Department for Transport

TAG Unit A1.3

User and Provider Impacts

May 2026

Department for Transport

Transport Analysis Guidance (TAG)

https://www.gov.uk/transport-analysis-guidance-tag

This TAG Unit is guidance for the **Appraisal Practitioner**

This TAG Unit is part of the family **A1 - Cost Benefit Analysis**

Technical queries and comments on this TAG Unit should be referred to:

Transport Appraisal and Strategic Modelling (TASM) Division

Department for Transport
Zone 2/25 Great Minster House
33 Horseferry Road
London
SW1P 4DR
tasm@dft.gov.uk

Contents

1. Introduction

1.1.1 Impacts on transport users and providers typically make up the majority of benefits for transport business cases. This TAG unit builds on the guidance on principles of cost-benefit analysis in transport appraisal in TAG Unit A1.1 – Cost Benefit Analysis and provides specific guidance on how impacts on transport users and providers (including travel time and vehicle operating cost savings) should be estimated, valued and reported in transport appraisal.

2. User benefits, consumer surplus and the Rule of a Half

2.1.1 Users perceive both money costs and time costs associated with the trips they make. When someone makes a trip these costs will be outweighed by the opportunities and potential benefits at the destination. This potentially exaggerates freedom of choice in the short term since, having made decisions about where to live, work or locate a business, individuals and businesses may have limited options about the trips they have to make. However, in the longer term, and for the purposes of appraisal, use of the transport system is assumed to be the result of a balanced consideration of pros and cons by each individual decision-maker, subject to all the various constraints which exist.

2.1.2 The calculation of transport user benefits is based on the conventional consumer surplus theory where consumer surplus is defined as the benefit which a consumer enjoys, in excess of the costs which he or she perceives. For example, if a journey would be undertaken provided it takes no more than 20 minutes, but not if it takes more than 20 minutes, then the benefit of the journey to the traveller is equivalent to a cost of 20 minutes of travel time. If actual travel time for the journey is only 15 minutes, then the traveller enjoys a surplus of 5 minutes.

2.1.3 The user impacts of a transport scheme which changes the perceived costs of travel should be assessed based on the change in this surplus. For example, if a scheme reduced the travel time in the example above to 12 minutes, it would increase the traveller's surplus by 3 minutes. The assessment of consumer surplus should incorporate changes to the following components of perceived cost:

- changes in travel time;

- changes in user charges, including fares, tariffs and tolls; and
- changes in vehicle operating costs met by the user (i.e. for private transport).

2.1.4 The surplus associated with making a journey will not be the same for everybody and depends on the benefit each individual derives from making that journey. Transport demand generally responds to changes in cost, with a reduction in cost leading to increased demand. It follows, therefore, that the benefit associated with any new trips will be lower than that for trips that were already being made (or else they would have been made before the reduction in cost). Therefore, transport demand can be represented by a traditional, downward-sloping demand curve where the demand curve shows the benefit associated with an additional trip at different levels of demand.

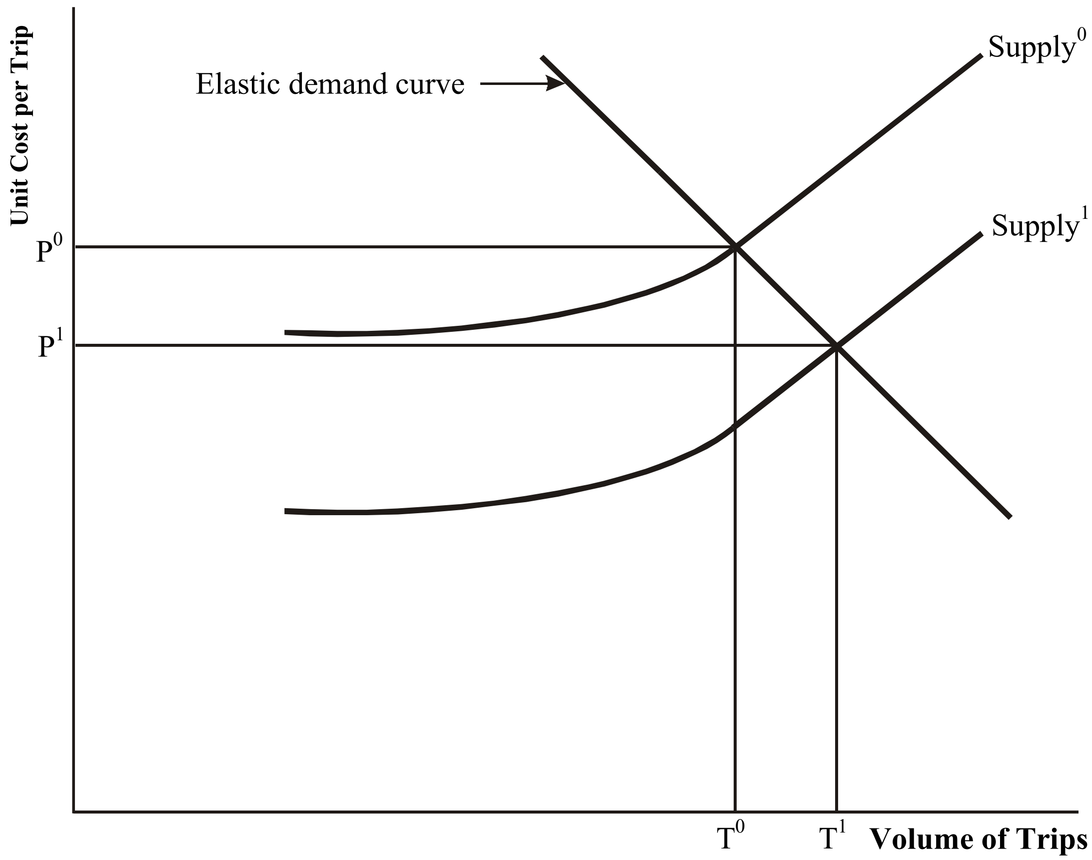
2.1.5 As demand increases congestion will lead to increasing costs of travel. Therefore, the costs of travel can be represented with a traditional, upward-sloping supply curve and the impact of a scheme can be considered as shifting the supply curve, changing the cost of travel. Figure 1 shows how the change in consumer surplus should be calculated within this framework for an intervention which reduces costs, shifting supply from $Supply^0$ to $Supply^1$.

2.1.6 Before the intervention there are T^0 trips with a cost per trip of P^0. After the intervention, the cost falls to P^1 and demand increases to T^1. The change in consumer surplus for existing travellers, who were already making trips before the intervention, is $T^0 \times (P^0 - P^1)$. The change in consumer surplus for new trips, based on the difference between their derived benefit (the demand curve) and the cost, is $\frac{1}{2} \times (P^0 - P^1) \times (T^1 - T^0)$. These terms can be combined to give the formula known as the ‘rule of a half’:

$$\text{Change in consumer surplus} = \tfrac{1}{2} \times (T^0 + T^1) \times (P^0 - P^1)$$

2.1.7 This formula forms the basis of the user benefit calculations performed by the Department’s appraisal software, TUBA.

Figure 1 Calculating the change in consumer surplus



2.1.8 In general, the true situation is highly complex compared with the above. The main substitutes and complements for travel from A to B are travel from A to other destinations, by other modes, using other routes and so on. However, provided that consistency can be achieved between the pattern of travel demand and the outturn, the rule of a half formula can be extended to cover network appraisal with many modes and origin/destination pairs. A useful source which discusses the principles and assumptions is Jones (1977).

2.1.9 It is implicitly assumed in the rule of a half formula that the demand curve is linear. If this is not the case, and the demand curve is convex to the origin, then the rule of half will tend to overstate the benefits. With small changes in cost the inaccuracy is not significant. The issue of large cost changes are discussed in detail in Nellthorp and Hyman (2001) and advice on how to address these situations is given in Appendix D:.

2.1.10 In some situations, for example when a mode is introduced or taken away, the perceived cost in the without-scheme (P^0) or with-scheme (P^1) will not be defined and the rule of a half formula fails. Examples of this situation include the introduction of a light rapid transit system, in an urban context, or the closure of a rural railway service. Guidance on these cases is given in the Supplementary Guidance – Appraisal of New Modes.

Special treatment of unperceived costs

2.1.11 Some costs that are incurred as a result of trip-making are considered not to influence travel decisions. Net changes in these 'unperceived' costs must be calculated and added to the results obtained by applying the rule of a half formula. Non-working car drivers are assumed not to perceive non-fuel elements of cost, such as tyres, maintenance and depreciation.

3. Disaggregation and attribution of user benefits

3.1.1 The question of who benefits from the scheme naturally arises. Will it be personal travellers, business travellers or freight? Rail travellers or car travellers? Urban or rural dwellers? Those in deprived areas relative to those in more affluent districts?

3.1.2 TAG Unit A1.1 – Cost Benefit Analysis describes how the main benefit of a willingness-to-pay calculus is that it provides more detail on who is affected but to answer these sorts of policy-relevant questions, a carefully-designed appraisal needs to feature:

- a forecasting model which is capable of separating its forecasts according to these categories of users and types of use of the transport system; and
- a user benefit analysis which preserves these categories and presents its results with an explicit breakdown of the benefits (and costs) by group.

3.1.3 Therefore, if there is a group within the population whose welfare is of particular policy importance, then both the forecasting model and the user benefit analysis need to be designed from the start to identify the impacts on this group. Guidance for the Technical Project Manager sets out the level of detail likely to be required in the breakdown of benefits, and indicates some extensions which may be desirable to address issues of distribution and equity within the Supporting Analysis.

3.1.4 It can be difficult to draw conclusions such as 'rail users benefit by £x million'. Imagine a corridor served by train and coach services as well as a road open to private car drivers. A proposed scheme will increase both rail and coach patronage, combined with some reduction in peak hour private car traffic on the road. 'Rail users', 'coach users' and 'car users' will clearly vary between the without-scheme case and the with-scheme case. Transport models typically provide the net effect of complex movements between modes, not individual users' behaviour in each case. Thus, it is impossible to say how many travellers switched from road to rail, how many from rail to bus and so on.

3.1.5 Therefore a consistent approach to attributing benefits is needed. When undertaking multi-modal studies, the approach advocated by Sugden (1999) should be adopted. This approach relates the breakdown of benefits to the mode of transport where the change in cost has occurred, and not to particular groups of travellers. The formula for attributing benefits to modes as the ‘source’ of those benefits is the rule of a half formula, applied at the modal level, e.g. for mode *m*:

$$ChangeInConsumerSurplus_m \approx RoH_m = \frac{1}{2}\sum_i \sum_j \left(T^0_{ijm} + T^1_{ijm}\right)\left(P^0_{ijm} - P^1_{ijm}\right)$$

3.1.6 Note that the benefits are given by the initial and final perceived costs on the mode, whatever the ‘cause’ of the cost change. For example, if an improvement on rail creates decongestion benefits on road, these benefits are attributed to the road mode[1].

3.1.7 The full set of formulae required to implement this approach is given in Appendix A:.

3.1.8 Research by Mott MacDonald and the Institute of Transport Studies, University of Leeds: ‘Valuing the social impacts of public transport’ (Mott MacDonald, 2013) developed an alternative method of disaggregating the benefits relating to non-work trips that would not take place without the intervention being appraised (i.e. ‘generated’ or ‘suppressed’ trips), referred to as ‘social impacts’ in the underlying research. More detail on this method, and how the results from it should be presented, is given in Appendix B:.

4. Values of travel time savings

4.1.1 A value of time savings is required to convert the forecast changes in travel time resulting from an intervention into monetary values that can be used in appraisal. The TAG Data Book contains values of travel time savings for working and non-working time that should be used in most economic appraisals of transport projects:

A1.3.1: Values of time per person (single year)

4.1.2 Market prices are often used to represent willingness-to-pay in cost-benefit analysis. However, although examples exist where travellers trade travel time for cost, market prices for travel time are not easily obtainable and, in the absence of market prices, alternative techniques are required to estimate willingness-to-pay. There are a range of approaches available and, while the

[1] If demand and supply curves shift simultaneously (because a scheme affects competing or complementary modes simultaneously) there is no unique attribution of benefits. However, in line with recommendations from Jones (1977) and Sugden (1999), the rule of a half formula as given should be used to attribute benefits by mode.

techniques, assumptions and resulting values vary, all of the methods aim to estimate values that effectively proxy for willingness-to-pay.

4.1.3 Revealed preference evidence is the most direct way to estimate willingness–to-pay, and is based on actual traveller behaviour (for example, surveys of users of the M6 Toll road and alternative routes). However, it is difficult to collect revealed preference data of sufficient quality and quantity to estimate robust values and provide the detail needed to fully populate a framework of values. In the absence of revealed preference evidence of sufficient quality, it is necessary to use alternative methods and techniques to estimate values.

4.1.4 The Department's approach is to take account of all the relevant evidence available and to seek to make reasonable judgments, in light of the best available economic theory and empirical evidence.

Current approach to deriving willingness-to-pay for travel time savings

4.1.5 The Department commissioned new primary research into the value of travel time savings (by land modes), which was completed in 2015.[2] This research derived values of travel time savings for both work and non-work travel, on a willingness-to-pay basis, using stated preference evidence. This research forms the basis for the values of time (excluding freight and professional driver values of time) that the Department currently recommends for use in appraisal.

4.1.6 A key distinction in the valuation of travel time savings is by journey purpose, and specifically between values for trips made on employers business (or working time), and non-working time values including commuting and all other leisure purposes.

4.2 Values of working time per person

4.2.1 Table A1.3.1 gives the average values of working time per person by mode and, for car and rail trips, by distance. These values apply only to journeys made in the course of work and this excludes commuting journeys. Businesses perceive travel costs in the factor cost unit of account. Therefore the perceived cost and the factor cost are the same for values of working time and these should be converted to the market price unit of account for appraisal (see TAG Unit A1.1).

4.2.2 Businesses benefit from reduced travel times in a number of ways, including improved access to suppliers or customers, which increases productivity by lowering the cost or raising the quality of inputs and widening the market which a business can serve. Therefore, it follows that businesses should be willing to pay for quicker journeys and it is this willingness-to-pay which forms the basis of values of working travel time savings.

[2] ITS Leeds (2013) 'Valuation of Travel Time Savings for Business Travellers: Main Report', Prepared for the Department for Transport [pdf], available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251997/vtts_for_business_main_report-dft-005.pdf

4.2.3 There are many real-world situations where business travellers choose to pay more for a quicker journey when a cheaper, slower alternative is available. For example, surveys found that around one third of M6 toll road users are travelling on employers' business and they stated that saving time compared to alternative routes was their main reason for using the toll road.[3]

Evidence of businesses' willingness-to-pay for travel time savings (excluding freight journeys and professional drivers)

4.2.4 As part of the new value of time research which was published in 2015, employers' business values of travel time were derived on a willingness-to-pay basis, based on stated preference evidence.[4] This is a significant move away from the previous 'cost-saving' approach (CSA) which had been used for many years, and addresses a number of concerns with the cost-saving approach. These include assumptions around productive use of travel time and perfectly competitive labour markets, which were expressed in the 2013 scoping study.[5]

4.2.5 The previous 'cost saving' approach was shown to yield values that are reasonably close to those obtained from willingness-to-pay evidence. However, a direct willingness-to-pay based approach for deriving values of time has the advantage of, in principle, being able to account for all the relevant factors determining the VTTS for employers' business trips. This is because, using willingness-to-pay approach, it is not necessary to formulate exactly how an employer arrives at the VTTS for its employees. Subjective willingness-to-pay valuations should capture all of the relevant benefits of saved travel time, mitigating some of the issues with the CSA set out above.

4.2.6 Therefore, in line with the recommendations from the 2015 VTTS study, willingness-to-pay based values of time for employers' business trips by car and public transport are recommended for use in appraisal.

Values of time for freight journeys and professional drivers

4.2.7 The values of time for road freight trips (including Light Goods Vehicles (LGVs) and Other Goods Vehicles (OGVs)) were subject to a significant joint programme of research between the Department and National Highways[6], published in 2025. As part of this, OGV values of travel time were derived using a willingness-to-pay approach, based on stated preference evidence[7]. The

---

[3] M6T Research Study – Stage 2 Utilisation Surveys, Faber Maunsell / AECOM (2008): https://www.gov.uk/government/publications/utilisation-surveys

[4] This research did not cover professional drivers or freight trips. The recommended values of time for these users are discussed in the following section

[5] ITS Leeds (2013) 'Valuation of Travel Time Savings for Business Travellers: Main Report', Prepared for the Department for Transport [pdf], available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251997/vtts_for_business_main_report-dft-005.pdf

[6] See main findings and primary study, plus links to peer review and peer review response at: https://www.gov.uk/government/publications/understanding-and-valuing-road-freight-travel-time

[7] From Arup et al (2023), 'Freight value of time and value of reliability: Final report', available at: https://www.gov.uk/government/publications/understanding-and-valuing-road-freight-travel-time

recommended OGV values were adopted from responses from 'carrier' businesses (e.g. hauliers), but are considered to represent a joint estimate of the willingness-to-pay of both carriers and 'shippers' (those that move cargo in the course of business, such as retailers) for timely delivery.

4.2.8 For freight LGVs, the stated preference estimates from the research were not considered sufficiently robust for recommending in guidance. Instead, an estimate derived from a combination of industry cost data and wage statistics is recommended. The resulting hourly value can be considered analogous to the OGV VTTS, reflecting the value to LGV freight operators of an hour of working vehicle use. The LGV value assumes that 100% of the cost components in the VTTS are time-dependent over the long-run. This is equivalent to the previous CSA, reflecting that appraisal aims to capture the economic (resource) value, once businesses have had time to fully absorb the impact of an intervention into their decision-making.

4.2.9 The VTTS for professional drivers (which includes taxis, PSVs and non-freight 'services' LGVs) are based on the CSA, in line with the conclusions from the 2013 business value of time scoping study.[8] For these categories of business travel, the CSA is viewed as an appropriate methodology for deriving the value of travel time savings. This is because their prime task is to deliver services or passengers to particular destinations, so 'work' and 'travel' are effectively one and the same.

Applying the values in appraisal (excluding freight journeys and professional drivers)

4.2.10 Employers' business values of time vary significantly over a number of characteristics, such as traveller income, trip time, trip cost and trip distance. Overall, a reasonable proportion of the variation in the values can be explained by trip distance, which tends to be correlated with income, time and cost.

4.2.11 Based on the recommendation from the 2015 study, employers' business values of time recommended for appraisal vary with distance and mode only. This variation is represented by a continuous function, where the value of time is assumed to vary with trip distance (average distance travelled between origin and destination, including access and/or egress where appropriate) according to a logistic functional form. The parameters of this function, including the minimum and maximum bounds, can be found in Table A1.3.1 of the TAG data book. The functional form is shown in box 1 below:

4.2.12 The continuous function described in Box 1 should be implemented as the preferred option for deriving the appropriate employers' business values of time for use in appraisal. As discussed in para 4.2.19 below there may be situations in which the application of a continuous function is not proportionate. In these circumstances it is the responsibility of the scheme promoter to demonstrate

[8] See p.136 of the report, available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251997/vtts_for_business_main_report-dft-005.pdf

that the approach used to reflect variations in the value of time is sufficiently robust and warranted.

4.2.13 When applying the function, it is necessary to calculate a value of time for each origin-destination pair using average distance from the base year assignment model. For each user class where distance based values of time apply (i.e. car and rail business trips), this should represent an average of distance skims for all modelled time slices (and income segments if income segmentation is used) weighted by the respective trip matrices. It may be desirable, for internal consistency, to symmetrise this distance matrix by taking the average of both directions, unless there are reasons why distance in one direction should be significantly different.

4.2.14 Where this is not feasible or proportionate, the base inter-peak distance matrix can be used. If inter-peak modelling is also judged to be disproportionate or unnecessary, peak period time slices may be used instead. These distance matrices should then be used in all modelled forecast years for all scenarios. This means that for any give origin-destination pair, the value of time will not vary between the without-scheme and with-scheme cases, or between low and high demand growth scenarios.

Box 1: Continuous function for VTTS (car and rail employers' business only)

The following functional form should be used for employers' business VTTS in appraisal, which is a logistic function of distance:

$$\mathrm{VTTS} = \frac{\mathrm{U}}{\left(1 + \mathrm{e}^{\frac{\mathrm{x_{mid}} - \mathrm{D}}{\mathrm{k}}}\right)}$$

Where the parameters are defined in the following table:

Parameter	Definition
$VTTS$	Value of travel time savings (£/hr)
D	Distance (measured in km)
U	Upper limit of the function (the 'asymptote') (measured in £/hr)
x_{mid}	Distance at the inflexion point of the curve (where $VTTS = {}^{U}/_{2}$) (measured in km)
k	A scale parameter which is inversely proportional to the steepness of the curve

Derivation of equation

The parameters of the logistic function are estimated from the NTS sample enumerated dataset using non-linear weighted least-squares regression, where VTTS is the dependent variable and distance is the independent variable. The weights used in the regression correspond to the distance for each trip record multiplied by the NTS trip weight for that record.

4.2.15 In cases where existing software or calculation routines do not support the calculation of assigned network distances, it may be proportionate to use other available distance information instead, such as the minimum network distance. It should be borne in mind that this could underestimate distances travelled, so where proportionate sensitivity tests should be conducted to understand the potential impact of using this simplified approach.

4.2.16 As set out above, the values of time should use the distance skims from the base year matrix. However, where forecast year distance matrices are significantly different from base year (due to committed schemes coming on-line during the lifecycle of the project), it may be reasonable to use forecast year without-scheme distance skims instead. This must be justified and the evidence supporting presented in the forecasting report.

4.2.17 The values of travel time savings are based on the total distance travelled between the origin and destination for each trip. Where a trip is made up of more than one stage the distance skims from models may not account for the full distance and hence consideration may be given to adjusting these skims to account for other stages. This adjustment must be justified and the evidence presented in the forecasting report.

4.2.18 In some circumstances, it may be disproportionate to apply the continuous function described above. For example, existing appraisal software may not have the capability to implement the continuous function. In these cases, the four discrete value of time bands set out in Table A1.3.1 of the TAG data book can be used instead. Where discrete bands are being considered, it should be borne in mind that survey data (where proportionate) could be used to support assumptions around typical trip distances, which could allow implementation of the continuous function. Where proportionate, the gathering of such information should be considered before the discrete bands are used for appraisal.

4.2.19 In a very limited number of cases, such as for example link-based, fixed matrix appraisal, a single average value of time may be appropriate. The results obtained using this method are likely to have much lower assurance than those obtained using the continuous function. These average values can be found in Table A1.3.1 of the TAG data book.

4.2.20 Any departure from the continuous function should be fully justified by the scheme promoter, in terms of evidence of the distribution of affected trips across different distances

Applying the values and sensitivity testing

4.2.21 There is a significant degree of uncertainty around the values of travel time savings in the course of work and analysts should undertake sensitivity tests to demonstrate the sensitivity of the appraisal results to the value used.

4.2.22 Based on the results of the most recent passenger value of time research, a sensitivity test of +/- 25% around values of time should be carried out. This represents the average size of the 95% confidence interval around the VTTS across all trip distances. For simplicity and proportionality, this test can be applied as an adjustment to the present value of time saving benefits for business travellers. For freight and professional drivers, a sensitivity test of +/-15% around values of time should be used. This is based on the 95% confidence interval around the OGV VTTS from the Arup et al (2023) study[9].

4.2.23 For staged journeys, the value of working time for the main mode (with the longest distance) should be used.

4.2.24 Using different values for each mode may appear to introduce inconsistency in appraisal since it suggests that those switching modes change their values of time. However, this is not the case because for any group (bus passengers, car drivers etc.) there will be a distribution of values around the average value for the group and the distributions for each group are likely to overlap. Therefore, the value of time for an individual within a group need not be the average value for that group and, when they switch mode, the individual will take up a different position in the distribution of values of time for their new mode, compared with that for their old mode. For example, a car driver with an above average value of time for car drivers could switch to rail, where their value of time might be below average.

4.2.25 Large changes between modes might alter the modal distributions sufficiently to significantly change the average values in the 'without scheme' and 'with scheme' cases. An alternative approach is to segment travellers by income group in the transport model, so that the average values of time for each mode are outputs of the modelling process, rather than inputs to the appraisal. This is discussed in more depth in TAG Unit M1.1 – Principles of Modelling and Forecasting. In circumstances where switching is high compared to the number of existing users, analysts should contact TASM Division, DfT for further advice.

4.2.26 It may be appropriate to make the simple assumption of a common working value of time for all travellers. The average value for all workers should be used with sensitivity tests carried out using the values disaggregated by mode.

4.3 Values of non-working time per person

4.3.1 The majority of journeys are not in the course of work, but in the traveller's own time, so table A1.3.1 also give the values of time savings for 'commuting' (travelling to and from the normal place of work) and 'other' (all other non-work trips, e.g. for leisure) journey purposes.

4.3.2 People implicitly put a value on their own time in that they will trade a cheaper, slower journey against a faster, more expensive one. The values in the TAG Data Book are based on research conducted by the Institute for Transport Studies (ITS) and Accent for the Department for Transport, reported in 2015, and published as 'Provision of market research for value of travel time savings and Reliability: Phase 2 Report'. The values have been converted to 2010 values and prices in line with the growth in income (with a GDP/capita elasticity

[9] Arup et al (2023), 'Freight value of time and value of reliability: Final report', available at: https://www.gov.uk/government/publications/understanding-and-valuing-road-freight-travel-time

of 1) and changes in prices (using the GDP deflator) between 2010 and 2014. The values are then reported in the TAG Data Book in the Department's current default base year.

4.3.3 Individuals' 'willingness to pay' for travel time savings will vary considerably, depending on factors like income, journey purpose and urgency, and the comfort and attractiveness of the journey. Values of time may therefore vary by:

- time spent on the same activity by different people, whose incomes and journey characteristics may vary; and
- time spent by the same individual on different journeys or parts of journeys.

4.3.4 Non-work time savings typically make up a large proportion of the benefits of transport investment. If values of time for appraisal are based on individuals' willingness to pay (behavioural values) which are related to income, then investment decisions will be biased towards those measures which benefit travellers with higher incomes. Investment would be concentrated into high-income areas or modes, and the interests of those on lower incomes, who may already suffer from relatively lower mobility and accessibility, will be given less weight. For this reason, the first source of variability is controlled for by the use of national average values in table A1.3.1, which should normally be adopted in transport appraisal.

4.3.5 Individual consumers perceive costs in the market price unit of account and therefore the perceived cost and the market price are the same for 'commuting' and 'other' purposes.

4.3.6 Based on the results of the most recent value of time research,[10] the recommended sensitivity testing ranges for the non-work values of time are given below:

Table 1: Recommended sensitivity testing ranges: non-work values of time

Trip purpose	Recommended sensitivity testing range
Commute	+/- 25%
Other non-work	+/- 60%

4.3.7 As with the values of working time, this range should be applied in sensitivity testing. This analysis should be carried out and reported separately from analysis carried out on values of working time.

[10] Department for Transport (2015), 'Provision of market research for value of travel time savings and reliability: Phase 2 Report', available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470231/vtts-phase-2-report-issue-august-2015.pdf

4.4 Value of time multipliers

4.4.1 There is consistent evidence that people and businesses will pay more to save time spent in certain conditions, compared to 'average' conditions. Specifically, WTP for saving walking and waiting time is found to be greater than for an equivalent saving of in-vehicle time. Based on the results from a meta-analysis covering over 130 estimates of wait time multipliers across Europe,[11] the values of time in table A1.3.1 of the TAG Data Book should be factored by 2 for time spent waiting for public transport. This multiplier should also be applied to time spent accessing or interchanging between modes of transport by walking or cycling. This applies to all journey purposes.

4.4.2 An alternative method to valuing wait time is to use 'service frequency penalties' that represent the 'cost' of a given frequency in terms of equivalent additional in-vehicle time. Where evidence is available to support a robust valuation on this basis, and these values have been used for modelling/forecasting, they should also be used for appraisal.[12] More guidance on this can be found in TAG unit A5.3.[13]

4.4.3 There is a wide body of evidence suggesting people and businesses have a greater willingness-to-pay for time savings in congested and crowded conditions. For rail appraisal, the recommendations set out in PDFH should be used. For other modes, while latest research shows support for varying the VTTS according to crowing/congestion levels, more research is needed before reliable values can be derived on a robust basis.[14]

4.5 Increases in values of time over time

4.5.1 Both the work and non-work values of time (excluding journeys by LGV or OGV) are assumed to increase with income over time with an elasticity of 1.0[15]. The TAG Data Book Annual Parameters table includes forecasts of real GDP growth per head, which is the measure of income used, and the resulting growth rates which should be applied to the values. Different growth rates are provided for use in modelling and appraisal, the latter using the Office for Budgetary Responsibility's estimate of long-run labour productivity as the basis for forecast year growth.

---

[11] Value of Time Multipliers: A Review and Meta-Analysis of European-Wide Evidence, Wardman et al (2013).

[12] For example, PDFH contains service frequency penalties for rail, which should be used for appraisal if they have been used in forecasting as well.

[13] https://www.gov.uk/government/publications/webtag-tag-unit-a5-3-rail-appraisal-may-2018

[14] See p.217 of the 2015 report, available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470231/vtts-phase-2-report-issue-august-2015.pdf

[15] Elasticity is the relative response of one variable to changes in another variable. The phrase "relative response" is best interpreted as the percentage change. In this context, the inter-temporal income elasticity of the value of time, is the percentage change in the value of time (over time) measured against the percentage change in income (over time). The elasticities are based on findings from Abrantes & Wardman (2010).

4.5.2 As a result of the research into road freight values of travel time[16], LGV and OGV VTTS are subject to different assumptions on growth over time. Namely, freight VTTS is assumed to grow at a rate that blends real wage growth for the wage-related component of VTTS, with the GDP deflator for the residual component. Non-freight LGV VTTS are assumed to grow with income with an elasticity of 1.0, implying that the average LGV VTTS grows at a weighted average of the freight and non-freight rates. These series are included in the TAG Data Book Annual Parameters table.

4.5.3 The results of applying the growth forecasts, for use in modelling, are given in:

A1.3.2: Forecast values of time per person

4.6 Values of time per vehicle

4.6.1 The TAG Data Book provides data on vehicle occupancy rates; how they are forecast to change over time; and proportions of travel by journey purpose, time of day and vehicle type:

A1.3.3: Vehicle Occupancy (2000); Annual percentage change in car passenger occupancy

A1.3.4: Proportion of travel and trips in work and non-work time

4.6.2 These variables are combined with the relevant values of time per person to give values of time per vehicle in the Department's base year and forecast values per vehicle:

A1.3.5: Value of time per vehicle (single year)

A1.3.6: Forecast value of time per vehicle

5. Vehicle operating costs

5.1.1 Use of the transport system gives rise to operating costs for the user. These include fuel and non-fuel costs, where non-fuel costs include oil, tyres, vehicle maintenance and mileage-related depreciation (meaning allowance is made for the purchase of new vehicles[17]).

[16] See main findings and primary study, plus links to peer review and peer review response at: https://www.gov.uk/government/publications/understanding-and-valuing-road-freight-travel-time
[17] For business cars, an allowance is also made for the decline in vehicle capital value (other than that accounted for by mileage related depreciation).

Fuel operating costs

5.1.2 The Department for Energy Security & Net Zero (DESNZ) recommend[18] that changes in energy consumption should be valued using the Long-Run Variable Cost (LRVC) of energy supply. The LRVC captures the net change in social welfare from a unit of energy consumption, whereas retail energy prices contain components accruing to other agents in society as transfers (taxes and profits) and an allowance for fixed costs (which do not change in the long run with a small sustained change in energy use). Therefore for a marginal change in energy use, the difference between the retail price and LRVC will accrue as either taxation to Government or additional profit to firms.

5.1.3 Retail prices are however required for the accurate calculation of the Rule of a Half, given consumers perceive the total price paid, inclusive of these superfluous elements. Therefore, to ensure that appraisals accurately reflect the final social welfare impacts of changes in energy use, a two-stage process is required to accurately calculate user benefits arising from energy use. Firstly, to calculate fuel costs as perceived, and secondly to 'add back in' the residual components of the retail price which are not resource costs (from here termed ‘Non-variable costs’, or NVC), leaving the LRVC as the final measure of the change in social welfare.

5.1.4 Fuel costs for use in appraisal are given in:

A1.3.7: Fuel and electricity price forecasts

5.1.5 based on fuel price forecasts published in Supplementary Green Book guidance on valuation of energy use and greenhouse gas emissions[19]. For business and freight trips, the perceived fuel cost should include fuel duty but not VAT (which is reclaimable). These costs are perceived in the factor cost unit of account and so should be converted to market prices using the indirect tax correction factor (see TAG Unit A1.1). Fuel costs for non-work trips, which are perceived in the market prices unit of account, should include both fuel duty and VAT.

5.1.6 Fuel consumption is estimated using a function of the form:

$$L = (a + b.v + c.v^2 + d.v^3) / v$$

Where:
L = consumption, expressed in litres per kilometre;
v = average speed in kilometres per hour; and
a, b, c, d are parameters defined for each vehicle category.

5.1.7 The parameters for these equations were derived[20] to be consistent with the latest fleet composition and projections and methods used in the National

[18] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[19] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

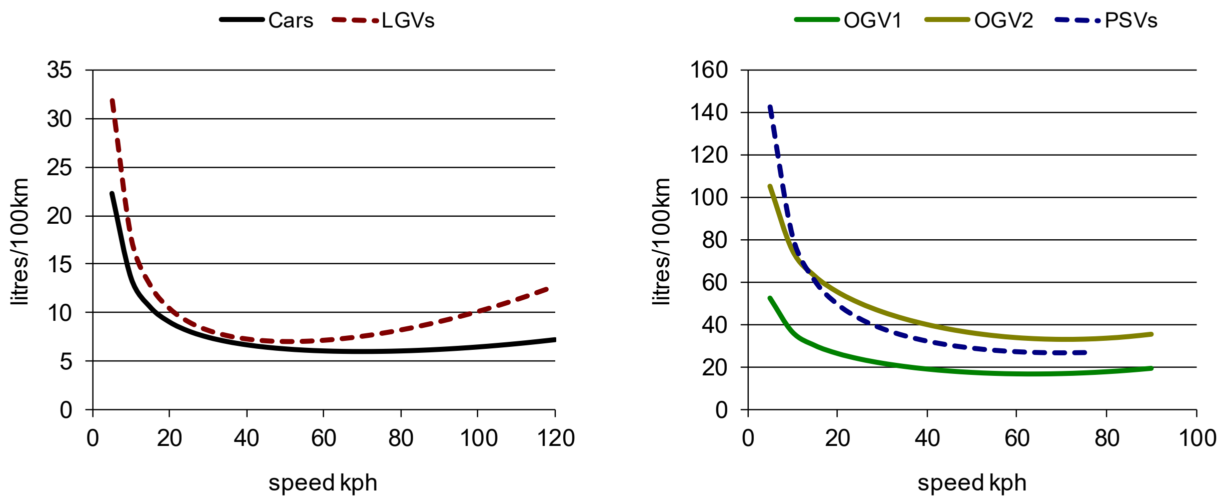
[20] Ricardo-AEA unpublished report “Production of Updated Emission Curves for Use in the National Transport Model” dated 24 February 2014.

Atmospheric Emissions Inventory (NAEI), which can be found at: http://naei.defra.gov.uk/. The parameters, by vehicle type, are given in:

A1.3.8: Fuel/energy consumption parameters

5.1.8 Figure 2 shows how fuel consumption varies with speed, using these functions.

Figure 2 - fuel consumption rates at different speeds (2010 fleet)



5.1.9 The proportion of cars and LGVs using petrol, diesel or electric fuel is required to calculate the averages for cars and LGVs shown in Figure 2. These proportions, and forecast changes over time, are given in:

A1.3.9: Proportions of vehicle kms by fuel type

5.1.10 Fuel efficiency is expected to improve over time, meaning that these parameters will decrease over time. Fuel efficiency improvement assumptions (with negative values representing improved efficiency) are given in:

A1.3.10: Forecast fuel efficiency improvements

A1.3.11: Forecast fuel consumption parameters

5.1.11 The parameters in the fuel consumption equation (in litres/km) can be multiplied by the cost of fuel (in pence per litre) to give a fuel cost equation (in pence per km). The forecast costs of fuel, changes in the fleet mix and efficiency improvements can then be combined to provide forecasts of the fuel cost equation by vehicle type and journey purpose:

A1.3.12: Forecast fuel cost parameters (work)

A1.3.13: Forecast fuel cost parameters (non-work)

5.1.12 NVCs encompass the residual components of retail price, after removing the LRVC, taxes, and any relevant carbon costs (the latter two components being accounted for elsewhere in appraisal). The forecast series of NVCs for use in appraisal are derived from DESNZ estimates of the LRVC, and are displayed in:

A1.3.7: Fuel and electricity price forecasts

5.1.13 NVCs are added back into the appraisal as an offset to the perceived fuel benefit (which is calculated using retail prices as per Appendix A). Specifically:

NVC impact = $((T^1 \times C^1) - (T^0 \times C^0))$ x NVC x MarketPriceAdjustment

5.1.14 Where T represents the number of trips in either Do-Something (1) or Do-Minimum (0), C represents the fuel consumption per trip (in litres or kWh) in a given scenario, year and fuel type, 'NVC' represents the per unit NVC value, and 'MarketPriceAdjustment' is applied given the NVC saving term arises in the factor cost unit of account to businesses (such as energy suppliers), and hence should be converted to market prices for appraisal.

5.1.15 The total fuel benefit is the sum of the (retail price) fuel cost benefits (as per Appendix A) and the NVC impacts.

5.1.16 By calculating NVCs appropriately (i.e. following the above two-stage process), traded carbon costs (e.g. relating to the consumption of electricity) are left within the perceived fuel benefit calculation, because only the NVC (which excludes carbon) is deducted from the full retail price. The valuation of traded carbon in appraisal should follow guidance set out in TAG Unit A3 – Environmental Impact Appraisal, including applying an appropriate “double-counting” adjustment. For petrol and diesel, non-traded carbon values are used to value changes in greenhouse gas emissions.

Non-fuel operating costs

5.1.17 The elements making up non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time). The non-fuel elements of VOC are combined in a formula of the form;

$$C = a1 + b1/V$$

where;
C = cost in pence per kilometre travelled;
V = average link speed in kilometres per hour;
a1 is a parameter for distance related costs defined for each vehicle category; and
b1 is a parameter for vehicle capital saving defined for each vehicle category (this parameter is only relevant to non-freight working vehicles).

5.1.18 The parameter values, in resource costs (i.e. excluding indirect taxation), are given in:

A1.3.14: Non-fuel resource vehicle operating costs

5.1.19 Non-fuel VOC parameters for work and non-work cars and private LGVs have been derived in accordance with methods outlined in 'Review of Vehicle Operating Costs in COBA (EEA Division, DoT 1990-91)'. Non-fuel parameters for all other vehicles have been updated from the 'Transport Economics Note (DfT 2001)'.

5.1.20 The 'a1' term represents the marginal resource costs of oil, tyres, mileage and maintenance related depreciation[21], which are assumed to be fixed costs per kilometre. The difference between the work and non-work values reflects the difference in the composition of the vehicle fleet in work and non-work time (in work time, a large proportion of mileage is by cars with large engine sizes with higher non-fuel VOCs).

5.1.21 The 'b1' term in the non-fuel VOCs represents changes in the productivity of cars, non-freight work LGVs and PSVs in working time. Both OGV and LGV freight VTTS capture changes in time-related depreciation, as previously captured by the b1 parameter. The b1 parameter should therefore not be applied to OGVs and freight LGVs, to avoid double-counting this effect in appraisal.

5.1.22 It is assumed that non-fuel VOCs are only perceived during work time. Therefore, for work purposes non-fuel VOCs should be included in generalised cost and benefits estimated using the rule of a half (and converted from the factor cost to market price unit of account in appraisal).

5.1.23 For non-work purposes, non-fuel VOCs should not be included in generalised cost or calculations of changes in surplus using the rule of a half. However, changes in users' expenditure on non-fuel VOCs are included in user benefits for non-work purposes. This should be calculated as the total change in expenditure on non-fuel VOCs, including indirect taxes (see Appendix A:). Therefore, the resource costs in table A1.3.14 should be multiplied by (1+VAT) to give non-fuel VOCs for non-work trips.

5.1.24 Non-fuel VOCs are assumed to remain constant in real terms over the forecast period because the main elements which make up non-fuel VOCs are subject to less volatility than fuel VOCs. However, will vary due to the forecast change in fleet mix and are given in:

A1.3.15: Forecast non-fuel resource vehicle operating costs

5.1.25 TAG Unit A1.2 – Scheme Costs provides further guidance on estimating bus and rail operating costs.

[21] The time component of depreciation is excluded since it does not vary with distance or speed. All depreciation for OGVs and PSVs is assumed to be time related. For cars and LGVs, evidence from second hand prices indicates that part of their depreciation is related to mileage; and therefore this element is included in the marginal resource cost. For OGVs and freight LGVs, the time-related depreciation element is captured in the VTTS only.

6. Reliability

6.1.1 The term reliability in this section refers to variation in journey times that individuals are unable to predict (journey time variability, or JTV). Such variation could come from recurring congestion at the same period each day (day-to-day variability, or DTDV) or from non-recurring events, such as incidents. It excludes predictable variation relating to varying levels of demand by time of day, day of week, and seasonal effects which travellers are assumed to be aware of.

6.1.2 Different methods to estimate reliability impacts have been developed for public transport and private vehicle trips on inter urban motorways and dual carriageways, urban roads, and other roads. All the methods require a unit to measure travel time variability and this is generally the standard deviation of travel time (for private travel) or lateness (for public transport). More detail on the methods described below is given in Appendix C:.

6.2 Inter urban motorways and dual carriageways

6.2.1 Research (Arup, 2004) found that, as long as demand is below capacity, incidents will be the main source of JTV, and DTDV is much less important except in urban areas where the two effects cannot be readily separated. In such circumstances, where demand is below capacity, the additional delays caused by congestion unrelated to incidents and any associated variability can be assumed to be allowed for in the journey time forecasts. In the case of delays due to incidents, a separate element for average delays will usually need to be added to the variability element. Additional research by National Highways to develop software has also been undertaken to incorporate DTDV into the calculations, where appropriate.

6.2.2 Existing methods of estimating reliability for dual carriageways and motorways assume a dual carriageway layout and are likely to use parameters based on data for motorways only. Incident delays can be estimated according to the average severity and length of each type of incident, the number of lanes blocked and the volume of traffic at the time. Changing the number of lanes available to traffic changes both the probability of encountering an incident (or its aftermath) and the delays caused by incidents. The resulting estimates of benefits cannot be taken to be as robust as those for time savings or accident reductions, but they are likely to be of more value to decision makers than a qualitative assessment.

6.2.3 For motorways and dual carriageways, alternative routes avoiding particular sections usually have limited capacity making it difficult for large numbers of drivers to divert if they encounter delays due to an incident. In the absence of significant “transient excess demand” (temporary periods of demand exceeding capacity), it may be sufficient to assume that incidents are the main source of unpredictable variability. However, it is important to note that the research underlying existing methods currently incorporate what are intended to be conservative assumptions, which will be refined in due course.

6.2.4 National Highways have a bespoke tool to estimate JTV benefits. Where JTV benefits are estimated, they should be incorporated in the appraisal as follows:

- The reliability benefits should NOT be included in the Analysis of Monetised Costs and Benefits (AMCB) table and thus not be included in estimates of the Net Present Value (NPV) and Benefit to Cost Ratio (BCR) for the transport intervention, but

- SHOULD be included in the Appraisal Summary Table (AST) for the transport intervention and thus be taken into account in the assessment of the overall value for money of the transport project.

6.3 Urban roads

6.3.1 In urban areas alternative routes are more readily available than on motorways and there are many ways for drivers to divert away from incidents which reduce capacity on a particular route. This affects the relative importance of incident and DTDV effects.

6.3.2 Building on previous research, Hyder Consulting, Ian Black and John Fearon (2007) developed a model to forecast changes in the standard deviation of travel time from changes in journey time and distance:

$$\Delta\sigma_{ij} = 0.0018\,({t_{ij2}}^{2.02} - {t_{ij1}}^{2.02})\,{d_{ij}}^{-1.41}$$

where:

$\Delta\sigma_{ij}$	is the change in standard deviation of journey time from i to j (seconds)
t_{ij1} and t_{ij2}	are the journey times, before and after the change, from i to j (seconds)
d_{ij}	is the journey distance from i to j (km).

6.3.3 To estimate the monetised benefit of changes in journey time variability, money values are needed. The reliability ratio enables changes in variability of journey time (measured by the standard deviation) to be expressed in monetary terms. The reliability ratio is defined as:

Reliability Ratio = Value of SD of travel time / Value of travel time

6.3.4 The recommended value for the reliability ratio for all journey purposes by car and non-freight LGVs, based on evidence from the most up-to-date passenger value of time study in the UK (‘Provision of market research for value of travel time savings and Reliability: Phase 2 Report’, ITS and Accent for the

Department for Transport, 2015), is **0.4**. Drawing on research into freight values of travel time and reliability[22], the equivalent ratios for OGVs and freight LGVs are **0.58** and **0.7** respectively (resulting in a weighted average LGV reliability ratio of **0.47**). Multiplying these values by the appropriate value of time for the purpose/vehicle type in question gives a value of reliability which can be used to estimate the reliability benefit in a formula similar to the rule of a half introduced in paragraph 2.1.6:

$$Benefit = -\frac{1}{2}\sum_{ij} \Delta\,\sigma_{ij} * \left(T_{ij}^{0} + T_{ij}^{1}\right) * VOR$$

Note that the value of reliability (VOR) is obtained by multiplying the value of time by the reliability ratio and T_{ij}^0 and T_{ij}^1 are number of trips before and after the change.

6.3.5 Although the model above can be used to estimate the effect of schemes and their reliability benefits in urban areas, a locally calibrated model or a local validation is preferable. Any estimates of reliability benefits using this method should be identified separately from other economic benefits and only reported in the AST.

6.4 Other roads

6.4.1 For journeys predominantly on single carriageways outside urban areas, it is not currently possible to estimate monetised reliability benefits. Instead, the assessment of changes in reliability should be based on changes in 'stress', the ratio of the annual average daily traffic (AADT) flow to the Congestion Reference Flow (a definition of capacity). Reliability of road journey times is believed (on the basis of work carried out for DfT's TASM Division) to decline as flows approach capacity. Thus, 'stress', is, with some limitations, considered to be a reasonable proxy for reliability. Detailed advice on stress, including the definition of Congestion Reference Flow, is provided in DMRB Vol 5, Section 1, Part 3, TA46/97.

6.4.2 The method to be used is described in detail in Appendix C.5 where a worksheet is provided so that values for improved reliability can be calculated and presented in a consistent manner.

6.5 Public transport

6.5.1 For most public transport journeys, the existence of timetabled arrival times means that it is usual to consider reliability in terms of lateness, defined as the difference between travellers' actual and timetabled arrival times. Adopting this definition means that arrival before the timetabled arrival time is usually ignored. Two measures of lateness must be considered: average lateness; and the variability of lateness, measured by the standard deviation of lateness.

[22] See main findings and primary study, plus links to peer review and peer review response at: https://www.gov.uk/government/publications/understanding-and-valuing-road-freight-travel-time

6.5.2 Therefore, the reliability ratio for public transport is defined as the ratio of the value of the standard deviation of lateness to the value of average lateness, where the value of average lateness is a factor of the value of travel time savings:

Reliability Ratio = Value of SD of lateness / Value of average lateness

Value of average lateness = factor * value of travel time

6.5.3 Based on evidence from the PDFH[23] the value of average lateness for public transport is 2.5 times the value of in-vehicle time. A reliability ratio of 1.4 is recommended for all purposes for all public transport modes.

6.5.4 Therefore both the mean lateness and the standard deviation of lateness should ideally be modelled. However, in many cases the information required to calculate the standard deviation of lateness will not be available. Bates et al (2001) suggested that it is the “pure” lateness effect which tends to dominate, because the effect of variability is less important given that rail passengers have already made some “compromises” in selecting arrival or departure time of their preferred scheduled train.

6.5.5 For rail, the PDFH recommendations on performance given in Table 1 of TAG Unit M4 – Forecasting and Uncertainty should be followed. The lateness factors in PDFH vary by flow type. For other public transport schemes, in the absence of better evidence, an uplift of 20% can applied to the value of wait time (2.0), giving a lateness factor of 2.4.

6.5.6 Bates et al recommend that early arrival is given the same weight as late arrival but with the opposite sign. However, early arrivals are not included in rail Public Performance Measure (PPM) data so it is recommended that early rail arrivals are treated as on time and excluded from calculations of the mean and standard deviation of delay.

6.5.7 Rail performance data distinguishes between ‘punctuality’, services arriving on time, and ‘reliability’, services being cancelled. Both factors contribute to journey time variability and should be included in assessment of reliability impacts. When a train is cancelled, the service interval (which is the delay for the passenger) should be multiplied by 1.5 to represent the greater disutility associated with waiting rather than being in the vehicle. This value should then be multiplied by the late time multiplier (for the given flow) as outlined in PDFH.

[23] PDFH is a technical document, summarizing research on the various factors affecting forecasts of demand for passenger rail services, published by the Passenger Demand Forecasting Council. It is not a public document and is only available on subscription from the Association of Train Operating Companies.

7. Impacts on transport providers

Public transport provider revenues

7.1.1 The change in transport provider revenues is given by the following equation for both work and non-work trips:

$$(M^1 - M^0) = \sum_{ij} T^1_{ij}\ M^1_{ij} - T^0_{ij}\ M^0_{ij}$$

7.1.2 where M^S is total revenue (with the S superscript representing the scenario); and M^S_{ij} is the revenue per trip, and T^S_{ij} the number of trips, between i and j. As businesses, transport providers perceive changes in revenue in factor costs so they should be converted to the market price unit of account.

Bus and rail operating costs

7.1.3 Formulations for public transport operating costs are less well established than for private vehicles (cars and goods vehicles) and may differ from study to study. In a simple highway appraisal, buses are treated as part of the traffic flow, and the operating cost formulae described in section 5 are applied, using the appropriate parameter values for PSVs. However, in a multi-modal study different options may result in the need for more or different levels and patterns of bus service provision.

7.1.4 TAG Unit A1.2 provides guidance on the factors that should be included in public transport operating costs. Care should be taken to ensure that operating costs, investment costs and subsidies are treated separately and correctly reported.

7.1.5 Costs should exclude VAT, which is recoverable by the operator, but should be multiplied by (1+t) to convert them to the market prices unit of account.

8. Impacts on indirect tax revenue

8.1.1 Indirect tax revenues accrue to the government which perceives those revenues in the factor cost unit of account. Therefore indirect tax revenues should be converted to the market price unit of account by multiplying by (1+t), the indirect tax correction factor. This conversion to market prices is included in the detailed equations for calculating the indirect tax impacts of work and non-work trips in Appendix A.5.

9. Annualisation

9.1.1 Transport models typically model periods of the day so that benefits estimated from model outputs have to be expanded to cover the whole day and then a full year. This might mean expanding benefits from a modelled hour to cover a longer period (e.g. expanding the weekday AM peak hour to cover a 3-hour weekday AM peak period for a whole year) but could also include estimating benefits in non-modelled periods from the modelled results (e.g. estimating off-peak or weekend benefits from a modelled inter-peak hour).

9.1.2 Separate annualisation factors should be used for each modelled period and should account for differences in flows, modes used and mix of journey purposes in the period modelled and the period that benefits are being expanded to cover.

9.1.3 Different annualisation factors may also be needed for vehicle flows, public transport patronage and revenues, mode shift and congestion relief benefits as the relationship between demand and congestion relief benefits is non-linear. In cases where there is significant congestion, benefits will increase more than proportionately with the level of demand. Where congestion is less of an issue, single annualisation factors may be appropriate.

9.1.4 The data sources used, and assumptions and calculations made, in deriving annualisation factors should be clearly documented and explained. It is particularly important to explain where different factors have been used (e.g. for public transport patronage and revenues and congestion relief benefits) and, where applicable, how annualisation factors have been derived for non-modelled periods.

10. Impacts during construction and maintenance

10.1.1 Costs to existing transport users due to the construction of a project and costs (or benefits) to users arising during future maintenance should be recorded in the TEE tables where they are likely to be significant.

10.1.2 Impacts during construction and/or future maintenance may be estimated using the same congested assignment package as used to predict the overall traffic effects of the scheme. Models may also be useful for options affecting public transport users if significant diversion is expected during construction and/or future maintenance. The TUBA program may be used to value delays to road and/or public transport users, using standard economic parameters. For options affecting public transport, the impact on operators' revenues should also be considered. For heavy rail, estimates should be based on the compensation regime between the train operators and infrastructure authority, typically Network Rail.

10.1.3 In some circumstances, it may be sufficient to use a simplified approach, based on evidence of unit costs per kilometre from other schemes. For road user delays, unit costs will vary with traffic levels, and thus it will be important to demonstrate that they are appropriate for the option being considered.

11. Reporting user benefits and transport provider impacts in the PA and TEE tables

11.1.1 Monetised benefits for transport users and private sector providers are summarised in the Transport Economic Efficiency (TEE) table. All benefits should be reported in present values and real prices, in the Department's base year, and in the market prices unit of account (see TAG Unit A1.1). Benefits should be reported as positive values and disbenefits (or costs) as negative values. The Department's appraisal software, TUBA, performs these calculations using the methods and values in this TAG Unit and the TAG Data Book and presents the results in the TEE table format.

11.1.2 User travel time, vehicle operating cost and user charge impacts should be included in the TEE table, as should user impacts during construction and maintenance (which should include both travel time and vehicle operating cost impacts). Monetised reliability impacts should not be included in the TEE table.

11.1.3 Impacts on business (including freight), commuting and other trips should be reported separately. The sub-totals for business, commuting and other indicate the distribution of gains (and, potentially, losses) from the option.

11.1.4 Benefits should be attributed to the mode and source of change as described in sections 2 and 3. For example, consider an option which reduces bus journey times with no change in fares, leading to an increase in bus demand. New bus passengers will pay fares but, as the level of fare has not changed, the net impact on both new and existing bus passengers, calculated using the rule of a half, will attribute all of the net benefit to the change in journey time. Therefore the benefits to bus passengers should be reported in the 'Travel time' row of the TEE table for each journey purpose. This means that the totals for 'User charges' (which are calculated with the rule of a half) and private sector provider 'Revenues' (which are calculated from changes in fare and demand) should not be expected to match.

11.1.5 If, in the same example, the option leads to mode switch and road decongestion, this will change both journey times and vehicle operating costs for road users. Therefore, the impacts reported in the 'Roads' column would be split between the 'Travel time' and 'Vehicle operating costs' rows.

11.1.6 Where not explicitly quantified in the modelling approach, the impacts on pedestrians, cyclists and others should be assessed using the method set out in TAG Unit A5.5 – Highway Appraisal.

11.1.7 The 'Private sector provider impacts' section of the TEE table should include estimates of changes in revenues (see section 7), operating costs and investments costs (see TAG Unit A1.2). Increases in revenue should be recorded as a positive value while costs should be recorded as a negative value in the TEE table. The disaggregation in the column headings is quite broad, meaning they include service operators' infrastructure providers. Following the decision to reclassify Network Rail as a Central Government Body[24], Network Rail spending and revenues should be considered to impact directly on the Broad Transport Budget. For example, additional operator costs reported in the TEE table need to account for track access charge payments, with the equivalent Network Rail revenues (and additional operating costs incurred by Network Rail) recorded in the Public Accounts (PA) table.

11.1.8 As discussed in TAG Unit A1.2, changes in grant or subsidy payments to private sector providers should be recorded in both the TEE and PA tables. An increase in subsidies paid to providers should be recorded as a positive value in the 'Grant/subsidy' row of the TEE table (a benefit to the provider) and a positive value in the corresponding row of the PA table (where a positive value represents a cost to the public sector).

11.1.9 When developers make contributions, the full investment cost should be attributed to either local or central government in the PA table, with negative values recorded in the 'Developer contributions' rows of both the TEE table (to show the cost to the developer) and the PA table (to show the reduction in cost to the public sector).

11.1.10 Changes in indirect tax revenue should be reported in the 'Indirect tax revenues' row of the PA table. Indirect tax revenues will increase where total fuel consumption increases. Though in most circumstances indirect tax and fuel cost impacts should be of the same sign, there may be some rare occasions when they have a different sign. Fuel cost impacts, are calculated using the 'rule of a half'. More detail on this is given in the TUBA Manual. As indirect tax revenues accrue to the government they are perceived in the factor cost unit of account and should be converted to the market price unit of account by multiplying by (1+t), the indirect tax correction factor.

11.1.11 TAG Unit A1.1 – Cost Benefit Analysis provides guidance on how costs reported alongside other elements covered by the appraisal in the Analysis of Monetised Costs and Benefits (AMCB) table and Appraisal Summary Table (AST).

[24] http://www.ons.gov.uk/ons/dcp171766_345415.pdf

12. References

Abrantes, P. and Wardman, M., Institute for Transport Studies, University of Leeds (2010), Meta-Analysis of UK Values of Time: An Update

Arup, AECOM, Institute for Transport Studies University of Leeds, and Significance (2023): Freight value of time and value of reliability: Final report

Arup, Bates, J., Fearon, J. and Black, I. (2004): Frameworks for Modelling the Variability of Journey Times on the Highway Network. Department for Transport, UK.

Bates, J., Polak, J., Jones, P and A. Cook (2001): 'The Valuation of Reliability for Personal Travel', Transportation Research Part E 37.

DfT, Transport Users Benefit Appraisal User Manual, TUBA User Guidance with accompanying TUBA software

EEA Division, Department of Transport (1990-91): Review of Vehicle Operating Costs in COBA.

Faber Maunsell / AECOM (2008), M6T Research Study – Stage 2 Utilisation Surveys

Hamer, R., De Jong, G., Kroes E and P, Warffemius (2005): The Value of Reliability in Transport.

Highways Agency: Design Manual for Roads and Bridges, Volume 5.

Hyder Consulting, Fearon, J. and Black, I. (2007): Forecasting Travel Time Variability in Urban Areas. Department for Transport, UK

Jones (1977): Urban Transport Appraisal published by Macmillan London

Mackie, P., Wardman, M., Fowkes, A.S., Whelan, G., Nellthorp, J. and Bates, J.. Institute for Transport Studies, University of Leeds (2003): Values of Travel Time Savings in the UK.

Mott MacDonald (2013): Valuing the social impacts of public transport: Final report.

Nellthorp, J. and Hyman, G. (2001): Alternatives to the rule of a half in matrix-based appraisal. Proceedings of European Transport Conference. [http://www.etcproceedings.org/paper/download/373]

Passenger Demand Forecasting Handbook (PDFH)

Sugden (1999) Review of cost/benefit analysis of transport projects

TEN; HETA (Mar 2001) Transport Economics Note, the primary source for information on: values of time; values for vehicle operating costs (fuel and non-fuel); and tax rates

TRL et al (2004). The demand for public transport: a practical guide. TRL Report 593 http://www.demandforpublictransport.co.uk/ [Accessed 2 October 2012]

Wardman, M., Batley, R., Laird, J., Mackie, P., Fowkes, A.S., Lyons, G., Bates, J. and Eliasson, J., Institute for Transport Studies, University of Leeds (2013), Valuation of Travel Time Savings for Business Travellers

Wheat, P., Wardman, M. and Bates, J., Institute for Transport Studies, University of Leeds (2012), Advice on Statistical Confidence of Appraisal Non-Work Values of Time

13. Document Provenance

13.1.1 This TAG Unit forms guidance on the estimation and reporting of scheme costs and user and provider impacts that was previously in TAG Units:

- 3.5.1 – The Public Accounts sub-objective;
- 3.5.2 – The Transport Economic Efficiency sub-objective;
- 3.5.3 – Transport Benefit Computation;
- 3.5.6 – Values of time and operating costs; and
- 3.5.7 – The Reliability sub-objective.

13.1.2 This TAG Unit also covers elements of guidance on benefit estimation previously included TAG Unit 3.9.2 – MSA Cost Benefit Analysis.

13.1.3 Guidance on methods for estimating the social impacts of bus interventions was added to the Unit as Appendix B in May 2014.

13.1.4 In November 2014 this TAG Unit was updated to provide guidance on how Network Rail costs should be treated and reported in appraisal following the decision to reclassify Network Rail as a Central Government body; and to reflect the Department's adoption of methods in PDFH v5.1 for assessing rail reliability.

13.1.5 In May 2025 this TAG Unit was updated with details of how to incorporate Non-Variable Costs in appraisal, and the addition of Appendix D, on large cost changes.

13.1.6 In May 2026 this TAG Unit was updated to reflect the latest research on road freight values of travel time.

Appendix A: Transport User Benefit Calculation

A.1.1 The extent to which the appraisal is disaggregated by mode, purpose, vehicle type, time period, vehicle availability or other category will be for analysts to decide. Whatever choice is made, the following calculations are applicable to the trip matrix for each category. However, it is important to distinguish between work and non-work trips, for two reasons:

- for non-working trips, some costs are assumed to be unperceived; and
- different (overall) indirect taxation rates apply to work and non-work trips, because VAT is levied only on final consumption (and thus only applicable to non-work trips), whereas duties are levied on all purchases (thus applying to work and non-work trips alike).

A.1.2 To accommodate these distinctions, the following discussion presents separate results for work and non-work trips. The Department's appraisal software, TUBA, carries out the calculations described here.

A.1.3 The notation in this appendix is based on that from Sugden (1999). The superscript *i* represents the scenario (0 for the without-scheme case and 1 for the with-scheme case), while the subscripts *i* and *j* denote values for specific zone to zone movements. As described in section 3, benefit calculations should be carried out by mode of transport, with benefits attributed on the basis of where changes in cost occur. Therefore the calculations described here should be applied at a modal level. For simplicity a modal subscript has not been included. The following list provides a summary of all the terms used in this appendix.

S^i_{ij} consumer surplus for travellers between i and j;

P^i_{ij} perceived cost of trip between i and j;

F^i_{ij} fuel cost of highway trips between i and j, including indirect taxes;

NV^i_{ij} non-variable cost of highway trips between i and j, including indirect taxes

N^i_{ij} non-fuel vehicle operating costs (such as tyres, maintenance, depreciation) of highway trips between i and j, including indirect taxes (note that, for non-work highway trips, N^i_{ij} is assumed to be unperceived);

M^i_{ij}	fares, tolls and other charges including parking, for trips between i and j;
	(Note that, for work trips, values of F^i_{ij}, N^i_{ij} and M^i_{ij} should exclude VAT but include all other indirect taxes.)
V^i_{ij}	'perceived' time cost of trips between i and j (note that $V^i_{ij} = J^i_{ij} * K_T$);
J^i_{ij}	journey time between i and j;
D^i_{ij}	distance between i and j;
L^i_{ij}	fuel consumed between i and j;
T^i_{ij}	number of trips between i and j;
K_T	value of time;
K_F	cost of fuel;
K_{NV}	non-variable cost component of fuel;
t	average rate of indirect tax on final consumption;
t_F	rate of indirect tax on fuel as a final consumption good;
t_F'	rate of indirect tax on fuel as an intermediate good;
t_N	rate of indirect tax on non-fuel vehicle operating costs as final consumption goods;
t_N'	rate of indirect tax on non-fuel vehicle operating costs as intermediate goods;
t_M	rate of indirect tax on fares, tolls and other charges as final consumption goods;
t_M'	rate of indirect tax on fares, tolls and other charges as intermediate goods.
	(Note that the taxation rates relating to costs as intermediate goods are applicable to work trip costs, while the rates for costs as final consumption goods are applicable to non-work trip costs.)

A.2 User benefits

A.2.1 Total user benefits are defined as:

- For work trips: $(S^1 – S^0)(1+t) = ½ (1+t) \Sigma_{ij}(T^1_{ij} + T^0_{ij})(P^0_{ij} – P^1_{ij})$; and

- For non-work trips: $(S^1 – S^0) – (N^1 – N^0) = ½ \Sigma_{ij}(T^1_{ij} + T^0_{ij})(P^0_{ij} – P^1_{ij}) – \Sigma_{ij}(T^1_{ij} N^1_{ij} – T^0_{ij} N^0_{ij})$

A.2.2 For work trips, costs are perceived in the factor cost unit of account and so are multiplied by (1+t) to convert to market prices. For non-work trips, non-fuel operating costs are assumed to be unperceived costs so the change in non-fuel operating cost ($N^1 – N^0$) must be added to the rule of a half calculation.

A.2.3 Perceived costs comprise user charges (M), vehicle operating costs (F for fuel and N for non-fuel) and travel time ($V = J \times K_T$). The impacts of a scheme should be calculated and reported for each of these components of perceived costs.

A.2.4 Fares and charges (M) will often not be directly related to distance travelled. For example, tolls may be restricted to selected links in the network, and may be ‘entry point’ based, rather than distance based. Bus and train fares may vary by route, and do not apply to the access stages of journeys.

A.2.5 Fuel costs (F) should be based on the cost of fuel and fuel consumed: $F^i_{ij} = K_F L^i_{ij}$, where K_F should include VAT for non-work trips but should not include VAT for work trips. The preferred method of calculating L^i_{ji} is by application of the Transport Economics Note (TEN) formula (parameters adjusted) on a link by link basis, since this allows variations in speed during the journey to be taken into account, but this is not possible within a matrix-based appraisal package. The formula in section 5 of this TAG Unit provides an acceptable approximation of consumption per kilometre and can be multiplied by trip distance (D^i_{ij}) to give fuel consumed (L^i_{ji}).

A.2.6 Non-variable costs (NV), which represent the residual components of retail fuel prices which are not resource costs, tax or carbon costs, as set out in section 5 of this TAG Unit, should be calculated based on the non-variable component of fuel costs (K_{NV}) and fuel consumed (L^i_{ij}).

A.2.7 Non-fuel operating costs (N) should be calculated using the formula described in section 5 and time costs should be calculated by multiplying journey time (J^i_{ij}) by the appropriate value of time (K_T).

A.2.8 For work trips the disaggregated benefits are given by:

- user charges: $½(1 + t) \Sigma_{ij}(T^1_{ij} + T^0_{ij})(M^0_{ij} – M^1_{ij})$;
- vehicle operating costs: $½(1 + t) \Sigma_{ij}(T^1_{ij} + T^0_{ij})(F^0_{ij} + N^0_{ij} – F^1_{ij} – N^1_{ij})$;
- non-variable cost savings: $K_{NV}((T^1_{ij}L^1_{ij}) - (T^0_{ij}L^0_{ij}))$;
- travel time: $½(1 + t) \Sigma_{ij}(T^1_{ij} + T^0_{ij})(V^0_{ij} – V^1_{ij})$

A.2.9 And for non-work trips:

- user charges: $\frac{1}{2} \Sigma_{ij}(T^1_{ij} + T^0_{ij})(M^0_{ij} - M^1_{ij})$;
- vehicle operating costs: $\frac{1}{2} \Sigma_{ij}(T^1_{ij} + T^0_{ij})(F^0_{ij} - F^1_{ij}) - \Sigma_{ij}(T^1_{ij} N^1_{ij} - T^0_{ij} N^0_{ij})$;
- non-variable cost savings: $K_{NV}((T^1_{ij}L^1_{ij}) - (T^0_{ij}L^0_{ij}))$;
- travel time: $\frac{1}{2} \Sigma_{ij}(T^1_{ij} + T^0_{ij})(V^0_{ij} - V^1_{ij})$.

A.2.10 The benefits to non-work (or consumer) trips should be split by 'commuting' and 'other' trip purposes. Therefore the calculations above should be performed separately for these journey purposes.

A.3 Disaggregating travel time benefits by magnitude of time saving

A.3.1 The Appraisal Summary Table requires time savings to be reported by magnitude in bands of: 0 to 2 minutes; 2 to 5 minutes; and more than 5 minutes. This requires the calculation of time savings by six time bands:

- Less than -5 minutes;
- -5 to -2 minutes;
- -2 to 0 minutes;
- 0 to 2 minutes;
- 2 to 5 minutes
- Greater than 5 minutes.

A.3.2 The values calculated for the equivalent negative and positive time bands should be combined to give the net impact for the three time bands required in the AST. Analysts might wish to provide finer bands of travel time savings as deemed appropriate for their particular project.[25] The travel time benefits for a given travel time savings band A can then be calculated as follows (note the summation range covers all origin-destination pairs for which the travel time saving $(J^0_{ij} - J^1_{ij})$ lies within the given band):

[25] These bands are suggested to ensure comparability between project appraisals. There is no evidence to support valuing time savings in these bands at a different rate from time savings in other bands.

- for work trips: $\frac{1}{2}(1+t)\sum_{ij;(J^0_{ij}-J^1_{ij})\in A}(T^1_{ij}+T^0_{ij})(V^0_{ij}-V^1_{ij})$; and

- for non-work trips: $\frac{1}{2}\sum_{ij;(J^0_{ij}-J^1_{ij})\in A}(T^1_{ij}+T^0_{ij})(V^0_{ij}-V^1_{ij})$.

A.4 Disaggregating travel time benefits by trip distance

A.4.1 A similar calculation can be undertaken to evaluate travel time benefits by trip distance band. The distance bands need to be defined (eg time savings for trips between 5 and 10 km). The travel time benefits for a given distance band A can then be calculated as follows (note the summation range covers all origin-destination pairs for which the without-scheme distance (d^0_{ij}) lies within the given band):

- for work trips: $\frac{1}{2}(1+t)\sum_{ij;(d^0_{ij})\in A}(T^1_{ij}+T^0_{ij})(V^0_{ij}-V^1_{ij})$; and

- for non-work trips: $\frac{1}{2}\sum_{ij;(d^0_{ij})\in A}(T^1_{ij}+T^0_{ij})(V^0_{ij}-V^1_{ij})$.

A.4.2 For some public transport models, the distance travelled on public transport is not calculated by the assignment software. In most cases, the highway distance may be used as a satisfactory approximation to public transport distance.

A.5 Impacts on indirect tax revenue

A.5.1 The impacts on indirect tax revenue form part of the Public Accounts analysis but are included here because the calculations are closely related to those carried out for the calculation of user benefits. It is important to note that indirect tax revenues should be included in the Present Value of Benefits (PVB), rather than the Present Value of Costs (see TAG Unit A1.1).

A.5.2 Calculating the changes in indirect tax revenue is a little more complicated than user benefits:

- work trips: $(F^1-F^0)t_F'(1+t)/(1+t_F') + (M^1-M^0)t_M'(1+t)/(1+t_M') + (N^1-N^0)t_N'(1+t)/(1+t_N')$

- non-work trips: $(F^1-F^0)(t_F-t)/(1+t_F) + (M^1-M^0)(t_M-t)/(1+t_M) + (N^1-N^0)(t_N-t)/(1+t_N)$

where:

- $(F^1 - F^o) = \Sigma_{ij} (T^1_{ij} \ F^1_{ij} - T^0_{ij} \ F^0_{ij})$
- $(M^1 - M^o) = \Sigma_{ij} (T^1_{ij} \ M^1_{ij} - T^0_{ij} \ M^0_{ij})$
- $(N^1 - N^o) = \Sigma_{ij} (T^1_{ij} \ N^1_{ij} - T^0_{ij} \ N^0_{ij})$

Appendix B: Monetising the Social Impact of Bus Travel

B.1 Introduction

B.1.1 There are economic, environmental and social benefits associated with bus travel and, in the context of transport scheme appraisal, the term ‘social benefits’ can have a number of different meanings. Socially, the existence of a bus service increases accessibility to social services and employment opportunities. Social benefits (such as reduced risk of social exclusion and having access to education) will therefore arise where bus users are able to access particular services that they would not otherwise have had easy access to.

B.1.2 Benefits of this sort are recorded in a number of areas in the Appraisal Summary Table (AST). For example, through monetised user benefits (calculated by the ‘rule of a half’) for commuting and other non-work users and qualitative assessments of ‘access to services’. This TAG Unit provides guidance on how the social benefits of bus trips that would not take place without the transport scheme being appraised can be separately identified and reported to provide more detail on the impacts of a scheme. Benefits relating to trips on employers’ business or trips that would switch mode/destination are not included in the method as, in the terminology of the underlying research, they represent ‘economic’ impacts.

B.1.3 The method is based on research by Mott MacDonald and the Institute of Transport Studies, University of Leeds: ‘Valuing the social impacts of public transport’ (Mott MacDonald, 2013). The basic principle is that the provision of bus services enables certain trips to take place that otherwise would not have done and therefore allows people to undertake a wider set of activities. The method calculates the benefit (gross of the transport costs) associated with these trips (and the activities they allow) that would not otherwise have been made.

B.1.4 These benefits are not additional to those calculated using the rule of a half, which include the benefits/disbenefits of more/fewer trips being made, net of the transport costs involved. Rather, this method provides greater information on the nature of those benefits by identifying the proportion attributable to the total (gross) benefit of trips and activities that would not otherwise have taken place without the intervention being appraised.

B.1.5 This unit can be applied to any transport scheme, policy, or other intervention which affects the number of bus trips being made. This is an optional piece of guidance should scheme promoters wish to ascertain more detail around the social impacts of buses.

B.2 Calculating the social benefits of trips that would not otherwise take place

B.2.1 Several steps are needed to estimate the social benefits of bus trips that would not have taken place without the intervention being appraised:

- Step 1 – Estimate the change in the number of bus trips caused by the intervention being appraised.
- Step 2 – Estimate what proportion of these would not take place if bus was not available.
- Step 3 – Apply the recommended values per trip to this proportion.
- Step 4 – Calculating the benefits over the appraisal period

B.2.2 A worked example of the method is provided accompanying the main Mott MacDonald report and can be accessed here.

Step 1 – Estimate the change in the number of bus trips

B.2.3 The first step is to estimate the change in bus trips due to the intervention in the opening year and at least one other forecast year. There will be a diversity of approaches to this assessment depending on the nature of the scheme and its size. For appraisal of an intervention that has not yet been implemented, this will be obtained from forecasts from a transport model. For post-opening evaluation of a scheme it will be calculated from observed data.

B.2.4 The change in bus trips should be segmented by the following variables:

- household car ownership (No cars, 1 car, 2 or more cars);
- trip purpose (Shopping and Leisure, Commuting, Education, Employers Business, Visiting Friends or Relatives, Personal Business or Healthcare); and
- concessionary travel pass ownership (i.e. whether the traveller has such a pass or not)

B.2.5 Where the required level of segmentation is not available from the original model then the proportions set out in the TAG data book can be used. Table A1.3.16 provides the required segmentation for a number of area types; figures should be used for the area type that most closely corresponds to the area affected by the intervention being appraised.

B.2.6 More detail on how to use this table, is given in section 2 in the monetising the social impact of bus travel report.

Step 2 – Estimate the proportion of trips that would not take place if bus was not available

B.2.7 The next step is to identify the proportion of the change in bus trips which are 'new' (or suppressed, in the case of a decrease in bus trips), rather than switching from an alternative mode. This proportion can be predicted using a model summarised in section 3 and Appendix A of the monetising the social impact of bus travel report.

B.2.8 A sensitivity test should be carried out in which the proportion of trips that would not take place is set at 21% for all segments. This figure comes from a summary of the evidence on diversion rates set out in Table 9.9 of TRL (2004) and corresponds to the proportion of new bus trips that are 'generated', i.e. do not switch from another mode.

B.2.9 The results from applying this model are presented in the TAG Data Book:

A1.3.17: Proportion of bus trips that would "not go" if bus not available

Step 3 – Apply the recommended values per trip

B.2.10 From Step 1 we have the change in the number of bus trips for a number of different segments, for one or more years of the appraisal period. From Step 2 we have the proportion of trips in each segment that would not travel if bus were not available. Applying the latter proportions to the former numbers gives us the number of trips in each segment that would not go if bus were not available in the opening and forecast year. The values are given in the TAG Data Book:

A1.3.18 – Value of the social impact per return bus trip

B.2.11 The social values are presented in pound per return trip in the Department's current default base year. It is important to note that these are values per return (two-way) trip. In most cases a transport model (or observed trip data) will provide information on single (one-way) trips. In these situations the number of single trips should be halved to provide an estimate of the number of return trips.

Step 4 – Calculate the benefits over the appraisal period

B.2.12 The final step is to calculate the present value of the benefits over the appraisal period. Typically, the calculations described above will only have been carried out for a subset of years in the appraisal period. The benefits should be interpolated and extrapolated over the appraisal period, in line with guidance in TAG Unit A1.1 – Cost-Benefit Analysis. This should include real growth in the values over time, in line with forecast growth in non-work values of time provided in the TAG Data Book Annual Parameters table. Finally, the profile of annual benefits should be discounted to the Department's standard base year and summed to give a present value (see TAG Unit A1.1).

B.3 Presentation of results

B.3.1 The results of this analysis should be presented in the Appraisal Summary Table. Typically, bus-related transport schemes affect fares and/or generalised journey times (comprising access and egress times, waiting and transfer times and in-vehicle time). The associated user benefits will be reported under the 'Monetary' column in the 'Business Users and Transport Providers' and 'Commuting and Other Users' rows of the AST, depending on the purpose of the trips and will form part of the Present Value of Benefits (PVB) in the Benefit-Cost Ratio (BCR).

B.3.2 Steps 1-4 above describe how to calculate the present value of the social benefit associated with bus trips that would not have taken place without the intervention being appraised (or will not take place as a result of it). These benefits are not additional to the user benefits that are estimated using the rule of a half and so should not be included in PVB or BCR calculations (more detail on this can be found in the monetising the social impact of bus travel report). Rather, the results should be included in the AST as follows:

- net (user benefits) impacts calculated by the rule of a half should be reported in the 'Monetary' column of 'Commuting and Other Users' and 'Business Users and Transport Providers' rows of the AST, as usual; and
- the value of the social impact (relating to non-work trips that would not take place without the intervention being appraised) should be reported in the 'Summary of key impacts' column in the 'Commuting and Other Users' row (to avoid double counting it should not be included in the 'Monetary' column).

B.3.3 This represents a relatively minor change from the existing reporting, with additional information in the 'Summary of key impacts' column. This is a slight amendment to the recommendations set out by Mott MacDonald and ITS Leeds in their report. Note – this is an optional piece of guidance and the above sets out how you should present the monetised social value in the AST if you wish to carry out this assessment.

Appendix C: Detail on methods to estimate reliability

C.1.1 Travel time variability (TTV), or Journey time variability (JTV), is defined as variation in journey times that travellers are unable to predict. Since the essence of any measure of variability (such as variance) relates the variations to the expected value, alternative definitions of the expected value will clearly have an impact. A failure to clarify this point in the past has led to much confusion of measurement. In general, it is sensible to remove as far as possible any non-random effects. The terms travel time variability and journey time variability will be used interchangeably throughout this guidance as they both mean the same thing.

C.1.2 Travellers are sensitive to the consequences of travel time variability, such as prolonged waiting times, missed connections and arrival at the destination either before or after the desired or expected arrival time. This leads to an analysis where the traveller is considered to be choosing between travel alternatives characterised by a distribution of consequences, defined in conventional generalised cost terms (cost, travel time, etc.), together with the impact on timing constraints.

C.1.3 Within the transport field, the impact of travel time variability is primarily on departure time. The framework in general has been related to the highway mode but can be expanded to take in the additional complexity of scheduled public transport services. The theory assumes that travellers choose the course of action which, bearing in mind the probabilities of different outcomes, has the highest value of expected utility (i.e. some version of "maximum expected utility" (MEU) theory).

C.1.4 The major source of the disutility associated with travel time variability is scheduling cost. Analysis is based on the model due to Small (1982) which specifies the following utility/generalised cost function.

- $U = \beta_1 C + \beta_2 SDE + \beta_3 SDL + \beta_4 D_L$ (1)
- Where:
- C is the travel time;
- SDE is schedule delay early – amount of time one arrives early at the destination;
- SDL is schedule delay late – amount of time one arrives late at the destination; and

- D_L = 1 for late arrival, 0 otherwise.

- SDE and SDL are defined with respect to a preferred arrival time (PAT), normally defined as the start time of an activity (e.g., work start time).

C.1.5 Noland and Small (1995) further developed the scheduling cost model to take travel time variability into account. This led to the following model, independent of the distribution of travel times:

- $U = \beta_1 E(C) + \beta_2 E(SDE) + \beta_3 E(SDL) + \beta_4 P_L$ (2)

- Where:

- E[X] is the expected value (mean) of X; and

- P_L is the probability of arriving late.

C.1.6 If there is travel time variability then, with the reasonable assumption that $\beta_2 < \beta_3$, there is a need to allow a certain amount of slack time when choosing departure time to maximise expected utility by reducing the risk of late arrival and more importantly the probability of being late.

C.1.7 It has been shown empirically that if travellers are able to optimise their choice of departure time on a continuous basis, the sum of the terms [β_2 SDE + β_3 SDL] is closely related to the standard deviation of travel time. This provides some justification for the widespread use of standard deviation as the relevant component in the utility function to indicate the effect of travel time variability. Strictly speaking, this relies on the departure time being continuously variable (as with the car mode).

C.1.8 Most of public transport is characterised by the existence of a timetable, with only discrete possibilities for departure. As can be expected, this leads to further disutility associated with the service interval. The utility theory framework can be expanded to combine the continuous analysis and service interval analysis at some increase in complexity. For each advertised departure time, we can estimate the expected utility of travelling on that service. We then choose that departure time from the discrete set of services available that delivers the greatest expected utility.

C.1.9 While the underlying theory is compatible, the need for rail appraisal to take explicit account of the average delay relative to scheduled time tends to dominate the calculations, both because this delay appears to attract a greater level of disutility than would a corresponding increase in scheduled time, and because the effect of variability per se is less important in the light of the scheduling "compromises" which rail passengers have to make in any case. A further practical difference is the PDFH recommendation to ignore the effect of early arrivals.

C.1.10 For a fuller description of the theoretical background, see Bates et al (2001). A discussion of the translation of theory into practical methodology for highways can be found in Arup (2004) and PDFH for public transport.

C.2 Calculating averages and Variance

Private vehicle travel

C.2.1 Journey times vary due to a large number of factors including the time of day, the location of the origin and destination, the distance and the road or service types along the route. Such systematic variation has no relevance for JTV (except possibly where travellers making a “new” journey base their expectation of journey time on other journeys that they consider “similar”).

C.2.2 JTV arises from unpredictable variation, and can occur on journeys by any mode. On the rail side, all variation arises from what are effectively operational anomalies. On the highway side, unpredictable variation arises from day-to-day variability (DTDV); incidents; and operational effects which cause anomalies for bus services.

C.2.3 The reliability of a journey to work by road, which normally takes 30 minutes but typically encounters delays of 20 minutes on one random weekday and 10 on another each week, can be derived by the following set of equations:

$$\bar{X} = \frac{\sum_n x_n}{n}$$

C.2.4 Where $\bar{X}$ is the average journey time, x_n is the travel time on day *n* and *n* is the number of days used in the analysis. Hence, Average journey time = 30*3/5 (3 normal days) + (30+20)/5 (long delay) + (30+10)/5 (shorter delay) = 36 minutes per trip.

C.2.5 The variance in the journey time is calculated by examining the average[26] of the sum of the squares of the difference from the mean. This is as follows:

$$\sigma^2 = \frac{\sum_n \left(x_n - \bar{X}\right)^2}{n}$$

Hence Variance σ^2 is 1/5 ((50-36)^2 + (40 – 36)^2 + (30 – 36)^2 + (30 – 36)^2 + (30 – 36)^2) = 64 minutes squared (of which 39 minutes squared (i.e. (50-36)^2/5) comes from the longest delay)

[26] If the pattern under consideration is based on only a small number (n) of observed journey times when calculating variances the average of the squares of the difference from the mean should be multiplied by a factor n/(n - 1).

C.2.6 The currently recommended measure of reliability, the standard deviation, equals 8 minutes per trip (the square root of the variance).

Rail

C.2.7 While the basic results for a similar journey by rail are identical, the existence of a scheduled time (according to the rail timetable) means that we can also calculate average “lateness”. Suppose the timetabled journey time is in fact 35 minutes. Then the “normal” journeys lasting 30 minutes will arrive early. The calculations will be different according to whether early arrival is treated as a) negative lateness or b) “on time” arrival. In the former case, we have:

Average lateness = – 5 *3/5 (3 “normal” days: early arrivals) + (20 – 5)/5 (long delay) + (10 – 5)/5 (short delay) = 1 minute per trip

As before, the variance turns out to be 64 minutes squared.

C.2.8 In the latter case, however, where we measure the lateness of early arrivals as zero, we have

Average lateness = 15/5 (long delay) + 5/5 (short delay) = 4 minutes per trip.

Variance of lateness = $(15)^2$ / 5 + $(5)^2$ /5 – mean lateness^2 = 45 + 5 – 16 = 34 minutes^2

C.2.9 The second method set out above is recommended as it represents a pragmatic approach. An example, showing both methods of calculation of the standard deviation, is given in Table 2, below.

Table 2 Calculation of mean and variance of lateness (based on one week[27])

Timetabled Arrival Time Day	Actual Arrival	Lateness (mins)	Lateness squared
0730 Monday	0730	0	0
0730 Tuesday	0734	4	16
0730 Wednesday	0728	-2 - otherwise 0 in recommended approach	4 - otherwise 0 in recommended approach
0730 Thursday	0740	10	100
0730 Friday	0750	20	400
0800 Monday	0820	20	400
0800 Tuesday	0800	0	0
0800 Wednesday	0802	2	4
0800 Thursday	0810	10	100

[27] While the illustration only shows one week, several weeks’ observations should be used of all journeys operated in the chosen period.

0800 Friday	0800	0	0
Total No of observations (n)	10	64 - otherwise 66 in recommended approach	1024 - otherwise 1020 in recommended approach
Average	= col total/ No of obs	6.4 - otherwise 6.6 in recommended approach	102.4 - otherwise 102 in recommended approach.
Square of average lateness			40.96 in recommended approach – otherwise 43.56
Variance[28]	= Difference	(Minutes squared)	61.44 - otherwise 58.44 in recommended approach
Standard Deviation	= square root	(Minutes)	7.84 - otherwise 7.64 in recommended approach

C.3 Highway Reliability in Urban Areas Approach

C.3.1 In urban areas alternative routes are more readily available than on Motorways and there are many possibilities for avoiding incidents which reduce capacity on a particular route. This avoidance behaviour contributes to the day to day variability on the alternative routes and affects the balance between incident and day to day variability effects. Models predicting journey time variability from all sources are therefore the most relevant and prototype models using congestion indices were developed as part of the London Congestion Charging study in 1993.

C.3.2 An improved form of those models based on north London data was developed using additional survey data collected in Leeds (2003) as set out in Arup (2004). In 2007, Hyder Consulting in collaboration with Ian Black and John Fearon were commissioned by the DfT to further develop the travel time variability relationships for a wider sample of urban routes. These routes are spread over the 10 largest urban areas in England as identified in DfT's Public Service Agreement (PSA). The improved model is now available as set out below. Its derivation is set out in Hyder, 2007.

C.3.3 The recommended form of model forecasts the Coefficient of Variation (CV) from Distance (d) and Congestion Index (ci) terms for each origin to destination flow in the urban area. The Coefficient of Variation (CV) is the ratio of the standard deviation of travel time to the mean travel time.

$$CV = 0.16\,ci^{1.02}\,d^{-0.39}$$

[28] If the pattern under consideration is based on only a small number (n) of observed journey times, when calculating variances the average of the squares of the difference from the mean should be multiplied by a factor n/(n - 1).

C.3.4 The Congestion Index "ci" is defined as the ratio of mean travel time to free flow travel time, so that the model can be rearranged to forecast the Standard Deviation of Journey Time from Journey Time (t) and Distance (d). The areas on which the relationship was based comprised average free flow speeds of 37 to 47 kph (km/hr)[29]. Using a constant average free flow speed of 44.5 kph and expressing this as 0.01236 km per second, the change in journey time variability (represented by $\Delta\sigma_{ij}$) is given, if distances do not change, by the formulations presented in paragraph 6.3.2 of this TAG Unit. Journey time variability is defined as a function of variables which are already provided as inputs to the standard economic appraisal program TUBA.

C.4 Local survey for the calibration of Urban Variability Models

C.4.1 The Hyder et al model form can be used to estimate the effect of schemes and the order of magnitude of their variability benefits in urban areas. Although the model above can be used to estimate the effect of schemes and their reliability benefits in urban areas, a locally calibrated model or at least a local validation is preferable.

C.4.2 Data from established sources such as HATRIS and ITIS/CJAM (which was the source for the Hyder work), or a local survey similar to Arup's work, and a locally calibrated model should be considered. The resulting data should be analysed to establish whether the relationship, which Hyder, Black and Fearon developed, is applicable or whether different parameters or in extreme cases different relationships should be used. Further guidance on this is available from DfT's TASM Division.

C.5 The stress based approach to the assessment of reliability impacts of road proposals

C.5.1 The stress based approach is only appropriate where the other approaches described above are not feasible. The change in stress is essentially a proxy for change in reliability. The approach does not provide a direct quantification of changes in reliability or reliability benefits. In addition, it is not a precise or comprehensive method and can only provide a very broad indication of the impact of a proposal on reliability.

C.5.2 This approach is based on the change in 'stress' (within the range 75% to 125%) as a result of the proposal, combined with the numbers of vehicles affected. Stress is the ratio of counted or measured annual average daily flow to the congestion reference flow. Where a proposal provides a new route, the approach takes account of improvements in reliability for those remaining on the old route as well as those transferring to the new. This approach is very similar to that taken in assessing time saving and vehicle operating cost benefits. Thus, proposals providing modest improvements for large volumes of traffic may be more highly rated than those providing large improvements for small volumes.

---

[29] For consistent units in the equation the speed must be defined in terms of km per second.

C.5.3 To take account of possible 'bottleneck' effects, where the effect of one link or junction operating close to capacity affects the reliability of an extended length of road, the method focuses on those key links/junctions, rather than the whole length of road.

C.5.4 Referring to the worksheet below, the following information needs to be provided, for the year in which the proposal is implemented:

for the key link on the existing road (the 'old route'):

- the percentage stress in the without and with scheme scenarios - these may differ because the flow changes (if the proposal is a bypass, for example); because the Congestion Reference Flow changes (if the proposal is an on-line improvement, for example); or both (if the proposal is a bypass accompanied by traffic management on the old route, for example); and

- the **with scheme** annual average daily traffic flow.

Where a new route is provided by the proposal, for the key link on the new route:

- the percentage stress in the with scheme scenario (clearly, there cannot be a new route in the without scheme scenario); and

- the **with scheme** annual average daily traffic flow.

C.5.5 The percentage stress in the without and with scheme scenarios should be entered in the Quantitative column of the Appraisal Summary Table. Where the proposal provides a new route, the value for that route should be used.

C.5.6 The difference in stress should be calculated for the old and new routes (where appropriate). Note that the same without scheme value should be used for both calculations. If any stress value is less than 75% or greater than 125%, the calculation should be based on values of 75% or 125% as appropriate. The assessment for each route is the product of flow and difference in stress. These results are summed to provide the overall assessment.

C.5.7 Thus, it is not appropriate to present the numeric result of the calculations outlined above. Instead, the result should be used to assist in reaching an appropriate textual score, using the following guidelines:

- Values in excess of 3 million will usually be assessed as **Large** *(***Beneficial** if the value is positive, **Adverse** if it is negative) - these will be high flow routes with moderate or large differences in stress, or moderate flow routes with large differences in stress;

- Values between 1 and 3 million will usually be assessed as ***Moderate*** - these will be high flow routes with small or moderate differences in stress, moderate flow routes with moderate differences in stress, or low flow routes with moderate or large differences in stress;

- Values between 200 thousand and 1 million will usually be assessed as **Slight** - these will be high and moderate flow routes with small differences in stress, and low flow routes with moderate differences in stress; and

- Values less than 200 thousand will usually be assessed as ***Neutral***.

C.5.8 Other considerations may justify a different assessment - they should be noted in the Summary of key impacts. For example, the performance of junctions is not included in the measure of stress.

C.5.9 This approach is not suitable for proposals affecting junctions alone. Nevertheless, such proposals on roads carrying large volumes of traffic may make a substantial contribution to reliability. In addition, the approach is not suitable for estimating changes in reliability during construction and maintenance. Where either of these considerations apply, a comment should be made in the Summary of key impacts column, entering 'not applicable' in the Quantitative and Qualitative columns.

Worksheet B1 Stress-based reliability impact worksheet

	Old Route (i)	New Route (ii)
Without scheme stress (a)		not applicable
With scheme stress (b)		
Difference in stress (c=a-b, restricting a and b to the range 75% - 125%)		
With scheme AADT flow (d)		
Overall impacts (e=c*d)		
Overall assessment (e(i) +e(ii)):		

Note: Where a new road route is provided, the Quantitative column should contain values a(i) and b(ii). Where no new road route is provided, use values a(i) and b(i).

Reference sources: ____________________

Assessment scores: ____________________

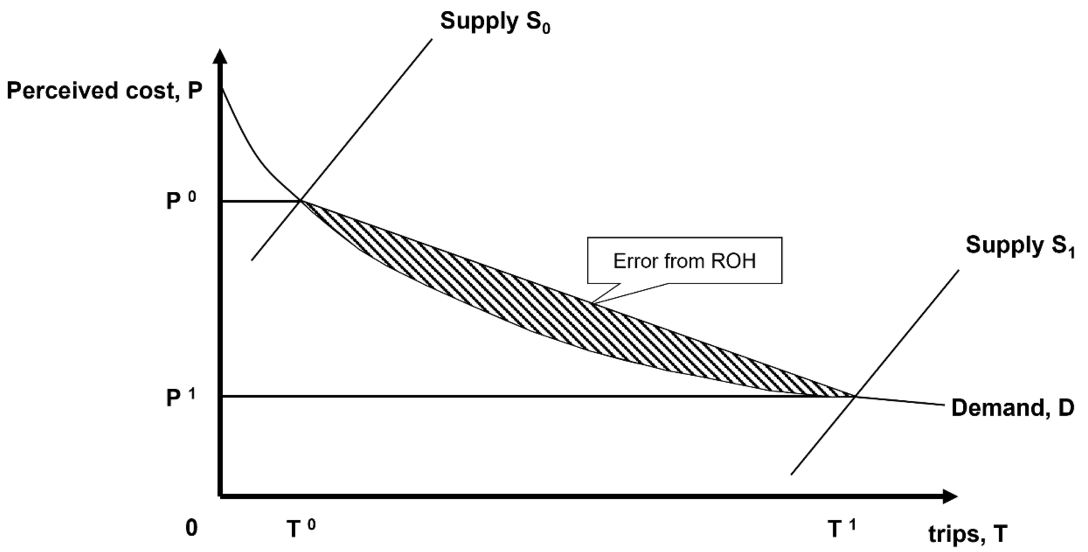
Qualitative comments: ____________________

Appendix D: Guidance on dealing with large cost changes

D.1 Problems with the Rule of Half

D.1.1 If the change in generalised cost between the DM and DS is too large then the rule of half (ROH) can become inaccurate[30]. The key issues can be summarised as follows.

Figure 3 Possible error due to ROH calculation



D.1.2 When a transport scheme is implemented there is a shift in the supply curve (S0 to S1 in Figure 3), usually resulting in a change in travel costs. The user benefits of the scheme are given by the change in consumer surplus, shown by the shaded area, which is the sum of the consumer surplus from trips that were already made before the scheme, and from new trips made after the scheme.

D.1.3 This surplus can only be calculated precisely if the exact shape of the demand curve is known between the DM and DS points. In practice this is rarely the case and so the demand curve is approximated by a straight line (BC). The change in consumer surplus is then the area of the trapezium ABCD, which is given by the ROH:

$$\frac{1}{2}(T^0 + T^1)(P^0 - P^1)$$

where T is the number of trips and C are perceived costs of trips and the superscripts 0 and 1 indicate the do minimum and do something respectively.

[30] Nellthorp and Hyman (2001)

This can lead to an error compared with the true benefits, as shown by the hatched area on the graph labelled 'Error from ROH'. The larger the change in cost the less accurate the linear approximation is likely to be.

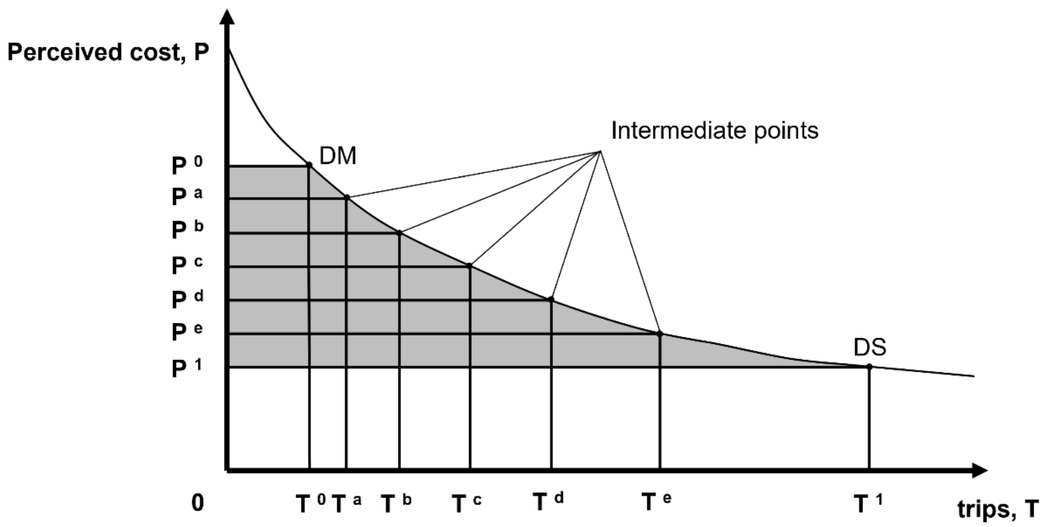
D.1.4 Conventionally demand curves in demand-supply diagrams are drawn as curves that are convex to the origin (as in Figure 3), suggesting an overestimation of the magnitude of (dis)benefits with ROH. However, some demand curves (such as the logit curve) also include a concave segment, where the benefits would be underestimated. The error does not occur with linear demand curves.

D.2 Reducing error from ROH with Numerical Integration

D.2.1 Nellthorp and Mackie (2001) consider a number of solutions to the problem. Their preferred solution is referred to as Numerical Integration (NI), and it is illustrated in Figure 4. This method involves using additional points (referred to here as intermediate points) on the demand curve between the DM and DS and approximating the curve as a series of straight lines. In effect this means applying ROH to each pair of adjacent points in turn.

D.2.2 This is also the solution that is implemented in the Department's appraisal software, TUBA. See guidance in section D.3.

Figure 4 Use of Numerical Integration (extended trapezoidal rule) to reduce error due to ROH



D.2.3 In the field of numerical analysis this particular form of numerical integration is known as the extended trapezoidal rule. Its error term[31] is $O\left(\frac{(C^0-C^1)^2}{(N-1)^2}\frac{\partial^2 T}{\partial C^2}\right)$ where N is the number of points used (including the DM and DS). So using three points, that is the DM, the DS, and one intermediate point, can reduce the error

[31] An error term O(X) means that the error is equal to some unknown constant times X. In the above error term represents the value of the second derivative of the demand function evaluated at an unspecified point in the interval (T^0,T^1)

by approximately a factor of 4. Using five points (DM, DS, and three intermediate points) will reduce the error by approximately a factor of 16.

D.2.4 The above description of the problems and solutions relating to ROH is based around a change in behaviour caused by a shifting supply curve. The same principles apply equally in the case of a shifting demand curve caused by, say, the change in the cost of a competing mode.

D.3 Dealing with error from ROH in TUBA

D.3.1 Setting up a TUBA run to implement NI is straightforward. Trip and cost data need to be defined for the intermediate point(s) in the same way as they normally are for the DM and DS. The only change compared with a normal run is to add the trip and cost matrices for the intermediate points to the INPUT_MATRICES table. Instead of using the scenario label '0' (DM) or '1' (DS) the labels 'a', 'b', 'c', 'd', 'e' are used to refer to the 1st intermediate point, 2nd intermediate point etc. (point 'a' being closest to the DM). Certain restrictions on the order of the points are described in the manual.

D.3.2 If intermediate points are used in TUBA it is not necessary to define them for every user class, or indeed even for every OD. The points can be specified only for selected user classes and ODs (with the exception that format 1 matrices must contain data for all ODs). However, it is expected that it will normally be easier to generate the necessary data for all ODs. Where data for intermediate points are not defined TUBA will use the DM and DS data as in a standard application.

In addition to the facility to add intermediate points TUBA also provides a number of diagnostics to help decide whether the points are necessary. These are discussed in section D.4.

D.3.3 Note that the use of intermediate points in TUBA will only affect user benefits that are calculated using ROH. These are:

- User time benefits
- User charge benefits
- User fuel VOC benefits
- User non-fuel VOC benefits (for working vehicles only)

All other benefits, revenues and scheme costs are unaffected.

D.3.4 Anyone using intermediate points in TUBA is requested to contact the TUBA support team with their experience and any problems to help improve this document and/or the software.

D.3.5 The following sections tackle the key practical questions for using intermediate points; these key questions are:

- ‘When is it necessary to use intermediate points?
- How many are needed?
- How is the data calculated?

D.4 When is it necessary to use intermediate points?

D.4.1 Nellthorp and Hyman (2001) suggest that the ROH is acceptable (i.e. the error is less than ±10%) provided that the change in generalised cost AND the change in the number of trips are both less than 33%.

D.4.2 For cost changes up to 70%, a single additional point should be sufficient. For larger cost changes, three additional points will normally be required.

D.4.3 This advice should be seen as applying for each OD movement, for each user class/mode. It will only be worth using intermediate points if those ODs with large cost changes contribute a significant proportion to the total benefits. Often, the ODs with the largest cost changes will have the largest (dis)benefits per trip, but in some projects the majority of benefits are contributed by ODs with small cost changes.

D.4.4 Any application of TUBA will fall into one of the following categories, reflecting different magnitudes of cost changes and therefore different levels of accuracies in the ROH. These can occur together in a single TUBA run with each user class/mode falling into a different one of the below categories:

1. Fixed trip matrix appraisal (inelastic demand): Using ROH will always give the exact user benefits and there is no need to use intermediate points, however large the cost change between the DM and DS. This is typically the case when only reassignment responses to a scheme have been modelled.

2. Variable trip matrix appraisal with existing modes: The inaccuracy due to the ROH depends on the size of the cost change and the shape of the demand curve. The latter makes it difficult to provide general rules on when intermediate points are needed.

3. Variable trip matrix appraisal with new mode(s): There will almost always be large cost changes between the pseudo-DM and the DS and at least one intermediate point will be required. A more detailed discussion on dealing with new modes in TUBA can be found in the Appraisal of New Modes guidance.

D.4.5 Broadly corresponding to the categorisations above, TUBA checks the ratio of DM to DS costs (for times and distances) and issues:

- a warning if the ratio is less than 2/3 or exceeds 1.5; and
- a serious warning if the ratio is less than 1/3 or exceeds 3.

D.4.6 If a detailed comparison of options is required, a greater accuracy in the estimation of ROH may be required (for example, error less than ±5%)

D.4.7 TUBA provides a number of diagnostics for identifying large cost changes and their contribution to overall benefits. Before discussing them in more detail it should be noted that the Nellthorp and Hyman advice is based on total generalised cost. However, TUBA deals with each component of cost separately and does not combine them into a single generalised cost at any stage. Therefore TUBA can only check the change in individual components. It does not take account of the fact that a large increase in one component (e.g. toll) can be partially offset by a decrease in another component (e.g. time). Large cost changes (time and distance) are identified by warnings and serious warnings in the TUBA output file, as set out above.

D.4.8 The TUBA .tbn output file gives the total travel time benefit partitioned according to the percentage change in trips and times, for each mode and modelled year. In each case TUBA will advise what proportion of the total benefits fall into the Nellthorp and Hyman category of needing intermediate points. Whether intermediate points are needed partly depends on the level of accuracy needed in the estimation of benefits, but generally if a large proportion of benefits fall into the warning category intermediate points should be considered.

D.4.9 The situation with large changes in charges is more complicated. Most applications of TUBA involving these will be road user charging introduced where it does not currently exist. In this case the percentage change in cost is undefined. It is largely up to the user to make an assessment of the impact of the charge on the total generalised cost and whether this is large enough to warrant intermediate points. However, until more experience is gained in this area the advice is to test with one intermediate point for schemes involving the introduction of significant user charging. Depending on the outcome the user must decide whether more intermediate points are required.

D.4.10 The remaining component of generalised cost and user benefit for consideration is vehicle operating cost (VOC). VOC (dis)benefits for individual ODs are normally small compared with time or charge (dis)benefits and it is not expected that intermediate points will be needed to improve the estimate of VOC benefits alone. Any user with a counter example where VOCs are a significant source of benefits and there are large changes in time and/or distance is asked to contact the TUBA helpdesk for advice.

D.4.11 It should be noted that testing with a number of simple demand models has shown that intermediate points are probably only needed in a small minority of cases Analysts considering using intermediate points in TUBA can refer to the TUBA support team for any necessary assistance, through the TUBA web site.

D.5 How many intermediate points

D.5.1 To minimise the risk of unnecessary model runs an incremental approach to intermediate points is recommended:

1. A single intermediate point, with costs as the average of DM and DS
2. Three intermediate points (including the point generated from 1. above)[32]

D.5.2 Having run TUBA with one intermediate point it will be necessary to decide whether additional points are needed. As noted in D.2.3, if E is the error of the ROH with no intermediate points then the error with a single intermediate point is approximately E/4. Therefore E can be estimated as 4/3 times the difference between user benefits calculated with no intermediate point, and with one intermediate point[33].

D.5.3 Then if E/4 is large compared with total user benefits (more than around 10%) additional intermediate points will be needed. The table below gives an example:

Table 3 Example of error estimation with intermediate point

Calculation	Value
Total benefits from standard TUBA run	3164
Total benefits from TUBA with 1 intermediate point	2774
Difference	390
Estimate of ROH error, E = 4/3 x difference	520
Estimate of error with a single intermediate point (=E/4)	130
As a % of total benefits with 1 intermediate point	4.7%
Required accuracy of benefit estimate	±10%
Additional points needed?	No

[32] The costs of the intermediate points ideally need to be equally spaced. Using a second intermediate point in addition to the point used in step (a) would not achieve this, although it should still give an improved estimate of benefits. It is expected that more than one intermediate point would only be required in very rare cases.

[33] Here E is actually the first error term of the Euler-Maclaurin summation formula. In some cases the remaining error terms will be significant and E will not be a good approximation to the true error. However, it is considered that the procedure outlined above is a reasonable rule of thumb. An alternative interpretation is that E/4 is the difference between the benefit estimate using the extended trapezoidal rule (used by TUBA) and Simpson's rule. The latter almost always gives a better estimate, but if the difference between the two is small then the overall error from the extended trapezoidal rule should also be small. In any case an improved estimate of benefits can be obtained by subtracting 1/3 of the ROH estimate from 4/3 of the estimate with 1 intermediate point. However, at this point we do not propose suggesting this to users.

D.5.4 Similarly, the error with 3 intermediate points will be around 16/E and if this is too large then additional points will be needed. However, it is not anticipated that this situation will arise in practice - if it does please contact the TUBA helpdesk for advice (tuba@atkinsrealis.com).

D.5.5 Note that running TUBA with a single intermediate point will provide an estimate of the error in the benefit calculation. This is potentially useful in establishing whether benefit estimates are robust and can be used even if the TUBA warning messages do not indicate an intermediate point is required, although this is by no means a requirement.

D.6 Generating intermediate points

D.6.1 It is recommended that the costs of the intermediate points are evenly spaced. This usually gives the optimum improvement in the accuracy of the benefit estimate[34] and is required to be able to estimate the error in the benefit estimation (see above). Clearly if a single intermediate point is very close to either the DM or DS it will have very little impact on the estimate of benefits.

D.6.2 Generating intermediate cost matrices from DM and DS costs is straightforward, using spreadsheets and/or the modelling software's matrix manipulation facilities. The appropriate costs to use are given in the following table:

Table 4 Costs for intermediate points

Number of intermediate points	Costs
One intermediate point	$0.5P^0 + 0.5P^1$
Three intermediate points (two additional points required)	$0.75P^0 + 0.25P^1$ $0.25P^0 + 0.75P^1$
Note: P^0 is the DM cost, P^1 is the DS cost.	

D.6.3 Note that 'cost' here is used generically. TUBA takes costs in terms of time, distance and charge. Intermediate matrices for each of these needs to be calculated separately according to the above table. As with DM and DS matrices, data needs to be provided at the origin/destination/user class/year level, although as noted elsewhere it is not necessary to provide intermediate data for every OD, user class and year.

D.6.4 Having calculated the appropriate costs for the intermediate point(s) the next step is to pass them through the demand model. The resulting trip matrices, along with the costs, provide the necessary TUBA input for the intermediate point. **Note that it is not necessary to run the model to 'equilibrium' in conjunction with a supply (assignment) model**. This is because the intermediate point is required to be a point on the demand curve. There will be

[34] There will be cases where a different arrangement of intermediate points gives a more accurate result, however this cannot be known beforehand

some (unknown) supply curve for which this is an equilibrium, but we are not concerned with what that curve may be.

D.6.5 This method also ensures that the costs of the intermediate points remain evenly spaced and avoids the difficulty of, for instance, changing the assignment model to represent 'half' a bypass. Note that the normal DM and DS still need to be equilibria calculated in the usual way.

D.7 Intermediate points in TUBA: summary

D.7.1 For each intermediate point required:

1. Use a matrix manipulation program/spreadsheet to generate cost matrices in the form required by the demand model[35]

2. Feed these cost matrices into the demand model

3. Take the trip matrices from the demand model output

4. Use the cost matrices from step 1 and the trip matrices from step 3 as the intermediate point data for TUBA

D.7.2 A flowchart illustrating the overall process is given in Figure 5.

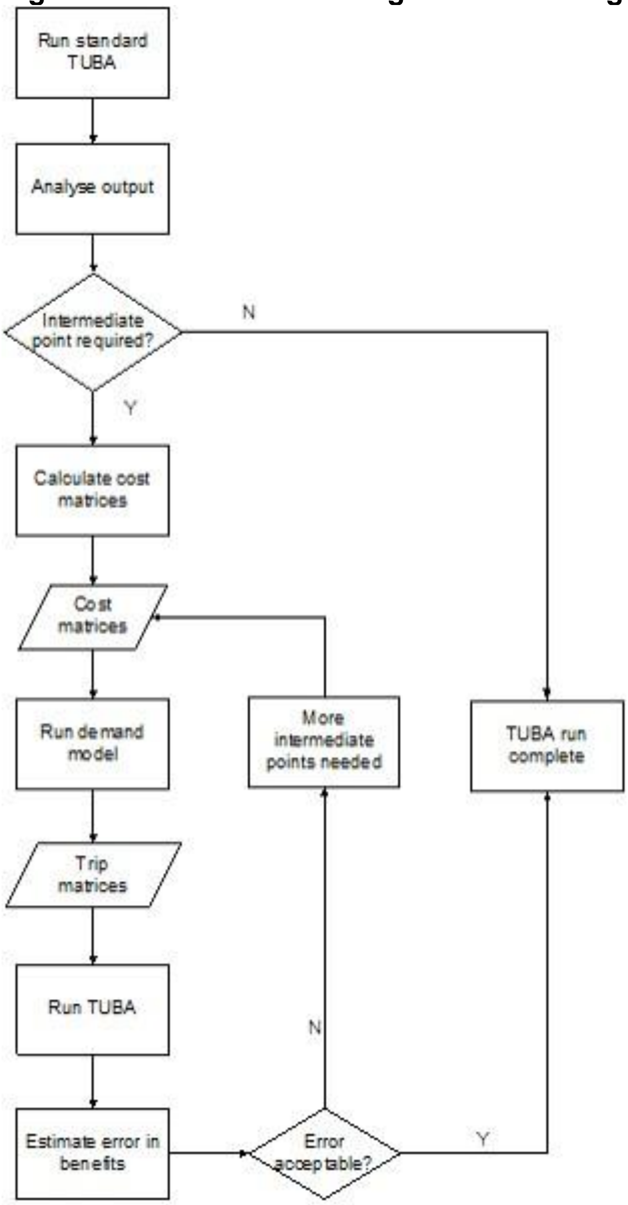
D.7.3 This approach will work for most cases where the demand model is distinct from the assignment model. In some cases, demand and supply are more integrated. A typical example will be elastic assignment models where the demand adjustment is integrated into the assignment procedure. In such cases the demand function is usually separable[36] and for a given set of forecast costs it is reasonably straightforward to apply the demand function using the software's matrix manipulation facilities. This is covered in more detail in the next section.

D.7.4 If you are using TUBA and the models you're using are not covered by the above advice, please contact the TUBA helpdesk (tuba@atkinsrealis.com).

[35] For incremental/pivot point formulations the reference (pivot) cost/trips need not be changed. If different references are used for the DM and DS then it is recommended that the DS data is used

[36] That is the demand for a given OD pair depends on the cost for only that OD pair.

Figure 5 Flowchart for using TUBA with large cost changes



D.8 Generating intermediate points with elastic assignment models

D.8.1 Some highway assignment packages offer an elastic assignment option for modelling variable demand. In this case the demand model is closely integrated with the assignment model and there is no separate demand 'black box' into which costs can be input and from which trip matrices can be output. In this case the cost and trip matrices will need to be generated using matrix manipulation facilities, either those offered as part of the software suite, or externally, e.g. in a spreadsheet.

D.8.2 The first step is to obtain the cost matrices for the intermediate point:

- Skim matrices of individual cost components (time, distance, and possibly charge) and generalised cost for the DM and DS

- Create matrices for the intermediate point according to Table 6 for each cost component (needed for input to TUBA) and for the generalised cost

Table 6 How various inputs are used in TUBA

User benefit parameters and inputs	Input to TUBA as:	Tax rates applied in TUBA to give perceived costs	
		Consumer trips	*Business trips*
Values of travel time	Perceived costs	None	None
Vehicle operating costs			
- Fuel	Resource costs	Fuel final (includes duty & VAT)	Fuel intermediate (includes duty but not VAT)
- Non-fuel	Resource costs	Non-fuel final (includes VAT only)	Non-fuel intermediate (excludes VAT)
- User Charges	Perceived costs (see Section 2.5 of the TUBA User Manual)	None (TUBA assumes Charges final, which may include VAT, already applied)	None (TUBA assumes Charges final, which may include VAT, already applied)

D.8.3 Having obtained the intermediate cost matrices the next step is to calculate the corresponding trip matrix:

- Read in the following matrices to the matrix manipulation program:

  X1: the reference cost matrix (as input to DS elastic assignment)

  X2: the reference trip matrix (as input to DS elastic assignment)

  X3: the intermediate point generalised cost matrix

- Calculate the intermediate point demand according to the elastic demand function being used. For example, if a power elasticity function is used the intermediate point is calculated using the following formula:

  X1*((X3/X2)*p)

  where p is negative and is the elasticity parameter specified in the elastic assignment procedure.