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for Transport

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User and Provider Impacts

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Transport Analysis Guidance (TAG)

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This TAG Unit is guidance for the **APPRAISAL PRACTITIONER**

This TAG Unit is part of the family **A1 – COST BENEFIT ANALYSIS**

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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 Supply⁰ to Supply¹.
- 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':

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

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

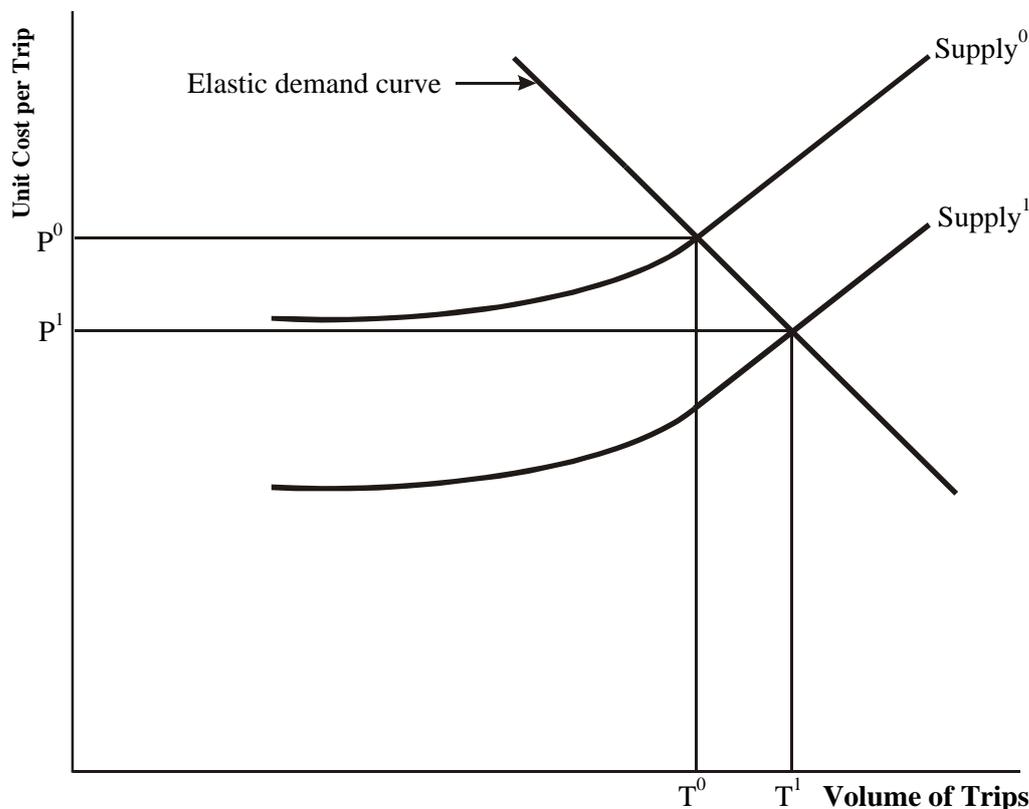


Figure 1 - Calculating the change in consumer surplus

- 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 very small changes in cost the inaccuracy is not significant.
- 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. Typical 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.
- 2.1.11 The issues of large cost changes and the introduction of new modes are discussed in detail in Nellthorp and Hyman (2001) and advice on how to address them is given in [TUBA guidance](#).

Special treatment of unperceived costs

- 2.1.12 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 :

$$\text{ChangeInConsumerSurplus}_m \approx \text{RoH}_m = \frac{1}{2} \sum_i \sum_j (T_{ijm}^0 + T_{ijm}^1) (P_{ijm}^0 - P_{ijm}^1)$$

- 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 mode¹.
- 3.1.7 The full set of formulae required to implement this approach is given in Appendix A.

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 in to 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:

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.

[A1.3.1: Values of time per person \(single year\)](#)

4.2 Values of working time per person

- 4.2.1 [Table A1.3.1](#) gives the values of working time per person by mode. 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 resource 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 increase 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.
- 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 road².
- 4.2.4 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 techniques, assumptions and resulting values vary, all of the methods aim to estimate values that effectively proxy for willingness-to-pay.
- 4.2.5 Revealed preference evidence is the most direct way to estimate willingness-to-pay, and is based on actual business 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.
- 4.2.6 The Department's approach is to take account of all the relevant evidence available and to seek to make reasonable judgments, in light of economic theory. This includes the information available on distance-weighted average hourly incomes of business travellers.

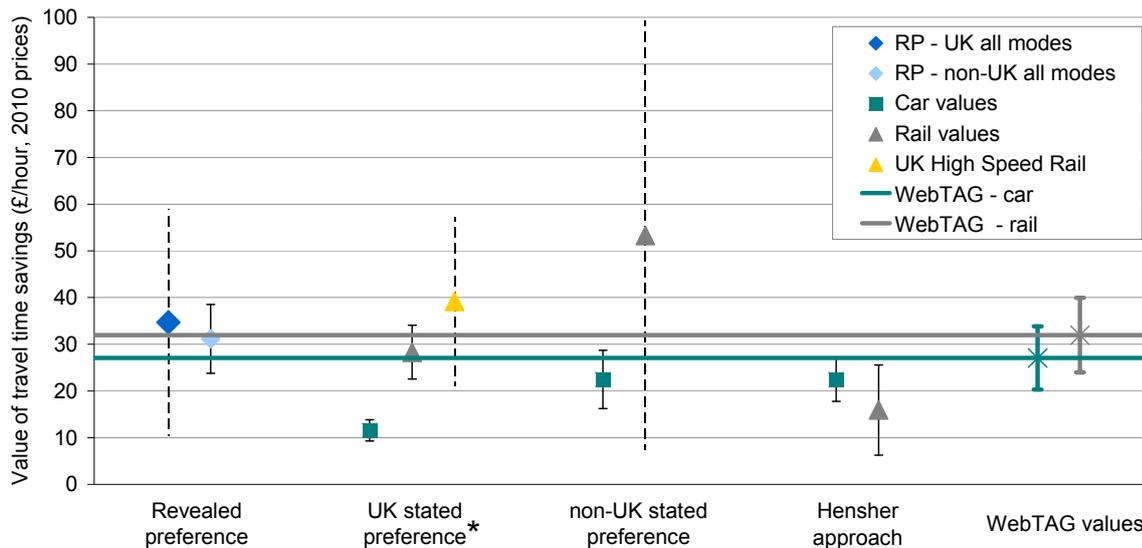
Evidence of businesses willingness-to-pay for travel time savings

- 4.2.7 The Department commissioned a review of the different methods, including a review of UK and international evidence on the values they produce: 'Valuation of Travel Time Savings for Business Travellers', by the Institute for Transport Studies, University of Leeds (ITS Leeds), 2013. Alongside revealed preference evidence and the Department's current approach, this review considered stated preference evidence, collected from survey responses to realistic, hypothetical choices, and the 'Hensher' approach, which builds on the Department's current approach with explicit assumptions about how travel time would be used with and without the scheme being assessed.
- 4.2.8 The review provides valuable insights on businesses' willingness-to-pay for travel time savings, but also raised concerns about inconsistencies and uncertainties in the current evidence base. Figure 2 summarises values from this review along with the car driver and rail passenger values recommended for use in transport appraisal in [Table A1.3.1](#) (labelled "WebTAG values"). The figure also provides ranges around the values to indicate the degree of confidence in the estimates.

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

4.2.9 The figure shows a wide range of values, with significant variation in estimates across the techniques, modes of transport analysed and study locations. The wide ranges around the revealed preference data result from the small number of available studies and reflect the difficulties in obtaining this data. The “WebTAG values” are towards the centre of the range of values and correspond closely with the average values from the available revealed preference evidence. Based on this summary of the current evidence, the Department is firmly of the view that the “WebTAG values” presented in [Table A1.3.1](#), represent a reasonable estimate of willingness-to-pay for travel time savings in the course of work.

Figure 2 – Values of travel time savings in the course of work resulting from different valuation techniques



Sources: Valuation of travel time savings for business travellers, ITS Leeds, 2013; and DfT analysis

Notes:

- * ITS Leeds’ report raised concerns over the approach taken in many UK Stated Preference studies to explaining how company travel policy should be considered and who should be assumed to pay for, and benefit from, travel time savings. There is therefore a concern that the values could reflect more personal, than business valuation, likely leading to a downward bias in the values shown in the chart.
- 1. The solid line error bars represent robustly calculated confidence intervals. The dotted lines are indicative representations of potential variability as the sample sizes are not sufficient to support calculation of formal confidence intervals.
- 2. Revealed preference data are taken directly from the ITS report, with the ranges based on the reported standard errors.
- 3. The Stated preference data for UK car and non-UK rail and car are derived by pooling the urban and inter-urban “valued” data from the ITS report. The mean values have been calculated on a travel time-weighted average basis, with 2008-10 National Travel Survey data, with the ranges calculated as the weighted average standard error. The SP data for UK rail are based on the mean and standard errors reported for inter-urban rail “valued” due to the very small number of UK urban rail studies.
- 4. The High Speed Rail values are based on the 3 reports covered by ITS Leeds most relevant to the UK domestic HSR market: Bates (2012), Atkins (2009) and SDG (2002). The range is based on the standard error of the mean of 5 values from these studies, meaning the sample is too small to be considered a robust, formal confidence interval.
- 5. The Hensher approach values are calculated using the parameters included in the ITS report and the values given in Table 1. The range represents the range of parameter values recommended in sensitivity testing in ITS Leeds’ report.
- 6. The WebTAG values have been calculated with data from the 2008-2010 National Travel Survey, 2009 Labour Force Survey and 2008 Labour Cost Survey. The range around them represents the +/-25% sensitivity testing recommended in this unit.

Applying the values and sensitivity testing

4.2.10 The wide range of values resulting from different approaches presented in Figure 2 shows the 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.

4.2.11 Where specific evidence is not available, or where business time savings form a relatively small proportion of total benefits, a sensitivity test of +/-25% of the values given in [Table A1.3.1](#) may be used, based on the tests recommended in ITS Leeds’ report. While this does not encompass the full range of values resulting from ITS Leeds’ review, it is sufficiently wide to reflect the range of values resulting from the different approaches used to estimate willingness-to-pay.

- 4.2.12 For simplicity and proportionality, this test can be applied as an adjustment to the present value of time saving benefits for business travellers. As the key uncertainty around willingness-to-pay for travel time savings relates to business passengers, rather than professional drivers, time savings for goods vehicles and other freight modes should not be included in the sensitivity testing.
- 4.2.13 Where specific willingness-to-pay evidence is available, sensitivity tests should represent the uncertainty around the willingness-to-pay of business travellers most affected by the scheme. The tests should be developed with evidence from studies relating to the modes of transport and market (e.g. urban or long-distance trips) most relevant to the scheme. Useful sources of information for developing sensitivity tests may include ITS Leeds' evidence review in Valuation of Travel Time Savings for Business Travellers or studies undertaken as part of development of the transport model used to assess the scheme.
- 4.2.14 Where specific evidence is used to inform sensitivity tests, both 'high' and 'low' tests should be developed (that is, using values both greater and smaller than those given in [Table A1.3.1](#)). In such circumstances, analysts should contact TASM division, DfT to agree the appropriate range of values to be tested.

Box 1: Future development of values of working time

In their report Valuation of Travel Time Savings for Business Travellers, 2013, ITS Leeds set out a number of options for development of the values of travel time savings in the course of work. Due to the uncertainties and inconsistencies in the existing evidence, the Department believes that fresh empirical evidence on business travellers' willingness-to-pay for travel time savings is required.

The Department plans to undertake research to collect new evidence of business travellers' willingness-to-pay for travel time savings, which will improve our understanding of the current uncertainties and result in future revisions to the values and ranges provided in this Unit.

Before undertaking any new research, the Department will engage widely with stakeholders on the methods and valuation techniques which merit further investigation and the form this research should take.

- 4.2.15 In appraisal, travel time savings on employer's business are valued the same regardless of the stage of the journey, e.g. there is no weighting to take account of passengers' reluctance to walk or wait. This is because the time saved is assumed to be gained in productive working time and the travel activity is therefore irrelevant. For staged journeys, the value of working time for the main mode (with the longest distance) should be used.
- 4.2.16 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.
- 4.2.17 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.

4.2.18 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 do not take place during working hours, 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) for the Department for Transport, reported in 2003, and published as 'Values of Travel Time Saving in the UK'. The values have been re-based with 2008-2010 National Travel Survey data and converted to 2010 values and prices by uplifting to reflect growth in the values with income (with a GDP/capita elasticity of 1) and changes in prices (using the GDP deflator).

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 average values in [table A1.3.1](#), which should normally be adopted in transport appraisal.

4.3.5 One specific application of the second type of variability is that there is consistent evidence that people will pay more to save walking and waiting time than they will for an equivalent saving in in-vehicle time. Therefore the 'commuting' and 'other' values in the TAG Data Book should be factored by 2.5 for time spent waiting for public transport and by 2 for time spent accessing or interchanging between modes of transport by walking or cycling.

4.3.6 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

4.3.7 Further research by ITS Leeds, 'Advice on Statistical Confidence of Appraisal Non-Work Values of Time', 2012, estimated the statistical confidence intervals around the values for 'commuting' and 'other'. The confidence intervals widen over time due to the impact of GDP growth. Analysis of applying the lower and upper confidence interval values to a wide range of schemes showed that the impact is approximately +/-25% of the present value of non-work time savings.

4.3.8 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.

4.4 Increases in values of time over time

- 4.4.1 Both the work and non-work values of time are assumed to increase with income over time with an elasticity of 1.0³. 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. The results of applying the income growth forecasts, are given in:

[A1.3.2: Forecast values of time per person](#)

4.5 Values of time per vehicle

- 4.5.1 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](#)

- 4.5.2 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 vehicles⁴).

Fuel operating costs

- 5.1.2 Fuel costs for use in appraisal are given in:

[A1.3.7: Fuel and electricity price forecasts](#)

- 5.1.3 based on fuel price forecasts published by the Interdepartmental Analysts' Group⁵. 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.

- 5.1.4 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.

³ 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 For business cars, an allowance is also made for the decline in vehicle capital value (other than that accounted for by mileage related depreciation).

⁵ http://www.decc.gov.uk/en/content/cms/about/ec_social_res/iag_guidance/iag_guidance.aspx

5.1.5 The parameters for these equations were derived⁶ from the New UK Road Vehicle Emission Factors Database, which can be found at: <https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009>. The parameters, by vehicle type, are given in:

A1.3.8: Fuel/energy consumption parameters

5.1.6 Figure 3 shows how fuel consumption varies with speed, using these functions.

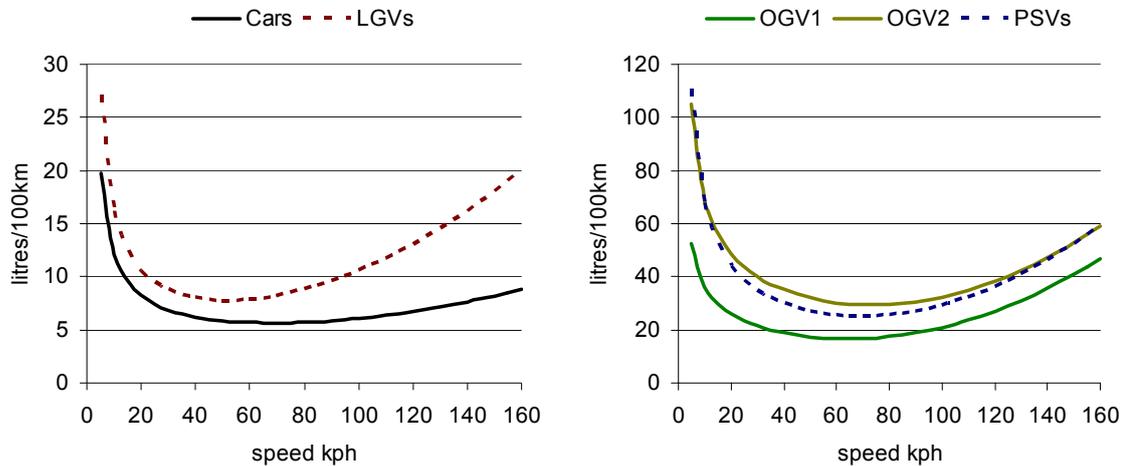


Figure 3 – fuel consumption rates at different speeds (2010 fleet)

5.1.7 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 3. These proportions, and forecast changes over time, are given in:

A1.3.9: Proportions of vehicle kms by fuel type

5.1.8 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

5.1.9 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)

Non-fuel operating costs

5.1.10 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;

$$C = a1 + b1/V$$

⁶ TRL unpublished report "Fuel Consumption Equations" dated 29 September 2008.

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 working vehicles).

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

[A1.3.14: Non-fuel resource vehicle operating costs](#)

5.1.12 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)'.

5.1.13 The 'a1' term represents the marginal resource costs of oil, tyres, mileage and maintenance related depreciation⁷, 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).

5.1.14 The 'b1' term in the non-fuel VOCs represents changes in the productivity of cars, goods vehicles and PSVs in working time.

5.1.15 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).

5.1.16 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.

5.1.17 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](#)

5.1.18 [TAG Unit A1.2 – Scheme Costs](#) provides further guidance on estimating bus and rail operating costs.

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.

⁷ 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.

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 B.

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 the Highways Agency 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 The Highways Agency 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:

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

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, based on evidence compiled for a workshop arranged by the Netherlands Ministry of Transport (The Value of Reliability in Transport, 2005), is 0.8. Multiplying this value by the appropriate value of time for the purpose 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:

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

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 B.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.
- 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 PDFH⁸ the value of average lateness for public transport is broadly the same as the value of time spent waiting for public transport, 2.5 times the value of in-vehicle time⁹, and the value of the reliability ratio ranges from 0.6 to 1.5 for public transport. 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 Consequently a 20% uplift of the lateness factor, resulting in a lateness factor of 3, is an acceptable proxy for the additional disutility incurred as a result of variability in delay. In some cases, for example where data on delays at intermediate stations is not available, it may be appropriate to use a different value but this should be supported with evidence.
- 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. To make allowance for the total lateness caused by cancelled trains the service interval should be multiplied by 1.5. This is in line with the notion that the delay impacts on waiting rather than in-vehicle time, which incurs higher disutility than in-vehicle time. The resulting lateness should then be multiplied by the lateness factor of 3 to capture the full costs of poor performance.

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

⁸ 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.

⁹ This is based on factors of 1 and 3 for perceived and unperceived average lateness, respectively, and evidence that only 25% of rail passengers perceive average lateness.

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. For example, for rail, this means that additional operator costs can be reported in the TEE table without the need to account for track access charge payments and allocate the costs between the track authorities (e.g. Network Rail) and service operators (e.g. TOCs).
- 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 [Public Accounts \(PA\)](#) 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 \(AST\)](#).

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, 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.

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 Hand 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

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.

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

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

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

N_{ij}^i 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_{ij}^i is assumed to be unperceived);

M_{ij}^i fares, tolls and other charges including parking, for trips between i and j ;

(Note that, for work trips, values of F_{ij}^i , N_{ij}^i and M_{ij}^i should exclude VAT but include all other indirect taxes.)

V_{ij}^i ‘perceived’ time cost of trips between i and j (note that $V_{ij}^i = J_{ij}^i * K_T$);

J_{ij}^i journey time between i and j ;

D_{ij}^i distance between i and j ;

L_{ij}^i fuel consumed between i and j ;

T_{ij}^i number of trips between i and j ;

K_T value of time;

K_F cost 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: $(S^1 - S^0)(1+t) = \frac{1}{2} (1+t) \sum_{ij} (T_{ij}^1 + T_{ij}^0) (P_{ij}^0 - P_{ij}^1)$; and
- For non-work trips: $(S^1 - S^0) - (N^1 - N^0) = \frac{1}{2} \sum_{ij} (T_{ij}^1 + T_{ij}^0) (P_{ij}^0 - P_{ij}^1) - \sum_{ij} (T_{ij}^1 N_{ij}^1 - T_{ij}^0 N_{ij}^0)$

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: $F_{ij}^i = K_F L_{ij}^i$, where K_F should include VAT for non-work trips but should not include VAT for work trips. The preferred method of calculating L_{ij}^i 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_{ij}^i) to give fuel consumed (L_{ij}^i).

A.2.6 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_{ij}^i) by the appropriate value of time (K_T).

A.2.7 For work trips the disaggregated benefits are given by:

- user charges: $\frac{1}{2}(1+t) \sum_{ij} (T_{ij}^1 + T_{ij}^0) (M_{ij}^0 - M_{ij}^1)$;
- vehicle operating costs: $\frac{1}{2}(1+t) \sum_{ij} (T_{ij}^1 + T_{ij}^0) (F_{ij}^0 + N_{ij}^0 - F_{ij}^1 - N_{ij}^1)$; and
- travel time: $\frac{1}{2}(1+t) \sum_{ij} (T_{ij}^1 + T_{ij}^0) (V_{ij}^0 - V_{ij}^1)$

A.2.8 And for non-work trips:

- user charges: $\frac{1}{2} \sum_{ij} (T_{ij}^1 + T_{ij}^0) (M_{ij}^0 - M_{ij}^1)$;
- vehicle operating costs : $\frac{1}{2} \sum_{ij} (T_{ij}^1 + T_{ij}^0) (F_{ij}^0 - F_{ij}^1) - \sum_{ij} (T_{ij}^1 N_{ij}^1 - T_{ij}^0 N_{ij}^0)$; and

- travel time: $\frac{1}{2} \sum_{ij} (T_{ij}^1 + T_{ij}^0)(V_{ij}^0 - V_{ij}^1)$.

A.2.9 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.¹⁰ 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 ($J_{ij}^0 - J_{ij}^1$) lies within the given band):

- for work trips: $\frac{1}{2} (1+t) \sum_{ij: (J_{ij}^0 - J_{ij}^1) \in A} (T_{ij}^1 + T_{ij}^0)(V_{ij}^0 - V_{ij}^1)$; and
- for non-work trips: $\frac{1}{2} \sum_{ij: (J_{ij}^0 - J_{ij}^1) \in A} (T_{ij}^1 + T_{ij}^0)(V_{ij}^0 - V_{ij}^1)$.

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_{ij}^0) lies within the given band):

- for work trips: $\frac{1}{2} (1 + t) \sum_{ij: (d_{ij}^0) \in A} (T_{ij}^1 + T_{ij}^0)(V_{ij}^0 - V_{ij}^1)$; and
- for non-work trips: $\frac{1}{2} \sum_{ij: (d_{ij}^0) \in A} (T_{ij}^1 + T_{ij}^0)(V_{ij}^0 - V_{ij}^1)$.

¹⁰ 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.

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:

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

Appendix B – Detail on methods to estimate reliability

- B.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.
- B.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.
- B.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).
- B.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).
- B.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.
- B.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.
- B.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 $[\beta_2 SDE + \beta_3 SDL]$ 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).

- B.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.
- B.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.
- B.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.

B.2 Calculating averages and Variance

Private vehicle travel

- B.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”).
- B.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.
- B.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:

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

- B.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 = $30 \times 3/5$ (3 normal days) + $(30+20)/5$ (long delay) + $(30+10)/5$ (shorter delay) = 36 minutes per trip.
- B.2.5 The variance in the journey time is calculated by examining the average¹¹ of the sum of the squares of the difference from the mean. This is as follows:

¹¹ 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 $n/(n - 1)$.

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

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)

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

Rail

- B.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.

- B.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 = $(15)^2 / 5 + (5)^2 / 5 - \text{mean lateness}^2 = 45 + 5 - 16 = 34$ minutes²

- B.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 1, below.

Table 1 Calculation of mean and variance of lateness (based on one week¹²)

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
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 ¹³	= Difference	(Minutes squared)	61.44 - otherwise 58.44 in recommended approach
Standard Deviation	= square root	(Minutes)	7.84 - otherwise 7.64 in recommended approach

B.3 Highway Reliability in Urban Areas Approach

- B.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.
- B.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.
- B.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.

¹² While the illustration only shows one week, several weeks' observations should be used of all journeys operated in the chosen period.

¹³ 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 $n/(n - 1)$.

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

B.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)¹⁴. 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.

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

B.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.

B.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.

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

B.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.

B.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.

B.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.

B.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

¹⁴ For consistent units in the equation the speed must be defined in terms of km per second.

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.

- B.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.
- B.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.
- B.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**.
- B.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.
- B.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: _____