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Congested Values of Travel Time (CVTT)

Re-analysis of the 2014/15 SP Study

Richard Batley, Thijs Dekker & Peter Mackie

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ITS

CONGESTED VALUES OF TRAVEL TIME (CVTT)

RE-ANALYSIS OF THE 2014/15 SP STUDY

Glossary of terms and abbreviations

Free-Flow (FF) – travel time if unhindered by any other vehicle (but including waiting time at signalised intersections)

Delay – additional travel time due to interactions with other vehicles

Light Congestion (LC) – can travel close to the speed limit most of the time, but have to slow down every so often

Heavy Congestion (HC) – speed is noticeably restricted and frequent gear changes are required

Travel Time – sum of FF and Delay, giving rise to total travel time for a journey

Value of Travel Time (VTT) – unit value of a minute (or hour) saving of travel time

Value of Travel Time Reliability (VTTR) – unit value of a minute of variability in travel time

Congested Value of Travel Time (CVTT) – unit value of a minute spent in LC or HC

Generalised Cost (GC) – combined time and money costs of a journey converted into monetary units

Link – a section of a route

Route – a collection of links comprising an origin-destination journey

Junction – an intersection of contiguous links

Commute – journeys to/from a normal place of work/education carried out in own time

Other Non-Work (ONW) – other journeys carried out in own time

Employer Business (EB) – journeys to/from other places of work carried out in employer's time

1 Introduction

1.1 Background

A team from the Institute for Transport Studies (ITS) at the University of Leeds has been engaged by the Department for Transport (DfT) to re-analyse Stated Preference (SP) data on the Congested Value of Travel Time (CVTT) collected in 2014, and advise on the implementation of CVTT multipliers within modelling and appraisal.

In 2014/15, the Department commissioned Arup, ITS Leeds & Accent to undertake a major study using SP methods to value various aspects of travel time across modes and journey purposes. More specifically, in the case of car, there were three distinct SP games:

- SP1 considered time vs. cost
- SP2 considered time vs. cost vs. reliability
- SP3 considered time vs. cost vs. congestion

All three games allowed estimation of some version of a 'headline' nationally representative average Value of Travel Time (VTT) suitable for use in appraisal. The latter two games also allowed estimation of multipliers of the headline VTT to reflect the Value of Travel Time Reliability (VTTR) and CVTT respectively.

In relation to CVTT specifically, Arup et al. reported the following conclusions and recommendations:

- *'We have found clear evidence of values of reliability and of variation in VTT with traffic conditions and crowding. In this context, it is appropriate to note that current*[1] *WebTAG guidance on VTT incorporates reliability multipliers, but not multipliers for traffic conditions and crowding.*

R2: We recommend that the Department should undertake work to examine the case for extending the scope of VTT guidance to include multipliers for traffic conditions and crowding'.

- *'We have estimated VTT using three different SP games (SP1: time vs. cost; SP2: time vs. cost vs. reliability; SP3: time vs. cost vs. crowding/congestion).*

R4: In the immediate term, we would recommend the values from SP1 as the basis for the 'headline' VTT, since these provide the closest comparator to the 2003[2] *game, and most readily lend themselves to implementation in appraisal. It should be clarified that we interpret VTT*

[1] This statement refers to 'current' practice in 2015.

[2] The previous national VTT study reported in 2003 (Mackie et al. 2003).

from SP1 as referring to 'average' travel conditions, rather than free-flow or uncrowded conditions'.

- *'If however crowding/congestion data at an appropriate level of detail can be sourced, then there is a case for basing 'headline' VTT on appropriately weighted values from SP3 – instead of SP1.*

R5: We recommend that the Department should undertake further work to examine the viability of using SP3, and its relative advantages/disadvantages against SP1'.

After a period of reflection and consultation, the Department decided not to include CVTT multipliers within the major 2017 update to VTT guidance in TAG Unit A.1.3. This was partly because of concerns about their robustness; the multipliers appeared very high for some purposes, implying that car travellers would be willing to travel significantly longer distances to avoid heavy traffic. There were also concerns about the practicability of implementing CVTT multipliers in modelling and appraisal.

Therefore, based on the findings from the 2014/15 study, DfT updated TAG by adopting the headline VTT from SP1 and a multiplier for VTTR from SP2 – but did not adopt the multipliers for CVTT from SP3. Apart from annual uplift to reflect GDP growth, these TAG values have not to date been revised further.

1.2 The basis of the 2014/15 estimates of CVTT

SP1 of the 2014/15 study considered trade-offs between travel time and cost assuming 'Average' traffic congestion but certainty of travel time. SP3 further decomposed travel time according to three traffic levels – namely 'Free-Flow' (FF), 'Light Congestion' (LC) and 'Heavy Congestion' (HC). Having adopted SP1 as the headline VTT, it might seem natural to express CVTT from SP3 as multipliers of the SP1 values – remembering that SP1 represented Average congestion. On this basis, the 2014/15 estimates of these multipliers are given in Table 1.1 by journey purpose – noting that they encompass a wide range from 0.42 (in the case of Free-Flow for Employer Business) to 1.89 (in the case of Heavy Congestion for Other Non-Work). The latter is particularly high by accepted standards.

Table 1.1: CVTT multipliers from SP3 – expressed relative to Average traffic conditions from SP1

Traffic conditions	***Commute***	***EB***	***OtherNW***
Free-Flow	0.51	0.42	0.47
Light Congestion	0.72	0.68	0.83
Heavy Congestion	1.37	1.26	1.89

Whereas the focus of the 2014/15 study was valuation, the current workstream is concerned also with modelling and appraisal. In the modelling context especially, it is more natural to express CVTT as a multiple of the VTT for FF (as opposed to Average) traffic conditions (Table 1.2). Since the terminology has a degree of precedent, we will refer to multiples of the VTT for FF as 'M' multipliers[3].

Table 1.2: CVTT multipliers from SP3 – expressed relative to FF traffic conditions (aka 'M' multipliers) from SP3

Traffic conditions	*Commute*	*EB*	*OtherNW*
Free-flow	1.00	1.00	1.00
Light congestion	1.40	1.61	1.76
Heavy congestion	2.66	2.99	3.98

The distinction between Tables 1.1 and 1.2 highlights two broad approaches that could potentially be followed for deriving a headline VTT and associated congestion multipliers, namely:

- **Approach 1:** derive the headline VTT from SP1, and multipliers from SP3.
- **Approach 2:** derive both the headline VTT and multipliers from SP3, where the headline VTT would in this case be a weighted average of time spent in FF, LC and HC from SP3.

1.3 CVTT workstream

The Department is now undertaking a root and branch review of the case for incorporating congestion multipliers in modelling and appraisal, and has to date commissioned three reports:

1. The 2018 report from WSP, RAND Europe and Mott Macdonald on 'Congestion Dependent Values of Time in Transport Modelling', dated March 2018 and in the public domain. The remit of this study was to explore the implementation of congested VTTS multipliers in practical modelling and appraisal.
2. The 2019 follow-on report by WSP et al., which extended their work to a more substantive implementation in the PRISM multi-modal model of the West Midlands.
3. The 2020 Forward Look report commissioned from ITS Leeds, which reviewed the 2018 and 2019 reports and formulated a position on the applicability of the 2014/15 congestion multipliers to modelling and appraisal.

[3] Although the definition of the M multipliers will be further nuanced later in this report.

WSP et al. (2018) were commissioned by DfT to conduct a feasibility study into the incorporation of congestion multipliers in highways and other transport models. The report considers various insights on this topic, namely:

- a technical review of the CVTT estimates emanating from the 2014/15 study by Arup, ITS Leeds & Accent;
- a literature review of CVTT estimates from the UK and elsewhere in Europe;
- empirical testing of the route choice implications of CVTT using Trafficmaster data for a small sample of OD pairs.

WSP et al. (2018) concluded that: '*…there is a strong body of evidence that travel time is valued more highly in congested conditions. However, that evidence is currently insufficient to allow us to formulate VTT as a function of congestion in a way that would allow it to be included in modelling and appraisal. Further work is therefore required to get to the position where congestion-dependent VTT could become a TAG requirement'.*

The scope of the WSP et al. (2019) study encompassed the following tasks:

- 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.

The transport model adopted as a testbed was the Policy Responsive Integrated Strategy Model (PRISM). This is a detailed model of the West Midlands Metropolitan Area, which links separate Highway and Public Transport Assignment Models (HTAM and PTAM respectively) with a Variable Demand Model (VDM). The following specific tests were implemented:

i) Test CVTT in the base year highway assignment, to investigate how it affects the model validation.

ii) Test 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 focussed upon a hypothetical major road scheme.

iii) Use the results of ii) 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.

Informed by these tests, WSP et al. (2019) concluded that: '*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, it would not be acceptable to include the multipliers in the appraisal without also using them in the supporting transport modelling…Further work would be required before this can be recommended as the standard approach in WebTAG'.*

ITS Leeds (2020) were tasked to respond to three overarching questions:

- Has the WSP et al. (2019) CVTT study met its objectives?
- How would the Department implement CVTT in appraisal and what are the barriers to this?
- What are the future research needs for CVTT?

ITS Leeds concluded that WSP et al. (2019) had '*demonstrated through the case study that it is technically feasible to represent CVTT in modelling and appraisal. There is no technical showstopper. The issues are (a) whether there is enough behavioural evidence to support a value of M different from unity; (b) whether M multipliers should be deployed in appraisal only or throughout modelling and appraisal; and (c) what testing regime would be required to enable the Department to move forward from case study to implementation in guidance with confidence'.*

ITS Leeds recommended a number of additional desk studies which could help to move the CVTT workstream forward incrementally, in advance of more substantive testing. These studies included the following:

a) A small piece of re-analysis of 2014/15 SP1 and SP3 to examine the relationships between CVTT values, journey purpose and journey length.

b) Further work to compare the relative merits of Approaches 1 and 2 in deriving:

    i) Some notion of a headline VTT representing Average traffic conditions[4]

    ii) CVTTs for both FF and congested travel time based on a single M value of 2

    iii) CVTT as a continuous function of congested travel time

c) A small piece of re-analysis of WSP et al. (2019) to examine the implied elasticities arising from the future year forecasts.

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[4] The weighted average VTT would need to be populated with data on travel times for FF and congested conditions – and this provokes the question of whether such data should be scheme specific or national averages (with the latter perhaps segmented to reflect some notion of scheme type).

d) A review of work elsewhere on continuous values of CVTT together with consideration of how such values could be used to map on to model outputs such as FF time and congested time.

In essence, the current commission undertakes tasks a), b) and d), whilst the WSP et al. team has in parallel been re-commissioned to undertake task c) as well as work to examine the impact of using CVTT during matrix building and its implications for modelling and appraisal.

1.4 Layout of this report

Section 2 to follow introduces some of the theoretical concepts that underpin the valuation of congested travel time. Each of the subsequent five sections is then devoted to one of the following questions which constitute the terms of reference for the current study:

- **Section 3:** Based on the 2014/15 data, looking at games SP1 and SP3, how do CVTT values differ by journey purpose and journey length?

- **Section 4:** When looking at determining headline VTT, what are the relative advantages and disadvantages of using SP3 compared to using SP1?

- **Section 5:** Upon the completion of the re-analysis, do the researchers anticipate there to be a requirement to commission new SP studies (using updated travel data), in order to provide reliable CVTT values for implementation in TAG assuming application of a continuous travel function? If so, what would be the recommended scope for such further study?

- **Section 6:** What are the different options for undertaking any new SP research, and their relative merits? In particular, how can a continuous function relating CVTT to congestion be accommodated, and how can reliability and CVTT be robustly separately identified?

- **Section 7:** Finally, what are the relative advantages and disadvantages of using SP, compared to RP data? What would be a recommended scope for such further study? Can the two be considered as complementary with reference to CVTT?

Having responded to these questions, **Section 8** provides synthesis, whilst **Section 9** issues recommendations.

2 Theoretical background

2.1 Opening comments

This section of the report introduces a series of theoretical concepts which underpin the economics of congestion, dealing firstly with the inherent engineering relationships, and secondly with how these feed through into the economic relationships which will be our primary focus in the remainder of the report.

2.2 The engineering model

Underpinning the economics of congestion are a series of engineering relationships which were first derived by Greenshield (1934), as shown in Figure 2.1 below.

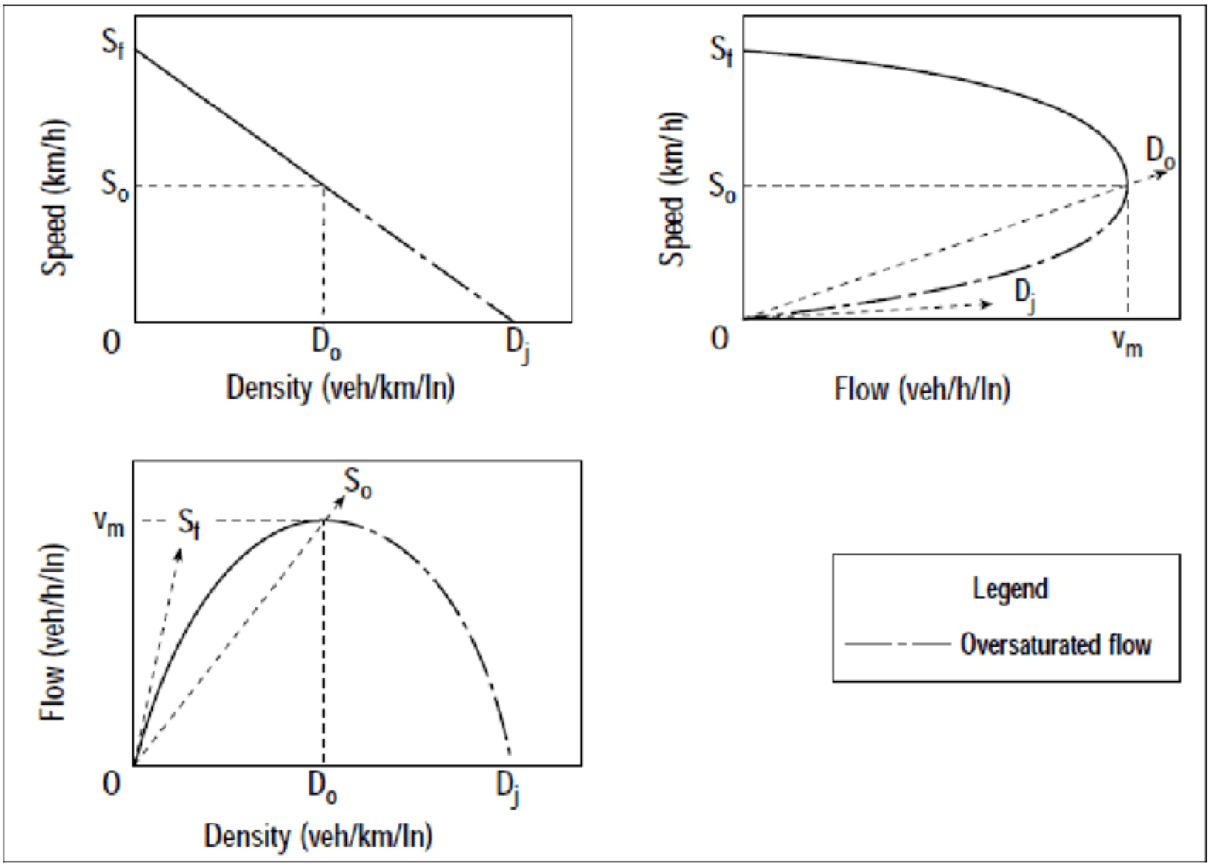

Figure 2.1: Engineering relationships between speed, density and flow on uninterrupted flow facilities (source: Greenshield, 1934)

With reference to the top left panel of the figure, it is assumed that under conditions of uninterrupted flow, speed and density are linearly related. Representing this more formally:

$$v = a - b \cdot k \tag{2.1}$$

where:

v = speed (km/hour)

k = density (vehicles/km)

a = Free-Flow speed (i.e. speed where density is zero)

b = marginal impact of density on speed (i.e. slope of the speed-density function)

a/b = queue density (vehicles/km/lane)

The a and b parameters are typically estimated by collecting field data on speed and density, and then fitting a regression through the data points.

With reference to the bottom left panel of the figure, substituting for speed within the general speed-flow-density relationship using equation (2.1) yields the following:

$$q = (a - b \cdot k) \cdot k \qquad (2.2a)$$

or

$$q = a \cdot k - b \cdot k^2 \qquad (2.2b)$$

Where:

q = flow (vehicles/hour)

Note that (2.2b) gives rise to the observed quadratic relationship between flow and density, and furthermore provides a means of determining the density at which flow is maximised, thus:

$$\frac{dq}{dk} = a - 2bk \qquad (2.3)$$

Setting dq/dk = 0 yields:

$$k = \frac{a}{2b} \qquad (2.4)$$

Therefore, at the density given above, flow is maximized.

Finally, with reference to the top right panel of the figure, substituting for k within (2.1) using (2.4) gives rise to the quadratic relationship between flow and speed, and furthermore determines the speed at which flow is maximized:

$$v = a - b \cdot \left(\frac{a}{2b}\right) \qquad (2.5a)$$

Or

$$v = \frac{a}{2} \qquad (2.5b)$$

In other words, maximum flow occurs when traffic is flowing at half of the free-flow speed.

Finally, substituting for optimal speed and density within (2.2b) using (2.5b) and (2.4) respectively yields the maximum flow:

$$q = \left(\frac{a}{2}\right) \cdot \left(\frac{a}{2 \cdot b}\right) \qquad (2.6a)$$

or

$$q = \left(\frac{a}{2}\right) \cdot \left(\frac{a}{2 \cdot b}\right) = \frac{a^2}{4b} \qquad (2.6b)$$

The key findings from these relationships can be summarised:

- **When density is zero, flow is zero because there is no traffic on the road.**
- **As density increases, flow increases to some maximum.**
- **When maximum density is reached – here characterised in terms of queue density – traffic is gridlocked and flow falls to zero.**

That is to say, as density increases from zero, flow increases to some maximum, but further increase in density will cause flow to decrease until gridlock is reached.

2.3 The economic model

Having laid out the inherent engineering relationships, let us now turn our attention to the corresponding economic relationships, which have been considered by Evans (1992), Vickrey (1969), Neuberger (1971), De Meza & Gould (1987) and Walters (1961), among others[5].

A key point noted by Evans (1992) is that, in the literature on the economics of congestion, confusion is often caused by the fact that the variable factor (vehicles plus drivers) is under the control of the ultimate consumer of the final product (journeys completed). He observed that, in a conventional consumption/production context, the demand for a factor of production (e.g. labour) is derived from the demand for the product – such that the consumer's decision to buy the product is separable from the employee's decision to work for the wage offered. By contrast, in the context of road congestion, the decision to carry out a journey is confounded with the decision to put a vehicle on the road.

Evans' framework (Figure 2.2) was motivated by the critique that previous expositions of the economics of congestion had represented demand in terms of traffic flow (e.g. Neuberger, 1971; De Meza & Gould, 1987). He asserted: '*But whereas consumers choose whether to buy goods given the price, they do not choose a traffic flow given the price. The traffic flow is an endogenous variable resulting from the characteristics of the road and interactions among road users. They actually make a choice whether, given the cost of a journey, they should put*

[5] Note that this body of work refers to generalised congestion. There is a separate, but related, literature dealing with the specific phenomenon of 'bottleneck congestion' (e.g. Vickrey, 1963, 1969; Arnott et al., 1990), which has attracted particular interest in the economics of congestion.

their vehicles on the road. Thus the decision to undertake a journey affects the number of vehicles on the road, or density, directly and traffic flow only indirectly'.

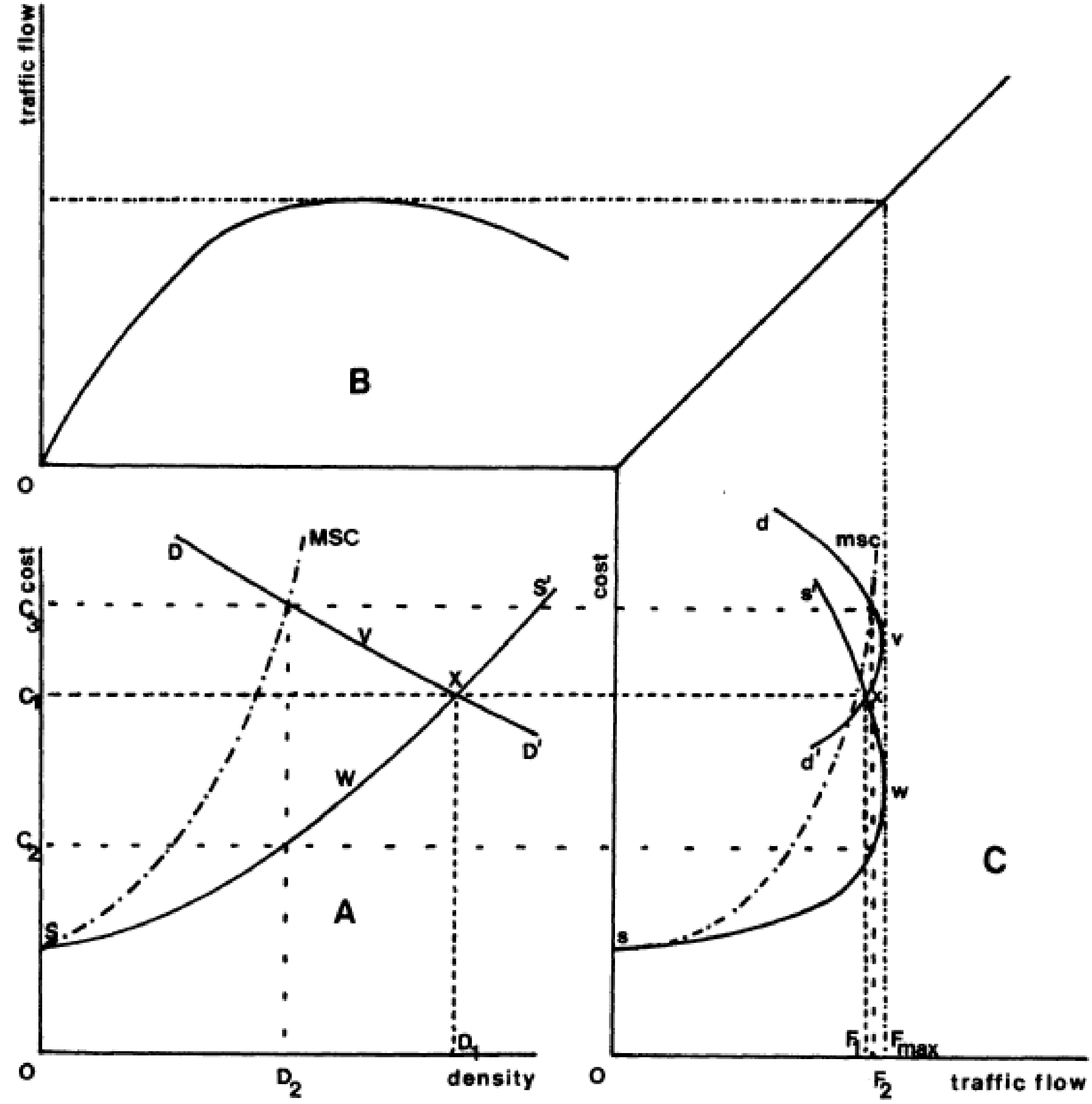

Figure 2.2: Economic relationships between speed, density and flow on uninterrupted flow facilities (source: Evans, 1992)

On this basis, and with reference to panel A of Figure 2.2, the 'true' demand function DD' relates density to the 'generalised cost' (GC) of the journey, including the time costs imposed by congestion. This gives rise to a downward sloping function, such that the higher the GC of the journey, the fewer vehicles are put on the road. Turning to the supply-side, the more vehicles that are put on the road, the greater the level of congestion and, it follows, the greater the GC of the journey. The SS' function represents the average generalised cost at different levels of traffic density – this is effectively the cost of joining the road incurred by each additional motorist ignoring the impacts on other motorists; since these are the costs perceived by the motorist, SS' also corresponds to the supply function. By contrast, the MSC function represents the increasing marginal generalised cost that each additional motorist imposes on all other motorists.

With reference to panel B, this simply reproduces the flow-density relationship from earlier. Since traffic speed decreases as density increases, flow as a function of density reaches a peak and then declines.

With reference to panel C, which is derived from panels A and B, the ss' function represents the average generalised cost relating to congestion in a simple interaction model and the msc function is the associated marginal generalised cost, both of which now relate to the speed-flow relationship (as opposed to density in panel A). In this context, a relationship is established between physical traffic flows and GC, such that the faster the travel the lower the GC, all else equal. On this basis, the ss' function in panel C represents the average generalised cost at different levels of traffic flow. Given the inverse relationship between speed and GC, ss' gives rise to the reverse of the speed-flow curve, with the positively-sloped portion corresponding to the negatively-sloped section of the speed-flow curve. The msc curve accounts for the congestion costs that each additional user places on existing traffic flow. The dd' function is a derived demand curve reflecting the way in which the desired traffic flow changes as the GC changes with more/less vehicles being put on the road.

In the absence of traffic restraint, traffic density in panel A will be determined where the demand for road space (DD') equals the average cost (SS') of joining the road – at D1. This exceeds the optimal density, where road users take account of the impedance they impose on others, which is where MSC is equated with demand – at D2. Relating this to traffic flow in panel C, the optimal flow is where the msc curve intersects the derived demand curve – at F2.

The key findings from these relationships can be summarised:

- **When density is zero, MSC is zero because there is no traffic on the road.**
- **As density increases, MSC increases to the societal optimum where it intersects demand.**
- **Noting that the societal optimum does not correspond to the maximum flow, it is not necessarily efficient to completely eliminate congestion.**

2.4 Relating these relationships to the present study

The theoretical background described above provokes a number of comments in relation to the present study:

- First and foremost, theory provides a basis for linking valuations of congested travel time to speed/density/flow relationships via the construct of a generalised cost function.

- Second, as conventionally formulated, GC is taken to be the sum of vehicle operating cost and travel time multiplied by the unit value of travel time (varying by user class).

- Third, the concept of congested values of travel time introduces the notion that the unit value of a minute spent in 'congested' conditions (somehow defined) may be greater than a minute spent in 'normal' conditions (somehow defined). This might reflect the stress and inconvenience of delay and/or the discomfort and annoyance of queuing in traffic.

- Fourth, with reference to panel A in Figure 2.2, the functional relationship between generalised cost (both average and marginal) and density is shown to be concave up increasing – such that generalised cost increases with density and at an increasing rate. This suggests not only that a congested minute may be valued more than a normal minute, but that a congested minute may be valued more the longer is spent in congestion.

- Fifth, whilst panel A represents generalised cost as a smooth continuous non-linear function, practical implementation of this is difficult, and pragmatic convention has been to employ a linear approximation.

3 Based on the 2014/15 data, looking at games SP1 and SP3, how do CVTT values differ by journey purpose and journey length?

3.1 Opening comments

This section of the report reports the principal analysis task of the current commission, which involved re-analysing the 2014/15 data with a particular focus on how the congested values or multipliers (depending on how they are presented) vary by journey purpose and journey length. The section is organised as follows. Section 3.2 provides a summary of the data used for re-analysis. Section 3.3 summarises the structure of the original choice models from 2014/15 and makes the link to CVTT and congestion multipliers. Section 3.4 sets out a modelling approach to study the properties of CVTT and congestion multipliers by journey purpose and journey length. Section 3.5 reports the results of the re-analysis and Section 3.6 provides a synthesis of the results.

3.2 The data used for re-analysis

In late 2014, SP survey data were collected for different journey purposes (Commute, EB, and Other Non-Work) and modes (car, bus, rail and other public transport). In this re-analysis, only the data relating to car journeys is considered. For car journeys, congestion was included as an explicit attribute in SP3. For bus journeys, congestion was also included as an attribute of SP3, but such impacts are outside the scope of this re-analysis. The 2014/15 SP data will therefore be re-analysed for all three journey purposes by car. The same data cleaning criteria have been applied to the data such that the samples match those used in the 2014/15 study and allow for the fairest comparison of results.

As described in Section 1 of this report, each respondent was presented with three different SP games covering respectively:

- SP1 – a simple time vs. cost trade-off
- SP2 – trade-offs between time, cost and travel time reliability
- SP3 – trade-offs between time spent in different crowding conditions (Free-Flow, Light Congestion, and Heavy Congestion) and cost

In the 2014/15 study, these three SP games were jointly estimated (see Section 3.3), and this joint model was estimated separately for each journey purpose. As such, three choice models by journey purpose (Commute, EB and ONW) from the 2014/15 study are relevant to present interests (see Table 4.11 in the 2014/15 final report, Arup et al. (2015), pp138-140). The focus of this re-analysis is on the CVTT, which requires consideration of SP1 and SP3, and SP2 will not therefore be considered further.

3.3 Summary of the choice models used in the 2014/15 study

As per convention in VTT studies, the choice models estimated in the 2014/15 study are grounded in the logit formulation but comprise several unique features that are worth elaborating on to provide a better understanding of the modelling approach. For a full description of the modelling approach, the interested reader is referred to Hess et al. (2017) and the final report of the 2014/15 study (Arup et al., 2015). For the purposes of this re-analysis, a high-level overview is provided below and, in the analysis that follows, only minimal changes are made to the original model specification.

3.3.1 Random Valuation

In SP1, respondents are presented with a simple trade-off between travel time and travel cost for two alternative routes, and asked which route they would choose. At the point of indifference between the two routes, the ratio of difference in travel costs over the difference in travel times gives rise to the notion of the *boundary value of time* (BVTT), as defined below:

$$BVTT = -\frac{(TC_1 - TC_2)}{(TT_1 - TT_2)} \qquad (3.1)$$

Where TC_1 and TT_1 are the travel cost and travel time of route 1 respectively, and similarly for route 2. In effect, selecting the fast but expensive option will reveal that a respondent's VTT is above the BVTT, whereas selecting the slow but cheap option will reveal that a respondent's VTT is below the BVTT. Following Cabral et al. (2016), use of the concept of BVTT allows for directly estimating the VTT; this is also known as working in *Random Valuation* space as opposed to *Random Utility* space. A benefit of working in Random Valuation space is that the VTT is directly estimated, as opposed to Random Utility space where the VTT must be derived indirectly as the ratio of the marginal utility of travel time over the marginal utility of travel cost.

3.3.2 Multiplicative error term

On top of working with Random Valuation space, the 2014/15 study adopts what is known as a multiplicative (as opposed to additive) error structure (Fosgerau & Bierlaire 2009). As pointed out by Hess et al. (2017), the multiplicative error structure allows for the error variance of utility to increase with utility whereas for an additive error structure the error variance of utility is assumed to be constant. In the context of this re-analysis, this implies that the error variance of the logit model is increasing with the length of the trip as represented by longer journeys at higher costs – which is considered a reasonable assumption.

3.3.3 Observed and unobserved heterogeneity in the VTT

The 2014/15 model allows the VTT to vary by trip and traveller characteristics. Elasticities are estimated to infer the extent that the VTT varies by travel time, distance, cost and income. Additional parameters are estimated to determine how traveller characteristics, such as age and gender, affect the VTT. Similarly, a set of covariates is estimated to capture variation in the VTT by characteristics of the trip. For example, travelling with others could lower an individual's VTT for a given journey. Such observed heterogeneity in the VTT is modelled in the form of multipliers, typically relative to a base category such that, for example, a value of 0.75 for female travellers would indicate that their VTT is 75% of that of male travellers whilst controlling for other variables.

Since it is not practically feasible to capture all relevant factors driving variations in the VTT, any remaining heterogeneity in the VTT is captured by means of a mixed logit, or random parameter, specification. That is, the base VTT parameter is assumed to follow a distribution across the population. The 2014/15 study assumed the base VTT parameter to follow a log-uniform distribution. This distributional form has two desirable features. Firstly, it ensures that the VTT is strictly positive in the population of interest. Secondly, and relative to the log-normal density, the log-uniform density has less mass in the upper tail, implying that there is a smaller probability of people having an extremely high VTT.

3.3.4 Reference dependence (or size and sign effects)

The SP choice tasks presented to respondents in the 2014/15 study were all designed around a self-reported reference trip. That is, the presented attribute levels for travel time and travel cost embodied positive and negative variations around the self-reported travel time and travel cost. From behavioural economics, it is well known that respondents act differently to gains and losses (e.g. shorter and longer and (or) cheaper and more expensive journeys). The 2014/15 study incorporated such phenomena in the design and model by following the framework of De Borger & Fosgerau (2008). That is to say, the model accounts for:

- sign effects, highlighting that, in absolute terms, the marginal (dis)utility of losses (e.g. higher travel times or costs) may be greater than the marginal utility of gains; and
- size effects, highlighting that respondents may become more or less sensitive, in marginal utility terms, when gains/losses in travel time (or cost) are increasing in size.

3.3.5 Design characteristics

The 2014/15 model also accounts for variables that are related to the design of the SP games. The most important one for this re-analysis is that by jointly modelling SP games 1-3, multipliers are estimated allowing for the possibility that the VTT revealed in SP1 may be different from that revealed in SP3. Such differences can be attributed to differences in SP presentation, i.e. variations in attributes across SP games, as well as variations in the definition of travel time. For car journeys, SP3 separates out travel time into three different traffic conditions (Free-Flow, Light Congestion and Heavy Congestion) whereas SP1 assumes Average traffic conditions across the full journey. These multipliers are therefore relevant when contrasting the VTT with the CVTT and deriving the corresponding congestion multipliers.

A set of scale parameters is estimated indicating whether the degree of error variance in the logit model is different across the different SP games. Furthermore, a set of covariates is included controlling for artefacts of the SP presentation that should be unrelated to the VTT. For example, whilst the SP presentation was to some extent randomised, there are covariates accounting for any systematic effects associated with left-hand-side vs. right-hand-side choices in the SP games, and with the ordering of SP2 before vs. after SP3. Such covariates are not used to determine the nationally representative VTT taken forward to TAG, but do allow for a cleaner representation of the VTT.

3.3.6 Behavioural and appraisal VTTs and the congestion multiplier

The estimated choice models provide estimates of how VTTs vary across individuals and the trips they are making. In relation to unobserved heterogeneity in the VTT, a mean or expected VTT can be derived for a given trip and person. Hess et al. (2017) explain how a 'reference free' VTT can be obtained, by taking the geometric mean of the VTT over the gain and loss domains. However, the non-linearity of gains and losses still plays a role, and hence the recommended VTTs from the 2014/15 study depend on the size of the proposed change in travel time. This is known as the 'deltaT' effect.

In translating these behavioural VTTs into appraisal VTTs suitable for adoption in TAG, the key requirement is to correct for the representativeness of the SP sample of travellers and trips *vis-à-vis* the travelling population as a whole. In the 2014/15 study, this was achieved by applying the modelled behavioural relationships to the sample of travellers and trips recorded in the National Travel Survey (NTS) over the period 2010-2012. The choice model was applied to each trip in the NTS, and a VTT derived accordingly, assuming a deltaT of 10 minutes. A weighted average of these VTTs across all NTS trips was then taken, where the weights were based on the NTS trip weights and distance. The trip weights act as expansion factors such that the NTS sample provides a nationally representative picture of trips taking place. The above process was automated using an 'Implementation Tool' coded in the R language. Having followed the above process, it was decided in 2014/15 that 'headline' VTTs (segmented by journey purpose, and also by mode and distance in the case of EB) for adoption in TAG should be based on SP1[6].

A corresponding headline value taking account of traffic conditions (i.e. CVTT) could be derived analogously, by assuming that the journey is conducted entirely in FF, LC or HC conditions. Alternatively, a headline VTT could be derived as a weighted average of the time spent in each of the three traffic conditions[7]. It is the comparison between SP1 and SP3 values and between traffic conditions in SP3 that establishes the notion of a congestion multiplier.

As previously discussed in Section 1.2, congestion multipliers arise as the ratio of a given CVTT versus a given base VTT. In terms of the 2014/15 study, the two most immediate options for the base VTT are either the SP3 value for FF or the SP1 value for Average congestion. Equation 4.45 in the 2014/15 report highlights that the congestion multiplier (i.e. the ratio of two VTTs) depends on two factors. First, it depends on the game specific multiplier, which estimates how FF, LC and HC are valued relative to Average congestion in SP1, and second, it depends on the

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[6] This was Approach 1 to deriving the headline VTT outlined in Section 1.2.

[7] This was Approach 2 to deriving the headline VTT outlined in Section 1.2.

level of reference dependence associated with the specific VTT. For example, when FF is taken as the base VTT and we are interested in the congestion multiplier of HC relative to this base, the multiplier reduces to the ratio of the game specific multipliers for HC and FF, because the level of reference dependence is constant within SP3. However, when the SP1 VTT is taken as the base, the congestion multiplier is driven by i) the estimated game specific multiplier for HC as per the previous example, plus ii) differences in the degree of reference dependence between SP1 and SP3. Taking SP1 as the base for the congestion multiplier thus introduces a degree of confounding between the disutility of congestion and the length of the trip (through deltaT).

3.4 Proposed modelling approach and working hypotheses

To better understand the impact of journey length and purpose on the CVTT and its associated multipliers, it was decided that the analysis should only focus on the two relevant SP games, namely SP1 and SP3. Removing SP2 data, however, meant that the original choice models needed to be re-estimated and validated. With fewer observations available to estimate the joint model, it could well be that certain variables are no longer significant, due to increased standard errors, or changes in the size or even sign of the parameters. The objective was, however, to remain faithful to the original choice model specification as far as possible.

Initial analysis revealed that, in re-estimating separate choice models on SP1 and SP3, the SP1 relationships were largely comparable to the original 2014/15 model estimated on SP1-3. However, the same exercise for SP3 proved more problematic. A possible explanation is that, by splitting the travel time into three separate components, SP3 is the game with the largest number of attributes. With a reduced number of observations (only five (i.e. from SP3 alone) instead of fifteen observations (i.e. five from each of SP1-3) per respondent), the model must determine how the VTT varies across individuals and trips with less information available. In the case of SP1, this is somewhat easier since only two attributes are involved – travel time and travel cost. The SP3 models revealed very high levels of unobserved heterogeneity in the VTT, resulting in very high CVTTs, such that even the expected CVTT for FF was higher than the VTT for Average traffic conditions from SP1. This was considered undesirable. Consequently, it was decided to jointly estimate choice models on SP1 and SP3, since this would minimise the amount of model simplification that was needed, and ensure consistency of approach across SP1 and SP3.

That said, two sets of simplifications were imposed. The first simplification was to remove reference dependence. On the one hand, this was imposed because reference dependence is a confounding influence on the congestion multiplier of SP3 values relative to SP1, as argued at the end of Section 3.3. On the other hand, the original specification of reference dependence for SP3 was based at the level of total travel time, not the amount of time spent in the different traffic conditions. Retaining this functional form would seriously prohibit alternative functional forms for representing the impact of journey length on CVTT and the corresponding multipliers.

The second simplification concerned the self-reported share of travel time spent in LC and HC during the reference trip, which was represented by variables in the original choice models for Commute and ONW. These variables resulted in a higher VTT, but the associated parameters were insignificant at the 95% confidence level. The likelihood was that, in the absence of SP2, these variables would become less significant still. Moreover, retaining these variables in the model would have introduced two distinct representations of congestion: a) the degree of congestion self-reported for the reference trip; b) the degree of congestion presented in the SP choices. It is the latter dimension that is of interest to this study, and it was therefore decided to remove the variables based on self-reported traffic conditions.

After making the above simplifications, the model assumes there is a base VTT, which varies due to traveller, trip and design characteristics. Moreover, the VTT is assumed to follow a distribution in the population due to unobserved preference heterogeneity. In the simplest form we can then specify the attractiveness of the two alternatives in SP1 by:

$$V_{SC} = \mu_{SP1} \cdot \ln(BVTT) \qquad (3.2)$$

$$V_{FE} = \mu_{SP1} \cdot \ln(VTT) \qquad (3.3)$$

Where V_{SC} refers to the utility of the slow but cheap route, and V_{FE} to the utility of the fast but expensive route. μ_{SP1} represents the scale parameter of SP1 and is inversely related to the error variance. $BVTT$ denotes the boundary value of time in each choice task as described in Section 3.3.1. The VTT is the value of travel time for a given person for a given trip. The parameters of that function for VTT are estimated in the analysis. The ln() functional form facilitates the implementation of multiplicative errors in estimation software (see Section 3.3.2).

The utility functions for SP3 can be described in a similar fashion by

$$V_j = -\mu_{SP3} \cdot \ln\left(VTT \cdot \left(\lambda_{FF} \cdot FF_j + \lambda_{LC} \cdot LC_j + \lambda_{HC} \cdot HC_j\right) + TC_j\right) \qquad (3.4)$$

Where V_j refers to the utility of alternative *j*, and *j* takes the value of either 1 or 2 as only two choices are presented to respondents in all SP games. μ_{SP3} represents the scale parameter of SP3 and is inversely related to the error variance. *VTT* and its associated parameters are identical to the VTT used in SP1 because the two datasets are jointly analysed. Of interest to the present study are the three λ parameters, which capture the multipliers of the Free-Flow (FF), Light Congestion (LC) and Heavy Congestion (HC) traffic conditions relative to the Average traffic conditions described in SP1.

In relation to the motivating question of this re-analysis (i.e. *'Based on the 2014/15 data, looking at games SP1 and SP3, how do CVTT values differ by journey purpose and journey length?'*), elasticities of the VTT with respect to cost, time and distance are estimated. These variables are highly correlated with journey length and the estimated elasticities in the 2014/15 study already indicate that the VTT is increasing with journey length. In the aforementioned model structure, the congestion multiplier is constant relative to the VTT, whilst the latter is allowed to vary with journey length.

The presented model specification should be considered as an alternative base model for the VTT. In the same vein as the original 2014/15 models, the estimates for the new base model reveal the extent to which the VTT varies across travellers and trip characteristics. Instead of feeding these new choice models into the 2014/15 Implementation Tool, this study will examine the impact on the CVTT by means of studying the sample of SP respondents. Not only does this involve a smaller amount of work proportionate to the study budget, but it also means that this study does not seek to deliver new headline VTTs for TAG. Rather its main purpose is to better understand how the CVTT and congestion multipliers vary by journey length and journey purpose.

To address this research question, two variations of the new base model will be analysed:

1. An alternative specification for SP3 where the absolute time spent in a given traffic condition is replaced by the share of time spent.
2. An extension to the model specification for SP3 which examines whether the disutility of travel time spent in the various traffic conditions is non-constant. That is, does the crowding multiplier increase the longer drivers spent in Light and Heavy Congestion conditions?
3. An extension of the model specification for SP3 where the congestion multipliers vary by journey length. This is achieved by interacting the time, distance and cost elasticities with the congestion multipliers. This will enable us to address the question of whether the congestion multipliers are increasing with journey length in general and not just by traffic conditions.

3.5 Results

3.5.1 Results for the Commute sample

The analysis of the Commute sample starts by comparing estimates of the CVTT and related congestion multipliers from the new base model on SP1 and SP3, relative to the original 2014/15 model estimated firstly on SP1-3 and then on SP1 and SP3 only.

As highlighted in Section 3.4, the choice models will be applied to the SP sample as opposed to the representative NTS sample to obtain an estimate of the CVTT and the congestion multipliers. Table 3.1 highlights that when the original 2014/15 choice model is applied to the SP data the CVTT estimates are higher than those coming out of NTS sample (i.e. through the Implementation Tool). There are two reasons for this. First, the SP sample contains on average longer and more expensive trips, because it is more difficult to intercept travellers on short journeys. Second, the CVTT measures in the SP sample are unweighted, such that there is no correction for representativeness using expansion or distance weights.

The second model in Table 3.1 removes the SP2 data from the joint model – but otherwise maintains the original 2014/15 model specification. The smaller dataset reduces the log-likelihood, but has only a marginal impact on the estimated model parameters and the resulting CVTT measures. Most notably, a slight reduction in the VTT for SP1 is observed. This is due to a lower estimate of the reference dependence effect found for SP1. The SP3 values for the different traffic conditions and associated multipliers are, however, comparable to the results based on the full dataset. The impact of removing SP2 is therefore marginal.

When additionally applying the simplifications of removing the reference dependence effects and the self-reported congestion effects in the new base model, more substantial changes are observed to the model parameters and the CVTT values. Removing the reference dependence effects causes, as expected, an increase in the degree of unobserved preference heterogeneity. In addition, the estimated congestion multipliers increase relative to the original model specification. Note that in the new base model specification, the estimates are a direct estimate of the congestion multiplier, since the confounding effect of reference dependence has been removed. The income, cost and time elasticities all become smaller in magnitude, highlighting that the VTT is still increasing with journey length but to a smaller extent. All other parameters are comparable to the original model specification.

By sacrificing a significant degree of non-linearity in the model, it is not surprising that the model fit decreases. The changes in parameter estimates, however, highlight that reference dependence effects vary across individuals and are not independent of journey length. Further research could examine the relationship between these variables in more detail. Removing reference dependence is, however, an essential simplification to enable more in-depth study of the congestion multipliers, and hence the new base model is our preferred specification for the purposes of this study. Altogether, the net effect is that for the new base model the mean VTT in the SP sample for SP1 decreases from 12.48 £/hr to 10.17 £/hr, whereas the SP3 VTTs and congestion multipliers increase relative to the original Commute model specification.

We now proceed to discuss the three variations around the new base model as set out at the end of Section 3.4. The results are reported in Table 3.2. The first alternative specification does not work with the absolute time spent in different traffic congestion, but rather with the *share* of time spent in the different traffic conditions. On this basis, the indirect utility function for SP3 changes to:

$$V_j = -\mu_{SP3} \cdot \ln\left(TC_j + VTT \cdot TT_j \cdot \lambda_{FFT}^{\left(\frac{FFT_j}{TT_j}\right)} \cdot \lambda_{LCT}^{\left(\frac{LCT_j}{TT_j}\right)} \cdot \lambda_{HCT}^{\left(\frac{HCT_j}{TT_j}\right)} \right) \quad (3.5)$$

Where TT_j refers to the total travel time and the multipliers are associated with a power term relating to the share of travel time spend in that condition. When all travel time is spent in one of the traffic conditions, λ has the same impact as in the original specification and hence its interpretation remains that of the congestion multiplier.

Table 3.1: Contrasting the new base model for Commute against the original 2014/15 study

	2014/15 model		***Original 2014/15 model on SP1 and SP3 data only***		***New base model***	
Respondents		922		922		922
Observations		13830		9220		9220
Final LL		-7332.67		-4787.29		-4823.29
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	-0.356	-1.74	-0.373	-1.71	-0.675	-3.37
b_log(VTT)	3.706	15.62	3.656	14.78	4.323	20.96
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 travel time	1.000		1.000		1.000	
SP2 travel time	1.599	4.05				
SP2 std dev of travel time	0.580	-4.75				
SP3 Free-Flow	0.697	-2.26	0.696	-2.12	0.808	-1.62
SP3 Light Congestion	0.977	-0.14	0.976	-0.14	1.129	1.02
SP3 Heavy Congestion	1.856	2.98	1.852	2.74	2.103	5.91
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.580	6.10	0.514	5.10	0.444	4.93
cost elasticity	0.679	3.70	0.585	2.96	0.536	3.03
time elasticity	-0.624	-2.62	-0.467	-1.83	-0.202	-0.91
Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
unstated income	2.477	0.65	1.407	0.27	2.152	1.45

unknown income	1.426	1.16	1.075	0.17	0.877	-0.33
refused income	0.770	-1.30	0.748	-1.21	0.871	-0.61
female (base=male)	1.367	2.26	1.359	2.00	1.225	1.53
aged 17-29 (base =30+)	1.365	1.76	1.293	1.35	1.277	1.39
Self-employed (base = any other)	1.667	1.97	1.883	2.16	1.875	2.42
Travel cost paid by company (base = respondent or other paid)	2.219	3.09	2.369	2.79	2.374	3.24
trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
Travelling with others (base = travelling alone)	0.669	-3.37	0.732	-2.39	0.785	-1.96
driving on rural roads (base = urban or motorway)	0.812	-1.31	0.869	-0.79	0.757	-1.88
Light Congestion (base = Free-Flow)	1.402	1.57	1.272	1.02		
Heavy Congestion (base = Free-Flow)	1.560	1.78	1.435	1.36		
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 cheap option on left	0.884	-3.26	0.886	-3.26	0.901	-3.19
SP3 cheap option on left	0.928	-1.37	0.928	-1.36	0.916	-1.45
SP2 scale multiplier if SP2 befor SP3	0.894	-2.63				
scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.198	14.71	1.218	14.54	1.408	19.69
muSP2	7.738	18.05				
muSP3	5.664	14.65	5.645	14.33	5.676	17.06

Reference dependence parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	
Beta_tt_SP1	-0.400	-3.64	-0.382	-3.24	
Beta_tt_SP2	-0.156	-2.84			
Gamma_tt_SP1	-0.213	-3.52	-0.207	-3.44	
Eta_tt_SP1	0.257	4.34	0.251	4.30	
Eta_tc_SP1	0.127	2.18	0.118	2.07	
Eta_tt_SP2	0.087	1.43			
Eta_tc_SP3	0.277	1.51	0.287	1.51	
VTT in SP sample (£/hr)	mean		mean		mean
SP1	13.09		12.48		10.17
SP3FF	6.72		6.65		8.22
SP3LC	9.42		9.33		11.48
SP3HC	17.89		17.70		21.39
Ratio of VTT	mean		mean		mean
SP3-FF/SP1	0.51		0.53		0.81
SP3-LC/SP3-FF	1.40		1.40		1.40
SP3-HC/SP3-FF	2.66		2.66		2.60

Table 3.2: Impact of different model specifications on the choice models and CVTT for the Commute sample

	New base model		***Share of time spend in conditions***		***Quadratic impact of congestion***		***Exponential impact of congestion***	
Respondents		922		922		922		922
Observations		9220		9220		9220		9220
Final LL		-4823.29		-4818.19		-4819.34		-4811.24
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	-0.675	-3.37	-0.682	-3.40	-0.678	-3.38	-0.692	-3.42
b_log(VTT)	4.323	20.96	4.333	21.05	4.326	20.98	4.352	20.90
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 travel time	1.000		1				1	
SP3 Free-Flow	0.808	-1.62	0.874	-1.12	0.831	-1.40	0.758	-2.00
SP3 Light Congestion	1.129	1.02	1.139	1.10	1.013	0.09	0.920	-0.59
SP3 Heavy Congestion	2.103	5.91	2.352	6.56	1.996	5.27	1.917	4.94
					est	rob t-ratio (0)	est	rob t-ratio (0)
SP3 congestion quadratic					0.162	2.14		
SP3 congestion exponential							0.105	2.92
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.444	4.93	0.442	4.90	0.446	4.95	0.438	4.82
cost elasticity	0.536	3.03	0.540	3.04	0.533	3.01	0.529	2.97
time elasticity	-0.202	-0.91	-0.207	-0.93	-0.210	-0.95	-0.220	-0.98

Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
unstated income	2.152	1.45	2.197	1.48	2.152	2.71	2.128	1.42
unknown income	0.877	-0.33	0.883	-0.31	0.870	2.29	0.886	-0.30
refused income	0.871	-0.61	0.875	-0.59	0.871	4.13	0.872	-0.61
female (base=male)	1.225	1.53	1.229	1.56	1.219	1.50	1.218	1.48
aged 17-29 (base =30+)	1.277	1.39	1.279	1.40	1.284	1.42	1.287	1.43
Self-employed (base = any other)	1.875	2.42	1.880	2.43	1.886	2.44	1.878	2.41
Travel cost paid by company (base = respondent or other paid)	2.374	3.24	2.391	3.25	2.379	3.23	2.408	3.21
Trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
Travelling with others (base = travelling alone)	0.785	-1.96	0.784	-1.97	0.787	-1.94	0.779	-2.03
driving on rural roads (base = urban or motorway)	0.757	-1.88	0.759	-1.86	0.758	-1.87	0.757	-1.87
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 cheap option on left	0.901	-3.19	0.901	-3.19	0.901	-3.19	0.901	-3.18
SP3 cheap option on left	0.916	-1.45	0.914	-1.46	0.916	-1.42	0.911	-1.51
Scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.408	19.69	1.409	19.72	1.412	19.74	1.411	19.75
muSP3	5.676	17.06	5.634	16.16	5.591	16.50	6.188	16.30
VTT in SP sample (£/hr)	mean		mean		Mean		mean	
SP1	10.17		10.21		10.13		10.14	
SP3FF	8.22		8.93					

SP3LC	11.48	11.63
SP3HC	21.39	24.02
Ratio of VTT	mean	mean
SP3-FF/SP1	0.81	0.87
SP3-LC/SP3-FF	1.40	1.31
SP3-HC/SP3-FF	2.60	2.70

Table 3.3: Illustration of the VTT for different 30 minutes trips associated with different traffic conditions based on the base and shares models

Absolute (minutes)		***Shares (%)***		***Multiplier***		***Average VTT (£/hr)***		***Absolute change in average VTT (£/hr)***		***Relative change in VTT (%)***	
FF	LC	FF	LC	Base model	Shares model	Base model	Shares model	Base model	Shares model	Base model	Shares model
30	0	100%	0%	0.81	0.87	8.22	8.93				
25	5	83%	17%	0.86	0.91	8.76	9.33	0.54	0.40	1.07	1.05
20	10	67%	33%	0.91	0.95	9.30	9.75	0.54	0.42	1.06	1.05
15	15	50%	50%	0.97	1.00	9.85	10.19	0.54	0.44	1.06	1.05
10	20	33%	67%	1.02	1.04	10.39	10.65	0.54	0.46	1.06	1.05
5	25	17%	83%	1.08	1.09	10.94	11.12	0.54	0.48	1.05	1.05
0	30	0%	100%	1.13	1.14	11.48	11.63	0.54	0.50	1.05	1.05

For this shares-based specification, the growth rate of the VTT will be constant for every additional minute spent in congested conditions. The disutility of travel time in congested conditions is therefore non-constant and increasing when more time is spent in more severe congestion conditions. The estimated parameters of the choice model are largely consistent with the new base model, but we do observe small increases in the VTT and crowding multipliers. The change is largest for the congestion multiplier on HC (relative to SP1), which increases from 2.10 to 2.35. Within SP3 the relative congestion multipliers remain constant.

To illustrate the VTTs associated with the new base model and the shares-based model, Table 3.3 assumes a 30-minute trip of which a proportion is spent in Light Congestion. Both models adopt their respective expected VTTs for SP1 (based on the SP sample) as the base, respectively £10.17 and £10.21. The results highlight that when the full 30 minutes are spent in Free-Flow or Light Congestion, the multipliers are consistent across the base and shares-based models. For each additional five minutes of travel time in Light Congestion, the new base model increases the average VTT per hour by £0.54 (per hour). For the shares-based model, the average VTT increases more rapidly with every five additional minutes of Light Congestion. The rate of this increase is, however, constant at 5%. This is the first piece of evidence that disutility increases with relatively more time spent in congested conditions. The fit of the shares-based model is better than the new base model, thus lending support to the above conjecture.

An alternative way to accommodate non-constant disutility of travel time spent in congested conditions, is by adjusting the new base model through adding a quadratic term to the disutility of travel time. That is, the model is specified in terms of absolute travel time and includes in addition to the linear effects from the base model the quadratic term $\lambda_{CG} \cdot \left(LCT_j^2 + HCT_j^2\right)$, thus:

$$V_j = -\mu_{SP3} \cdot \ln\left(VTT \cdot \left(\lambda_{FFT} \cdot FFT_j + \lambda_{LCT} \cdot LCT_j + \lambda_{HCT} \cdot HCT_j + \lambda_{CG} \cdot \left(LCT_j^2 + HCT_j^2\right)\right) + TC_j\right) \tag{3.6}$$

In earlier specifications of the quadratic model, the quadratic effect was separated out for Light and Heavy Congestion, with each having their own parameter. The estimated parameters were not significantly different from each other and hence the parameters were assumed to be identical in the model specification reported here. This does not mean that it is the total amount of travel time of which the square is taken – that still happens at the level of Light and Heavy Congestion separately. The multiplier for Light Congestion conditions, relative to SP1, can be described by $\lambda_{LCT} + \lambda_{CG} \cdot LCT_j$ and since the estimated parameter for the quadratic effect in Table 3.3 is positive, the multiplier is increasing with every additional minute spent in congested conditions. Table 3.4 shows the value of the multiplier when a given number of minutes is spent in a congested condition. Every additional minute of FF time is treated the same whereas the multipliers for LC and HC are increasing at a linear pace.

Table 3.4: Multipliers at a given time spend in a given condition relative to SP1 (quadratic)

	Minutes				
Multiplier	10	15	20	25	30
Free-Flow	0.831	0.831	0.831	0.831	0.831
Light Congestion	1.067	1.094	1.121	1.147	1.174
Heavy Congestion	2.050	2.077	2.104	2.131	2.158

The model fit of the quadratic model is slightly worse than that of the shares-based model, but both support the notion of increasing multipliers when more time is spent in congested conditions – either in a relative or absolute terms. Further improvements in model fit can be observed when replacing the quadratic effect with an exponential effect (see Table 3.2). The exponential effect is additional to the linear effect and, in common with the quadratic effect, the parameters for Light and Heavy Congestion are assumed to be common.

$$V_j = -\mu_{SP3} \cdot \ln\Big(VTT \cdot \Big(\lambda_{FFT} \cdot FFT_j + \lambda_{LCT} \cdot LCT_j + \lambda_{HCT} \cdot HCT_j + \lambda_{CG} \cdot \big(\exp(LCT_j) + \exp(HCT_j)\big)\Big) + TC_j\Big) \tag{3.7}$$

Comparing the exponential model with the quadratic, the VTT for SP1 in the sample is roughly equal, but the multiplier for Light Congestion decreases. Table 3.5 further illustrates that the multiplier for Light Congestion is smaller for the exponential model for the presented lengths of time, and the same applies to Heavy Congestion.

Table 3.5: Multipliers at a given time spent in a given condition relative to SP1 (exponential)

	Minutes				
Multiplier	10	15	20	25	30
Free-Flow	0.758	0.758	0.758	0.758	0.758
Light Congestion	1.044	1.054	1.066	1.079	1.093
Heavy congestion	2.041	2.052	2.064	2.076	2.090

It is striking that the parameter estimates across the models presented in Table 3.2 are remarkably robust against the changing model specifications. We interpret this, together with the observed increases in model fit, that there is strong support in the Commute data that the congestion multipliers, and hence the CVTT, is increasing with additional time spent in congested conditions. This effect comes on top of the increases in VTT with journey length due to the cost and time elasticities, irrespective of traffic conditions.

We investigated interactions between the time and cost elasticities and the individual components of travel time in SP3, but did not find definitive statistical evidence of such interactions. In the other two journey purpose samples to follow, we encountered similar results – most likely due to the additional data requirements – and this will not therefore be further reported on. As a result, we assume that the journey length effect and the increasing disutility of spending time in congestion are two distinct but complementary effects causing the CVTT to vary with distance and traffic conditions.

3.5.2 Results for the EB sample

The same approach has been adopted for the EB sample and the main results will be discussed in this sub-section. Table 3.6 provides the model specifications for, respectively, the original choice model of the 2014/15 study estimated on SP1-3, the same model but estimated on SP1 and SP3 only, and finally the new base model on SP1 and SP3 only but with reference dependence effects removed. The original model specification used here did not include variables on the self-reported time spent in Light and Heavy Congestion in the reference trip.

The findings for Table 3.6 are consistent with those for the Commute sample. The parameter estimates are of the same order of magnitude and have the same sign when removing the SP2 data from the analysis. Slightly larger variations in parameter estimates are observed relative to Commute, but the overall impact on the VTT and congestion multipliers is negligible. Additionally, removing the reference dependence effects from the model increases the amount of unobserved heterogeneity and the estimated congestion multipliers are slightly smaller. Overall, the VTT for SP1 decreases slightly compared to the original 2014/15 model. The loss in likelihood from removing reference dependence is smaller than observed in the Commute model, and we can therefore be confident that the new base mode is not performing substantially worse than the original 2014/15 model.

Table 3.7 reports comparisons of the alternative model specifications with the new base model. Again, the shares-based model fits better than the new base model, supporting the notion that the CVTT increases when relatively more time is spent in congested conditions. As explained before, the growth rate of the CVTT is constant in this specification, but the absolute change is increasing when relatively more time is spent in congested conditions. This change in specification has some impact on the estimated congestion multipliers, but the other parameters in the choice model are robust to the change in specification. The VTT for SP1 (based on the SP sample) is comparable to that of the new base model, but the VTT for travelling in Free-Flow conditions turns out higher and the same applies to travelling in Heavy Congestion conditions.

Table 3.8 provides an illustration of the changes in the VTT associated with spending 30 minutes in different splits of FF and LC. When all time is spent in FF, the shares model gives a higher VTT than the new base model, but both models give a comparable VTT when the full 30 minutes are spent in LC. Accordingly, the absolute step sizes for the base model are larger but constant, whereas for the shares-based model these are smaller but increasing with time spent in LC. The relative change in the shares model is around 5% when time spent in LC increases.

Table 3.6: Contrasting the new base model for EB against the original 2014/15 study

	Original 2014/15 model		***Original 2014/15 model on SP1 and SP3 data only***		***New base model***	
Respondents		917		917		917
Observations		13755		9170		9170
Final LL		-6933.43		-4471.64		-4489.77
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	0.515	3.61	0.476	3.18	0.400	2.70
b_log(VTT)	3.373	18.31	3.322	17.17	3.456	22.90
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 travel time	1.000		1.000		1.000	
SP2 travel time	1.140	0.82				
SP2 std dev of travel time	0.876	-1.04				
SP3 Free-Flow	0.572	-4.54	0.545	-5.07	0.445	-8.36
SP3 Light Congestion	0.921	-0.74	0.882	-1.16	0.731	-4.14
SP3 Heavy Congestion	1.708	4.23	1.644	4.00	1.371	3.96
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.300	3.64	0.234	2.87	0.223	3.05
distance elasticity	0.239	3.41	0.210	2.91	0.180	2.92
cost elasticity	0.451	2.63	0.429	2.39	0.460	2.86
time elasticity	-0.454	-2.29	-0.342	-1.63	-0.235	-1.31

Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
unstated income	0.503	-2.41	0.646	-1.27	0.725	-0.95
unknown income	9.310	2.90	5.758	3.18	4.050	3.48
refused income	0.581	-1.43	0.547	-1.65	0.597	-1.47
Company would buy savings come what may (base=buys if benefits>costs, or unknown)	1.304	1.34	1.315	1.33	1.361	1.74
Company would not buy time savings (base=buys if benefits>costs, or unknown)	0.443	-9.51	0.444	-9.41	0.488	-8.94
Self-employed costs not covered (base=costs covered)	0.563	-3.04	0.559	-3.31	0.590	-3.30
Self-employed (base=paid employment)	0.677	-2.56	0.650	-2.95	0.676	-2.97
Trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
trip with London base origin & destination (base=any other)	1.753	1.42	1.460	1.08	1.571	1.41
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 time shown above cost (multiplicative effects coding)	0.888	-2.52	0.890	-2.53	0.900	-2.64
SP2 scale multiplier if SP2 befor SP3	1.153	2.52				
Scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.735	16.90	1.735	17.03	1.837	21.38
muSP2	6.370	10.95				
muSP3	7.260	16.16	7.253	16.02	7.253	16.80
Reference dependence parameters	est	rob t-ratio (0)	est	rob t-ratio (0)		

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Beta_tt_SP1	-0.114	-1.61	-0.115	-1.57		
Beta_tt_SP2	-0.449	-5.10				
Beta_tc_SP1	0.101	1.83	0.082	1.42		
Gamma_tt_SP1	-0.129	-3.58	-0.124	-3.48		
Gamma_tt_SP2	-0.063	-1.94				
Gamma_tc_SP3	-0.158	-2.11	-0.157	-1.98		
Eta_tc_SP2	0.196	2.14				
VTT in SP sample	mean		mean		mean	
SP1	17.85		17.29		16.78	
SP3FF	7.51		7.31		7.47	
SP3LC	12.09		11.82		12.27	
SP3HC	22.42		22.02		23.00	
ratio	mean		mean		mean	
SP3-FF/SP1	0.42		0.42		0.45	
SP3-LC/SP3-FF	1.61		1.62		1.64	
SP3-HC/SP3-FF	2.98		3.01		3.08	

Table 3.7: Impact of different model specifications on the choice models and CVTT for the EB sample

	New base model		***Shares model***		***Quadratic model***	
Respondents		917		917		917
Observations		9170		9170		9170
Final LL		-4489.77		-4480.55		-4486.83
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	0.400	2.70	0.403	2.73	0.410	2.77
b_log(VTT)	3.456	22.90	3.457	22.87	3.460	22.96
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 travel time	1.000		1.000		1.000	
SP3 Free-Flow	0.445	-8.36	0.541	-7.63	0.467	-7.81
SP3 Light Congestion	0.731	-4.14	0.741	-3.95	0.684	-4.61
SP3 Heavy Congestion	1.371	3.96	1.557	5.33	1.318	3.29
					est	rob t-ratio (0)
SP3 congestion quadratic					0.028	2.06
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.223	3.05	0.222	3.02	0.222	3.04
distance elasticity	0.180	2.92	0.181	2.93	0.182	2.93
cost elasticity	0.460	2.86	0.466	2.90	0.462	2.88
time elasticity	-0.235	-1.31	-0.245	-1.36	-0.248	-1.38
Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)

unstated income	0.725	-0.95	0.726	-0.96	0.725	-0.96
unknown income	4.050	3.48	4.080	3.50	4.081	3.49
refused income	0.597	-1.47	0.603	-1.43	0.596	-1.47
Company would buy savings come what may (base=buys if benefits>costs, or unknown)	1.361	1.74	1.371	1.77	1.365	1.74
Company would not buy time savings (base=buys if benefits>costs, or unknown)	0.488	-8.94	0.489	-8.91	0.489	-8.93
Self-employed costs not covered (base=costs covered)	0.590	-3.30	0.589	-3.31	0.590	-3.29
Self-employed (base=paid employment)	0.676	-2.97	0.675	-2.99	0.676	-2.98
Trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
trip with London base origin & destination (base=any other)	1.571	1.41	1.565	1.39	1.579	1.43
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 time shown above cost (multiplicative effects coding)	0.900	-2.64	0.899	-2.68	0.900	-2.63
Scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.837	21.38	1.842	21.40	1.843	21.40
muSP3	7.253	16.80	7.309	16.35	7.214	16.59
VTT in SP sample	mean		mean		mean	
SP1	16.78		16.76		16.71	
SP3FF	7.47		9.07			
SP3LC	12.27		12.42			

SP3HC	23.00	26.09
ratio	mean	mean
SP3-FF/SP1	0.45	0.54
SP3-LC/SP3-FF	1.64	1.37
SP3-HC/SP3-FF	3.08	2.88

Table 3.8: Illustration of the VTT for different 30 minutes trips associated with different traffic conditions based on the base and shares models

Absolute (minutes)		***Shares (%)***		***Multiplier***		***Average VTT (£/hr)***		***Absolute change in average VTT (£/hr)***		***Relative change in VTT (%)***	
FF	LC	FF	LC	Base model	Shares model	Base model	Shares model	Base model	Shares model	Base model	Shares model
30	0	100%	0%	0.45	0.54	7.47	9.07				
25	5	83%	17%	0.49	0.57	8.27	9.55	0.80	0.49	1.11	1.05
20	10	67%	33%	0.54	0.60	9.07	10.07	0.80	0.51	1.10	1.05
15	15	50%	50%	0.59	0.63	9.87	10.61	0.80	0.54	1.09	1.05
10	20	33%	67%	0.64	0.67	10.67	11.18	0.80	0.57	1.08	1.05
5	25	17%	83%	0.68	0.70	11.47	11.79	0.80	0.60	1.07	1.05
0	30	0%	100%	0.73	0.74	12.27	12.42	0.80	0.64	1.07	1.05

The results for the quadratic model in Table 3.7 are consistent with those obtained in the Commute sample. The quadratic model has a worse fit than the shares model, but it outperforms the new base model. A positive and significant quadratic term is estimated for the time spent in LC and HC, which results in increasing multipliers when additional time is spent in congested conditions (see Table 3.9). The degree of non-linearity identified in the EB sample is, however, smaller than the Commute sample. In the Commute sample, the exponential model specification outperformed the quadratic model. But in the EB sample, the exponential model specification encountered convergence issues and the model could not be estimated.

Table 3.9: Multipliers at a given time spent in a given condition relative to SP1 (quadratic)

	Minutes				
Multiplier	10	15	20	25	30
Free-Flow	0.467	0.467	0.467	0.467	0.467
Light Congestion	0.693	0.698	0.703	0.707	0.712
Heavy congestion	1.328	1.332	1.337	1.342	1.346

3.5.3 Results for the ONW sample

In this sub-section, we follow the same approach for ONW journeys as was followed for Commute and EB journeys. Table 3.10 presents the choice modelling results for the original 2014/15 specification on SP1-3, the original 2014/15 specification without the SP2 data and the new base model on SP1 and SP3 omitting both reference dependence and self-reported congestion. Removing SP2 data has similar impacts to those seen in the previous two sub-sections. Most parameter estimates are of the same order of magnitude and size, but some changes are observed. Specifically, the lower bound and spread of the log-uniform distribution are reduced, which causes the average VTT for SP1 in the sample to decrease relative to the full SP1-3 dataset. This also has an impact on the SP3 VTTs, because the congestion multipliers are constant relative to the original model. Further removing reference dependence and self-reported congestion again shows that the model specification is robust to these simplifications. An increase in the SP1 VTT and congestion multipliers is observed, but the relative magnitudes between the different traffic conditions are constant. Similar to the two preceding sub-sections, the new base model loses some flexibility, but the estimates and values form a good point of departure.

Table 3.10: Contrasting the new base model for ONW journeys against the original 2014/15 study

	Original 2014/15 model		***Original 2014/15 model on SP1 and SP3 data***		***New base model***	
Respondents		977		977		977
Observations		14655		14655		14655
Final LL		-7585.74		-4930.148917		-4957.96
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	-0.884	-2.65	-0.437	-1.47	-0.448	-1.53
b_log(VTT)	3.714	19.16	3.568	17.14	3.852	21.12
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 travel time	1.000		1.000		1.000	
SP2 travel time	2.187	5.52				
SP2 std dev of travel time	0.812	-1.48				
SP3 Free-Flow	0.501	-4.43	0.539	-3.83	0.573	4.63
SP3 Light Congestion	0.880	-0.90	0.949	-0.37	0.996	7.52
SP3 Heavy Congestion	1.995	4.05	2.154	4.78	2.254	10.69
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.682	7.76	0.618	6.57	0.547	6.60
cost elasticity	1.049	6.56	1.035	5.95	0.990	6.16
time elasticity	-0.927	-4.72	-0.918	-4.23	-0.743	-3.76
Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
unstated income	1.012	0.03	1.088	0.20	0.979	-0.05
unknown income	0.300	-5.89	0.367	-4.44	0.394	-4.51

refused income	0.864	-0.77	0.916	-0.41	0.975	-0.13
aged 17-39 (base =40+)	1.453	2.52	1.470	2.50	1.427	2.59
household with 2+ adults (base=1 or no adults)	0.698	-3.47	0.717	-3.00	0.748	-2.78
1+ car owned (base=no cars)	2.683	1.91	1.658	1.45	1.495	1.43
2+ motorcycles owned (base=1 or 0 motorcycles)	0.467	-1.65	0.304	-4.04	0.332	-4.01
Trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
1+ nights away (base=day return)	1.552	2.14	1.595	2.11	1.502	2.12
Light Congestion (base=Free-Flow)	1.355	1.51	1.209	0.93		
Heavy Congestion (base=free-flow)	1.462	1.57	1.425	1.36		
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 cheap option on left	0.926	-2.00	0.928	-2.00	0.940	-1.91
SP3 cheap option on left	0.954	-0.85	0.957	-0.81	0.957	-0.77
Scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.301	16.53	1.309	16.64	1.406	20.43
muSP2	7.539	16.92				
muSP3	5.941	17.07	5.964	17.03	5.865	16.93
Reference dependence parameters	est	rob t-ratio (0)	est	rob t-ratio (0)		
Beta_tt_SP1	-0.137	-1.91	-0.157	-2.08		
Beta_tt_SP2	-0.244	-4.96				
Beta_tc_SP1	0.103	1.78	0.083	1.40		
Gamma_tt_SP1	-0.107	-2.75	-0.109	-2.77		
Gamma_tt_SP2	-0.061	-1.79				

Eta_tt_SP1	0.224	4.20	0.216	4.10	
Eta_tcS_P2	0.224	2.88			
VTT in SP sample	mean		mean		mean
SP1	9.29		8.64		8.50
SP3FF	4.40		4.07		4.86
SP3LC	7.73		7.16		8.47
SP3HC	17.52		16.25		19.16
Ratio	mean		mean		mean
SP3-FF/SP1	0.47		0.47		0.57
SP3-LC/SP3-FF	1.76		1.76		1.74
SP3-HC/SP3-FF	3.98		4.00		3.94

Table 3.11: Impact of different model specifications on the choice models and CVTT for the ONW sample

	New base model		***Shares model***		***Quadratic model***	
Respondents		977		977		977
Observations		14655		14655		14655
Final LL		-4957.96		-4953.82		-4955.05
Parameters of base VTT distribution	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
a_log(VTT)	-0.448	-1.53	-0.472	-1.61	-0.428	-1.47
b_log(VTT)	3.852	21.12	3.881	21.14	3.862	21.13
Game specific VTT multipliers	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)

SP1 travel time	1.000		1.000		1.000	
SP3 Free-Flow	0.573	4.63	0.758	-2.16	0.629	-2.84
SP3 Light Congestion	0.996	7.52	1.060	0.46	0.945	-0.42
SP3 Heavy Congestion	2.254	10.69	2.816	7.21	2.221	5.79
					est	rob t-ratio (0)
SP3 congestion quadratic					0.064	2.04
Key elasticities	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
income elasticity	0.547	6.60	0.550	6.55	0.547	6.55
cost elasticity	0.990	6.16	1.002	6.20	0.995	6.19
time elasticity	-0.743	-3.76	-0.756	-3.80	-0.756	-3.83
Traveller covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
unstated income	0.979	-0.05	0.978	-0.06	0.980	-0.05
unknown income	0.394	-4.51	0.403	-4.40	0.395	-4.51
refused income	0.975	-0.13	0.988	-0.06	0.977	-0.12
aged 17-39 (base =40+)	1.427	2.59	1.438	2.62	1.436	2.62
household with 2+ adults (base=1 or no adults)	0.748	-2.78	0.745	-2.82	0.746	-2.80
1+ car owned (base=no cars)	1.495	1.43	1.516	1.47	1.470	1.39
2+ motorcycles owned (base=1 or 0 motorcycles)	0.332	-4.01	0.328	-4.16	0.323	-4.22
Trip covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
1+ nights away (base=day return)	1.502	2.12	1.511	2.13	1.498	2.10
Design covariates	est	rob t-ratio (1)	est	rob t-ratio (1)	est	rob t-ratio (1)
SP1 cheap option on left	0.940	-1.91	0.939	-1.95	0.940	-1.91

SP3 cheap option on left	0.957	-0.77	0.953	-0.82	0.956	-0.77
Scale parameters	est	rob t-ratio (0)	est	rob t-ratio (0)	est	rob t-ratio (0)
muSP1	1.406	20.43	1.411	20.52	1.413	20.49
muSP3	5.865	16.93	5.869	16.45	5.815	16.73
VTT in SP sample	mean		mean		mean	
SP1	8.50		8.58		8.47	
SP3FF	4.86		6.5			
SP3LC	8.47		9.09			
SP3HC	19.16		24.15			
Ratio	mean		mean			
SP3-FF/SP1	0.57		0.76			
SP3-LC/SP3-FF	1.74		1.40			
SP3-HC/SP3-FF	3.94		3.72			

Table 3.12: Illustration of the VTT for different 30 minutes trips associated with different traffic conditions based on the base and shares models

Absolute (minutes)		***Shares (%)***		***Multiplier***		***Average VTT (£/hr)***		***Absolute change in average VTT (£/hr)***		***Relative change in VTT (%)***	
FF	LC	FF	LC	Base model	Shares model	Base model	Shares model	Base model	Shares model	Base model	Shares model
30	0	100%	0%	0.57	0.76	4.87	6.50				
25	5	83%	17%	0.64	0.80	5.47	6.87	0.60	0.37	1.12	1.06
20	10	67%	33%	0.71	0.85	6.07	7.27	0.60	0.40	1.11	1.06
15	15	50%	50%	0.78	0.90	6.67	7.69	0.60	0.42	1.10	1.06
10	20	33%	67%	0.86	0.95	7.27	8.13	0.60	0.44	1.09	1.06
5	25	17%	83%	0.93	1.00	7.87	8.60	0.60	0.47	1.08	1.06
0	30	0%	100%	1.00	1.06	8.47	9.10	0.60	0.50	1.08	1.06

Proceeding in the same manner as before, Table 3.11 compares the alternative model specifications with the new base model. The shares-based model again fits better than the new base model, supporting the notion that the CVTT increases when relatively more time is spent in congested conditions. As explained before, the growth rate of the CVTT is constant in this specification, but the absolute change is increasing when relatively more time is spent in congested conditions. This change in specification has some impact on the estimated congestion multipliers, especially with the FF multiplier becoming larger. As a result, the multipliers of Light and Heavy Congestion relative to FF are somewhat reduced but still of the same order of magnitude. The other parameters in the choice model are robust to the change in specification.

Table 3.12 provides an illustration of the changes in the VTT associated with spending 30 minutes in different splits of FF and LC. When all time is spent in FF, the shares model gives a higher VTT than the new base model – replicating what was observed in the EB model. The difference between the two VTTs declines when a larger share of the 30 minutes is spent in LC. The absolute step sizes for the base model are larger but constant, whereas for the shares-based model these are smaller but still increasing with time spent in LC. The relative change in the shares model is around 6% when time spent in LC increases.

The results for the quadratic model in Table 3.11 are consistent with those obtained in the Commute and EB samples. The quadratic model has worse fit than the shares model, but better than the new base model. A positive and significant quadratic term is estimated for the time spent in LC and HC, which results in increasing multipliers when more time is spent in congested conditions (see Table 3.13). The degree of non-linearity identified in the ONW sample falls between that of the Commute and EB samples. Like the EB model, convergence issues prevented estimation of the exponential model. However, both the shares model and the quadratic model support the notion that CVTT multipliers increase with the time spent at any given congestion level.

Table 3.13: Multipliers at a given time spent in a given condition relative to SP1 (quadratic)

	Minutes				
Multiplier	10	15	20	25	30
Free-Flow	0.629	0.629	0.629	0.629	0.629
Light Congestion	0.966	0.977	0.987	0.998	1.009
Heavy Congestion	2.243	2.253	2.264	2.275	2.285

3.6 Synthesis

In this section, we have re-analysed the SP1 and SP3 data from the 2014/15 study to explore how the CVTT and congestion multipliers vary by journey purpose and journey length. The analysis focused on car journeys made for Commute, EB and ONW. The input data was identical to that used in the 2014/15 study, but responses to SP2 (on reliability) were removed from the joint analysis.

To better understand the CVTT and its related congestion multipliers several simplifications were applied to the original choice models. Firstly, reference-dependence effects were removed from models because these effects influence the correspondence between SP1 and SP3 values, and as a result confound the interpretation of congestion multipliers and reference dependence. Secondly, variables controlling for the length of time spent in different types of congestion during the self-reported reference trips were removed from the original models because they were found to be insignificant. Joint analysis of SP1 and SP3 facilitated comparison across these SP games and improved empirical identifiability of the choice models.

The adjustments made to the choice models result in slightly lower SP1 values and higher SP3 values and accordingly higher congestion multipliers relative to the 2014/15 study. These findings are robust to alternative representations of the functional form for time spent in different travel time conditions. **Altogether, the re-analysis does not indicate concerns relating to the quality of the original data analysis.** We obtain robust findings that, for the sample analysed, the CVTT and related congestion multipliers are higher than typical results from previous studies (see earlier discussion in Section 1). **Indeed, our results are indicative of congestion multipliers that may be slightly higher than those originally reported in 2014/15.** Part of this can be attributed to the confounding between reference dependence and congestion in the original model specification.

Further tests reveal that the congestion multipliers are non-constant. Additional disutility is obtained when people travel longer in congested conditions, and as a result the congestion multipliers are increasing with the amount of time spent in a given traffic condition. This effect is strongest on commuting trips, but empirical support is found that the congestion multiplier is increasing across all journey purposes. Our results suggest that these non-constant congestion multipliers are a direct result of discomfort from spending time in congested conditions and not of journey length per se.

The non-constant congestion multipliers come on top of increases in VTT with journey length due to the inclusion of cost and time elasticity irrespective of the traffic conditions. We have attempted to study the interactions between these two effects in the analysis, but were unable to estimate models that were sufficiently stable and reliable for reporting. As a result, we assume that the journey length effect and the increasing disutility of spending time in congestion are two distinct but complementary effects causing the CVTT to vary with distance, traffic conditions and journey purpose.

Despite the clarity of these findings, we are however conscious of barriers towards their implementation in modelling and appraisal. Firstly, the congestion multipliers used in the SP3 model correspond to the traffic conditions described in the 2014/15 SP experiment, but these cannot be directly related to any continuous metric of congestion – as would be needed by network modellers. Second, our finding of increasing congestion multipliers with more time spent in congested conditions are not readily implementable in network models – which require constant values of time and multipliers. These issues of implementation will be considered further in Section 5 of this report.

4 When looking at determining headline VTT, what are the relative advantages and disadvantages of using SP3 compared to using SP1?

4.1 Opening comments

Section 1 of this report identified two possible approaches for deriving the 'headline' VTT in combination with CVTT multipliers from the 2014/15 study, referred to as Approaches 1 and 2. Approach 1 to the headline VTT is currently adopted in TAG – but CVTT multipliers have not to date been adopted at all. Since these headline VTTs are not entirely separable from their associated CVTT multipliers, our response to the above question will comment on the different options for deriving the headline VTT, before doing likewise for the associated multipliers. The section closes by synthesising the key issues facing the Department and outlining options for moving forward.

4.2 How should the 'headline' VTT be derived from the 2014/15 study?

Approach 1 to the headline is VTT is based on SP1 of the 2014/15 study, which was a simple time vs. money game assuming certainty of arrival time and 'average' congestion levels. Estimates of the headline VTT from the SP sample were converted into nationally representative estimates appropriate for TAG, segmented by journey purpose and, in the case of EB, also by mode and distance. Despite this segmentation, it is arguable how representative such values are across the full range of journeys (e.g. different levels of reliability and congestion). On a more technical point, the SP1 values from the 2014/15 analysis exhibited significance 'reference effects' – as a result, a given 'deltaT' value (the change in travel time relative to the reference journey) had to be assumed in order to derive representative VTTs suitable for adoption in TAG[8]. By contrast, SP3 did not exhibit reference effects in the VTT[9], and there is thus no requirement to impose a similar assumption when deriving representative VTTs.

TAG distinguishes between three different versions of the headline VTT, expressed in terms of a) factor cost, b) perceived cost and c) market price. In the case of EB, VTT at factor cost and perceived cost are one-and-the-same. In the case of Commute and ONW, VTT at perceived cost and market price are one-and-the-same. Convention is that network modelling should employ VTTs at perceived cost, since these are the values which dictate behaviour, and

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[8] Recall from Section 3 that the re-analysis of the 2014/15 data has removed reference effects.

[9] To be more precise, some reference dependence parameters for SP3 were estimated, but these particular ones cancel out in taking the geometric mean over the gains and loss domain to get the reference-free VTT.

appraisal should employ VTTs at market prices, since these are the values which best represent the opportunity cost of public funds.

Approach 2 to the headline VTT is based on SP3 of the 2014/15 study, which was a time vs. money vs. congestion game, but assuming certainty of arrival time. This presentation might appear more realistic than SP1[10], but in order to derive nationally representative VTTs for adoption in TAG, it would be necessary to take a weighted average based on the proportion of time spent in FF vs. LC vs. HC. It would seem difficult to align these categories with any objective measure of congestion – without clear definitions – and especially so when aggregating across the full range of journeys.

Furthermore, an empirical finding from 2014/15 was that SP respondents reported spending roughly equal proportions of time in FF, LC and HC – casting doubt on the ability of respondents to accurately self-report the weights needed to derive the headline VTT (Table 4.1). Whilst Table 4.1 indicates considerable similarity across journey purposes in terms of shares, some variations become apparent if we instead look at absolutes. ONW drivers reported spending 64 minutes on average in congestion as compared with 44 minutes for Commute. This suggests a bias towards relatively long trips in the SP sample, but also highlights that, in absolute terms, ONW spent considerably more time in congested conditions than Commute. This could – at least in part – account for the particularly high CVTT in the case of ONW.

Table 4.1: Average shares of congested driving conditions in the SP sample (with absolute minutes in brackets)

	Commute	***Employees' business***	***Other non-work***
Free-flow	0.33 (13.99)	0.34 (54.58)	0.36 (35.59)
Light Congestion	0.36 (17.41)	0.40 (58.70)	0.41 (37.85)
Heavy Congestion	0.31 (17.48)	0.26 (39.40)	0.23 (26.08)

Based on the 2014/15 study, the balance of arguments would still seem to be in favour of deriving the headline VTT via Approach 1 – on the basis that Approach 2 is not readily implementable without some defensible means of drawing association between subjective and objective measures of congestion. If this challenge could be overcome, perhaps through enhanced SP (or indeed RP) research, then the balance of arguments could shift in favour of Approach 2.

All of the above should be qualified by noting that the discussion has been specific to car. There is a question of whether and how Approach 2 could be translated to public transport –

[10] This is discussed in more detail in Section 6.

and in a manner that ensures modal parity. By comparison, Approach 1 would seem more generalisable across modes.

4.3 How should the CVTT multipliers be derived from the 2014/15 study?

There is strong evidence from both the 2014/15 study and meta-analysis (e.g. Wardman & Ibanez, 2012) that drivers place a higher disutility on driving in congested conditions than in FF conditions. However, the evidence does not extend to an understanding of the reasons underlying this.

Intuition suggests that the higher disutility of congested driving is for a mixture of reasons: the higher cognitive load associated with the number of driving decisions per minute, higher annoyance associated with driver behaviour, pushing in etc., and increased uncertainty about arrival time at the destination. But we do not know the composition of that mixture, nor what is perceived and taken into account in advance and what is unperceived/unexpected. This is awkward because we conjecture (a) that there is an overlap between congestion and reliability and (b) that unexpected and unplanned delay minutes are 'worse' in disutility terms than expected delay.

The CVTT estimates from 2014/15 appear high by normal standards – especially so for Heavy Congestion in the case of Other Non-Work – but it is difficult to know why. As part of the quality assurance process around the 2014/15 study, all aspects of analysis (e.g. questionnaire and SP design, data collection, choice modelling, and conversion from behavioural to appraisal values) were subjected to detailed review and audit by SYSTRA and Imperial College London (2015). Whilst this uncovered no substantive faults with the analysis, it remains possible that some anomaly in the data and/or modelling remains undetected.

With regards to the SP3 presentation, WSP et al. (2018) queried the pictorial images used in SP3 to distinguish between FF, LC and HC[11]. These were subjected to cognitive testing by the Arup et al. team before application, but it is possible that the description and/or imagery around the three congestion levels induced confusion and/or some inherent bias.

As well as possible anomalies in the data, another possible explanation for high CVTTs could be some anomaly in the choice modelling. However, as described in Section 3 of this report, the current study has revisited the 2014/15 model, replicating the final models from that study, before developing simplified models jointly estimated on SP1 and SP3 only (i.e. removing SP2 from consideration). This exercise has detected no substantive faults with the 2014/15 choice model and found that, in terms of the CVTT multipliers based on Approach 1, the simplified model is largely corroborative of the original model. Indeed, the CVTT multipliers are slightly higher in the simplified model based on SP1 and SP3 only – partly due to a lower SP1 VTT in the revised model.

[11] This is discussed further in Section 6 of this report.

Alternative functional forms have been tested, in particular examining the introduction of non-linearity between GC and time spent at the different levels of congestion. Congestion multipliers are found to increase with time spent in congestion but, as will be explained further in the following section, non-linear functions are not readily implementable in models such as PRISM.

Finally, relating the previous discussion of reference effects to CVTT, note that Approach 1 entails multipliers linking SP3 to SP1[12]. These multipliers give rise to ratios of the travel time valuations from SP3 and SP1 (i.e. Table 1.1) which embody reference effects – since these effects were prevalent in the 2014/15 analysis of SP1[13]. Thus, the VTTs and CVTTs estimated in the 2014/15 analysis are subject to reference effects in Approach 1, but neither is subject to reference effects in Approach 2.

4.4 Synthesis and options

A significant question in our minds has been how the Department would implement congested values of time in practice via appraisal guidance. We sought advice on this and the response was that we should assume the need for dual running. That is to say, at least initially, some appraisal work would be undertaken using an approach along the lines being studied in the WSP work and this report. But there would still be a need for a set of representative average values as in current guidance for use without congestion multipliers in a range of policy and appraisal work. So the position reached can be summarised as follows.

For modelling, we want values based on behavioural evidence. If evidence shows that congested time is weighted higher in utility terms than FF time, then that should be reflected in the GC formulation in demand and assignment modelling. We believe that there is ample national and international evidence that this is indeed the case. **Our re-analysis of the 2014/15 data has shown that the derived multipliers are high and robust to modelling scrutiny** – but that does not eliminate the possibility that there could be other sources of concern in terms of assurance (e.g. data quality). It was noted earlier in Section 1.2 of this report that, from a modelling perspective, it is more natural to express CVTT as multipliers of FF (i.e. in the form of M multipliers). This perhaps raises the question of whether there is a case for an 'Approach 3', where the headline VTT is expressed in terms of FF. Having defined the headline VTT, the question then arises as to how to configure the problem so as to elicit the CVTT multipliers. Are the multipliers the same across time, space, purpose? If not, what level of disaggregation is appropriate? A decision is required on whether the 2014/15 SP3 work, further analysed in this report, is a sufficient basis for usable M values or whether additional work is needed. As will be discussed in the following section, the ad hoc categorisation of FF, LC and HC used in SP3 severely constrains the transformation between the engineering relationships and economic relationships detailed in Section 2. Breaking this cycle would require a continuous function, but such changes would require a re-design and

[12] This is discussed in more detail in Section 5.

[13] Again, recall from Section 3 that the re-analysis of the 2014/15 data has removed reference effects.

formulation of the SP3 data collection. There are also issues of implementability in network models.

Turning to appraisal, we presume that the principles underpinning TAG guidance are to remain unchanged. Therefore, in the case of car, there is a need for representative average values by journey purpose and, in the case of EB, distance also. For reasons of transparency and auditability, we think that – for the immediate future at least – appraisal VTTs should continue to be derived from SP1 or its successor. **For appraisal, we think there are some short-term options for strengthening evidence and guidance[14], but these centre around the use of SP1 with improved estimates of the multipliers (i.e. Approach 1)**. Following the modelling discussion, the Department could in the longer term consider the case for moving headline values to FF, presented with a table/formula for congested values. These would then be applied in TUBA via some formulation of GC combining FF and congested time, to forecast outputs for changes in the quantities of FF and congested time.

The Department could in addition provide a table of VTTs in average traffic conditions, for use in applications where the FF and congested time method was not being used. This is effectively the status quo. There would then be a significant onus on TAG to provide advice on when the Free-Flow VTT plus congestion multipliers should be used and when a simple VTT in average traffic conditions would be considered adequate. Such advice would be informed by comparative testing (focussing especially on outturn traffic flows and VfM) of the two alternative approaches on a wide range of scheme types.

[14] Specific options are discussed in Sections 6 and 7.

5 Upon the completion of the re-analysis, do the researchers anticipate there to be a requirement to commission new SP studies (using updated travel data), in order to provide reliable CVTT values for implementation in TAG assuming application of a continuous travel function? If so, what would be the recommended scope for such further study?

5.1 Opening comments

In the course of their 2018 and 2019 studies, the WSP et al. team demonstrated that, with some caveats, it is feasible to implement CVTT in modelling and appraisal, and that this could have a significant impact on the design and appraisal of transport schemes. WSP et al. concluded that CVTT should be included in both modelling and appraisal (as opposed to one or the other). We agree with this conclusion.

Whereas WSP et al. have focussed on modelling and appraisal, the ITS Leeds team undertaking the current study has focussed on the valuation of the congestion multipliers themselves. The two strands of work interface through the construct of the GC function, which converts the time and money costs of travel into a common numeraire (money). However, questions remain as to the composition and formulation of that function, and these questions will be the subject of this section of the report.

5.2 Properties of the GC function

WSP et al. (2018) advised that, in order to implement CVTT in assignment models, there is a requirement for some measure of link/junction impedance as a function of travel time – here denoted v(T), where T is travel time – which exhibits the following necessary and/or desirable properties:

1. v(T) should be a continuous and increasing (or at least non-decreasing) function of flow. Since T is already an increasing function of flow, it would be sufficient for v(T) to be a continuous non-decreasing function of T.

2. It should be possible to apply v(T) to each link and turn separately, with no information required on the characteristics of the rest of the route, e.g. v(T) cannot depend on the average level of congestion on the route.

3. The route generalised cost should be the sum of the generalised costs on each of the constituent links and turns.

4. The coefficients of the generalised cost function should be fixed for a given user class, e.g. they should not vary between alternative routes.

5. The function should already be available within highway assignment software, or require minimal software modifications.

6. In application, there is a need to extract actual times and speeds from the model for downstream analysis (including, but not limited to, journey time validation, noise, air quality and carbon appraisal). So, simply modifying the parameters of existing speed-flow (or flow-delay) curves would not be sufficient.

These requirements provoke a number of reflections:

- **If assignment models treat links independently and a journey is the aggregate of several links, then both the VTT and the CVTT need to be constant in the dimension of length (time or distance). This exposes a possible inconsistency in current TAG guidance, to the extent that recommended VTTs for EB vary by distance.** Some practical demand models, including the VDM within the PRISM model used by WSP et al. (2019) as their test bed, have been adjusted to accommodate distance-based VTTs, alongside variations in VTT by the standard mode/purpose segmentations. By contrast, assignment models, including those within PRISM, employ the conventional mode/purpose segmentations but otherwise assume a constant VTT. Whilst the latter restriction observes the above properties of the GC function, it creates inconsistency in the treatment of distance-based values across demand and supply.

- If a constant multiplier is required with regards to 'length' (being time or distance), then the ability to aggregate would seem to eliminate the representation of non-linearities in models (even if there is empirical evidence from Section 3 that they exist).

5.3 Linear additive formulation

The simplest function satisfying the above properties is the linear additive form. Other suitable functions might exist; directly factoring the flow cost curve could be another possibility. However, further work would need to be conducted to explore other candidate forms and their ability to satisfy the required properties.

Adopting the linear additive form in their 2019 work, WSP et al. specified the following GC function:

$$v(T) = VTT_{FreeFlow} \cdot T_{FreeFlow} + VTT_{Delay} \cdot T_{Delay} \qquad (5.1)$$

where:

$T_{FreeFlow}$ is the Free-Flow 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)

For purposes of implementation in their case study using the PRISM model, WSP et al. (2019) populated (5.1) with the 2014/15 estimates of CVTT, via two sets of multipliers of VTT as follows.

The M multiplier

First, time units were 'normalised' by expressing VTT entirely in terms of FF, and then representing the incremental disutility of Delay via M multipliers, thus:

$$VTT_{FreeFlow} \cdot \left(T_{FreeFlow} + \left(M \cdot T_{Delay}\right)\right) \qquad (5.2)$$

Where $M = \frac{VTT_{Delay}}{VTT_{FreeFlow}}$.

Subsequently, three assumed values for CVTT were applied to the base year tests (namely 'Low' (M=1), 'Medium' (M=3) and 'High' (M=5)), whereas only the latter two values were applied to the future year tests. These assumed values covered the range of estimates from the 2014/15 study (Table 1.2).

The r multiplier

Second, since the TAG VTT is defined in terms of average traffic conditions, but (5.2) is defined in terms of FF, a second multiplier (r) was applied in order derive VTT_{FreeFlow} from TAG, i.e.

$$r = \frac{VTT_{FreeFlow}}{VTT_{Average}} \qquad (5.3)$$

Different r multipliers were used for different journey purposes, specifically: Commute = 0.6968; EB = 0.5718; OtherNW = 0.5008. The 2019 WSP et al. report notes that these were elicited from the relativities between the SP1 (VTT_{Average}) and SP3 (VTT_{FreeFlow}) values in the 2014/15 choice models[15].

The GC formulation (5.1), and transformations (5.2) and (5.3) through which (5.1) was aligned with the 2014/15 estimates of CVTT, provoke several points of comment:

1. **The WSP and ITS Leeds teams have adopted subtly different definitions of FF.** Within the VISUM platform that underpins PRISM, FF is defined as the travel time for a journey unhindered by any other vehicle (but including any waiting time at signalised intersections). By contrast, within the preamble which accompanied the 2014/15 SP survey, respondents were advised that FF refers to a journey where *'you can travel at your own speed with no problems overtaking'*.

[15] It is debatable whether these were the most appropriate multipliers to use – since these multipliers are based on behavioural VTTs rather than appraisal VTTs (where the latter are corrected for sample representativeness among other issues).

2. **The transformations (5.2) and (5.3) attempt to align ITS's notion of 'Congestion' with WSP's notion of 'Delay' – but these are somewhat different concepts.** WSP's approach was dictated by the functionality of VISUM, which allows analysis of Delay but not Congestion per se. Within VISUM, Delay is defined as the additional travel time above FF due to interactions with other vehicles. Within the preamble to the 2014/15 SP survey, respondents were advised that LC is where drivers '*can travel close to the speed limit most of the time, but have to slow down every so often'*, and HC is where *'speed is noticeably restricted and frequent gear changes are required'*. Intuitively, the two concepts are inter-related, to the extent that Congestion could cause Delay, but there is not a one-to-one relationship between the two. Moreover, in the 2014/15 study, SP3 was ostensibly focussed upon the discomfort associated with different levels of traffic, as distinct from SP2 which was focussed upon lateness relative to expected travel time and the associated variability of travel time. Indeed, VISUM's notion of Delay would not seem to readily align with either SP2 or SP3.

3. **Notwithstanding the previous point, (5.2) seeks to align a single[16] category of Congestion, either LC or HC, with Delay – but not both.** This reflects two inter-related considerations. First, the functionality of VISUM allows only a single category of additional impedance over and above FF. Second, following from point 2, there is no definitive means of drawing a functional relationship between the two qualitative levels of Congestion (i.e. LC and HC) and the single quantitative dimension of Delay.

4. The functional form of GC should not only be driven by modelling considerations, but economic theory plays an equally important role to successfully conduct appraisal exercises. Earlier work by, for example, Bruzelius (1981) dictates that linear additive GC is the only formulation that would preserve duality. In other words, more flexible functional forms would not enable analysist to derive preferences from observed choices and limit the applicability of the applied SP analyses. More recent work relaxes these constraints somewhat (e.g. Batley & Dekker, 2019) but particular consideration still needs to be given to the specification of the marginal disutilities of time and cost.

5.4 The case for new SP research

In our view, it is difficult to decouple considerations around the case for re-surveying CVTT from broader considerations around the case for re-surveying VTT and VTTR. Whilst a focussed survey around CVTT could in principle be conducted, congestion multipliers should pivot off some definitive notion of the headline VTT, and these should be distinct from the VTTR. **In practical terms, there are perhaps two broad ways of proceeding:**

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[16] This precludes the kind of relationship to the CI postulated in Section 4, since this would in effect generate a continuum of multipliers for different levels of Congestion/Delay.

- **The most defensible way of meeting the above requirements would be to commission a substantive update study encompassing all three interests in tandem, namely VTT, VTTR and CVTT.** In 2014/15, the focus was VTT and VTTR – and congestion was a supplementary interest. If the policy focus has now shifted such that congestion requires more priority, then the scope of SP research needs to be broadened, and resources committed accordingly for a major update study. If a major update were to be commissioned for car, then the question naturally follows whether – for parity of treatment – other modes should also be surveyed. Bearing in mind the marked changes in travel behaviour associated with the Covid pandemic, it would seem difficult to make the case for a major update to VTT, VTTR and CVTT for car without doing likewise for public transport.

- **On the other hand, if there was a lack of appetite (or budget) for such a wide-ranging study, then a less ambitious update study focussed on CVTT for car only could be scoped.** The scale of such a study would seem to dictate that the headline VTT would not be revisited; instead re-estimates of CVTT would need to pivot off the 2014/15 headline VTTs from SP1. In effect, the output of such a study would be a revision to Table 1.1 using Approach 1, but reframed to better align with the requirements of network modelling (see discussion to follow in Section 6). Whilst considerably cheaper than a comprehensive update, the downside of this approach is that it would not fully resolve questions around the extent to which headline VTTs from SP1 and SP2 values already capture some degree of congestion. Also, it would be debatable whether a study of this scale would deliver the level of assurance needed to justify update of TAG. On the other hand, by retaining the headline VTT for car, it could be argued that modal parity has been maintained at the pre-pandemic level – such that re-surveying across modes would be less of an imperative.

6 What are the different options for undertaking any new SP research, and their relative merits? In particular, how can a continuous function relating CVTT to congestion be accommodated, and how can reliability and CVTT be robustly separately identified?

6.1 Opening comments

The response to this question will essentially cover two considerations. First, how can an SP experiment be best designed to align with the GC function (5.1). Second, to what extent can valuations of congestion and reliability be dissected from one another.

6.2 Different options for undertaking SP research and their alignment with the continuous function

The answer to this question involves reconciling at least three separate considerations:

- What other approaches to SP research exist?
- To what extent can the congestion metric used in SP be aligned with that used in models?
- To what extent can the functional representation of impedance used in SP be aligned with that used in models?

In presenting congested travel time, the 2014/15 study employed a simplified version of that used in the M6 Toll study (AECOM), consolidating six levels of congestion into three (Figure 6.1). Description of each level of congestion was accompanied by an artificial stylised image of congestion, such that the imagery was generic to all respondents and did not introduce any extraneous factors which could influence responses.

	**Heavy traffic** – your speed is noticeably restricted and frequent gear changes are required
	**Light traffic** – you can travel close to the speed limit most of the time, but you have to slow down every so often
	**Free flowing** – you can travel at your own speed with no-problems over-taking

	Option A	Option B
One way travel cost	£37.60	£42.00
Traffic Conditions	1 hour and 45 minutes in heavy traffic 11 minutes in light traffic 2 hours and 53 minutes in free flowing traffic	2 hours and 11 minutes in heavy traffic 2 hours and 36 minutes in light traffic 57 minutes in free flowing traffic

Figure 6.1: Reproduction of SP3 from 2014/15

Having reviewed the most recent literature on CVTT, it would not seem that there is demonstrable evidence of success with materially different SP presentations. Perhaps the most serious alternative is that developed and applied by Hensher in a series of Australian studies (Figure 6.2). This game is effectively a hybrid of SP2 and SP3 from the UK – looking at reliability and congestion in combination – and three journey options as opposed to two in the UK game. However, our current focus is the treatment of congestion, which in Hensher's presentation involves a simple distinction between two congestion levels – 'time in free-flow' and 'time slowed down'. This approach would more readily align with equation (5.1) but would not give any resolution concerning the range of congestion levels and potential non-linearity of the function.

There is evidence of several successful applications of the Hensher design – to the extent that it has delivered robust and plausible valuations of congested travel time. However, it should also be acknowledged that a number of these applications have been in the context of toll road studies, where *ex post* evidence reveals systematic and substantial over-forecasting of demand for toll roads (i.e. relatively uncongested routes) *vis-à-vis* their untolled (i.e. relatively congested) alternatives. It would be prudent to review the Australian experience – focussing especially on the role of the congestion multiplier within demand modelling.

Perhaps a third way would be to develop a new version of SP3 which explicitly distinguishes between FF and delayed time (in the sense of 'number of minutes late'), but does not explicitly refer to congestion. Intuition suggests that congestion will be a principal cause of delay, but the attraction of this approach is that delay is an objective metric universally understood by both SP respondents and network modellers. Furthermore, **such a presentation would exactly align with equation (5.1).**

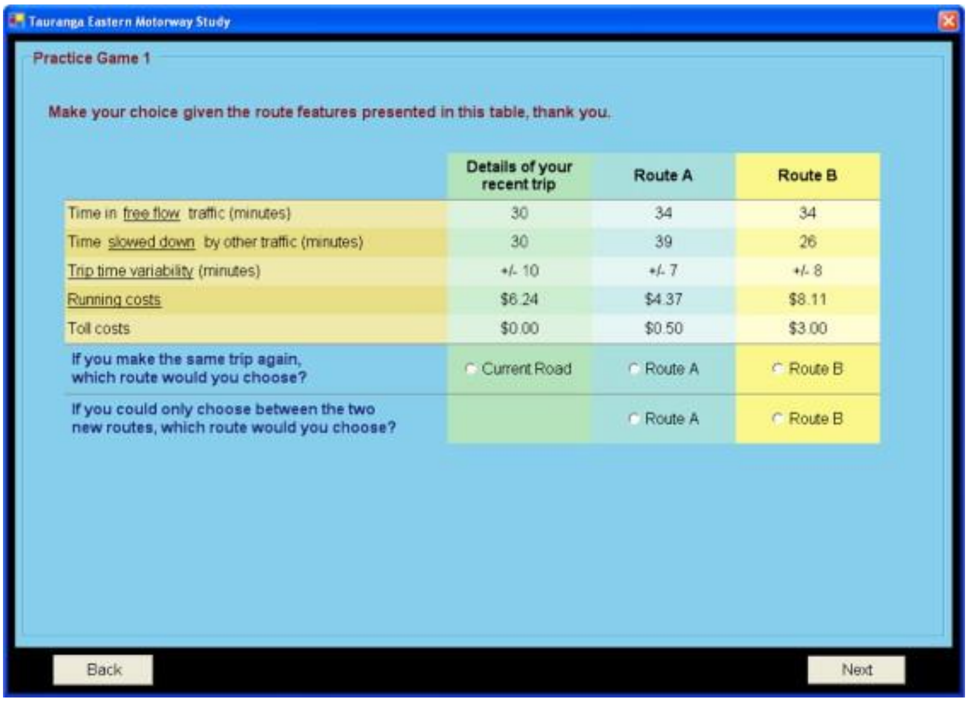

Figure 6.2: Alternative SP approach as used by Hensher

The analytical and policy benefit of new SP research along the lines suggested is that it would deliver a single definitive congestion multiplier for each journey purpose – and avoid the situation that we find ourselves in post-2014/15, where in practical terms a single congestion multiplier needs to be inferred from a range of evidence. Also, the same approach could be extended to LCV and HGV.

6.3 Valuing reliability and congestion

There is an intuitive linkage between the concepts of congestion and reliability – in the sense that variability in traffic levels can lead to variability in arrival time. Indeed, the preamble to SP2 in the 2014/15 study asserted that the reasons for (unreliability) could be *'breakdowns, unplanned roadworks, or general traffic'*. On this basis, and recalling that the reliability ratio was taken to be 0.4 across all journey purposes, there is an argument that this captures aspects of both reliability and congestion.

However, this position is less than ideal, since **there should be a clearer distinction between congestion and reliability – with intuition suggesting that the former should relate to traffic conditions in the mass of the travel time distribution, and the latter to more**

extreme events in the tail[17]. An attraction of the Hensher design is that, unlike the 2014/15 UK study, congestion and reliability are included as separate attributes within the same game, thereby addressing to some extent the problem of duplication/confounding. On the downside, the treatment of the travel time distribution is relatively simplistic, at least when compared to the 2014/15 UK study, and it is debatable how much insight can be gleaned on relative valuations within the mass vs. the tail. All things considered, there is a good argument for enhanced SP research that explicitly separates out i) recurrent congestion leading to modest delays and ii) relatively rare events leading to substantial delays. In terms of the Department's appraisal practice, this might mean incorporating the value of avoiding delay into Level 1 benefits via the congestion/delay multipliers while leaving the value of reducing delay due to extreme events in Level 2 and analysed through a different type of model.

On the issue of functional form, Section 3 of this report has demonstrated that non-linearities are discernible from SP data, but there are two inter-related challenges which are difficult to overcome, namely i) translating categorical descriptions of congestion (i.e. FF, LC, HC) into a continuous function, and ii) implementing non-linear functions in network models. These challenges require concerted research effort and there are no easy solutions.

[17] Having said that, we understand that, if the Strategic Road Network is subject to a prolonged disruption event lasting more than 6 hours, then National Highways views this as a matter of 'resilience' rather than reliability. Evidently, there is a need for a clear and consistent treatment of the various phenomena of interest (e.g. FF, congestion, reliability, resilience, etc.) across modelling and appraisal undertaken by DfT, NH and their respective stakeholders.

7 Finally, what are the relative advantages and disadvantages of using Stated Preference, compared to Revealed Preference data? What would be a recommended scope for such further study? Can the two be considered as complementary with reference to CVTT?

7.1 Opening comments

In the context of national VTT studies, SP is an extremely powerful methodology which continues to be universally adopted across all countries undertaking such studies. However, a fundamental critique of the methodology is that, by its very definition, SP is prone to hypothetical bias – do travellers do as they say they will do?

For this reason, **there is a natural interest in replacing SP with RP – such that estimates of VTT are based on observations of travel choice rather than statements of intent.** In a recent study for DfT, Arup & ITS Leeds (2017), the arguments for SP vs. RP were rehearsed in relation to updating TAG guidance on VTT – and these arguments remain valid and transferable to CVTT.

Arup & ITS noted: *'The primary challenge of estimating the VTTS, either from SP or RP data, is to isolate the effect of journey costs and time on individual travel decisions. SP methods essentially construct a 'laboratory condition' whereby journey time and cost are varied independently across choice tasks making it easier, from a statistical perspective, to isolate their impact on decisions. In RP this is much harder, since journey time and costs are highly correlated. Moreover, SP studies allow to study more travel decisions per traveller thereby increasing the number of observations in the dataset relative to RP'*.

Another key challenge identified by Arup & ITS is achieving a nationally representative sample. *'RP samples have potential to be more unrepresentative than SP samples (as the experimenter has less control). For example, the sample for smartphone based RP data is by definition restricted to smart phone users, which (although representing 70-80% of the population, and potentially a higher proportion of transport users) are likely to have a higher income level, and potentially, value of time, than the general population. As such, this would require "topping-up" with specifically targeted population segments, which has the potential to erode the cost savings from a move to RP'*. Of course, RP-based values could, in a similar manner to SP-based values, be corrected for representativeness using the NTS. But the issue is whether RP would require more correction than SP, perhaps undermining the level of assurance that can be given around the behavioural values.

7.2 The development of RP-based VTT surveys

With the advent of new forms of data, there would however seem to be some emerging possibilities for estimating VTT and CVTT using RP.

So-called ‘inclusive’ RP surveys, where smartphone users actively download an app[18] and respond to questions ‘on the go’ could give the necessary data on travel choice. Alternatively, many mobile phone users have GPS enabled on their devices and are increasingly transmitting passive information on travel choice – although such data may require non-trivial processing and interpretation, and is more prone to attrition through drop-out and underreporting (e.g. due to the phone or GPS being disconnected).

Supplementary data concerning the traveller and features of the trip can to some extent be inferred (e.g. determining origins and destination through the amount of time spent at specific locations) and/or directly elicited through questioning via the app. This is also scope for matching with journey-planning apps (e.g. Citymapper, viaMichelin, Google Maps), which typically offer choices of mode and route for a given journey, as well as cost, travel time, interchanges in the case of public transport, and in some cases congestion.

Considering VTT studies in general (as opposed to CVTT specifically), Arup & ITS noted a number of considerations in relation to RP data in this context, as follows:

1. **Passive data:** Celluar data accuracy varies depending on the generation (e.g. 2G / 3G / 4G / 5G), with newer generations producing more data at greater levels of resolution. GPS data offers significant spatial and temporal accuracy improvements over cellular data, but such data is generally unimodal (e.g. car SatNavs) or heavily sample biased.

2. **Mode choice:** Passive data does not readily identify the mode of transport. GPS combined with accelerometers can improve matters in this regard, but it remains challenging to separate cycle/walk from bus/car in congested urban conditions. In this context, it should be remembered that the UK has a tradition of i) surveying within-mode VTTs and ii) segmenting appraisal values for EB by mode used – such that it would be important to determine the mode used by the traveller.

3. **Vehicle type:** Vehicle type split is also difficult, such as commercial LGVs vs cars, but HGVs are easier to identify on the basis of location.

4. **Journey purpose:** Provided home and work locations can be determined, purpose splits can be achieved on the basis of Home-Based-Work, Home-Based-Other and Non-Home-Based, but identification of Business trips is more challenging.

5. **Individual attributes:** Mobile phone data does not readily reveal information about the traveller (e.g. income, gender, age, car ownership etc.), but some of this might be elicited from customer databases (or failing that, on request to the customers themselves). Naturally, this encounters important data privacy and confidentiality issues.

[18] Examples include apps such as Mobility Mosaic, rMove and Future Mobility Sensing.

6. **Geographical coverage:** Passive mobile phone data may have sufficient geographical coverage for representativeness, but specific apps could be more location or mode specific.

7.3 Specific considerations in relation to CVTT

A particular challenge with RP is obtaining robust data on non-chosen alternatives and the motivations for a particular choice. In order to estimate CVTT, there would be a requirement for a nationally representative dataset of car drivers and car journeys, whereby for each journey two to three route options are identified, and travel cost, travel time, travel time variability and congestion inferred for each such route. There would also be a need to infer the purpose of the journey, as well as various features of the driver.

Since each driver would in effect supply a single set of trade-offs, and RP is more prone to correlations between time and cost, the scale of data collection and assembly exercise would be considerably greater than that for SP. Navigation apps are beginning to tailor their service offering based on a traveller's individual characteristics and circumstances (including the incidence of congestion). In time, they may be able to infer VTT and CVTT based on the choices made. However, there is the risk of introducing endogeneity when artificial choice sets offer a poor approximation to the reality. Furthermore, isolating the travel choice from 'noise' (whether systematic or random) remains challenging.

7.4 Our assessment

Our assessment is that the picture has not materially changed since we last considered this question in 2017. **There are no near-to-market options for undertaking RP analysis of VTT or CVTT. However, the picture is evolving rapidly, and the answer could be quite different another five years down the line.** As the question alludes, the optimal solution here could ultimately be some form of joint RP/SP approach, which harnesses the strengths and mitigates the weaknesses of both. RP is by definition grounded in actual behaviour, whereas SP lends itself to the analysis of alternative policy scenarios which cannot presently be observed. In relation to CVTT specifically, SP would seem reliant on subjective measures of congestion (i.e. LC and HC), when RP might introduce more objective measures (e.g. the Congestion Index[19]). Whether network modelling can handle the latter is however a separate question.

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[19] $Congestion\ Index = \frac{T-FF}{FF} = \frac{Delay}{FF}$

8 Synthesis

Before arriving at recommendations, we think it is desirable to go slightly beyond our brief and reflect on the position the Department is in following the 2014/15 study, the WSP reports and this piece of work. This takes the form of a series of short paragraphs, intended to show the flow through to the recommendations.

1. From a conceptual standpoint, we are comfortable with the proposition that the quality of time might be heterogeneous and therefore that the disutility of a unit of time, and its monetary value, might vary. In public transport appraisal, crowding multipliers and different unit values for walk, wait, interchange are used. Congested time relative to uncongested time is no different.[20]

2. Formalising this proposition, the construct of generalised cost provides the theoretical link between the speed-flow-density relationships that give rise to patterns of congestion in highway network models and the notion of congestion multipliers.

3. The convention up to now in TAG has been to add up congested and uncongested time unweighted in both modelling and appraisal. But SP3 from the 2014/15 study provides strong evidence that car drivers attach higher disutility to congested time than uncongested. So if we had to choose a weighting scheme to add together congested and uncongested time, we would not choose unweighted adding up; we would want to place a higher weight on congested time. But there are some difficulties.

4. The first set of difficulties is that, from our intuition, travellers' attitudes to congestion could be quite context specific, for example:

    - Disutility may vary according to whether congestion is anticipated or unanticipated.

    - It may vary according to the frequency with which the journey is made, knowledge of the network, feasibility of re-routeing.

    - It may vary according to the scheduling constraints under which the journey is made and other journey characteristics, e.g. journey length and journey purpose.

[20] This is written within the framework of the willingness-to-pay (WTP) approach. Within the cost saving approach (CSA) used for commercial vehicles, it is reasonable to assume that the employer is indifferent between a unit of time spent in different traffic conditions, since he/she is paying for minutes.

So there is a question about whether from a behavioural perspective a single set of weights to cover all bases (regular vs. occasional journeys, long distance motorway journeys vs. short distance trips etc.) will suffice.

5. The second set of difficulties concerns the overlap between congestion and reliability. We interpret the higher disutility on congested time as partly a driver comfort phenomenon and partly an association between congested time and the disutility on excess time over the 'standard' or 'expected' time for the journey. We think there is a strong overlap between congestion and reliability which needs to be handled because TAG already has reliability values.

6. The third set of difficulties concerns the need for transformation from some measure of congestion understandable to SP respondents (which to date has generally been descriptive and categorical/discontinuous) to another measure (ideally objectively measurable and continuous) which is usable to network modellers.

7. We have studied the two WSP reports and followed the progress of their thinking on the third report with great interest. From the modelling perspective, the central message is that, within the state of the art, there are two essential requirements

    - Consistency between the demand modelling framework, assignment and appraisal. Their work demonstrates that simplified approaches such as handling congested VTTs in appraisal but not in modelling are unsatisfactory.

    - Achieving that consistency places some restrictions, essentially some form of linear transformation between time and the value of disutility of time. Their preferred option is to apply a multiplier to the metric of 'Delay', which has the advantage of being a continuous linear function and being implementable in models without large new investment. Delay is also an objective measure understandable to SP respondents.

8. WSP's proposal does carry with it a number of health warnings. Use of a single multiplier is simplistic and may not adequately reflect heterogeneity within and across schemes. For example, the precise definition of Free-Flow and Delay may be important to the result. In their 2018 work, WSP refer to other options such as factoring the speed/flow or flow/cost curves. Probably all such options would have various pros and cons including implementation cost.

9. All options require some evidence from outside the model as to the appropriate factor or multiplier to apply to Delay (vs. FF) or the flow/cost function. Depending on how that is done, there may need to be an intermediate step from SP results to the form required for implementation in models, e.g. transforming from Congestion to Delay.

10. Our appreciation of the DfT's policy towards TAG, especially the Level One Benefits modules, is that there should be a robust evidence base to provide decision support at scheme level and comparability within programmes. The hurdle to substantiate a case for change is quite high.

11. One question which is an important part of this hurdle is whether the evidence from the 2014/15 study suggests that a specification which includes congested time is preferable from a behavioural point of view to one which treats all in-vehicle time as the same. With that in mind, we have re-examined the choice between SP1 and SP3 from the 2014/15 work.

12. In this context, there are two broad approaches that could be followed for deriving a headline VTT and associated congestion multipliers from the 2014/15 study, namely:

    - Approach 1: derive the headline VTT from SP1, and multipliers from SP3.
    - Approach 2: derive both the headline VTT and multipliers from SP3, where the headline VTT would in this case be a weighted average of time spent in FF, LC and HC from SP3.

13. In our view, there are significant barriers to the implementation of Approach 2 using SP3 from 2014/15. This is because of question marks over the robustness of self-reporting of travel time spent in FF, LC and HC, and the difficulty (perhaps impossibility) of inferring the same data through more objective means. The latter would seem to require some method of translating between subjective and objective measures of congestion.

14. More generally, if the headline VTT for car were derived using Approach 2, then it would seem appropriate – on the grounds of modal parity – to adopt an analogous approach for public transport. This might be easier said than done.

15. All things considered, we feel that there is little scope in the immediate future to depart from Approach 1, in which case the focus should be on bolstering the evidence base around the CVTT multipliers linking SP1 and SP3, and ensuring alignment with the requirements of network modelling.

16. Overall, our judgement is that the TAG hurdle, as specified above, is some way off being jumped successfully. The work from the 2014/15 study is strongly indicative, but it would be necessary at least to address the following :

    - Context specificity and whether CVTT varies systematically urban/interurban, short/long distance etc.
    - Understanding the overlap between congestion and reliability and arriving at recommendations for both considered together.

- Deciding whether to formulate further SP work in terms of ‘Delay’ rather than ‘Congestion’ – so as to help bridge the gap to modelling (the Hensher approach).

- Deciding what SP design would be required to get a better handle on the scenarios presented to SP respondents vis-à-vis the continuous function.

- Considering whether RP approaches, which we interpret as GPS based or mobile phone based, could improve the evidence base, although we expect SP to remain the primary source in the near term.

- A further battery of testing to establish the implications for scheme appraisal against the full range of contexts in which TAG is used.

17. In the light of that, we now present our recommendations.

9 Recommendations

R1: In the near term, the policy focus should be on Approach 1 rather than Approach 2. That is to say, the headline VTT should be derived from SP1 and congestion multipliers from SP3.

R2: Whilst the headline VTTs from 2014/15 would seem robust, there are significant barriers to the implementation of the 2014/15 congestion multipliers in modelling and appraisal. On this basis, there is a good case for a commissioning new SP research focussed on re-surveying the congestion multipliers. This might be a bespoke piece of work or as part of a next generation national VTT study.

R3: Re-surveying the congestion multipliers is not without its challenges. Therefore, the prudent approach would be to first commission a scoping study to explore a number of technical issues, as follows:

- Context specificity and whether CVTT varies systematically urban/interurban, short/long distance etc.
- Understanding the overlap between congestion and reliability and arriving at recommendations for both considered together.
- Deciding whether to formulate further SP work in terms of 'Delay' rather than 'Congestion' – so as to help bridge the gap to modelling (the Hensher approach).
- Deciding what SP design would be required to get a better handle on the scenarios presented to SP respondents vis-a-vis the continuous function.
- Whether there is a role for RP data to help validate SP.

R4: Only once the above issues have been satisfactorily resolved, should resources be committed to a more substantive study to re-survey the congestion multipliers.

R5: Independently of actions taken to re-survey the congestion multipliers, a further battery of testing should be conducted to establish the implications of congestion multipliers for scheme appraisal against the full range of contexts in which TAG is used.

R6: Beyond the near term, a broader set of issues concerning guidance on CVTT should be considered, encompassing the following considerations:

- Review the policy and analysis requirements of headline VTTs vs. CVTT multipliers.
- Against those policy/analysis requirements, assess the relative merits of Approaches 1-3 (where the latter would formulate the headline VTT in terms of FF), as well as the implementation costs of each approach.

- Consider the policy/analysis benefits and risks of offering more than one of Approaches 1-3 in guidance.

- The above considerations should be cognisant of the need for consistency and complementarity across the complete VTT portfolio, encompassing all modes and all types of travel time.

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Annex: Headline VTTs and selective multipliers from the 2014/15 study

Table A.1: Appraisal VTTs for a Level 1 appraisal (routine appraisal of small and medium sized schemes) with illustrative distance bands (2014 perceived prices, £/hr)

<table>
<tr><th rowspan="2">Mode</th><th rowspan="2">Distance</th><th>Commute</th><th>Other non-work</th><th colspan="5">Employees' business</th></tr>
<tr><th>All modes</th><th>All modes</th><th>All modes</th><th>Car</th><th>Bus</th><th>'Other PT'</th><th>Rail</th></tr>
<tr><td>WebTAG (2014 prices and values)</td><td>All distances</td><td>7.62</td><td>6.77</td><td>25.47</td><td>24.43</td><td>15.64</td><td>24.72</td><td>30.07</td></tr>
<tr><td rowspan="4">All modes</td><td>All distances</td><td>10.03</td><td>5.49</td><td>18.23</td><td>16.74</td><td>-</td><td rowspan="4">8.33</td><td>27.61</td></tr>
<tr><td><20miles</td><td>8.27</td><td>3.62</td><td>8.31</td><td>8.21</td><td>-</td><td>10.11</td></tr>
<tr><td>20 to 100 miles</td><td rowspan="2">12.15</td><td>6.49</td><td>16.05</td><td>15.85</td><td>-</td><td rowspan="2">28.99</td></tr>
<tr><td>>=100 miles</td><td>9.27</td><td>28.62</td><td>25.74</td><td>-</td></tr>
</table>

Notes: Distance-weighted, Non-work income option 2 (household income = £49,684), Business income option 1, VTT is imputed for PT trips with zero cost, SP1 VTTs, Δ*t*=10, employers paying for EB trips, Tool version 1.1

Table A.2: VTT multipliers

		Commute	Employees' business	Other non-work
Car	Reliability ratio	0.33	0.42	0.35
	Free-flow	0.51	0.42	0.47
	Light Congestion	0.72	0.68	0.83
	Heavy Congestion	1.37	1.26	1.89
Bus	Value of early	-2.69	-	-3.20
	Value of late	2.88	-	2.52
	Plenty of seats free and did not have to sit next to anyone.	0.85	-	0.83
	A few seats free but had to sit next to someone/could not sit with people travelling with.	0.89	-	0.84
	A few seats free but had to sit next to someone/could not sit with people travelling with. Some standing.	1.00	-	1.00
	No seats free – a few others standing.	1.24	-	1.30
	No seats free – densely packed.	2.14	-	2.32
	Value of free-flow	0.99	-	1.22
	Value of slow down	1.39	-	1.36
	Value of dwell time	0.68	-	1.57
	Value of headway	1.68	-	1.60
'Other PT'	Value of early	-2.40	-1.66	-2.98
	Value of late	1.75	1.95	2.24
	Plenty of seats free and did not have to sit next to anyone.	0.95	1.00	1.00
	A few seats free but had to sit next to someone/could not sit with people travelling with.	0.97	1.00	1.00
	A few seats free but had to sit next to someone/could not sit with people travelling with. Some standing.	1.00	1.00	1.00
	No seats free – a few others standing.	1.13	1.17	1.10
	No seats free – densely packed.	1.70	1.78	1.87
Rail	Value of Early	-1.77	-1.55	-2.34
	Value of Late	2.86	2.76	3.21
	seated 50% load	0.73	0.75	0.72

		Commute	Employees' business	Other non-work
	seated 75% load	0.79	0.76	0.72
	seated 100% load	1.00	1.00	1.00
	seated 1 pass per m2	1.09	1.13	1.14
	seated 3 pass per m2	1.31	1.36	1.39
	standing 0.5 pass per m2	1.16	1.29	1.21
	standing 1 pass per m2	1.19	1.38	1.27
	standing 2 pass per m2	1.32	1.56	1.57
	standing 3 pass per m2	1.57	1.61	1.79
	standing 4 pass per m2	1.86	2.03	2.17

Note: SP2 VTT taken as base for reliability and early/lateness. SP1 VTT taken as base for car free-flow, light and heavy traffic. SP1 VTT taken to represent 100% occupancy of seats for PT.

Table A.3: Car VTT values from preferred choice models by type of time, and trip purpose (Income option 1, 2014 perceived prices, £/hr)

			Commute	Employees' business	Other non-work
Car	VTT	SP1	11.70	16.74	4.91
	Average travel time	SP2	15.36	25.49	10.67
	Value of sd travel time	SP2sd	5.00	10.79	3.77
	Free-flow	SP3ff	6.00	7.04	2.32
	Light Congestion	SP3lc	8.41	11.34	4.09
	Heavy Congestion	SP3hc	15.98	21.03	9.26

Notes: Distance-weighted, income option 1, based on sample enumeration from NTS 2010-2012 motorised trips; Δ*t*=10; Tool version 1.1 (fuel costs imputed and employers paying for EB trips).

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Table of Contents

Glossary of terms and abbreviations 3
1 Introduction 4
1.1 Background 4
1.2 The basis of the 2014/15 estimates of CVTT 5
1.3 CVTT workstream 6
1.4 Layout of this report 9
2 Theoretical background 10
2.1 Opening comments 10
2.2 The engineering model 10
2.3 The economic model 12
2.4 Relating these relationships to the present study 14
3 Based on the 2014/15 data, looking at games SP1 and SP3, how do CVTT values differ by journey purpose (commuting versus leisure) and journey length? 16
3.1 Opening comments 16
3.2 The data used for re-analysis 16
3.3 Summary of the choice models used in the 2014/15 study 17
3.3.1 Random Valuation 17
3.3.2 Multiplicative error term 17
3.3.3 Observed and unobserved heterogeneity in the VTT 17
3.3.4 Reference dependence (or size and sign effects) 18
3.3.5 Design characteristics 18
3.3.6 Behavioural and appraisal VTTs and the congestion multiplier 19
3.4 Proposed modelling approach and working hypotheses 20
3.5 Results 22
3.5.1 Results for the Commute sample 22
3.5.2 Results for the EB sample 32
3.5.3 Results for the ONW sample 39
3.6 Synthesis 47
4 When looking at determining headline VTT, what are the relative advantages and disadvantages of using SP3 compared to using SP1? 49
4.1 Opening comments 49
4.2 How should the 'headline' VTT be derived from the 2014/15 study? 49

4.3 How should the CVTT multipliers be derived from the 2014/15 study? 51

4.4 Synthesis and options 52

5 Upon the completion of the re-analysis, do the researchers anticipate there to be a requirement to commission new SP studies (using updated travel data), in order to provide reliable CVTT values for implementation in TAG assuming application of a continuous travel function? If so, what would be the recommended scope for such further study? 54

5.1 Opening comments 54

5.2 Properties of the GC function 54

5.3 Linear additive formulation 55

5.4 The case for new SP research 57

6 What are the different options for undertaking any new SP research, and their relative merits? In particular, how can a continuous function relating CVTT to congestion be accommodated, and how can reliability and CVTT be robustly separately identified? 59

6.1 Opening comments 59

6.2 Different options for undertaking SP research and their alignment with the continuous function 59

6.3 Valuing reliability and congestion 61

7 Finally, what are the relative advantages and disadvantages of using Stated Preference, compared to Revealed Preference data? What would be a recommended scope for such further study? Can the two be considered as complementary with reference to CVTT? 63

7.1 Opening comments 63

7.2 The development of RP-based VTT surveys 63

7.3 Specific considerations in relation to CVTT 65

7.4 Our assessment 65

8 Synthesis 66

9 Recommendations 70

References 72

Annex: Headline VTTs and selective multipliers from the 2014/15 study 74