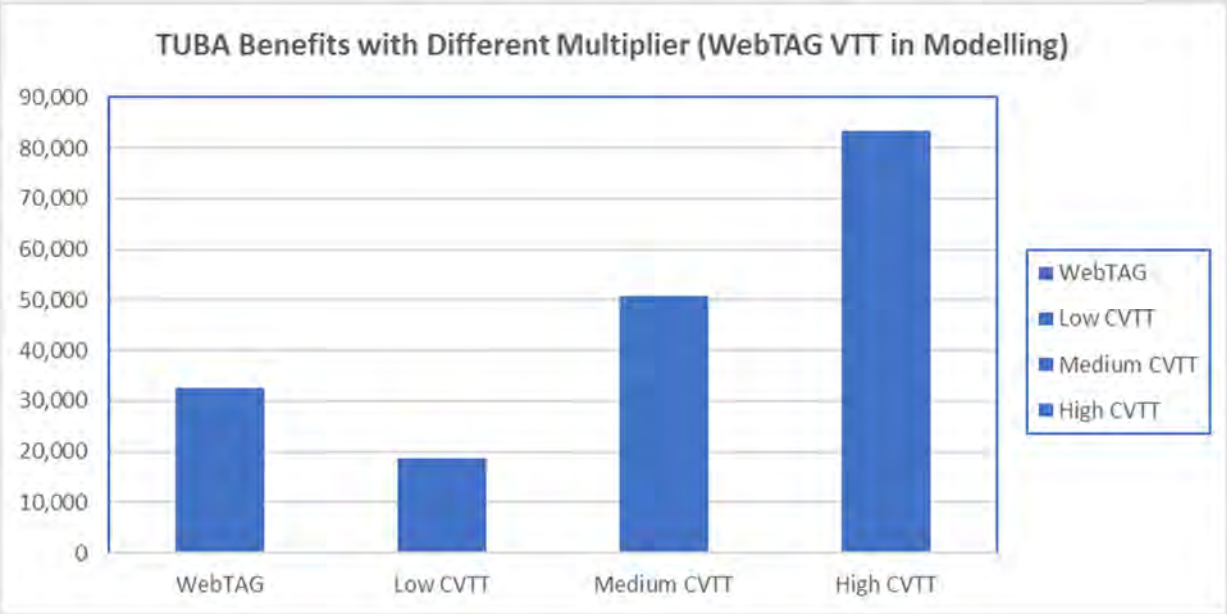
6.2.3. As can be seen, TUBA benefits produced for the WebTAG VTT, Low CVTT, Medium CVTT and High CVTT are £33m, £19m, £51m and £83m respectively.

6.2.4. It is anticipated that the TUBA test with the Low Multiplier would result in lower benefits compared to the WebTAG VTT due to the lower free-flow VTT. As the CVTT multipliers change to Medium and High values, the travel time saving benefits produced from the CVTT multipliers show an increase compared to the WebTAG VTTs, by a factor of 1.53 and 2.46 for the Medium and High Multipliers respectively.

6.2.5. Analysis of the benefits associated with the delay element only, show that the change in benefits produced for the Medium and High Multiplier compared to the Low Multiplier are the same as the respective change in the multiplier value.

6.2.6. Figure 42 below illustrates the TUBA benefits produced using different multiplier values and WebTAG CVTT.

Figure 42 TUBA Benefits (£000s) with Different Multipliers



6.2.7. Comparison of the benefits for the Low, Medium and High Multiplier to WebTAG VTT shows that change in the benefits are approximately half of the increase in the multiplier values. This is anticipated as the free-flow VTTs are about 50-70% of the WebTAG VTT.

6.2.8. This suggests that with current free flow VTTs, any appraisal with multiplier values of higher than two would likely result in larger benefits compared to using WebTAG VTTs.

6.2.9. The TUBA tests using the WebTAG VTT model show that the application of the CVTT multipliers result in plausible TUBA benefits compared to using WebTAG VTT.

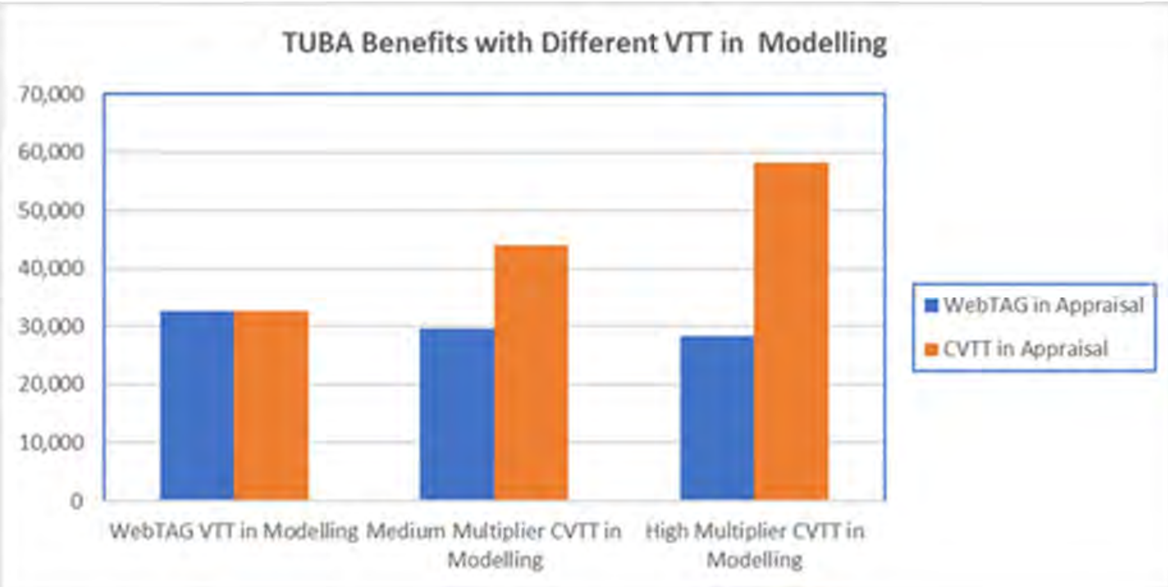
6.3. TESTS WITH CVTT MULTIPLIER MODELS

6.3.1. Table 31 and Figure 42 provide summaries of the TUBA runs with the Medium and High Multipliers applied in the model.

Table 31 TUBA Benefits (£000s) with Medium and High Multiplier CVTT Models

Benefit	CVTT with Medium Multiplier in Modelling				CVTT with High Multiplier in Modelling			
	WebTAG	Medium Multiplier CVTT			WebTAG	High Multiplier CVTT		
		Total	FreeFlow	Delay		Total	FreeFlow	Delay
Time Saving Benefit								
Commuting	9,262	16,510	1,425	15,085	8,256	21,853	1,729	20,124
Other	7,119	9,161	767	8,394	6,519	11,509	1,203	10,306
Business (Car)	10,147	13,472	1,967	11,505	10,750	17,440	3,324	14,117
Business (Freight)	5,696	7,483	1,143	6,340	4,827	9,332	1,117	8,216
Total	***32,224***	***46,626***	***5,302***	***41,324***	***30,352***	***60,134***	***7,371***	***52,763***
Fuel VOC	-3,696	-3,696	NA	NA	-3,498	-3,498	NA	NA
Non Fuel VOC	-3,279	-3,279	NA	NA	-4,983	-4,983	NA	NA
User Charges	1,854	1,854	NA	NA	2,379	2,379	NA	NA
Operator Revenues	-776	-776	NA	NA	-189	-189	NA	NA
Greenhouse Gas	-1,644	-1,644	NA	NA	-2,108	-2,108	NA	NA
Indirect Tax Revenues	4,974	4,974	NA	NA	6,417	6,417	NA	NA
Total	**29,657**	**44,059**	**5,302**	**41,324**	**28,370**	**58,152**	**7,371**	**52,763**

Figure 43 TUBA Benefits (£000s) with Different VTT Models



6.3.2. As can be seen, TUBA benefits produced from the modelling outputs with Medium and High Multipliers show higher benefits (with the multiplier values also applied in TUBA) compared to equivalent TUBA runs with WebTAG VTT. This increase in benefits using Medium and High Multipliers in both modelling and appraisal compared to WebTAG VTT is considered plausible given the multiplier values of 3 and 5 for the Medium and High CVTT respectively.

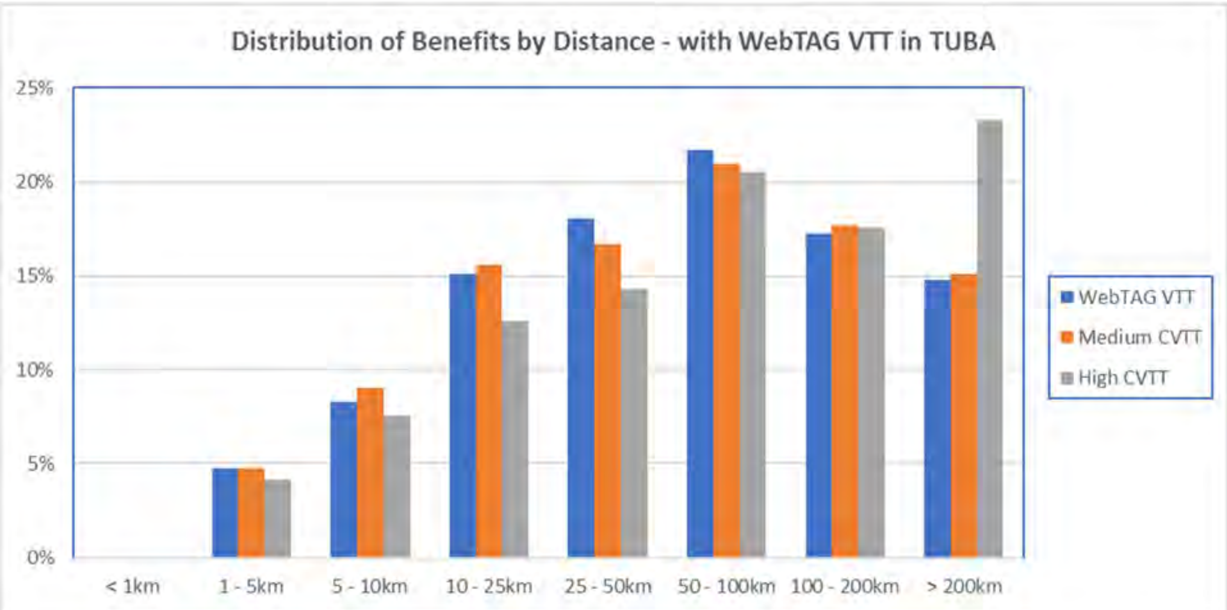
6.3.3. It is however noted that the TUBA time saving benefits show an increase of a factor of approximately 1.45 and 1.98 for the Medium and High Multipliers compared to the equivalent WebTAG VTT (used in both modelling and appraisal), as opposed to the 1.53 and 2.46 factor increases in the respective tests with the WebTAG VTT models. This is anticipated as the higher the CVTT multiplier that is applied, the more traffic will divert away from areas with higher congestion, thus resulting in lower benefits in the Medium and High Multiplier CVTT models compared with the WebTAG VTT model.

6.3.4. Analysis of the difference in TUBA benefits with WebTAG VTT used in appraisal shows that TUBA benefits reduce with the multipliers applied in the model. This is anticipated as the with the CVTT multiplier applied, more traffic will divert away from areas with higher congestion, thus resulting in lower benefits in the Medium and High Multiplier CVTT models compared with the WebTAG VTT model.

6.3.5. The impacts of CVTT multiplier models on the distribution of benefits by trip length with WebTAG VTT in appraisal can be seen in Figure 44 below where the results for the Medium and High Multiplier CVTT compared to WebTAG VTT show a reduction in the proportion of time saving benefits for shorter distance trips and an increase in proportion of time savings benefits associated with longer distance trips. It is noted that a significant increase in the proportion of benefits associated with long distance trips (>200km) can be seen in the High CVTT model compared to the WebTAG and Medium CVTT models. It is surmised that this impact is related to mainly external-external trips, which are only subject to routeing choice in the model and are not affected by demand model responses.

6.3.6. From Table 31 above it can be seen there is also an increase in non-fuel VOC dis-benefits as we move from WebTAG VTT to Medium CVTT and High CVTT. This is again expected, as with a CVTT multiplier applied, more trips will divert away from congested areas to longer alternative routes, including use of the scheme. This is consistent with the results in chapter 5 which show higher flows on the scheme with multipliers applied in the model.

Figure 44 Proportion of Time Savings Benefits by Travel Distance



6.4. ANALYSIS OF TUBA WARNINGS

6.4.1. Table 32 below provides a summary of the TUBA warnings produced from the three TUBA runs with WebTAG VTT used in appraisal. It is noted that only the TUBA runs with WebTAG VTT in appraisal are considered as the TUBA runs with free-flow VTT and delay VTT with various CVTT multipliers were used to produce travel time saving benefits only.

Table 32 TUBA Warning Summary

Description	WebTAG		Medium Multiplier		High Multiplier	
	Total	Serious	Total	Serious	Total	Serious
DM/DS travel time ratio lower than limit	605	0	808	0	263	0
DM/DS travel time ratio higher than limit	40,927	15	37,143	15	45,549	13
DM/DS travel distance ratio lower than limit	108,148	0	132,931	10	157,693	168
DM/DS travel distance ratio higher than limit	5,085	5,085	6,101	6,101	11,890	11,890
DM speeds less than limit	109		57		27	
DM speeds greater than limit	818		863		903	
DS speeds less than limit	109		57		33	
DS speeds greater than limit	830		897		919	
Total	**156,631**	**5,100**	**178,857**	**6,126**	**217,277**	**12,071**

6.4.2. As can be seen, the total number of TUBA warnings increase from the WebTAG VTT to the Medium Multiplier and to the High Multiplier, more specifically an increase in the number of warnings associated with ratios of do minimum/do something travel distance lower and higher than the warning limit. This suggests that higher numbers of origin and destination pairs have longer distance minimum cost paths, avoiding congestion, as the CVTT multiplier value becomes higher.

6.4.3. The increase in origin and destination pairs with longer distance minimum cost paths is also reflected in the reduction in the number of warnings associated with do minimum or do something speeds lower than the warning limit in the CVTT multiplier tests compared to the WebTAG VTT test.

6.5. SUMMARY

6.5.1. TUBA runs using the WebTAG VTT model show that changes in benefits in the tests with Low, Medium and High Multiplier are proportionate to change in multiplier values. The tests suggest that TUBA runs with a CVTT multiplier would result in higher benefits compared to the WebTAG VTT when the multiplier values are higher than two.

6.5.2. TUBA runs with Medium and High CVTT used in the model and the appraisal also show an increase in benefits compared to the TUBA runs with WebTAG VTTs.

6.5.3. It is however noted when WebTAG VTT is used in the appraisal the Medium and High Multiplier models produce lower benefits than the WebTAG VTT model. This is primarily due to vehicles choosing longer travel distances in response to the increase in CVTT multiplier value applied.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1. BASE YEAR RESULTS

7.1.1. PRISM AM peak base year (2016) highway assignments of the prior matrix were carried out with three different values of the congestion multiplier, along with WebTAG VTT.

7.1.2. The headline results are:

- Convergence: there is little difference in the level of convergence achieved, or the number of iterations required to achieve the specified stopping criteria;
- Run times: assignments with the congestion multiplier are quicker than the WebTAG VTT. Run times increase with the value of the multiplier;
- Flow differences: (congestion multiplier vs WebTAG): the pattern of flow differences varies by journey purpose. The pattern for Medium and High multiplier values is similar, varying only in scale. The pattern is quite different for the Low multiplier;

Validation:

- Link flow: there is not much difference between WebTAG VTT and the Low congestion multiplier. Validation deteriorates as the multiplier value is increased to Medium and then to High;
- Screenline flow: The low multiplier gives a slightly better validation than WebTAG VTT. Validation deteriorates as the multiplier value increases;
- Journey times: The impact is relatively small and there is no clear pattern.

7.1.3. It should be noted that the prior matrix still depends, to some degree, on the VTT used in the assignment. The results therefore do not fully reflect what would happen if congestion multipliers had been used throughout the model development.

7.2. FUTURE YEAR RESULTS

7.2.1. Congestion multipliers were added to the highway assignment and demand models. Future year model tests were carried out for a single year, 2036, with and without a hypothetical major road scheme. Two congestion multiplier values were tested (Medium and High), alongside WebTAG VTT.

7.2.2. The effects of using congestion multipliers in forecasting can be summarised as follows. Most of the effects are stronger with the High Multiplier than the Medium value:

- There is no adverse impact on either model run times or convergence;
- There is a reduction in the delay and total travel time experienced by car trips. There is also a tendency for increased travel distance, but to a lesser extent;
- With the Medium Multiplier the average outturn VTT is lower than WebTAG. With the High Multiplier it is greater than WebTAG for Employer's Business and Commute trips (but not Other);
- Multipliers affect modelled mode shares in the DM, but this may stem from not re-calibrating the demand model following the introduction of the multiplier;
- Multipliers increase the traffic induced by the scheme, whether that is by mode or destination choice. This may also be a consequence of the lack of re-calibration of the demand model;
- Combining route, mode and destination choices, the use of multipliers significantly increases flows on our test scheme;
- 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.

7.2.3. It should be noted that the forecasts all used the same validated base matrix in the pivoting process. Ideally this would have varied according to the value of the congestion multiplier. The results therefore do not fully reflect what would happen if congestion multipliers had been used throughout the model development. While this is unlikely to have affected the general pattern of the differences, it may have affected the scale[22].

7.3. TUBA RESULTS

7.3.1. TUBA runs using the WebTAG VTT model show that changes in benefits in the tests with Low, Medium and High Multiplier (in the appraisal only) are proportionate to change in multiplier values. The tests suggest that TUBA runs with a CVTT multiplier would result in higher benefits compared to the WebTAG VTT when the multiplier values are higher than two.

7.3.2. TUBA runs with Medium and High CVTT used in the model and the appraisal also show an increase in benefits compared to the TUBA runs with WebTAG VTTs.

7.3.3. It is however noted when WebTAG VTT is used in the appraisal the Medium and High Multiplier models produce lower benefits than the WebTAG VTT model. This is primarily due to vehicles choosing longer travel distances in response to the increase in the CVTT multiplier value applied.

7.3.4. Overall, while higher multipliers result in higher user benefits, the impact is considerably less when the multipliers are used in the model and not just in the appraisal.

7.3.5. As noted above, the modelling results do not fully reflect what would happen if congestion multipliers had been used throughout the model development. While this is unlikely to have affected the general pattern of the differences, it may have affected the scale.

7.4. CONCLUSION

7.4.1. The results presented in this report are from a small number of model runs, based on a single model area and scheme. The model runs use several simplifications which mean that congestion multipliers have not been used for every stage of the modelling process (specifically, the base year trip matrix development). Furthermore, we do not know the true value of the multiplier. Therefore, we cannot draw general conclusions from these results. However, if similar results were obtained from a wider sample of applications then we could potentially draw the following tentative conclusions about the impact of congestion multipliers on modelling:

- The use of a congestion multiplier is unlikely to have significant adverse impacts on either model run times or convergence; however:
- The use of a congestion multiplier could require larger model networks as there may be greater potential for re-routeing across a wider area;
- The use of a congestion multiplier could have a significant impact on modelled route, destination and mode choices;

[22] It is not obvious whether the scale of differences would have been more or less than reported.

- The use of a congestion multiplier could have a significant impact on modelled scheme flows, with implications for scheme design and appraisal;
- The use of a congestion multiplier could have a significant impact on user benefits. This impact is likely to be overstated if the multiplier is used only in the appraisal and not in the underlying modelling as well;
- There are unlikely to be significant technical problems for practitioners in implementing congestion multipliers, as long as software providers make the required functionality available.

7.5. RECOMMENDATIONS

7.5.1. Based on the results presented above, there is the potential for congestion multipliers to have a significant impact on the design and appraisal of transport schemes. However, application of the multipliers in appraisal without also using them in the supporting transport modelling would need to consider the potential to overstate benefits.

7.5.2. Further work is advocated before the use of multipliers is recommended as the standard approach in WebTAG.

7.5.3. As short-term extensions of the work described above we would recommend the following additional tasks:

- Repeating at least some of the tests for the less congested PRISM forecast year of 2026. Impacts on user benefits over the full 60 year appraisal period may be different than those from just 2036, which could affect the justification for pursuing further work on CVTT;
- Assigning the DM post-VDM matrices to the DS network. This would help us to understand whether the impact of the multiplier on scheme flows is mainly down to re-routeing, or to VDM responses.
- Undertaking realism testing of the modified demand models to determine how the sensitivity of the model varies by CVTT multiplier. This would help to understand to what extent the results obtained are a consequence of the demand model varying in sensitivity, rather than a fundamental characteristic of using CVTT multipliers;
- Depending on the outcome from the above, consider re-calibration of the demand model and repeating some, or all, of the tests;
- Investigating the impact of the simplifications used in the modelling to date. Specifically, what would be the impact on the validated base matrix if congestion multipliers were used (a) in the development of the prior matrices, and (b) in the matrix estimation process. Following on from this, if the impact turned out to be significant, how does it affect the forecasting results via the pivoting process.

7.5.4. Longer term, the following issues should be addressed before recommending the use of CVTT multipliers in WebTAG:

- Undertaking research to estimate a robust value for the multiplier in the 'free flow plus delay' generalised cost formulation. The reasons for this, and some initial thoughts on methodology, are discussed in the report of our previous work.

Assuming this confirms a multiplier significantly greater than 1, then further work would be required:

- Testing a wider range of schemes in a wider variety of models;
- Exploring how the multipliers could be incorporated into the most widely used transport modelling packages in the UK, including SATURN and DIADEM;

§ Investigating whether the use of multipliers only in highway modelling would bias scheme appraisal in favour of highway schemes. If so, an equivalent framework for public transport and active mode appraisal would need to be considered (noting that models that explicitly include crowding in public transport already implicitly place a higher value on travel time in overcrowded conditions).

Appendix A

Detailed TUBA results

A.1 TUBA BENEFITS BY JOURNEY PURPOSE AND TIME PERIOD

Table A.1 to Table A.5 provide a summary of TUBA benefits by time period and by journey purpose produced for the WebTAG VTT, Medium CVTT and High Multiplier in both modelling and appraisal[23].

Table A.1 TUBA Benefit (£000s) Summary – WebTAG VTT in Modelling and Appraisal

Period	Purpose	Time	User Charges	Fuel VOC	Non-Fuel VOC	Operator Revs	Indirect Tax	Total
AM Peak	Commuting	3,574	-73	-107	-619	186	381	3,342
AM Peak	Other	1,271	-7	-88	-269	62	205	1,173
AM Peak	Business (Car)	2,855	-118	-168	55	154	296	3,075
AM Peak	Business (Freight)	1,842	68	-354	162	-68	199	1,850
	Total	**9,543**	**-131**	**-717**	**-670**	**335**	**1,081**	**9,440**
Inter-Peak	Commuting	2,406	63	-115	-475	25	316	2,220
Inter-Peak	Other	3,985	390	-430	-831	-343	645	3,417
Inter-Peak	Business (Car)	5,572	540	-424	45	-442	683	5,974
Inter-Peak	Business (Freight)	3,455	307	-1,077	295	-307	607	3,281
	Total	**15,419**	**1,301**	**-2,046**	**-965**	**-1,068**	**2,251**	**14,892**
PM Peak	Commuting	3,986	-90	-71	-651	205	399	3,777
PM Peak	Other	1,777	27	-52	-301	42	203	1,695
PM Peak	Business (Car)	2,564	11	-107	73	21	286	2,848
PM Peak	Business (Freight)	1,376	-78	-190	101	78	106	1,393
	Total	**9,702**	**-130**	**-420**	**-778**	**346**	**993**	**9,713**
Total	Commuting	9,966	-100	-294	-1,745	416	1,096	9,339
Total	Other	7,034	410	-570	-1,401	-240	1,053	6,285
Total	Business (Car)	10,991	433	-699	173	-267	1,265	11,897
Total	Business (Freight)	6,674	297	-1,620	559	-297	911	6,523
	Total	**34,664**	**1,039**	**-3,183**	**-2,414**	**-387**	**4,325**	**34,045**

[23] Note these tables exclude greenhouse gas benefits, these are not disaggregated by time period in TUBA outputs and are therefore not reported here.

Table A.2 TUBA Benefit (£000s) – Medium CVTT in Modelling with WebTAG VTT in Appraisal

Period	Purpose	Time	User Charges	Fuel VOC	Non-Fuel VOC	Operator Revs	Indirect Tax	Total
AM Peak	Commuting	3,278	-65	-221	-727	227	461	2,953
AM Peak	Other	1,272	31	-139	-329	8	259	1,101
AM Peak	Business (Car)	2,695	69	-192	23	22	358	2,975
AM Peak	Business (Freight)	1,664	-234	-400	140	234	225	1,629
	Total	**8,910**	**-199**	**-953**	**-894**	**492**	**1,302**	**8,658**
Inter-Peak	Commuting	2,368	63	-196	-473	66	316	2,143
Inter-Peak	Other	4,075	-54	-474	-1,000	103	764	3,414
Inter-Peak	Business (Car)	4,971	1,263	-533	-77	-958	843	5,509
Inter-Peak	Business (Freight)	2,760	958	-799	226	-958	450	2,636
	Total	**14,173**	**2,230**	**-2,003**	**-1,324**	**-1,747**	**2,373**	**13,702**
PM Peak	Commuting	3,616	-8	-226	-766	192	494	3,303
PM Peak	Other	1,773	6	-86	-405	29	278	1,596
PM Peak	Business (Car)	2,481	-35	-166	24	118	379	2,801
PM Peak	Business (Freight)	1,272	-140	-262	85	140	147	1,241
	Total	**9,142**	**-177**	**-740**	**-1,062**	**479**	**1,298**	**8,941**
Total	Commuting	9,262	-9	-643	-1,966	485	1,271	8,399
Total	Other	7,119	-16	-700	-1,734	140	1,301	6,112
Total	Business (Car)	10,147	1,296	-891	-30	-818	1,580	11,284
Total	Business (Freight)	5,696	583	-1,462	450	-583	822	5,506
	Total	**32,224**	**1,854**	**-3,696**	**-3,279**	**-776**	**4,974**	**31,301**

Table A.3 TUBA Benefit (£000s) – Medium CVTT in Modelling and Appraisal

Period	Purpose	Time	User Charges	Fuel VOC	Non-Fuel VOC	Operator Revs	Indirect Tax	Total
AM Peak	Commuting	5,964	-65	-221	-727	227	461	5,639
AM Peak	Other	1,575	31	-139	-329	8	259	1,404
AM Peak	Business (Car)	3,329	69	-192	23	22	358	3,609
AM Peak	Business (Freight)	2,182	-234	-400	140	234	225	2,146
	Total	**13,049**	**-199**	**-953**	**-894**	**492**	**1,302**	**12,798**
Inter-Peak	Commuting	4,083	63	-196	-473	66	316	3,859
Inter-Peak	Other	5,245	-54	-474	-1,000	103	764	4,584
Inter-Peak	Business (Car)	6,877	1,263	-533	-77	-958	843	7,415
Inter-Peak	Business (Freight)	3,627	958	-799	226	-958	450	3,503
	Total	**19,832**	**2,230**	**-2,003**	**-1,324**	**-1,747**	**2,373**	**19,361**
PM Peak	Commuting	6,463	-8	-226	-766	192	494	6,149
PM Peak	Other	2,341	6	-86	-405	29	278	2,165
PM Peak	Business (Car)	3,266	-35	-166	24	118	379	3,586
PM Peak	Business (Freight)	1,675	-140	-262	85	140	147	1,644
	Total	**13,745**	**-177**	**-740**	**-1,062**	**479**	**1,298**	**13,544**
Total	Commuting	16,510	-9	-643	-1,966	485	1,271	15,647
Total	Other	9,161	-16	-700	-1,734	140	1,301	8,153
Total	Business (Car)	13,472	1,296	-891	-30	-818	1,580	14,609
Total	Business (Freight)	7,483	583	-1,462	450	-583	822	7,293
	Total	**46,626**	**1,854**	**-3,696**	**-3,279**	**-776**	**4,974**	**45,703**

Table A.4 TUBA Benefit (£000s) – High CVTT in Modelling with WebTAG VTT in Appraisal

Period	Purpose	Time	User Charges	Fuel VOC	Non-Fuel VOC	Operator Revs	Indirect Tax	Total
AM Peak	Commuting	3,032	131	-252	-1,088	209	730	2,761
AM Peak	Other	1,146	60	-141	-437	24	331	983
AM Peak	Business (Car)	2,938	-10	-208	15	144	455	3,334
AM Peak	Business (Freight)	1,490	-231	-338	129	231	190	1,472
	Total	**8,607**	**-51**	**-938**	**-1,381**	**608**	**1,706**	**8,550**
Inter-Peak	Commuting	2,181	-63	-200	-787	445	550	2,126
Inter-Peak	Other	4,006	200	-484	-1,255	-53	983	3,397
Inter-Peak	Business (Car)	5,476	963	-595	-117	-469	1,084	6,343
Inter-Peak	Business (Freight)	2,224	1,192	-535	166	-1,192	300	2,155
	Total	**13,887**	**2,292**	**-1,813**	**-1,994**	**-1,269**	**2,917**	**14,021**
PM Peak	Commuting	3,044	24	-222	-1,140	363	775	2,842
PM Peak	Other	1,366	142	-107	-559	-62	402	1,184
PM Peak	Business (Car)	2,336	152	-170	6	-10	478	2,792
PM Peak	Business (Freight)	1,112	-181	-248	85	181	139	1,089
	Total	**7,858**	**137**	**-746**	**-1,608**	**472**	**1,794**	**7,907**
Total	Commuting	8,256	92	-673	-3,016	1,016	2,055	7,730
Total	Other	6,519	402	-731	-2,251	-91	1,717	5,564
Total	Business (Car)	10,750	1,105	-972	-96	-335	2,016	12,468
Total	Business (Freight)	4,827	780	-1,121	380	-780	629	4,716
	Total	**30,352**	**2,379**	**-3,498**	**-4,983**	**-189**	**6,417**	**30,478**

Table A.5 TUBA Benefit (£000s) – High CVTT in Modelling and Appraisal

Period	Purpose	Time	User Charges	Fuel VOC	Non-Fuel VOC	Operator Revs	Indirect Tax	Total
AM Peak	Commuting	8,238	131	-252	-1,088	209	730	7,968
AM Peak	Other	2,211	60	-141	-437	24	331	2,047
AM Peak	Business (Car)	4,361	-10	-208	15	144	455	4,757
AM Peak	Business (Freight)	2,921	-231	-338	129	231	190	2,902
	Total	**17,731**	**-51**	**-938**	**-1,381**	**608**	**1,706**	**17,674**
Inter-Peak	Commuting	5,569	-63	-200	-787	445	550	5,514
Inter-Peak	Other	6,726	200	-484	-1,255	-53	983	6,117
Inter-Peak	Business (Car)	9,022	963	-595	-117	-469	1,084	9,889
Inter-Peak	Business (Freight)	4,248	1,192	-535	166	-1,192	300	4,178
	Total	**25,565**	**2,292**	**-1,813**	**-1,994**	**-1,269**	**2,917**	**25,698**
PM Peak	Commuting	8,046	24	-222	-1,140	363	775	7,844
PM Peak	Other	2,572	142	-107	-559	-62	402	2,389
PM Peak	Business (Car)	4,057	152	-170	6	-10	478	4,513
PM Peak	Business (Freight)	2,164	-181	-248	85	181	139	2,141
	Total	**16,838**	**137**	**-746**	**-1,608**	**472**	**1,794**	**16,887**
Total	Commuting	21,853	92	-673	-3,016	1,016	2,055	21,327
Total	Other	11,509	402	-731	-2,251	-91	1,717	10,554
Total	Business (Car)	17,440	1,105	-972	-96	-335	2,016	19,158
Total	Business (Freight)	9,332	780	-1,121	380	-780	629	9,221
	Total	**60,134**	**2,379**	**-3,498**	**-4,983**	**-189**	**6,417**	**60,260**

Comparison of the TUBA benefits with WebTAG VTT in appraisal show that:

- Benefits associated with Commute and Other reduces with the Medium and High Multiplier models compared to the WebTAG VTT model. This is expected as traffic would be more likely to find alternative routes to avoid delays with the CVTT multiplier applied in the model;
- Benefits associated with Car Employer's Business, whilst showing a reduction with the Medium Multiplier model, show an increase in the High Multiplier model compared with the WebTAG VTT model. This not consistent with the Commute and Other trip purpose results and will be impacted by several factors, including, for example, the routeing changes and VDM responses (or lack thereof for external to external movements) for those trips in the context of the multiplier values as well as the overall VTT; this has not been investigated further at this stage.
- Benefits show a smaller reduction in the Inter-peak period compared to those in the AM and PM peaks with Medium and High CVTT models compared to the WebTAG VTT model. This is expected as the AM and PM peaks are more congested than the Inter-peak therefore traffic would be more likely to divert away from congestion.

Comparison of benefits between the WebTAG VTT and the CVTT multipliers applied in both modelling and appraisal show that:

- Commute shows the largest increase in benefits out of the journey purposes, by a factor of 1.8 and 2.6 overall for the Medium and High Multipliers respectively compared to WebTAG VTT. This is expected as the Commute purpose has the largest adjustment factor to convert from WebTAG VTT to free-flow VTT;
- Inter-peak benefits show the smallest increase in benefits compared to the AM and PM peaks in both Medium and High Multiplier compared to WebTAG VTT. This is also expected as there is more congestion in the AM and PM peaks compared to Inter-peak.

A.2 TRAVEL TIME SAVING BENEFITS BY TRAVEL DISTANCE

Figure A.1 to Figure A.5 Time Saving Benefits – High CVTT in Modelling and Appraisal show the results of the TUBA time saving benefits by travel distance for each of the TUBA runs with WebTAG VTT, Medium CVTT and High Multipliers in both modelling and appraisal.

Figure A.1 Time Saving Benefits by Distance – WebTAG VTT in Modelling and Appraisal

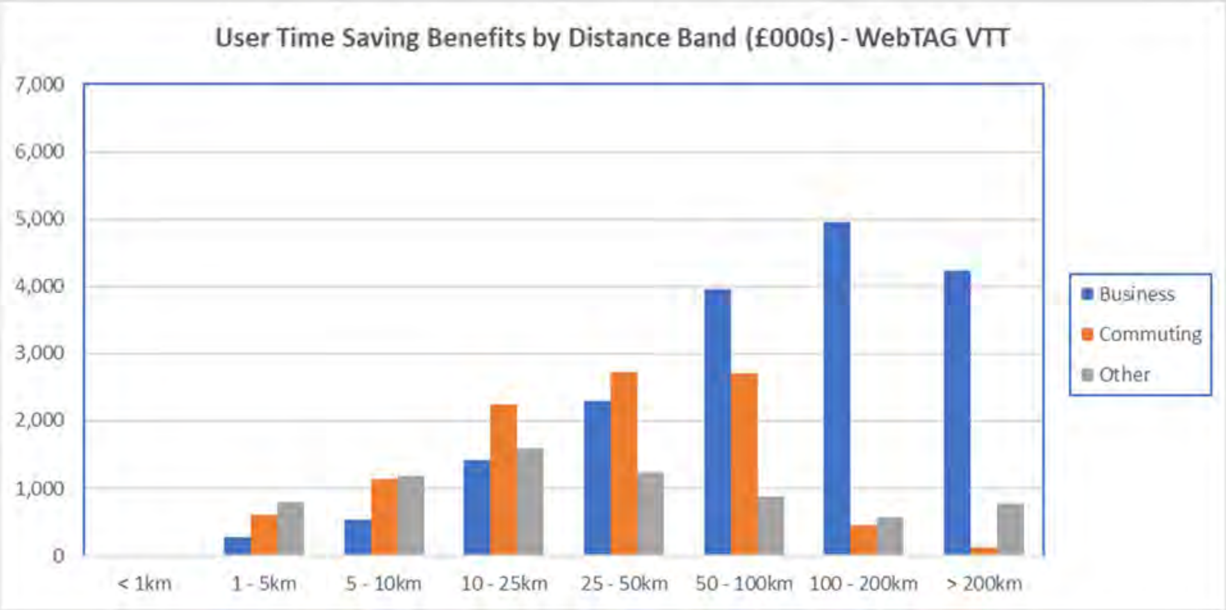


Figure A.2 Time Saving Benefits – Medium CVTT in Modelling with WebTAG VTT in Appraisal

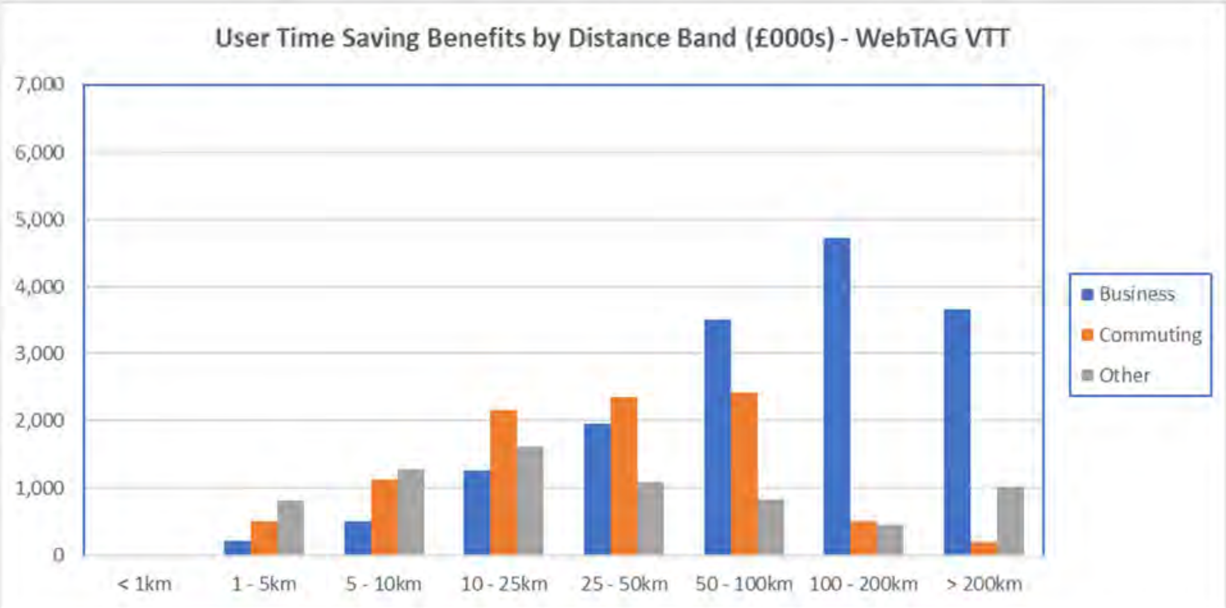


Figure A.3 Time Saving Benefits – Medium CVTT in Modelling and Appraisal

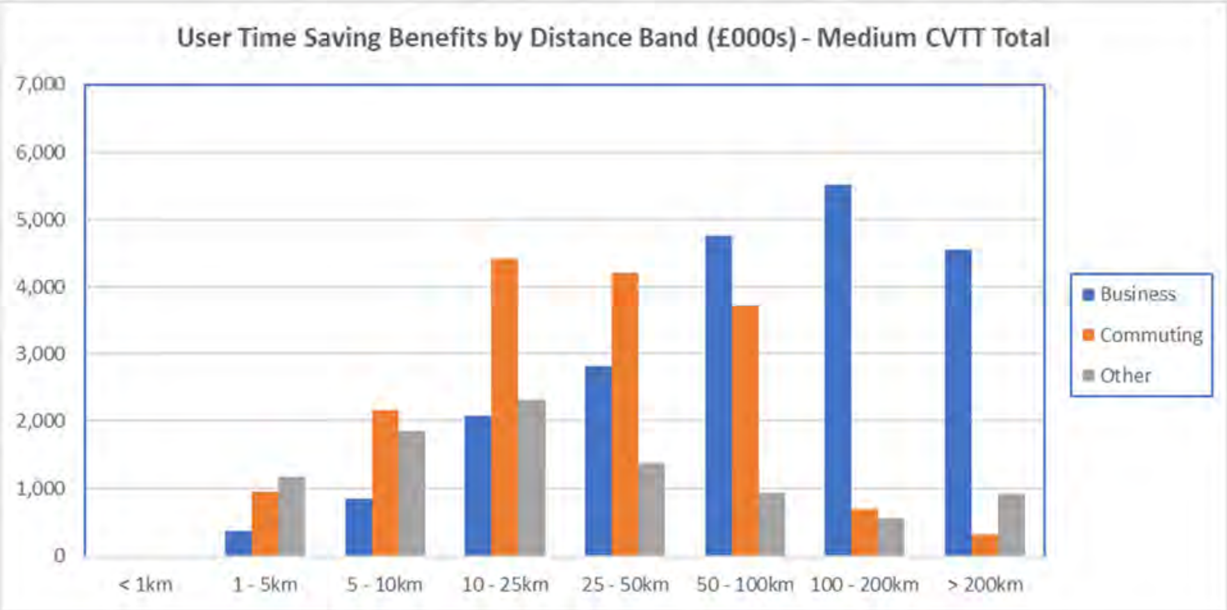


Figure A.4 Time Saving Benefits – High CVTT in Modelling with WebTAG VTT in Appraisal

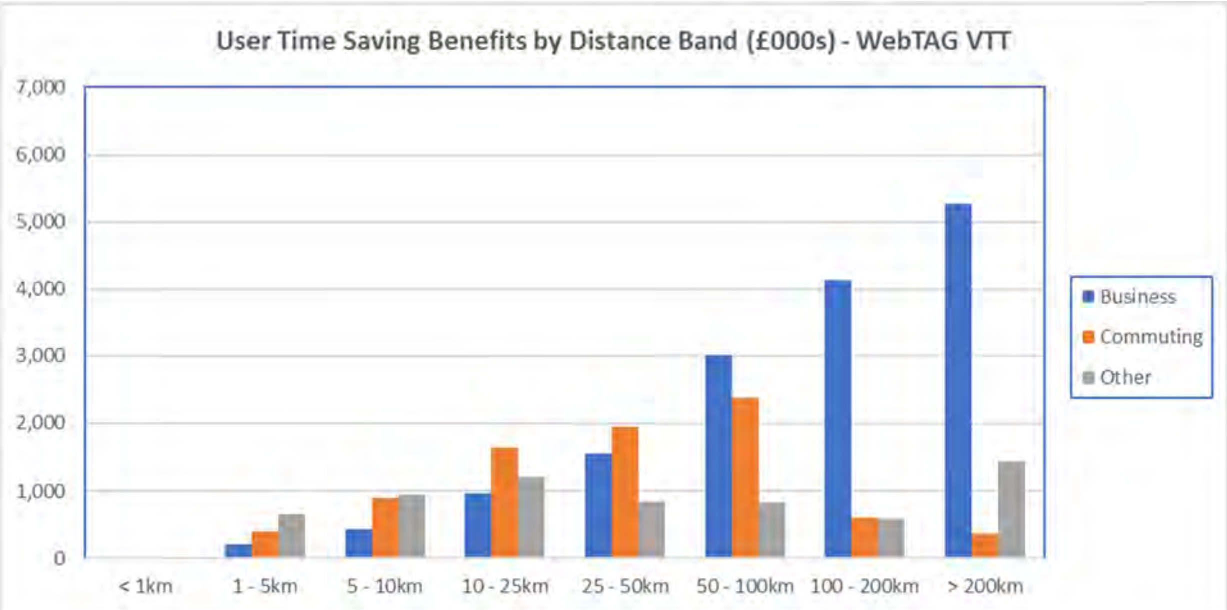
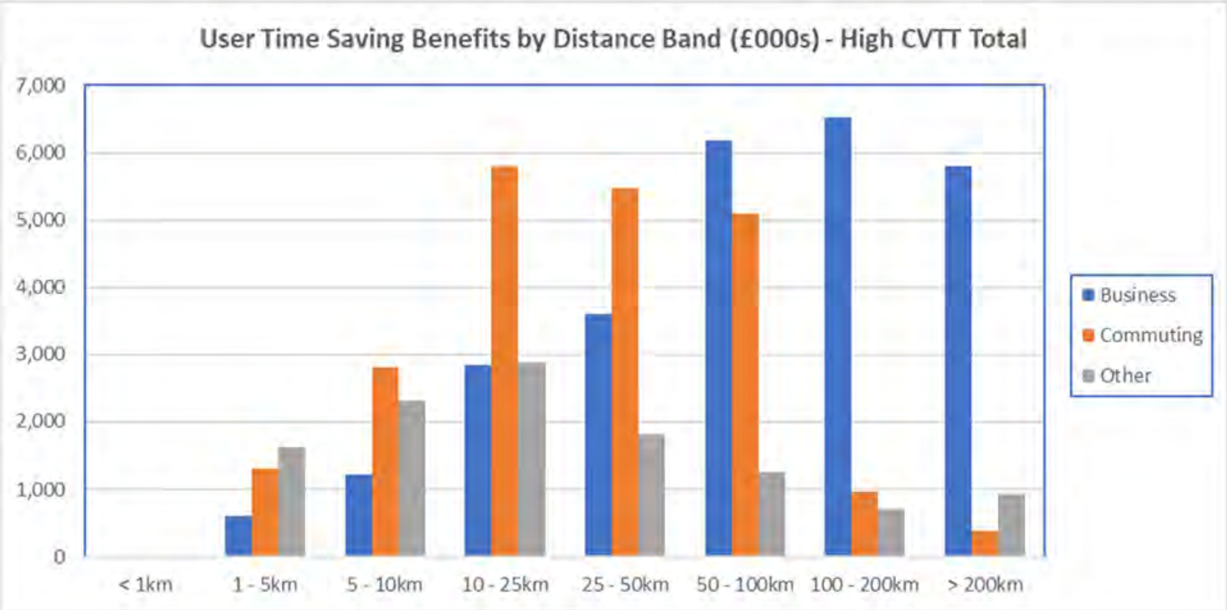


Figure A.5 Time Saving Benefits – High CVTT in Modelling and Appraisal

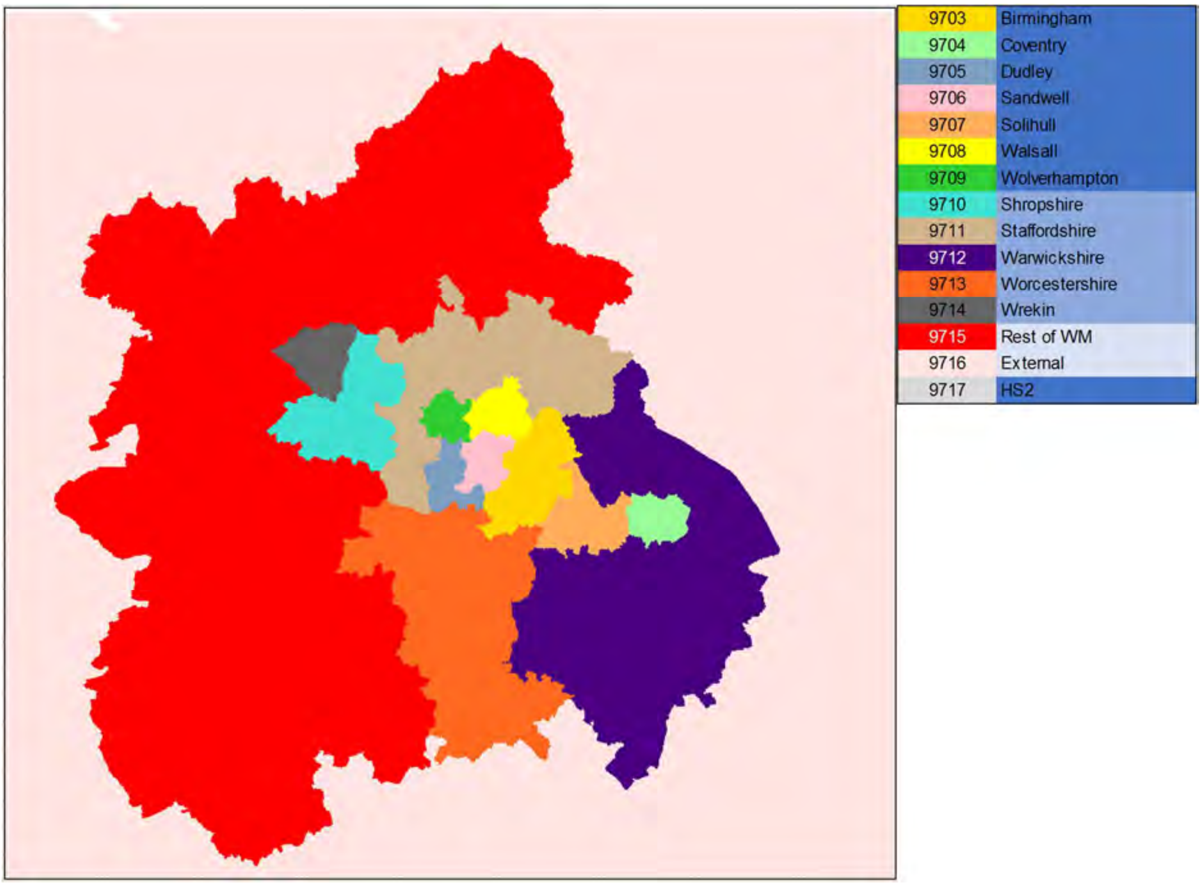


As can be seen, the TUBA results show a general increase in time savings benefits across all the distance bands with CVTT multipliers applied, however, there is a larger increase in benefits for the for the longer distance trips compared to shorter distance trips. This is anticipated as longer distance trips would tend to find more alternative routes available to avoid congested areas compared to shorter distance trips.

A.3 TUBA BENEFITS AT SECTORAL LEVEL

A sector system has been developed to enable spatial analysis of the results. This consists of 15 sectors; a plan of the sector system is provided in Figure A.6 below.

Figure A.6 Sector System



7.5.5. Figure A.7 to Figure A.11 Time Saving Benefits – High CVTT in Modelling and Appraisal**Error! Reference source not found.** below provide summary of TUBA time saving benefits at sectoral level.

Figure A.7 Sector Benefits – WebTAG VTT in Modelling and Appraisal

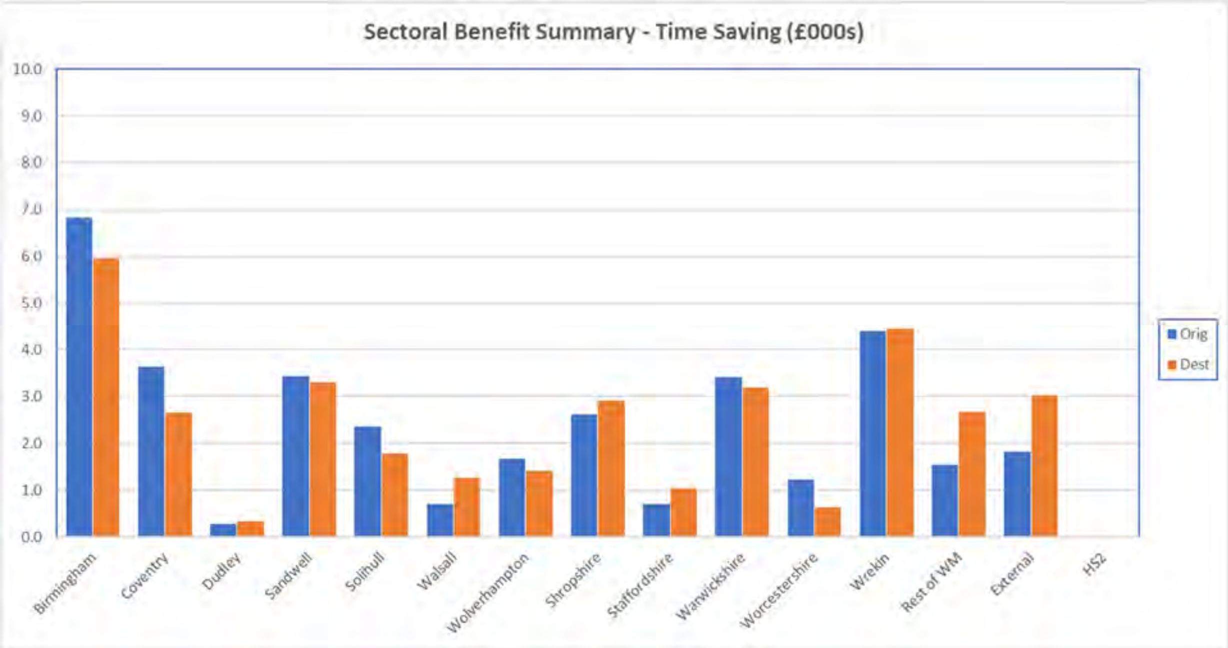


Figure A.8 Sector Benefits – Medium CVTT in Modelling with WebTAG VTT in Appraisal

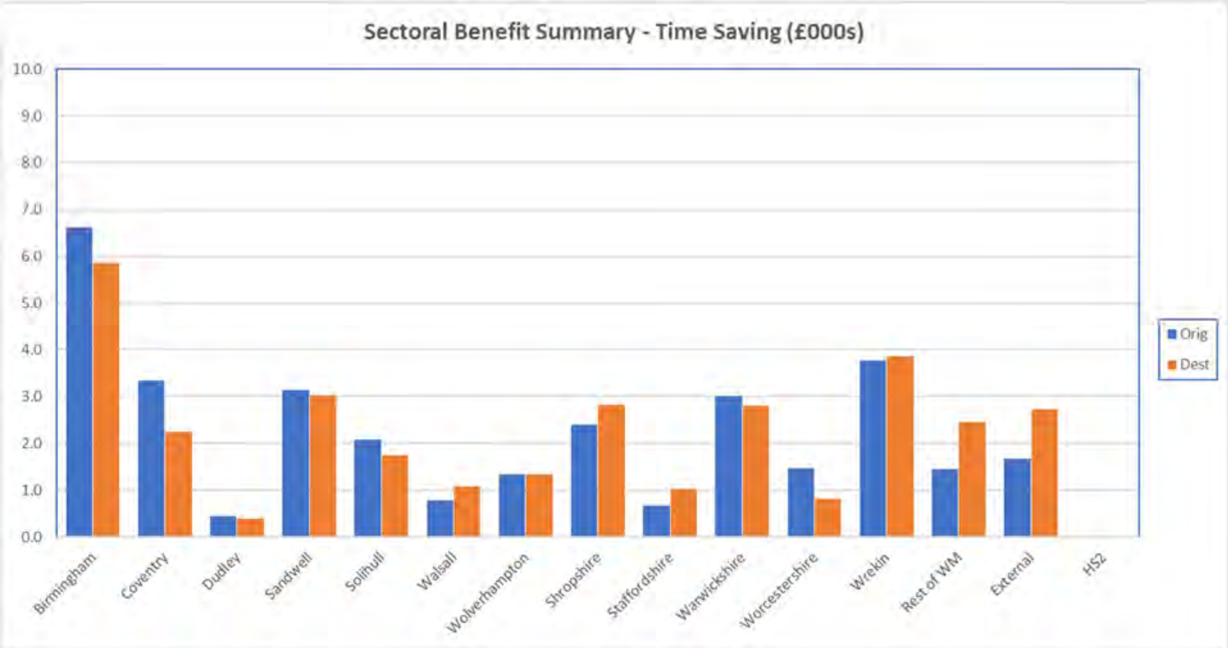


Figure A.9 Sector Benefits – Medium CVTT in Modelling and Appraisal

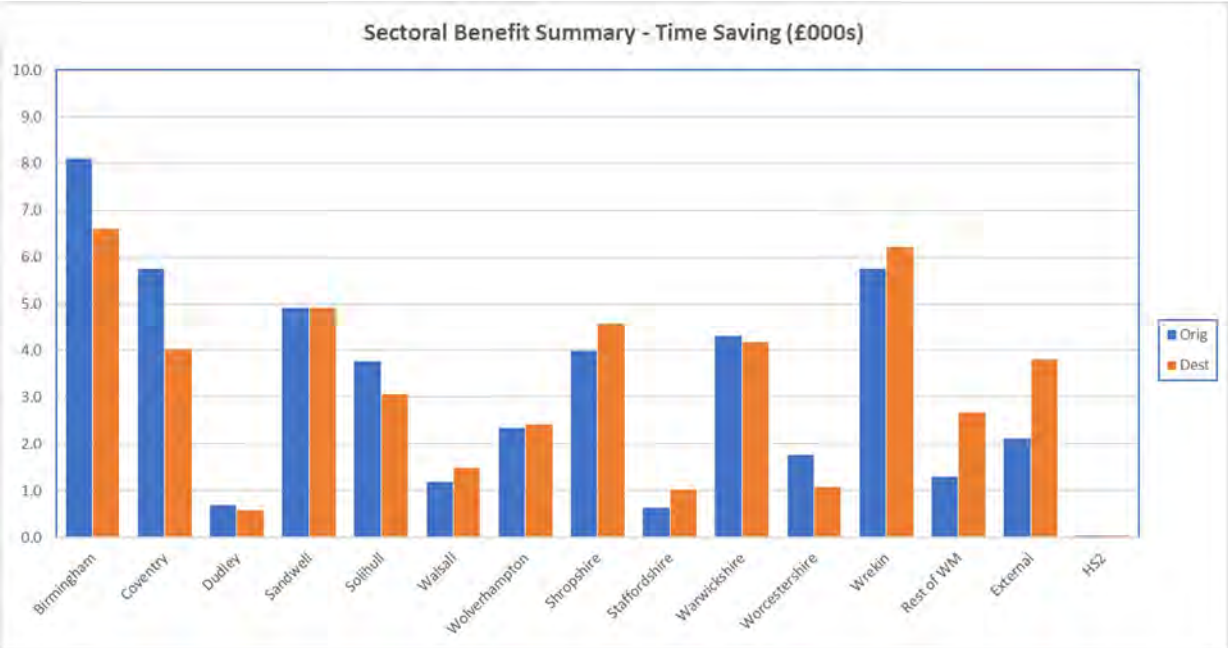


Figure A.10 Time Saving Benefits – High CVTT in Modelling with WebTAG VTT in Appraisal

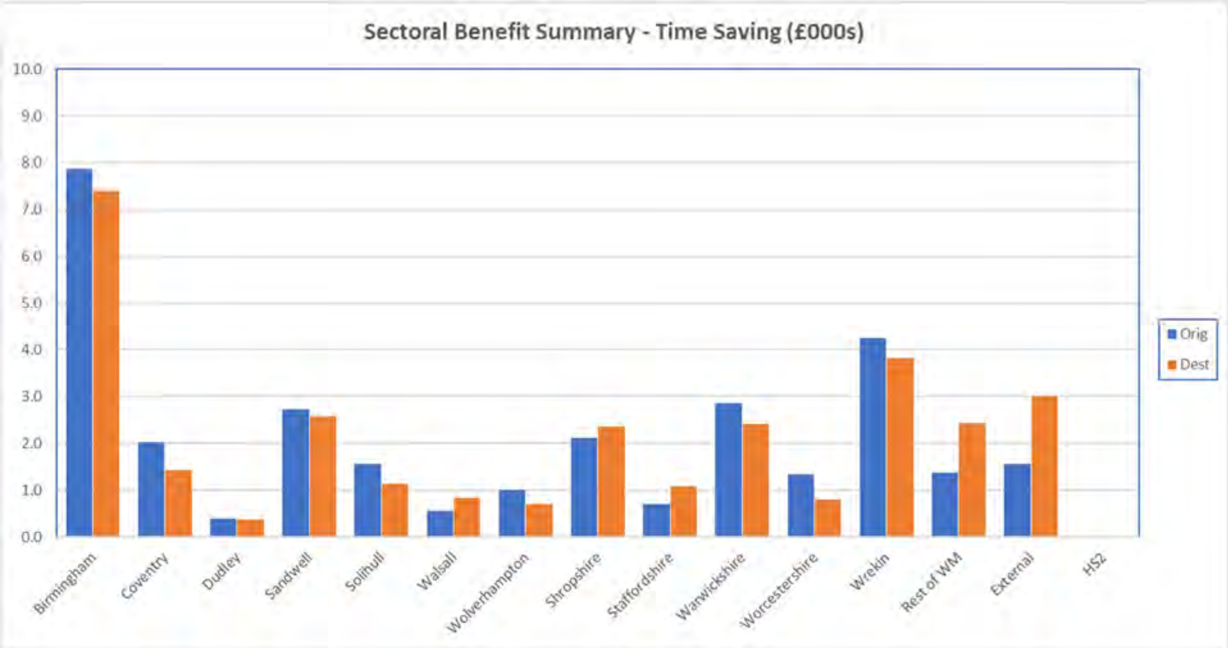
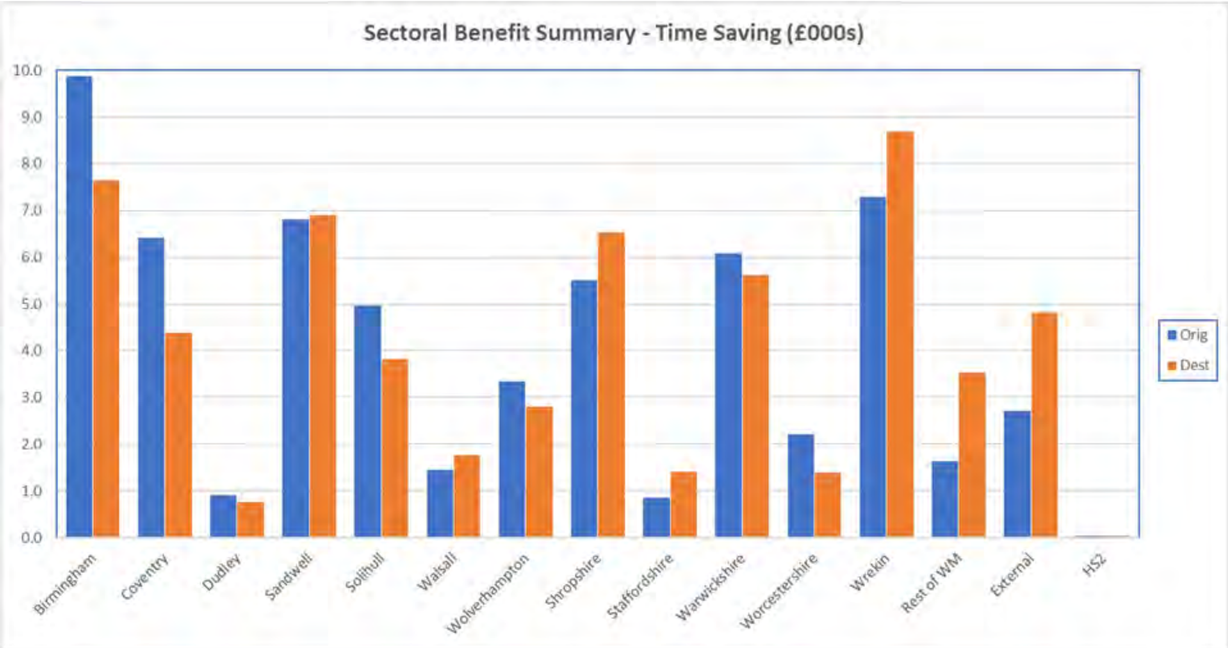


Figure A.11 Time Saving Benefits – High CVTT in Modelling and Appraisal



As can be seen, the TUBA benefits with CVTT multipliers generally show an increase in benefits across all the sectors within the modelling system.

Areas with high levels of congestion such as Birmingham, Coventry, Sandwell and Wrekin see a larger increase in benefits compared to other sectors with the CVTT multipliers applied, which is considered plausible given the multiplier is applied to delay time.

A.4 SUMMARY

This appendix provides a more in-depth summary of the TUBA benefits with different CVTT multipliers applied in modelling and appraisal.

Comparisons of benefits produced from the WebTAG VTT model compared with Medium and High Multiplier models (using WebTAG VTT in the appraisal) show plausible changes in benefits by journey purpose and time period.

Benefits produced for WebTAG VTT, Medium and High Multipliers in both modelling and appraisal also show plausible changes in benefits by journey purpose and time period.

Travel time saving benefits by distance travel show a larger increase in benefits for longer distance trips in the tests with CVTT multipliers applied, which is deemed plausible as longer distance trips tend to find more alternative routes to avoid congestion, particularly when the CVTT multipliers are applied in the model.

Sector benefits show a larger increase in benefits with CVTT multipliers applied for the more highly congested areas in the model as would be expected.

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