TUBA:
General Guidance and Advice

Version 1.9.6
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Department for Transport

ATKINS

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Contents

Section *Page*

1.	**Introduction**	**1-1**
2.	**Economic Appraisal using TUBA**	**2-1**
2.1	Method	2-1
2.2	Implementation in TUBA	2-3
2.3	Values of time	2-4
2.4	Vehicle operating costs	2-4
2.5	User charges	2-5
2.6	Scheme costs	2-6
3.	**Principles of user benefit calculation**	**3-1**
3.1	Theory	3-1
3.2	Within TUBA	3-2
4.	**Modes and submodes**	**4-1**
4.1	Definitions and Roles	4-1
5.	**Annualisation**	**5-1**
5.1	Time slices and time periods	5-1
6.	**Extracting matrices**	**6-1**
6.1	Skimming costs	6-1
6.2	Public Transport time costs	6-1
7.	**Converting model outputs to TUBA categories**	**7-1**
7.1	Overview	7-1
7.2	Purposes	7-1
7.3	Person types	7-1
7.4	Vehicle types/submodes	7-2
8.	**Public Transport Benefits**	**8-1**
8.1	Bus benefits	8-1
8.2	Rail operating costs	8-2
9.	**Interpolation**	**9-1**
9.1	Application	9-1
10.	**Sectoring**	**10-1**
10.1	Applications	10-1
11.	**Dealing with large cost changes**	**11-1**
11.1	Problems with the Rule of a Half	11-1
11.2	The TUBA solution	11-2
11.3	When to use intermediate points	11-3
11.4	How many intermediate points	11-5

11.5 Generating intermediate points 11-6
11.6 Generating intermediate points with elastic assignment models 11-8
12. Dealing with new modes 12-1
12.1 Overview 12-1
12.2 Generating intermediate points with elastic assignment models 12-1
12.3 The TUBA Solution 12-1
12.4 Alternative appraisal methods for new modes 12-3
12.5 Generating pseudo-DM data 12-4
12.6 Using TUBA with new modes 12-6
12.7 Intermediate points 12-6
13. Park and ride in TUBA 13-1
13.1 Methodology 13-1
14. References 14-1

List of Figures

Figure 2.1: Components of perceived cost of one litre of petrol, in 2010 prices 2-5
Figure 3.1: Supply/demand equilibrium showing consumer surplus 3-1
Figure 3.2: Change in consumer surplus 3-2
Figure 9.1: Interpolation and extrapolation with two modelled years 9-1
Figure 9.2: Phased construction and possible sources of error 9-3
Figure 11.1: Possible error due to ROH calculation 11-1
Figure 11.2: Use of numerical integration to reduce error due to ROH 11-2
Figure 11.3: Flowchart for using TUBA with large cost changes 11-8
Figure 12.1: Consumer surplus of a new mode 12-1
Figure 12.2: Triangle method for new modes 12-2
Figure 12.3: New mode and numerical integration 12-2
Figure 12.4: Overestimation of new mode benefits with inappropriate pseudo-DM 12-5

List of Tables

Table 2.1: How various inputs are used in TUBA 2-3
Table 2.3: Components of perceived cost of one litre of petrol, in 2010 prices 2-5
Table 9.1: Interpolation and extrapolation of benefits 9-2
Table 11.1: Example of error estimation with intermediate point 11-6
Table 11.2: Costs for intermediate points 11-6

1. Introduction

The aim of this document is to provide general guidance and advice on the application of TUBA. Assistance in actually running the software can be found in the user manual and the on-line help system.

The following sections are designed to cover some of the subjects raised in the user manual in more detail, providing useful information to help the user in editing the economics and scheme files and in extracting the necessary data from transport models. It is envisaged that as TUBA becomes more widely used extra sections will be added to the document.

The remaining sections cover the following topics:

- Section 2 - The approach to economic appraisal used in TUBA
- Section 3 - The principals behind the rule of a half
- Section 4 - Clarification of the distinction between modes and submodes
- Section 5 - Guidance on annualisation factors
- Section 6 - Extracting matrices from transport models
- Section 7 - Converting model outputs to TUBA categories
- Section 8 - Treatment of public transport benefits and costs
- Section 9 - Interpolation and extrapolation of data
- Section 10 - Sectoring
- Section 11 - Dealing with large cost changes
- Section 12 - Dealing with new modes
- Section 13 - Park and Ride

Any further queries on these, or other, topics should be sent to TUBA support desk (tuba@atkinsglobal.com).

2. Economic Appraisal using TUBA

2.1 Method

The approach used in the appraisal of transport schemes changed in the early 2000s following the publication of the Sugden report (Sugden 1999). In order to appraise multi-modal projects alongside road schemes, the Department moved from a method (or calculus) based on social costs and benefits (as used in COBA, for example) to one based on willingness to pay. At the same time the unit of account was changed from factor costs to market prices. (The boxes below provide brief explanations of these terms.) These changes did not affect the fundamental principles of appraisal, merely the presentation of results. However, it is important to note that the distinction between the two units of account is entirely separate from the distinction between the methods of accounting.

Methods of Cost Benefit Analysis

Method of social costs and benefits

The method (or calculus) of social costs and benefits seeks to measure the value to society as a whole of the resources used by, and the benefits created by, a project. It does not take account of payments made by one individual or organisation to another ('transfer payments') and thus cannot show how benefits are distributed between different parts of society. For example, consider a straightforward transaction: a person buys and drinks a can of beer. The method of social costs and benefits considers only the producer's cost of making the beer, and the person's enjoyment from drinking the beer. The amount paid by the consumer to the producer and any taxation paid to the government are transfer payments and thus are ignored.

Method of willingness to pay

The willingness to pay method aims to measure the costs and benefits experienced by each person or organisation as a result of a project, and then to sum these. When this method is used, there are often items which appear as benefits for one person or organisation and equally valued costs for another. Using the same example as before, the willingness to pay method would record:

- benefit to the consumer, equal to the greatest amount he or she would be willing to pay to gain the enjoyment of drinking the beer, less the price (including tax) he or she actually pays for the beer ('consumer surplus');
- benefit to the producer, equal to the amount it receives from the consumer (less tax), less its cost of making the beer ('producer surplus'); and
- a benefit to the government equal to the tax revenue that it receives.

Clearly, adding these three groups of benefits together will result in the payments between the consumer, the producer and the government cancelling out to provide the same overall result as the method of social cost and benefits. The difference between the two methods is simply a difference in presentation of the results. Because the willingness to pay method makes clear how a project

affects different economic interest groups, it is particularly useful when projects are sponsored by private sector firms.

For a more detailed discussion of these issues, see Professor Robert Sugden's 'Developing a consistent cost-benefit framework for multi-modal transport appraisal'.

Units of account

Market prices unit of account

The term 'market prices' is used to describe those prices paid by consumers for goods and services in the open market. The prices of most goods and services include indirect taxation, so the market prices unit of account can be characterised as 'including all indirect taxation'. (Indirect taxation refers to taxation levied on goods and services and therefore includes excises, duties and VAT). Note that even where the prices of goods and services do not include taxation (public transport fares, for example), they are still perceived by consumers in the market prices unit of account. Because consumers perceive the costs of goods and services in the market prices unit of account, it is assumed that they also perceive benefits they receive in the market prices unit of account. This is assumed to be the case even where benefits cannot be bought or sold in the open market, as is the case for time savings.

Factor cost unit of account

The prices paid by government for goods and services are not subject to indirect taxation (any tax that is paid by government bodies such as the Highways Agency is recovered by government and thus may be ignored). Therefore, government expenditure is not in the market prices unit of account. The term 'factor cost' is used to describe the prices paid by government and can be characterised as 'excluding all indirect taxation'.

Business costs are also free of most indirect taxation (though there are some exceptions - notably fuel duty). Therefore, business costs and benefits are also assumed to be in the factor cost unit of account.

Indirect tax correction factor

Prices measured in the factor cost unit of account can be converted to (or from) the market price unit of account by multiplying (or dividing) by the indirect tax correction factor, (1+t), where t is the average rate of indirect tax on goods and services in the open market.

There is no compelling reason to prefer one unit of account over the other, nor is the choice of unit of account necessarily linked to the choice of method of cost benefit analysis. However, if we focus on the resources used to produce output, it is more natural to use the factor cost unit of account. Similarly, if we focus on people's willingness to pay for final consumption, the market price unit of account seems more natural.

For a more detailed discussion of these issues, see Professor Robert Sugden's 'Developing a consistent cost-benefit framework for multi-modal transport appraisal'.

Further information is available in the Department's Transport Appraisal Guidance (https://www.gov.uk/transport-analysis-guidance-webtag and, specifically, TAG Units A-1 Cost-benefit Analysis[1], A-2 Scheme Costs[2] and A-3 User and Provider Impacts[3].

2.2 Implementation in TUBA

All costs and benefits reported by TUBA are based on willingness to pay and expressed in the market price unit of account.

In order to calculate willingness to pay based benefits to users, it is necessary to use perceived costs. Perceived costs are those costs which are actually experienced by users. Perceived costs are different for business and consumer trips because many businesses can claim VAT back on purchases. Note, however, that businesses cannot claim back fuel duty (fuel duty rebates should be treated as subsidy), so this is included in their perceived costs.

The need to express all results in the market price unit of account also requires business and consumer trips to be treated differently. Benefits to businesses are perceived in the factor cost unit of account. Therefore, it is necessary to convert business trip benefits to the market price unit of account. TUBA converts these benefits to the market price unit of account by multiplying by the indirect tax correction factor, see * in Table below.

The economic parameters and other economic inputs to TUBA are specified to enable these distinctions to be taken into account within the software without imposing excessive data input or manipulation requirements on users. The following paragraphs discuss how each group of economic inputs to TUBA is specified and outlines the way those inputs are used to calculate the costs and benefits output by TUBA. The following tables provide a summary of this information.

Table 2.1: 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)	None (TUBA assumes Charges final, which may include VAT, already applied)	None (TUBA assumes Charges final, which may include VAT, already applied)

[1] https://www.gov.uk/government/publications/webtag-tag-unit-a1-1-cost-benefit-analysis-november-2014
[2] https://www.gov.uk/government/publications/webtag-tag-unit-a1-2-scheme-costs-november-2014
[3] https://www.gov.uk/government/publications/webtag-tag-unit-a1-3-user-and-provider-impacts-november-2014

Table 2.2: Processing of costs

Investment costs	Input to TUBA in:	Converted in TUBA by:
Privately funded schemes		
HA schemes	Factor cost (see section 2.6)	Indirect tax correction factor
Maintenance Capital Expenditure		

2.3 Values of time

Values of time are input to TUBA as perceived costs. For consumer trips, values of time are perceived in the market price unit of account. However, for business trips, they are perceived in the factor cost unit of account. Thus, TUBA converts the time savings element of business trip benefits to the market prices unit of account by multiplying by the indirect tax correction factor, (1+t).

Values of time used in the default TUBA economic parameters file are taken from the Department's WebTAG TAG data book (Table A1.3.1)[4] .

2.4 Vehicle operating costs

Vehicle operating costs (VOCs) are input to TUBA as resource costs. (Resource costs exclude all taxes, including fuel duty.) Inputs to TUBA also include tax rates on fuel and non-fuel VOC for final and intermediate consumption. These rates are used in TUBA to calculate the appropriate perceived costs. The intermediate consumption rate is that paid by businesses and is applied to business trips; it includes fuel duty, but not VAT (which many businesses can claim back). The final consumption rate is that paid by private individuals and is applied to consumer trips; it includes both VAT and duty.

As for values of time, perceived VOCs for business trips are in the factor cost unit of account. TUBA converts the VOC savings element of business trip benefits to the market prices unit of account by multiplying by the indirect tax correction factor.

Vehicle operating cost parameters and values used in the default TUBA economic parameters file are taken from the Department's WebTAG TAG data book[5] (Table A1.3.7).

To illustrate the differences in perceived vehicle operating costs for business and consumer trips, Table 2.3 and Figure 2.1 show the components of the perceived cost of a litre of unleaded petrol for business and consumer trips in 2010 prices. Both have a resource cost of 42.6p and pay 57.2p in duty. In addition, consumer trips pay 17.5p in VAT. The consumer trip perceived cost of 117.3p/litre is the price paid at the pump and is in the market price unit of account. The business trip perceived cost of 99.8p/litre is the price paid by businesses and is, therefore, in the factor cost unit of account.

[4] https://www.gov.uk/government/publications/webtag-tag-data-book-december-2015

[5] https://www.gov.uk/government/publications/webtag-tag-data-book-december-2015

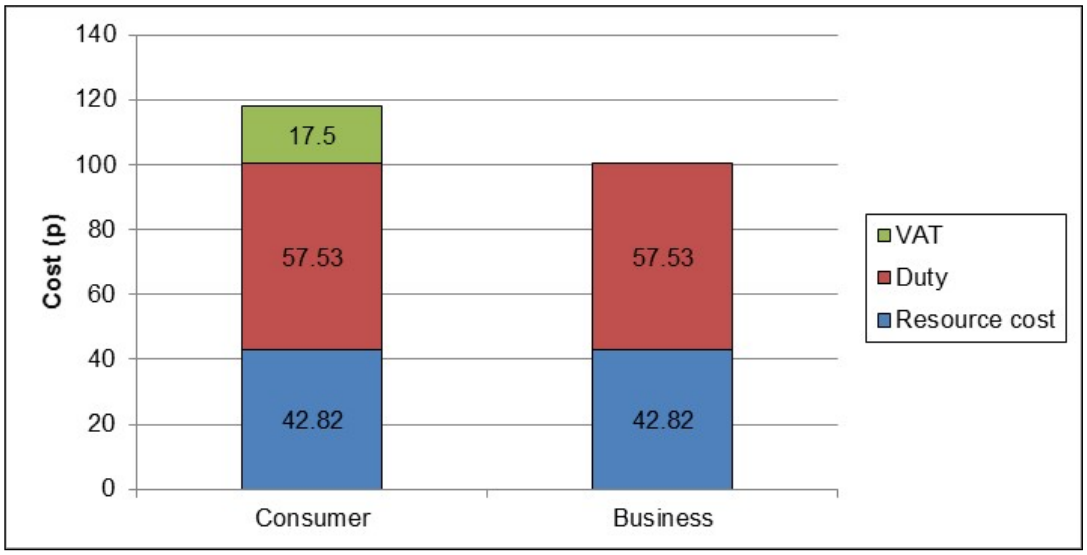
Table 2.3: Components of perceived cost of one litre of petrol, in 2010 prices

Component	Consumer	Business
Resource cost	42.82p	42.82p
Duty	57.53p	57.53p
VAT	17.5p	N/A*
Perceived cost	117.85p	100.35p

** Businesses have to pay VAT 'at the pump' but they can claim it back*

Source: WebTAG Databook Table A1.3.7

Figure 2.1: Components of perceived cost of one litre of petrol, in 2010 prices



2.5 User charges

User charges (tolls, parking charges, fares and so on) are input to TUBA as perceived costs. Inputs to TUBA also include tax rates on user charges for final and intermediate consumption. TUBA assumes that the values input for consumer trips include taxation at the final consumption rate. Because businesses can claim back VAT, perceived user charges for business trips are assumed to include taxation at the intermediate consumption rate. As for values of time and VOCs, perceived charges for business trips are in the factor cost unit of account. TUBA converts the user charges element of business trip benefits to the market prices unit of account by multiplying by the indirect tax correction factor.

TUBA also uses the user charges information to calculate operator revenues. Clearly, operators must pay any indirect taxes to the Government, thus operator revenues must be calculated net of all taxation. Thus, TUBA removes any indirect taxation before calculating operator revenues. Because businesses operate in the factor cost unit of account, TUBA converts the operator revenues to the market prices unit of account by multiplying by the indirect tax correction factor.

User charges for use by TUBA should be deflated to base year prices prior to input.

2.6 Scheme costs

Scheme costs incurred by businesses will be in the factor cost unit of account and should be entered as such, allowing TUBA to make the adjustment to market prices.

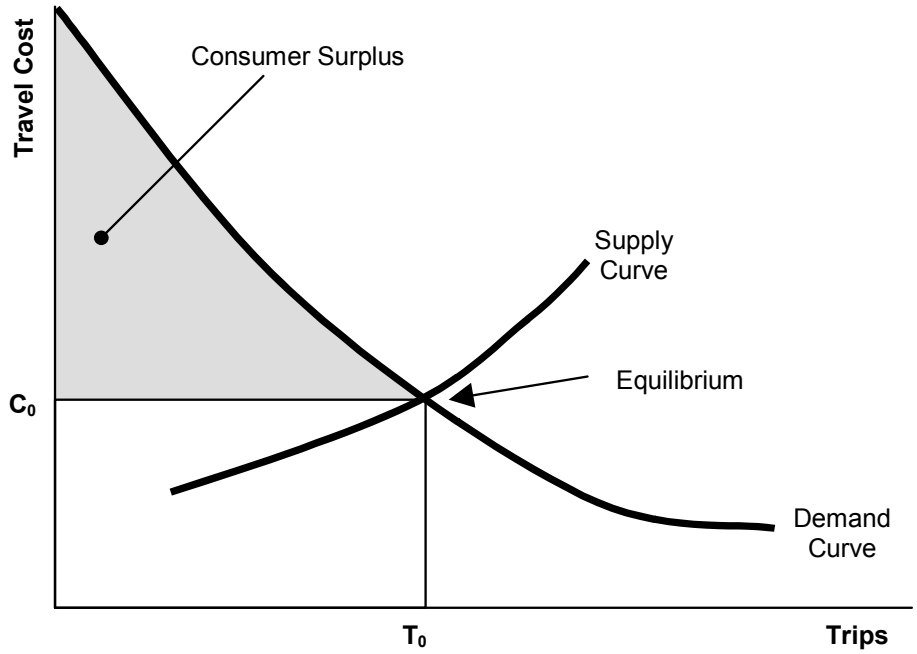
The Highways Agency (HA) does pay VAT on some elements of scheme construction cost. However, the HA is a Government body, so the VAT it pays can be regarded simply as an internal Government transfer. Thus, scheme costs for HA schemes should exclude recoverable VAT and be specified in the TUBA scheme file as being in the factor cost unit of account, allowing TUBA to make the adjustment to market prices.

3. Principles of user benefit calculation

3.1 Theory

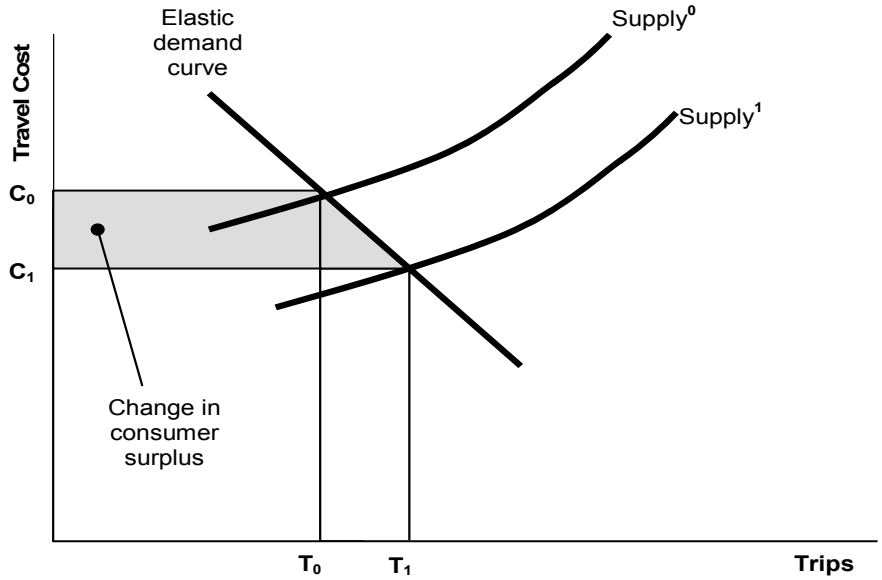
The appraisal of economic benefits relies on the transport system equilibrium being correctly assessed by the transport model(s). That is to say that the numbers of trips T_0 (demand) and system performance (supply) are in balance producing an average trip cost C_0. Figure 3.1 shows this equilibrium point between notional curves of demand and supply.

Figure 3.1: Supply/demand equilibrium showing consumer surplus



At this equilibrium point there are benefits to the consumer over and above the actual trip costs, that is, there is a difference between what they would be willing to pay and what they actually pay. This difference is the consumer surplus. Figure 3.2 shows the consumer surplus diagrammatically by the shaded area above the equilibrium trip cost.

Figure 3.2: Change in consumer surplus



We now consider the case where a transport scheme (the do something (DS) – the former situation is the do-minimum (DM)) is proposed that will reduce travel costs. This shifts the supply curve down as shown in Figure 3.2 and a new system equilibrium is found at the point where the demand is T_1 and the supply cost is C_1. The user benefits of the scheme are given by change in consumer surplus. This is shown by the shaded area on the graph. If we assume that the demand curve is linear between T_1 and T_0 then the change in consumer surplus is given by:

$$\frac{1}{2}(T_0 + T_1)(C_0 - C_1)$$

Calculated for each OD, user class, time slice and mode separately and then summed this is known as the 'rule of a half'. The assumption that the demand curve is linear will normally only be appropriate for relatively small changes in costs. Modifications to deal with large changes in cost are discussed in Section 11. Problems also arise during the appraisal of a new mode (see Section 12).

The above diagrams are a simplification of the actual situation. In most transport models there are a number of different OD pairs, different modes and different time periods, all of which interact in the demand and supply functions. However, the rule of a half is equally valid in these cases.

3.2 Within TUBA

In TUBA nearly all user benefits are calculated using the rule of a half. Benefits from changes in time, charge, fuel and non-fuel vehicle operating costs are calculated separately. The only user benefit that is not calculated using the rule of a half is non-fuel VOC for consumer trips. Full details of the user benefit calculations can be found in WebTAG Unit A1-3[6] .

[6] https://www.gov.uk/government/publications/webtag-tag-unit-a1-3-user-and-provider-impacts-november-2014

4. Modes and submodes

4.1 Definitions and Roles

Modes are the top level of aggregation in TUBA. Scheme costs are defined by mode and user benefit results in the TEE table are disaggregated by mode.

For much of the economic data it is necessary to have a greater level of disaggregation. For this reason each top level 'mode' is divided into one or more vehicle type/submode. Conventionally, vehicle type may be car, LGV (private), LGV (freight), OGV1 and OGV2. Cars, LGVs and OGVs constitute the main mode 'Road'.

Submode is a public transport equivalent of vehicle type. For instance the main mode of 'Rail' may comprise submodes 'Heavy Rail' and 'Light Rail'.

Most of the economic data in TUBA depend on vehicle type/submode rather than main mode, i.e.

- Value of time
- VOC coefficients (may be zero for non-highway submodes)
- Tax rates on charges, fuel and non-fuel VOC
- Default purpose splits
- Default person factors (vehicle occupancies)

5. Annualisation

5.1 Time slices and time periods

In TUBA a distinction is made between time periods and time slices. Time periods have standard definitions supplied in the economics file. They are:

- AM peak (weekday 0700-1000)
- PM peak (weekday 1600-1900)
- Inter-peak (weekday 1000-1600)
- Off-peak (weekday 1900-0700)
- Weekend

Standard data such as person factors (vehicle occupancy) and purpose splits are allowed to vary by time period.

The appropriate annualisation factors to apply depend on how the user chooses to divide up each time period into time slices. Some options for the AM peak are:

1. Single 1 hour time slice representing an average AM peak hour
2. Three 1 hour time slices 0700-0800, 0800-0900 and 0900-1000 covering the whole period
3. Six 30-minute time slices covering the whole period
4. Single 1 hour time slice from 0800-0900

The annualisation factor is given by *h x d* where *h* is the number of this time slice in the time period and *d* is the number of days a year containing the time period.

The year is divided up as follows:

- 253 peaked weekdays;
- 52 weekends;
- 8 bank holidays;

with a total of 8760 hours.

There are 253 (=d) AM peaks a year. In the Case 1 the benefits would first need to be multiplied by 3 (=h) to get from the time slice to the time period, giving an annualisation factor of 759. In cases 2 and 3, h=1 and the annualisation factor would be 253 for each time slice.

Case 4 is more complicated. The time slice 0800-0900 may be completely different from the peak shoulders and therefore cannot be extended to comprise the whole AM peak period.

If there are no modelled time slices for a given time period then TUBA cannot calculate benefits for that time period. It will often be the case that the modelled

time slices cover only part of a time period. For example, a model may only cover 1900-2200 of the off-peak period. This first part of the off-peak period is unlikely to be representative of the remaining period 2200-0700 and it may be inappropriate to extend the model results from the first part to cover the second part.

In general it will be extremely unlikely that a transport model covers every hour of the week. It is therefore necessary to make a compromise when calculating the benefits for time periods (or parts thereof) to cover unmodelled periods. There are two options:

- Ignore unmodelled periods; or
- Adapt the output from modelled periods to cover modelled periods.

Modelled periods can be ignored if it can be assumed that their contributions to overall benefits/disbenefits are negligible (this is likely to be the case for much of the off-peak) or, given the results from the other periods we can expect the user benefits to be positive and we can accept a conservative estimate of total benefits.

If the benefits, or disbenefits, from an unmodelled period (or part) are likely to be significant, then it is necessary to adapt the model output from other periods. It is not possible to make general recommendations as it very much depends on local circumstances, for example major shopping centres can be busier at weekends than during the weekday peaks, while other areas may have very little traffic at weekends.

Returning to Case 4 above where only the hour 0800-0900 is modelled in the AM peak. Assume an average interpeak hour is also modelled. There are a number of options for calculating benefits in the AM peak shoulders (0700-0800 and 0900-1000):

- Use the interpeak data;
- Use the peak hour data; or
- Modify the trip and/or cost data, for example reduce the 0800-0900 data with a factor derived from traffic counts, or costs and trips could be interpolated between the interpeak and the peak hour

A degree of judgement is needed to make this decision, which will mainly be based on the profile of count data. Some caution is needed when modifying cost matrices for this purpose. It should be noted that the user benefits depend on the differences in cost between the DM and DS and that this difference will tend to be greater the higher the costs in the DM. While it may be acceptable to factor trip matrices according to traffic counts, this is less reliable for cost data, as the relationship between trip numbers and costs is not linear, e.g. a 10% reduction in trips may lead to a 20% reduction in travel time.

When using results from one time period in another time period it is important that the correct purpose splits and vehicle occupancies are used. This is most easily done using the standard values supplied with TUBA.

6. Extracting matrices

6.1 Skimming costs

TUBA uses 4 types of matrix from the transport model:

- Trips
- Time
- Distance
- Charge

Extracting the trip matrices should present few problems. Trips should be defined as trips per hour and it is necessary to specify whether they are vehicle trips (as would be usual from a highway model) or person/passenger trips (from a PT model).

Extracting cost matrices (time, distance and charge) can present more problems, particularly in assignment models with multi-routing. A typical highway assignment model uses a generalised cost function of the form

$$\text{cost}=a \times \text{time} + b \times \text{distance} + c \times \text{charge}$$

where the a, b and c coefficients need to be calibrated for the model.

In a perfectly converged highway assignment using Wardrop Equilibrium the generalised costs on all used routes between an origin-destination (OD) pair would be equal. However, this does not mean that the individual components of the cost will be equal across routes. For instance there might be one route with a high charge (toll) and low time and another with a low charge but high time. In this case it is important that the OD travel time passed to TUBA is the average experienced by all trips, i.e. a weighted average across all used routes. For example, suppose two routes are used with travel times t1 and t2 and that the proportions using each route are p1 and p2, then the time T that should be used by TUBA is

$$T=p_1t_1+p_2t_2$$

The general principle is that where multiple routes are used a weighted average of time, distance and charge for each OD should be passed to TUBA, rather than just the costs on the 'current' best route. Most assignment packages offer the facility, although it is sometimes necessary to specify at run time that paths should be stored.

6.2 Public Transport time costs

In public transport models the journey time is often sub-divided into walk time, waiting time, transfer time and in-vehicle time. For behavioural modelling different weights may be applied to these components, for example walk and waiting time are often given twice the cost of in-vehicle time.

Regardless of what was used in behavioural modelling, WebTAG advises that the travel time for business trips should be the unweighted total OD travel time. For consumer (commute and other) trips waiting time should be weighted by a factor of 2.5 and walking and cycling time (when used to interchange between modes) weighted by a factor of 2.0.

Note that TUBA takes a single OD time as its input and cannot apply any weights to different components. Therefore the different components of travel time should be weighted and summed as necessary before input into TUBA.

7. Converting model outputs to TUBA categories

7.1 Overview

Matrices of trip numbers, travel times and, optionally, distances and charges must be input to TUBA for each user class that has been defined in the scheme file. Each user class represents a particular combination of purpose, person type and vehicle type/submode. It is possible that the categories of purpose, person type and vehicle type/submode used in the transport model do not correspond exactly to the standard TUBA definitions. This section discusses how to get around this problem.

7.2 Purposes

If the matrix data is not disaggregated at all by purpose then it is sufficient to define the purpose number as '0' in the user class definition, which denotes 'All purposes'. The trip matrix will then be split between the standard TUBA purposes according to the purpose splits defined in the economics file.

Alternatively the matrix data may be disaggregated by purpose, but perhaps using a different set of purposes to the standard TUBA purposes. In this situation there are two options. The simplest is to aggregate the trip data to the standard TUBA purposes. For instance the model may use commuting, employer's business, shopping and other purposes, while TUBA just has business, commuting and other. In this case employer's business corresponds to business and trips for shopping and model 'other' can be added together to get TUBA 'other' trips. This must be done outside of TUBA using appropriate matrix manipulation facilities.

The second option is to edit the TUBA economics file to include the new purpose definitions. This requires changing the definition of purposes under Categories->Purpose, which includes specifying whether a purpose is business or consumer. The value of time and default person type factors also depend on purpose and will need to be changed. For consistency the default purpose splits should also be changed.

7.3 Person types

The options for person types are basically the same as those for purposes. The 'all person-type' person type is normally used where there is a vehicle matrix. In this case the default person factors are used to calculate mean VOTs per vehicle. Trip data from public transport models will almost always be in passengers, which is the second standard person type. It is unusual to define trip data for the 'driver' person type.

As with purposes a more disaggregate level of person type can be dealt with by either aggregating the data or editing the economics file to include the new types. In the latter case values of time, which depend on person type, will need to be specified for the new person types. The default person type factors should also be changed.

A more disaggregate treatment of person types might be used to produce a more disaggregate representation of values of time. For modelling purposes, it may be

necessary to consider the distribution of the values of time with respect to income. If further information is required, contact Transport Appraisal and Strategic Modelling Division of the Department for Transport (see User Manual for contact details).

7.4 Vehicle types/submodes

While matrices can be input into TUBA for 'All purposes' and 'All person types' it is a requirement that, at a minimum, matrices are disaggregated by vehicle type/submode.

If only an 'All vehicle' matrix is available there are three options:

- Split the matrix externally to TUBA (using your modelling package's matrix manipulation facilities);
- Edit the economics file to create a new 'all vehicle' vehicle type, with appropriate VOT, VOC parameters etc.; save this as a new economic parameters file; or
- Use the 'factor' option in the INPUT_MATRICES table.

This last option is probably the simplest and is now described in more detail.

Suppose the vehicle matrix is for a 30 minute time slice. Normally a factor of 2 would be defined to give the trips in vehicles/hour. Suppose it is an all vehicle matrix with 12% LGVs and 88% cars then a factor of 0.24 would be used when defining it for the LGV user class and 1.76 when defining it for the car user class.

In this case only the trip matrix needs to split. The same time (or distance, or charge) matrix can be defined for each vehicle class. The charge matrix may differ by vehicle type, in which case the different vehicle types should be modelled separately.

8. Public Transport Benefits

8.1 Bus benefits

Bus data can be obtained from either a highway assignment model as vehicle trips or from a public transport model as passenger trips. It is important not to double count the benefits/disbenefits. There are a number of options, depending on whether a highway assignment model, a PT model, or both are used

8.1.1 Bus driver time and VOC benefits

Whether or not a PT model is used, the bus vehicle trip data from the highway model can be used to obtain bus driver time and VOC benefits. These should normally appear under provider operating costs rather than user benefits in the TEE table.

Bus drivers should be set up as a user class with vehicle type 'bus', purpose 'business' and person type 'driver'.

No charge (fare) matrix should be defined for this user class, unless there is a road toll payable by the bus operator.

Further information on bus operating costs can be found in WebTAG Unit A-2 Scheme Costs[7].

8.1.2 Bus passenger benefits

If there is no PT model available then the highway model must be used to give passenger benefits. In this case a bus passenger user class can be set up with vehicle type 'bus', purpose '0' (all purposes) and person type 'passenger'. In addition to the usual matrix factor a factor of 12.2 should be used to represent the average number of passengers per bus (or use a figure based on local data, if available). A fare matrix should always be defined if one is available.

If a PT model is available this should be used to obtain bus passenger benefits, with bus passengers set up as a user class with submode 'bus' and person type 'passenger'.

Note that in the standard economic parameters file the default purpose split for buses represents the split for bus passengers and should not be applied to bus drivers. Thus bus drivers must always be explicitly defined as 'business' purpose.

8.1.3 Summary

In summary, depending on which models are available:

- Highway assignment model only: use highway data to calculate bus driver/operator benefits and bus passenger benefits.
- PT model and highway assignment model: use PT model to calculate bus passenger benefits; use highway model to calculate bus driver/operator benefits.

[7] https://www.gov.uk/government/publications/webtag-tag-unit-a1-2-scheme-costs-november-2014

- PT model only: calculate bus passenger benefits; bus driver/operator benefits cannot be calculated by TUBA in this case.

8.2 Rail operating costs

Rail operating costs should specifically exclude all costs of establishing or improving a rail line, such as track construction, installation of power supply and signalling, construction of stops, termini and depots, and additional rolling stock. All of these are considered as capital expenditure outside the model, see WebTAG Unit A-2 Scheme Costs[8].

[8] https://www.gov.uk/government/publications/webtag-tag-unit-a1-2-scheme-costs-november-2014

9. Interpolation

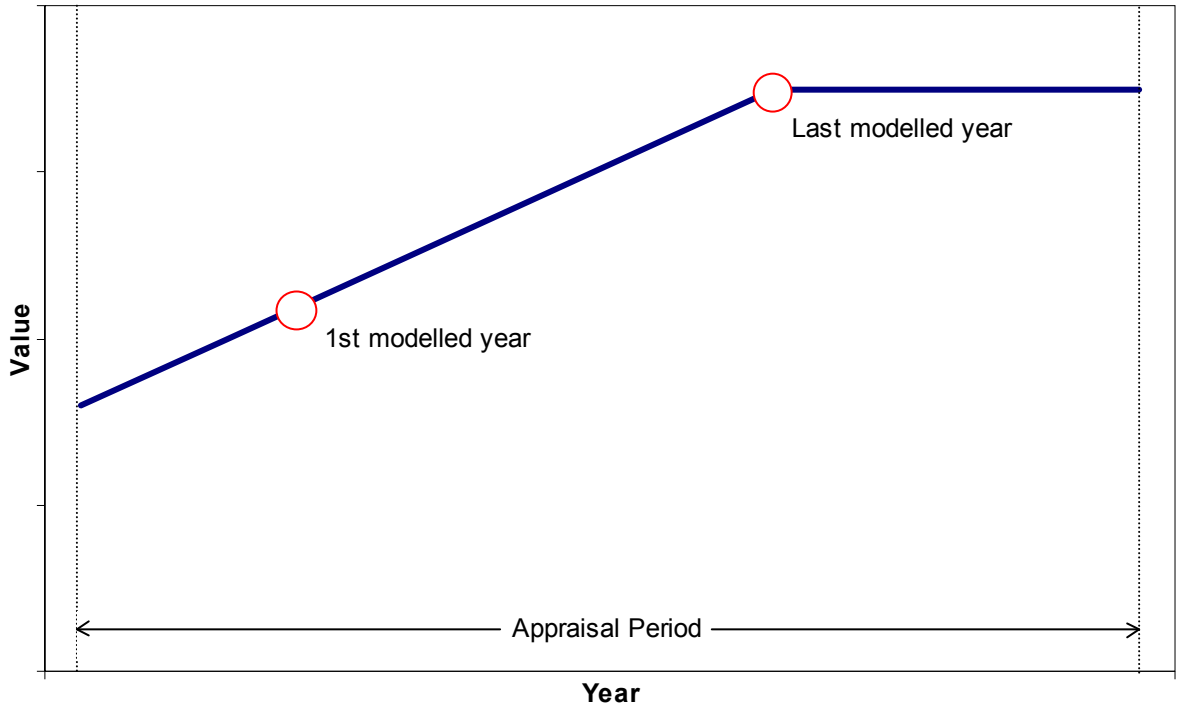
9.1 Application

It is very unusual to model every year of the appraisal period (usually 60 years). TUBA therefore interpolates and extrapolates data for modelled years to cover all years of the appraisal period. This is done for the following data:

- User benefits:
  - Travel time
  - VOC (fuel and non-fuel)
  - User charges
- Revenues:
  - Operator
  - Government indirect taxes
  - Fuel consumption

Data for years between two modelled years is linearly interpolated between those two years. For years before the first modelled year it is extrapolated from the first two modelled years. Beyond the last modelled year data is extrapolated using a horizontal line (before any user-defined change in the magnitude of benefits after the last modelled year is applied). This is illustrated in Figure 9.1 which shows a case with only two modelled years and no user-defined change in the magnitude of benefits after the last modelled year.

Figure 9.1: Interpolation and extrapolation with two modelled years



In most cases further adjustment of data to allow for changes in taxes, growth in GDP etc. takes place after interpolation and extrapolation. The following table shows the values to which interpolation and extrapolation are applied and the further adjustments that are made.

Table 9.1: Interpolation and extrapolation of benefits

Data	Values interpolated/extrapolated	Subsequent adjustments
Time benefits	Benefits in perceived costs, base year values	Application of VOT growth and conversion to market prices
Fuel benefits	Benefits in resource costs using base year consumption coefficients	Application of changes in efficiency and fleet composition, conversion to market prices.
Non-fuel benefits	Benefits in resource cost using base year coefficients	Application of changes in coefficients, conversion to market prices
User charge benefits	Benefits in resource costs	Conversion to market prices
Revenues	Changes in expenditure on VOC and charges	Application of tax rates (where appropriate) and conversion to market prices
Fuel consumption	Fuel consumption, DM and DS	Application of changes in efficiency and fleet composition

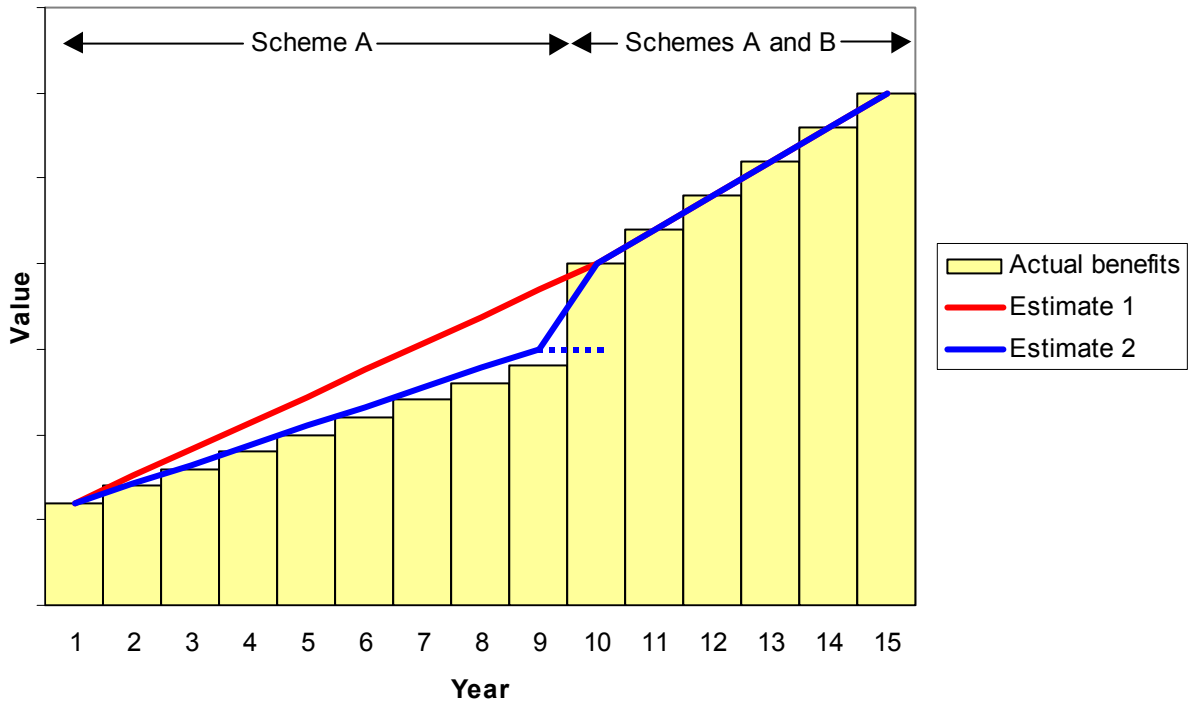
Finally, any user-defined change in the magnitude of benefits and revenues (BENEFIT_CHANGE table in the scheme file) is applied.

Interpolation and extrapolation of data clearly has implications when there is phased construction, i.e. a number of different schemes opening at different times. For instance, suppose there are two schemes, with Scheme A opening in Year 1 and Scheme B in Year 10. In this situation Year 9 should be modelled with Scheme A as the do something and Year 10 should be modelled with Schemes A and B. This gives a benefit stream as shown by the histogram in Figure 9.2. (Only the first 15 years are shown in Figure 9.2. It is assumed that Year 1 is modelled and that an additional year will be modelled, in this case Year 15 or later, beyond which the extrapolation will be horizontal.)

If Year 9 is not modelled and Year 10 is modelled with Schemes A and B then an element of the benefits from Scheme B will be interpolated for Years 2 to 9. This is shown by the red line in Figure 9.2, which indicates an overestimation of benefits.

It is strongly recommended that Year 9 is modelled. If for some reason it is not possible to obtain model results for Year 9 then as a coarse approximation it is acceptable to model Scheme A only in Year 10, but specify this as Year 9 to TUBA. Similarly, Year 10 DM is specified as Year 9 (as well as Year 10). This is shown by the blue line in Figure 9.2 . In this example this leads to a relatively small overestimate of benefits for Years 2 to 9.

Figure 9.2: Phased construction and possible sources of error



10. Sectoring

10.1 Applications

In TUBA a sector is a grouping of a number of zones. Each sector consists of one or more zones; any one zone can only belong to one sector, i.e. sector boundaries must respect zone boundaries.

Sectors have a number of roles:

- To convert highway and public transport results, which may have different zoning systems, to a common base.
- To reduce the number of ODs so that spatial analysis of user benefits is made more manageable.
- To reduce memory requirements and hence improve run times for very large problems.

While outputting results at OD level is not standard, the optional detailed results file contains user benefits disaggregated by origin and destination sector, as well as time period, person type, purpose, vehicle type and year. Even as few as 10 sectors will generate 100 OD pairs, so the number of sectors should be kept to the bare minimum.

Within TUBA aggregation of results to sectors takes place at the same time that time slices are aggregated to time periods, i.e. after user benefits have been calculated for each modelled year but before interpolation and extrapolation of results and the application of growth rates and taxes. Sectoring only affects the level of spatial detail in the (optional) detailed results file – none of the data in the standard output file, including total user benefits and revenues, is affected.

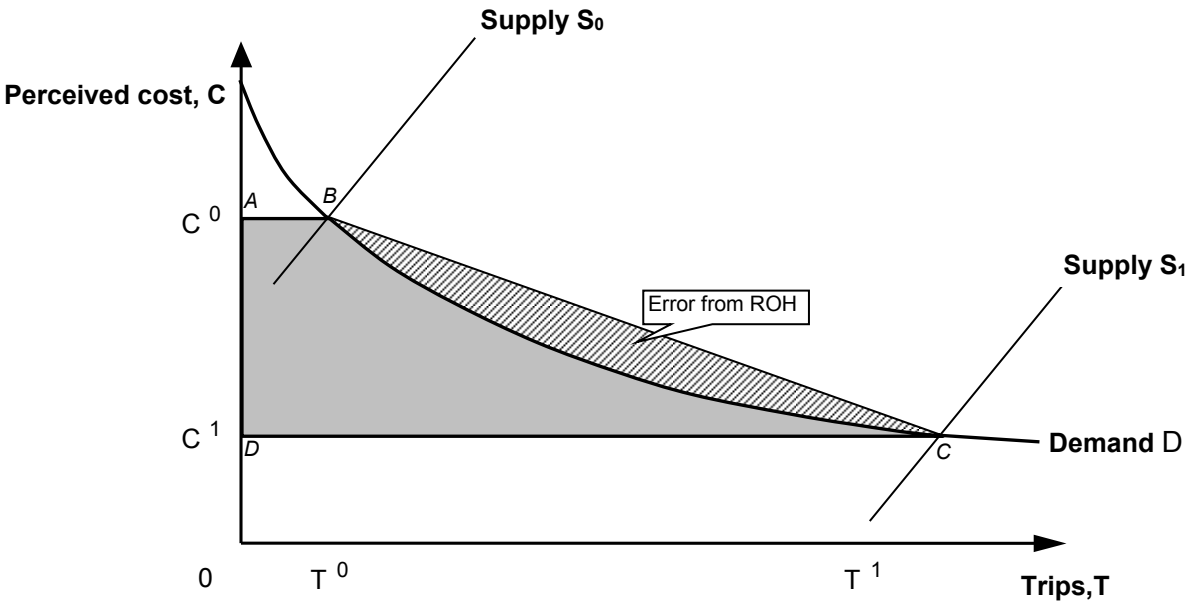
If an explicit sectoring file is not specified by the user, the TUBA default is to allocate all zones to a single sector to minimise memory requirements and run times.

11. Dealing with large cost changes

11.1 Problems with the Rule of a Half

TUBA uses the rule of a half (ROH) to calculate user benefits[9]. However, if the change in generalised cost between the DM and DS is too large then ROH can become inaccurate. A full description of the problems with ROH and large cost changes can be found in Nellthorp and Hyman (2001). The key issues can be summarised as follows.

Figure 11.1: Possible error due to ROH calculation



When a transport scheme is implemented there is a shift in the supply curve (S_0 to S_1 in Figure 11.1), 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. This 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:

$$\frac{1}{2}\left(T^0 + T^1\right)\left(C^0 - C^1\right)$$

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

[9] With the exception of non-fuel VOCs for non-working vehicles

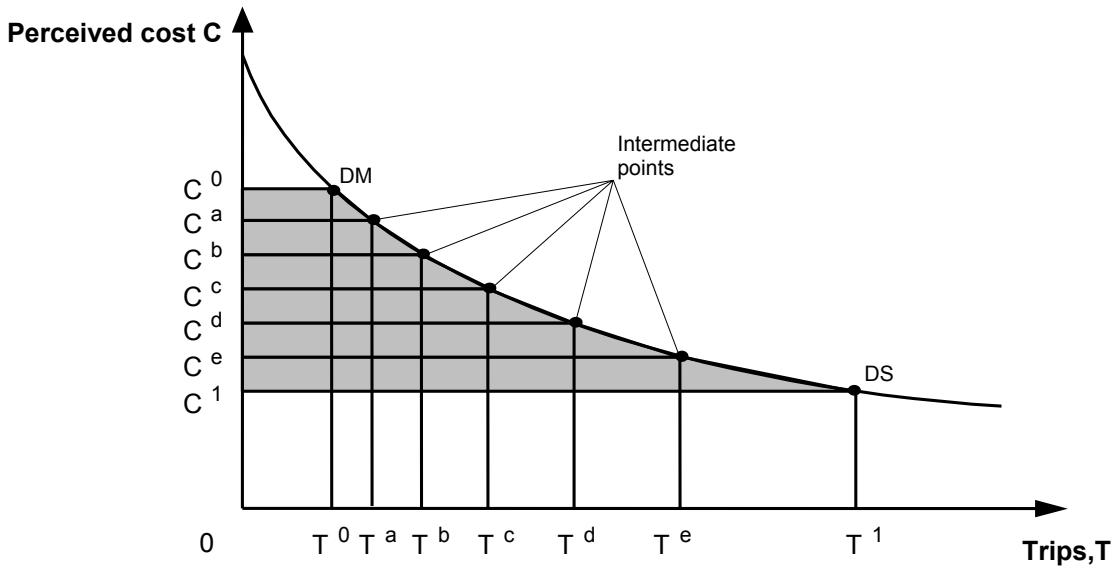
This can lead to an error compared with the true benefits, as shown by the hatched area on the graph. The larger the change in cost the less accurate the linear approximation is likely to be.

Conventionally demand curves in demand-supply diagrams are drawn as curves that are convex to the origin (as in Figure 11.1), 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. Of course the error does not occur with linear demand curves.

11.2 The TUBA solution

Nellthorp and Mackie (2001) consider a number of solutions to the problem. Their preferred solution, and the one implemented in TUBA, is referred to as Numerical Integration (NI). This is illustrated in Figure 11.2. It 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; this is done automatically by TUBA.

Figure 11.2: Use of numerical integration to reduce error due to ROH



In the field of numerical analysis this particular form of numerical integration is known as the extended trapezoidal rule. Its error term is $O\left(\frac{(C^0 - C^1)^3}{(N-1)^2}\frac{\partial^2 T}{\partial C^2}\right)$ where N is the number of points used (including the DM and DS)[10]. So using three points (one intermediate point) instead of two (just DM and DS) can reduce the error by approximately a factor of 4. Using five points (three intermediate) will reduce the error by approximately a factor of 16.

[10] An error term O(X) means that the error is equal to some unknown constant times X. In the above error term $\frac{\partial^2 T}{\partial C^2}$ represents the value of the second derivative of the demand function evaluated at an unspecified point in the interval (T^0,T^1)

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. In this case it is the non-linearity of the supply curve that introduces errors in ROH.

Setting up a TUBA run to implement NI is straightforward (see TUBA manual for details). 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.

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 11.3.

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.

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.

From a practical point of view the key questions are 'When is it necessary to use intermediate points?', 'How many are needed?' and 'How is the data calculated?'. These are covered in the following sections.

11.3 When to use intermediate points

Any application of TUBA will fall into one of the following categories:

- Fixed trip matrix appraisal (inelastic demand)
- Variable trip matrix appraisal with existing modes

- Variable trip matrix appraisal with new mode(s)

The above can occur together in a single TUBA run with each user class/mode falling into a different one of the above categories.

In the case of a fixed trip matrix TUBA 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.

With a variable trip matrix 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. This guidance represents a first attempt to provide advice and will be refined in light of users' experiences.

With new modes there will almost always be large cost changes between the pseudo-DM (defined in Section 12) and the DS and at least one intermediate point will be required. A more detailed discussion on dealing with new modes can be found in Section 12.

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%. For cost changes up to 70% a single additional point should be sufficient. For larger cost changes three additional points will normally be required. Broadly corresponding to this, TUBA checks the ratio of DM to DS costs (for times and distances) and issues a warning if it exceeds 1.5 or is less than 2/3, and a serious warning if it exceeds 3 or is less than 1/3. 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%)

This advice needs some qualification. It 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. Of course 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.

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. The size of the change that triggers each type of warning can be found in the TUBA manual.

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.

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.

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.

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. To avoid any unnecessary work users should contact the TUBA helpdesk (tuba@atkinsglobal.com) if they think they need to use intermediate points.

11.4 How many intermediate points

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

(a) A single intermediate point, with costs as the average of DM and DS

(b) Three intermediate points (including point generated from (a))[11]

Having run TUBA with one intermediate point it will be necessary to decide whether additional points are needed. As noted before, 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[12]. 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:

[11] *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.*

[12] *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.*

Table 11.1: 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

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@atkinsglobal.com).

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.

11.5 Generating intermediate points

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[13] 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 and DS it will have very little impact on the estimate of benefits.

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 11.2: Costs for intermediate points

Number of intermediate points	Costs
One intermediate point	$0.5C^0 + 0.5C^1$
Three intermediate points (two additional points required)	$0.75C^0 + 0.25C^1$ $0.25C^0 + 0.75C^1$

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

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

as noted elsewhere it is not necessary to provide intermediate data for every OD, user class and year.

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

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.

11.5.1 In summary

For each intermediate point required:

1. Use a matrix manipulation program/spreadsheet to generate cost matrices in the form required by the demand model[14]
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

A flowchart illustrating the overall process is given in Figure 11.3.

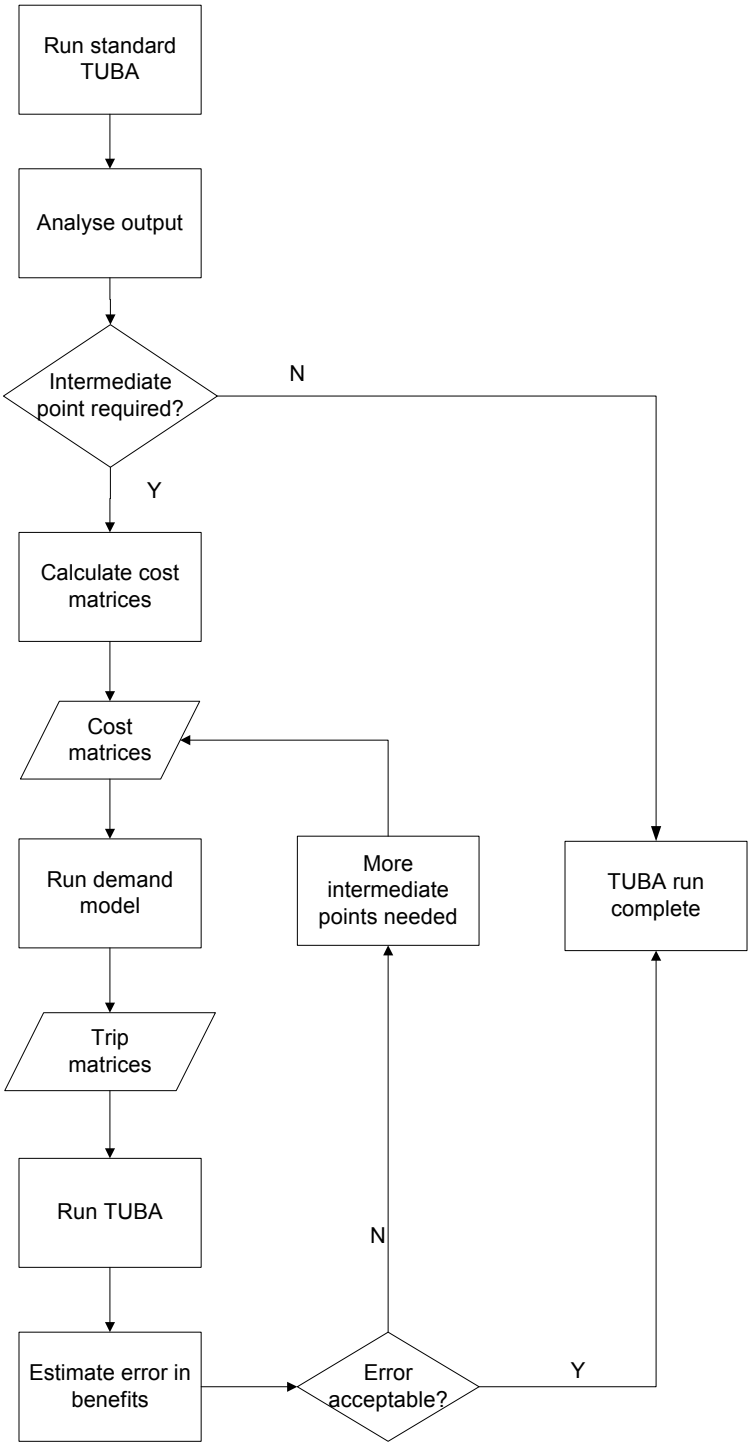
This approach will work for most cases where the demand model is distinct from the assignment model. In some cases demand and supply are more integrated. A typical example will be elastic assignment models where the demand adjustment is integrated into the assignment procedure. In such cases the demand function is usually separable[15] 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.

For any models not covered by the above advice please contact the TUBA helpdesk (tuba@atkinsglobal.com).

[14] *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*

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

Figure 11.3: Flowchart for using TUBA with large cost changes



11.6 Generating intermediate points with elastic assignment models

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.

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 2.1 for each cost component (needed for input to TUBA) and for the generalised cost

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

12. Dealing with new modes

12.1 Overview

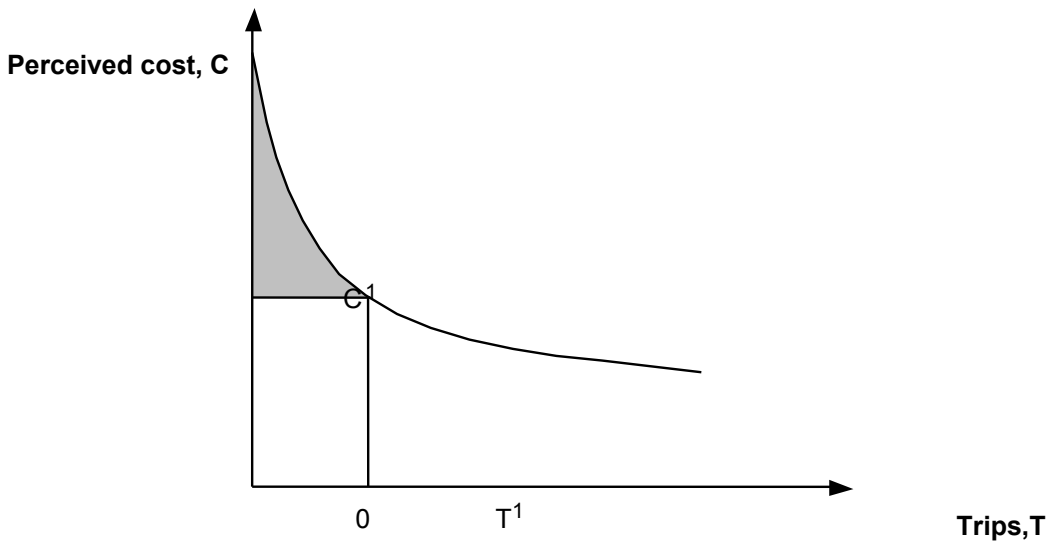
At its simplest a new mode (or submode) is one that is introduced into the DS but does not exist in the DM, a typical example being Light Rapid Transit (LRT). However, when viewed at the OD level there are a number of other cases that need to be treated in the same way as a new mode:

- The mode exists in the DM but only for certain ODs; it is then extended to serve other ODs. It needs to be treated as a new mode for the latter. An example might be a new LRT route in a city with existing LRT.
- The mode exists in the DM but the cost for some ODs is so high that it is not used. An example might be two nearby towns, rail travel between which in the DM involves a significant detour via a major interchange, but which have a direct rail link built in the DS[16]. It is not acceptable to use the actual DM cost in this case.

12.2 Generating intermediate points with elastic assignment models

When a new mode is introduced into the DS the corresponding DM data is undefined and therefore the rule of a half (ROH) cannot be applied. The consumer surplus is given by the shaded area in Figure 12.1.

Figure 12.1: Consumer surplus of a new mode



12.3 The TUBA Solution

Nellthorp and Hyman (2001) consider a number of solutions, including those presented in the Common Appraisal Framework (MVA et al, 1994). Their preferred method, implemented in TUBA, is called the triangle method and is illustrated in Figure 12.2. This involves defining a pseudo-do minimum point and

[16] *Users with this situation should be careful to ensure that zero DM trips are not the result of survey/sampling/matrix building problems*

then extrapolating the demand curve to the cost axis. The consumer surplus between the pseudo-DM and DS points is calculated using the ROH as normal (shaded area). The area of the hatched triangle is then added to the ROH benefits. There will usually be a large difference in cost between the pseudo-DM and the DS, requiring the use of numerical integration as shown in Figure 12.3 (see Section 2).

Figure 12.2: Triangle method for new modes

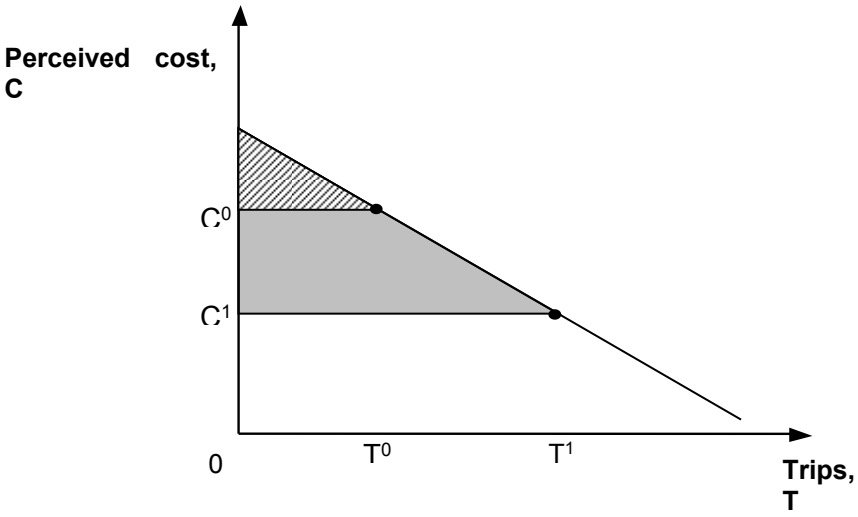
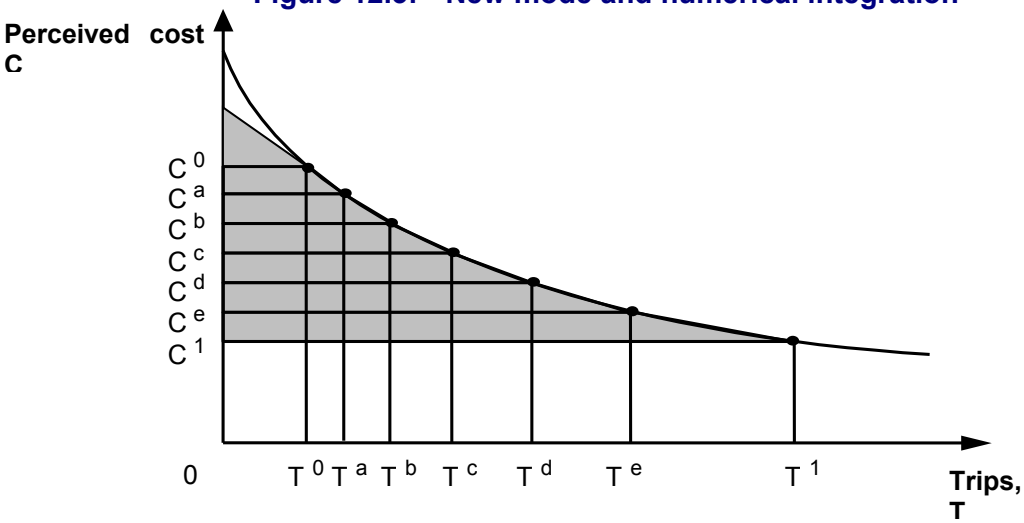


Figure 12.3: New mode and numerical integration



An advantage of the TUBA approach for dealing with new modes is that it does not require the user to explicitly identify the cost axis intercept.

Although usually referred to as the new mode problem, using TUBA nomenclature the same problem arises with new submodes or vehicle types.

12.4 Alternative appraisal methods for new modes

The next sections discuss in detail how to generate pseudo-DM data. However, it should be noted that in two particular cases a simpler approach may be adopted. The two cases relate to particular modelling methods where either:

- The new mode is a PT submode and submode choice for public transport is handled by the assignment, or
- The new mode takes all its patronage from an existing mode

The inclusion of these in this guidance note should not be interpreted as an endorsement of these modelling methods.

12.4.1 Submode choice for public transport handled by assignment

In some models the choice of public transport submodes (bus, guided bus, LRT, rail) is handled as part of the assignment process. There may be an explicit mode choice mode that predicts the car/PT split but the choice between, say, bus and LRT is handled in essentially the same way as the choice between two alternative bus routes. Typically a matrix of PT trips is input to the assignment and a matrix of PT costs output. Because inter-modal trips (i.e. the use of more than one PT mode) can be modelled, it may not be possible to obtain separate trip or cost matrices by PT submode. In terms of TUBA inputs such a model can therefore only provide matrices for a generic PT mode.

Dealing with new PT submodes in such an arrangement is mostly straightforward. For the DS the new submode and its route(s) are coded into the PT network and then the model is run as usual. PT costs can be obtained for the DM and the DS and the new mode problem identified above does not occur. The only complication is if the new submode introduces a PT service for an OD pair that had no service in the DM. In this case the new mode problem does arise for this OD pair, which will need to be dealt with by providing pseudo-DM data as discussed above.

The lack of matrices by submode places limitations on the TUBA appraisal. It means that user benefits and operator revenues cannot be calculated for each submode separately. In particular the costs and benefits for the new submode cannot be separated from the costs and benefits associated with any changes for existing submodes.

There are some difficulties associated with skimming costs. Theoretically the skimmed costs should be consistent with the choice model used in the assignment. It has been suggested that the use of composite costs would be better than flow-weighted averages. However, there are problems with this approach and the Department is currently considering the issues. In the meantime the recommendation is to skim costs as the passenger-weighted average across submodes and routes.

Economic parameters for a generic PT mode should be calculated from WebTAG TAG data book[17] (e.g. Table A1.3.1 for working values of time) using local values for the mix of traffic (e.g. bus/rail split) in the model area.

12.4.2 New submode takes all patronage from an existing submode

In some cases passenger flows for a new submode are assumed to come entirely from a single submode, e.g. all LRT users assumed to come from bus. In this case the existing submode DM costs can also be used for the new submode as these represent the actual costs faced in the DM by those who switch to the new submode in the DS. DM trips for the new mode will be zero.

If the switch involves a new PT-only (i.e. not park and ride) submode taking all its patronage from car then it is not possible to take into account VOC benefits using this approach. This is acceptable provided VOC benefits are not significant. In any case, from a purely modelling point of view it may be difficult to justify such a model structure, except in very special cases.

A further difficulty occurs if the existing submode has charges associated with it, as may be the case when LRT users all switch from bus. In this case the change in operator revenue by submode will not be correct, although the net change across all modes and the user charge benefit will be correct. This can be partially overcome by making sure that the DM charge and the DS charge are specified as separate types (e.g. bus fare in the DM and LRT fare in the DS). The TUBA output tables will then produce the change in revenue by charge type, from which the correct change in charge type by submode can be calculated. The TEE table can then be modified manually if required.

When using this approach described in the above paragraphs the new submode should not be identified as a new submode in the economics file.

12.5 Generating pseudo-DM data

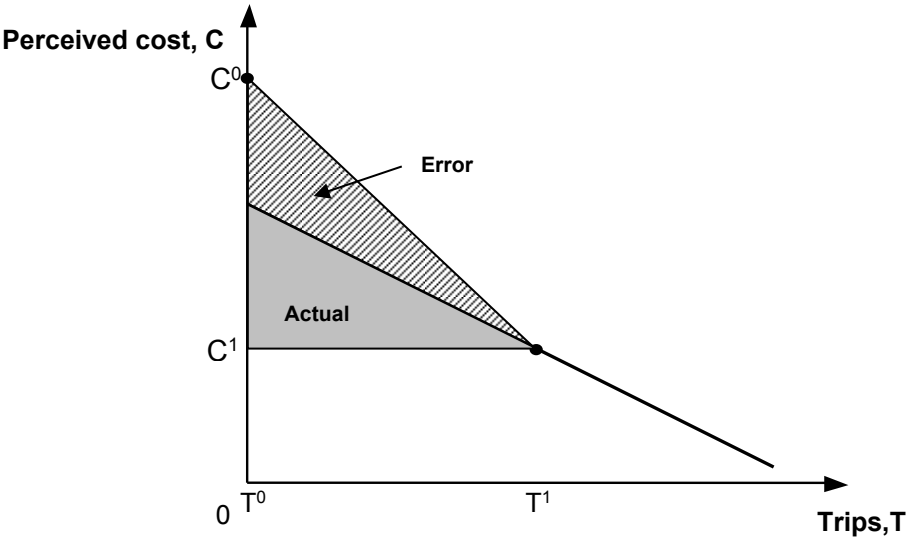
Generating the pseudo-DM data is a question of finding a set of costs which, when passed through the demand model, give very low (but non-zero) OD flows using the new mode, the aim being to find a point on the demand curve that is close to (but not on) the cost axis.

The appropriate pseudo-DM cost may vary between OD pairs and purposes, depending on the modelling structure.

It is very important that pseudo-DM costs for a given OD pair are not used just because they give zero demand. If the pseudo-DM point input to TUBA does have zero demand the associated cost should be the lowest cost that gives zero demand. Otherwise the cost could be set arbitrarily high, resulting in an overestimation of benefits - this is shown in Figure 12.4. However, in practice it is difficult and time consuming to verify that a cost that gives a zero demand is the lowest cost that will do so. In general it is better to have too many trips in the pseudo-DM than too few.

[17] https://www.gov.uk/government/publications/webtag-tag-data-book-november-2014

Figure 12.4: Overestimation of new mode benefits with inappropriate pseudo-DM



For this reason it is required that *all ODs have some trips in the pseudo-DM* (provided of course they have demand in the DS). There is also a risk where demand curves are asymptotic to the cost axis, where very high costs will give a very low (but non-zero) number of trips and benefits will again be overestimated.

Note that demand curves are usually convex near the cost axis, meaning the triangle method will tend to slightly underestimate this part of the consumer surplus, provided the pseudo-DM is not too close to the axis. Making sure that the pseudo-DM is not too close to the cost axis will therefore tend to provide a conservative estimate of benefits.

Finding the pseudo-DM cost that will produce the correct number of trips is potentially quite difficult. Nellthorp and Mackie (2001) recommend that the pseudo-DM has 0.02 times the DS number of trips. Finding the cost that gives rise to this demand is partly a matter of trial and error. However, an initial estimate can be found from the DS cost using the following approximation:

$$C_0 \approx C_1\left(\frac{E-0.98}{E}\right)$$

where E is the elasticity of the demand function at the DS[18].

Considering E in the range –0.1 to –0.5 gives DM costs between approximately 3 and 10 times the DS costs. For reasons already discussed it is better that there are too many trips in the DM rather than too few, so 3 times the DS cost is recommended as the starting point.

The appropriate pseudo-DM costs should also be considered with regard to the cost of other modes. If there are other modes that are not used for this OD then the pseudo-DM cost should be less than the cost of any unused modes. Similarly,

[18] *This approximation is based on the DS point elasticity of demand. An exact equation involving the arc elasticity of demand can also be derived. However, the arc elasticity of demand increases substantially when the DM number of trips is close to zero and it is not possible to state beforehand what value it will take between the DS and the correct pseudo-DM.*

it makes sense to for the pseudo-DM cost to be greater than the cost of any modes with a significant flow.

The individual components of the DS cost should be increased by the same factor in the pseudo-DM, i.e. the relative size of the individual components remains the same.

When running the demand model the costs used for the other modes should be the DS costs.

12.6 Using TUBA with new modes

The data inputs for a new mode in TUBA are the same as for other modes. Pseudo-DM matrix data should be treated like normal DM data and entered in the INPUT_MATRICES table as scenario '0'. New modes are identified via the 'New_mode?' (Y/N) column of the VEHICLE_TYPE/SUBMODE table of the economics file (see the TUBA manual for further details). This changes the standard TUBA calculations as follows:

- Calculation of additional 'triangle' for user benefits normally calculated with ROH
- Unlike normal DM, new mode pseudo-DM data does not affect the following calculations:
- Non-working vehicles non-fuel VOC user benefits
- Operator revenues
- Indirect tax revenues
- DM total user costs
- DM fuel consumption

Anyone using TUBA to deal with new modes is requested to contact the TUBA support team with their experience and any problems to help improve this document and/or the software.

12.7 Intermediate points

Using the methodology described above there will inevitably be some very large cost changes between the pseudo-DM and the DS, requiring the use of intermediate points (see Section 2). Nellthorp and Mackie (2001) recommend 3 intermediate points for new modes (in addition to the pseudo-DM). While experience is still being gained in this area we advise following the guidance set out in Section 2 starting with 1 intermediate point and then proceeding to 3 if necessary.

13. Park and ride in TUBA

13.1 Methodology

A park and ride trip in TUBA is defined as one which involves car and public transport (PT) legs. There are a number of respects in which appraising park and ride in TUBA differs from other modes. These are described in the following paragraphs.

P&R submodes need to be identified as such in the economics file. A P&R submode is set up in the standard economics file supplied with TUBA.

Time matrix: the time matrix provided for P&R trips should be the generalised time from the true origin to the true destination of the trip, i.e. including the car and PT legs. PT-related wait, walk and transfer times for non-working (consumer) trips should be weighted in accordance with Department for Transport guidance[19].

Distance matrix: the distance matrix provided for P&R trips should be the distance for the car leg only. In TUBA trip distance is used only for the calculation of vehicle operating costs (VOC).

Calculation of VOC benefits requires vehicle speeds. Normally these are calculated from the input distances and times. However, for P&R trips the time relates to the whole journey, not just the car part, so this is not possible. TUBA uses a global speed for the car leg of P&R ride trips which is defined in the scheme file. This is a simplification that is considered acceptable because VOC benefits are generally not a significant part of total benefits. If P&R VOC benefits are significant then please contact TUBA technical support (tuba@atkinsglobal.com).

P&R trip matrices must be supplied in one of the following two ways:

- As vehs/hr with person type '0' specified for the user class.
- As persons/hr with separate user classes for drivers and passengers (the driver trip matrix should be identical to the vehicle matrix)

Charges applicable to P&R trips will often include parking charges and PT fares. The former is normally per vehicle (can also be seen as per driver), the latter per person. The charge matrices input into TUBA must be compatible with the trip matrices, i.e.:

- If person type '0' is used then all charges must be on a per vehicle basis. This may require the PT passenger fare matrix to be factored up according to the average occupancy, which can be done using the 'factor' column of the INPUT_MATRICES table
- If separate user classes for drivers and passengers are used then any parking charge matrix (charge per vehicle) should be specified for the driver user class only. PT fares (per person) should be specified for both user classes, typically with the same matrix for both.

[19] https://www.gov.uk/government/publications/webtag-tag-unit-m2-variable-demand-modelling

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Contents

Section *Page*

A. Definition of large cost changes **A-1**

List of Tables

Table A.1: Data Checks A-1
Table A.2: Limit Values A-1

A. Definition of large cost changes

The definition of large cost changes needs some clarification. Currently TUBA checks the ratio of the DM to DS cost (time and distance separately) and issues a warning or serious warning according to the value as follows:

Table A.1: Data Checks

Value of r	Action
r<A or r>D	Serious warning
A<r<B or C<r<D	Warning
B<r<C	OK, no warning

The values of A, B, C and D are:

Table A.2: Limit Values

A	B	C	D
0.33	0.67	1.5	3.0

This has the advantage in that it is 'symmetric', i.e. a DM cost of X and a DS cost of Y gives the same level of warning as a DM cost of Y and a DS cost of X. Compare this with the Nellthorp and Hyman proposal which says there will be problems with ROH if the cost change (expressed as a function of the DM cost) is greater than 33%. Suppose the DM cost is 100 and the DS cost is 140. The percentage difference is 40% and the user would be recommended to use an intermediate point. If on the other hand the DM cost is 140 and the DS cost is 100, then the percentage difference is 28.6% and the user would not be recommended to use an intermediate point. Clearly if the demand curve is the same in the both cases the true benefit, and the error due to ROH would be identical.

It is clear that a 'symmetric' indicator is needed. In addition to the ratio test currently used there are the following alternatives:

- Difference expressed as a percentage of the larger (or smaller) of the DM and DS costs
- Difference expressed as a percentage of the mean of the DM and DS costs

The former is essentially equivalent to the current ratio test (the value of one can be deduced from the value of the other). At the moment we do not have any real evidence to justify one measure over the other, or as to the appropriate threshold values to trigger a warning. This is illustrated by the following charts which illustrate the % error from using the ROH as a function of the change in cost.

In view of these results we do not propose changing the existing checks in TUBA, or the threshold values for issuing warnings. The checks have been extended to cover changes in trips.

Figure A.1: Error in ROH versus ratio of DM to DS costs.

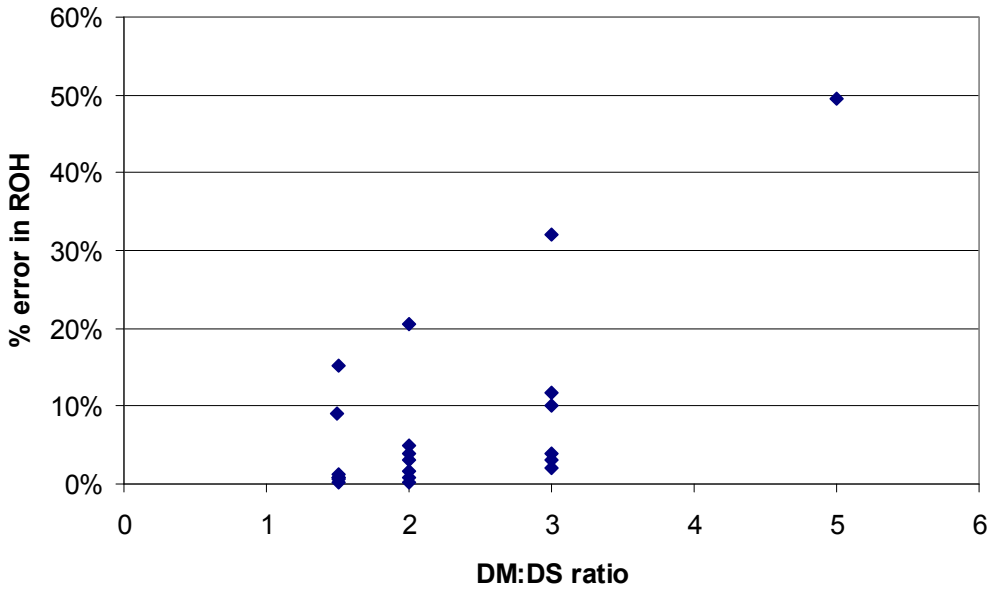
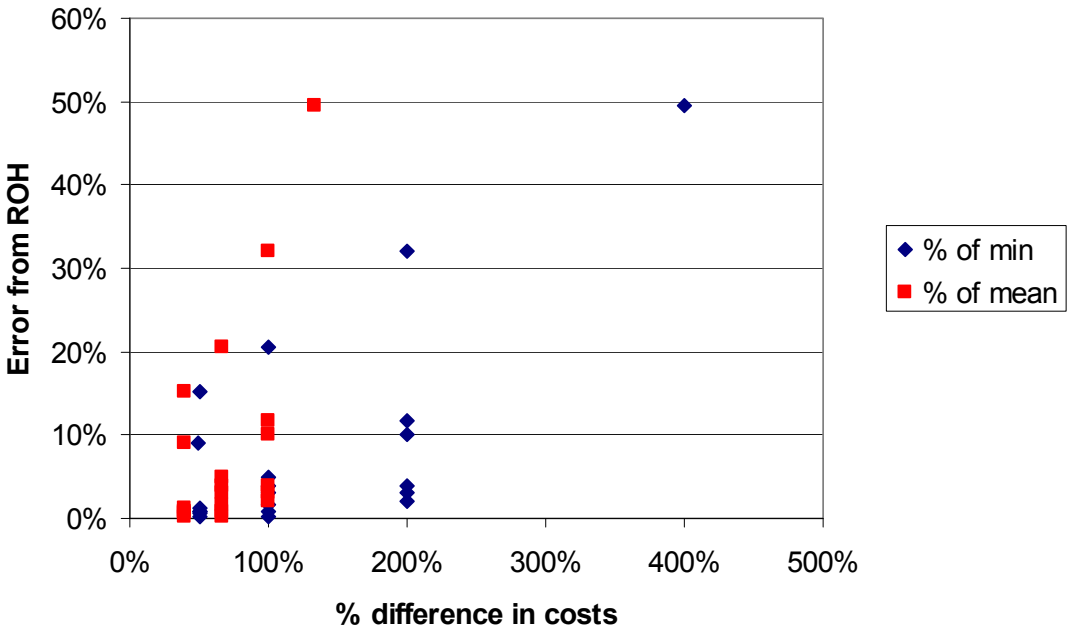
Figure A.2: Error in ROH versus % difference between DM to DS costs.