DEVELOPMENTS IN VARIABLE DEMAND MODELLING

Andrew Gordon and Chris White
Mott MacDonald
Frederic Oladeinde and John Collins
Department for Transport

Acknowledgements and Disclaimer

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1. INTRODUCTION

For many years the Department for Transport's guidance on traffic appraisal was based on the assumption that the only important response to changes in travel costs, for example due to new road improvement schemes, was rerouting or reassignment. This assumption of a fixed demand matrix was changed with the publication of the 1994 SACTRA report 'Trunk Roads and the Generation of Traffic'. This identified that variable demand could undermine the justification of a transport scheme and led to the 1997 Guidance on Induced Traffic. However, most variable demand modelling since that date has used simple elasticity methods rather than modelling different responses explicitly (trip frequency, mode choice, distribution and time period choice).

To address this issue the Department is issuing advice that provides a basic understanding of variable demand modelling. This advice is for project managers and modellers, and sets out basic good current practice. It assumes a familiarity with assignment modelling to forecast how traffic will be distributed across the road network, and describes how to estimate the likely changes in demand as travel times and costs change. In parallel with this advice the Department is also releasing software (called DIADEM) enabling models of variable demand to be implemented relatively simply.

2. THE ADVICE

2.1 Overview

The advice has been released through the Department's Transport Analysis Guidance site, WebTAG (www.webtag.org.uk) as two series of units, one at 'project manager' level and one at 'expert' level.

An overview of the advice and a description of the underlying principles are set out in *Variable Demand - Overview* (TAG 2.9.1) and *An Introduction to Variable Demand Modelling* (TAG Unit 2.9.2). This material is aimed at project managers and provides useful background information.

The detailed advice for analysts is provided as four TAG units: *VDM Preliminary Assessment Procedures* (TAG Unit 3.10.1) that defines criteria to enable analysts to decide whether the effects of variable demand seriously undermine the justification for their scheme; *VDM Scope of the Model* (TAG Unit 3.10.2) gives the guidance required to specify the scope of a variable demand model; the form of variable demand mechanisms and the circumstances when they are suitable to be used are described in *VDM Key Processes* (TAG Unit 3.10.3); *VDM Convergence Realism and Sensitivity* (TAG Unit 3.10.4) sets out appropriate convergence standards together with the required realism and sensitivity tests needed to provide evidence about the robustness of the model.

The advice replaces existing Departmental guidance on Induced Traffic Appraisal (in DMRB 12.2.2) and extends the types of scheme for which the effects of variable demand on scheme benefits and the level of induced traffic has to be estimated quantitatively.

A brief summary of the important aspects of the variable demand modelling advice at the expert level is provided in the following sections.

2.2 VDM Preliminary Assessment Procedures (TAG Unit 3.10.1)

The guidance presumes that all assessments will explicitly model variable demand. However it may be acceptable to limit the assessment to a fixed-demand assessment if the scheme satisfies the following criteria:

- The scheme is quite modest both spatially and in terms of its effect on travel costs. Schemes with a capital cost of less than £5 million can generally be considered as modest; *or*

- There is no congestion on the network in the forecast year (10 to 15 years after opening), in the absence of the scheme; *and*

- The scheme will have no appreciable effect on competition between private and public transport in the corridor(s) containing the scheme.

In order to establish a case for omitting variable demand modelling, it is also recommended that preliminary quantitative estimates of the potential effects of variable demand on both traffic levels and benefit are made, for example by using an existing variable demand model.

2.3 VDM Scope of the Model (TAG Unit 3.10.2)

In modelling demand, some segmentation by trip and traveller type is essential: at minimum there should be categorisation by trip purpose (at least home-based work/education, employer's business, and 'other' purposes); some form of distinction between travellers with and without a car available is also very desirable, especially where mode-choice is to be considered.

The amount of detail required in demand modelling will depend upon the particular application, since the effort and cost involved should be commensurate with the investment being assessed and the scale of its effects. Where a multi-level variable demand model is appropriate, it should include a distribution mechanism, and it will generally be desirable to include other mechanisms which can generate or suppress car trips as congestion reduces or grows.

2.4 VDM Key Processes (TAG Unit 3.10.3)

Most current large-scale transport demand models use a mathematical model (known as a hierarchical logit choice model) and this choice mechanism is described for mode choice, destination choice etc. and is recommended as current best practice.

Unless there are strong reasons for not doing so, the choice models should be incremental, predicting only the relative changes in trip numbers from the observed trip matrix, rather than fitted absolute models, which try to reflect the key details of the base trip pattern.

The sensitivity parameters that govern the strength of the choice mechanisms are difficult to calibrate to the local circumstances in the absence of extensive data. For many purposes it may be satisfactory to base them on the illustrative values provided, which were obtained from a review of current multi-stage demand models. If relevant and robust locally-calibrated parameters are available (from existing local models, for example), they should be used, provided the modeller is confident of their applicability and produces relevant documentation. Detailed justification for the parameters should be assembled particularly where they differ significantly from the relative strengths of the illustrative values.

In modelling demand, time of day choice (i.e. choosing whether to travel in the peak or off-peak, or at the height of the peak or in the shoulders) is potentially important. However, as its modelling is complicated and uncertain, it is recommended here only where strong differentials in cost are expected to arise between the time periods, or where peak congestion forecasts become unrealistically high.

On the basis of recent evidence, in general, the choice hierarchy which the Department expects to see adopted is: change in trip frequency, choice of main mode and macro time period (time period 2-3 hours), choice of destination, micro time period choice (time period of the order of 15 minutes), and choice of route and public transport mode. However, the relative importance of the different travel demand mechanisms may vary from one area to another, perhaps sufficiently to require a different sequence (hierarchy) of logit choice mechanisms for some areas for some trip purposes.

2.5 VDM Convergence Realism and Sensitivity (TAG Unit 3.10.4)

It is essential that the demand model be subjected to "realism tests" to ensure that its response to changes in travel times and costs is plausible. If the responses differ from the accepted norms the advice explains how the model should be adjusted until an acceptable performance is achieved. The sensitivity of the result to the more uncertain parameter values should also be tested.

The calculation must be iterated cyclically between the traffic assignment and the travel demand model(s) to obtain a stable solution. The degree of convergence of this iteration is very important, and needs to be stringently monitored to ensure that any uncertainty in the final result is acceptably small. Advice is provided on how to measure convergence and appropriate levels that need to be reached.

3. DIADEM

3.1 Overview

DIADEM (Dynamic Integrated Assignment and DEmand Modelling) is software designed to enable practitioners to easily set up variable demand models that are consistent with the advice in WebTAG. As part of its development work was carried out to:

- Develop algorithms for improving convergence between supply (assignment) and demand models,
- Implement these algorithms in user friendly software that also enables users to set up WebTAG-compliant variable demand models as easily as possible,
- Investigate the impact of supply/demand convergence on the robustness of the estimate of economic benefits from a scheme

The following sections present the results of this work.

3.2 Algorithm development

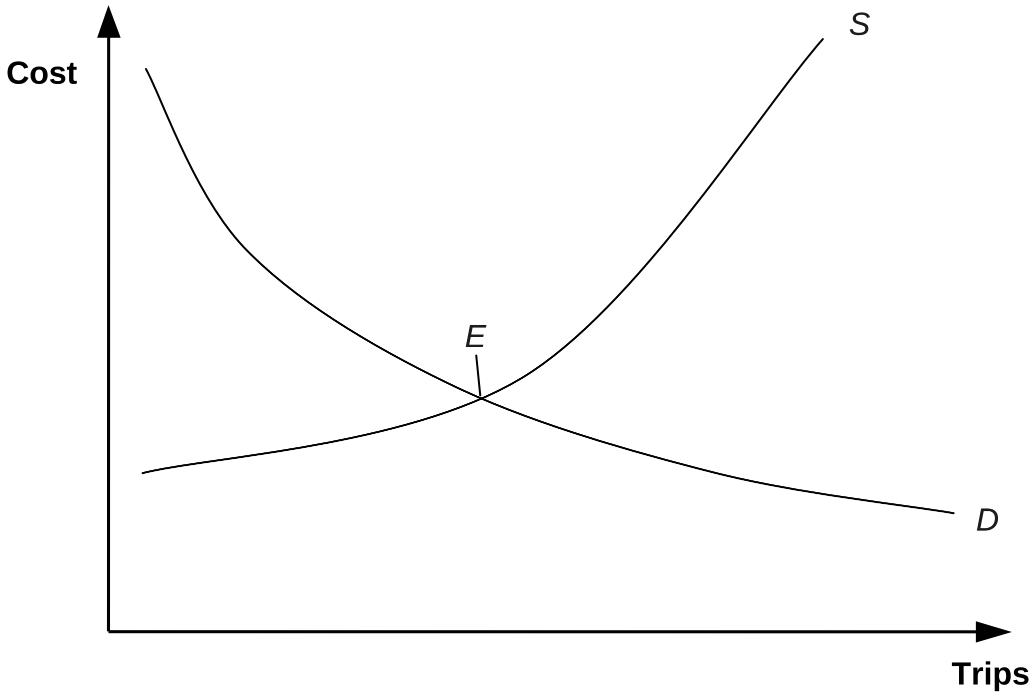

Figure 1. Equilibrium between supply and demand.

Figure 1 provides a simplified representation of the problem that the DIADEM algorithms are trying to solve, that is finding the equilibrium between demand and supply. The demand for travel is represented by the demand curve *D*. This shows how demand decreases as the generalised cost of travel increases. Here the generalised cost represents a combination of various elements. For highway travel these will be in-vehicle travel time, vehicle operating costs (mainly fuel) and other out of pocket expenses such as parking charges and road tolls. For public transport travel they will include in-vehicle travel time, walk time, wait time, transfer penalty and fare.

On the other hand the supply curve *S* represents how the cost of travel increase as the volume goes up. For highway travel this represents increased travel times as traffic, and hence congestion, goes up. The equivalent for public transport would be increased crowding on services.

DIADEM allows the user to specify the form of the demand curve. The form of the supply curve is determined by an external traffic assignment model, which is used by DIADEM to evaluate how travel costs change in response to changes in flow. Currently DIADEM can be linked with CONTRAM and SATURN assignment models.

One of the aims of DIADEM, or indeed most demand modelling systems, is to find the equilibrium point where demand and supply are in balance. This is given by the point *E* at the intersection of the demand and supply curves. In practice it is not possible to calculate this point exactly. An iterative process or algorithm is required to estimate *E.* The aim is to get a better estimate of *E* at each iteration. The convergence of the algorithm gives an indication of how robust the estimate of *E* is and therefore whether it can be used for further analysis of the scenario being forecast. The importance of good convergence is discussed later in this paper.

A good algorithm will reach an acceptable level of convergence as quickly as possible. Three algorithms are available within the DIADEM software. For a detailed description of the algorithms please see Mott MacDonald (2003).

Algorithm 1 in DIADEM represents a considerable improvement in speed and level of convergence over many other commonly used methods such as the method of successive averages (MSA) and the cobweb method.

3.3 Demand modelling in DIADEM

Simple elasticity methods use a demand function where the demand for highway travel between a given origin-destination zone pair is a function only of the generalised cost of travel between that zone pair. The new advice in WebTAG recognises that elasticity methods are an oversimplification and that it is often necessary to take account explicitly of the cost of all travel alternatives. When travel costs change trips are unlikely to disappear completely but will instead choose alternative modes or destinations or travel in different time periods. DIADEM therefore offers the choice to model the following traveller responses explicitly, using the incremental hierarchical logit model:

- Change of frequency
- Change of mode
- Change of time period
- Trip redistribution (singly or doubly constrained)

The order of the responses can be altered to reflect, for example, that their relative sensitivities may differ by trip purpose.

Two elasticity models, power and exponential, are also available in DIADEM.

Forthcoming developments in DIADEM include an absolute demand model, as there are occurrences when this may be needed, for example for modelling a new mode when an incremental model cannot be used. Ultimately it is planned to include a method called HADES for modelling micro-departure time choice.

3.4 Software

Figure 2 shows the structure of the DIADEM software. The user sets up all the necessary input data via a standard Windows interface (Figure 3 shows an example input screen). Then they start the main DIADEM run. The input data is passed to the DIADEM engine. The engine passes trip matrices to the external assignment model (CONTRAM or SATURN) and automatically carries out the assignment, from which it skims costs. These costs are then run through the demand model which is embedded in DIADEM. The trip matrices output by the demand model are then combined with those from the previous iteration according to the particular algorithm being used. This process is repeated until convergence has been achieved. The final output is the best estimate of the equilibrium trip matrix and associated costs.

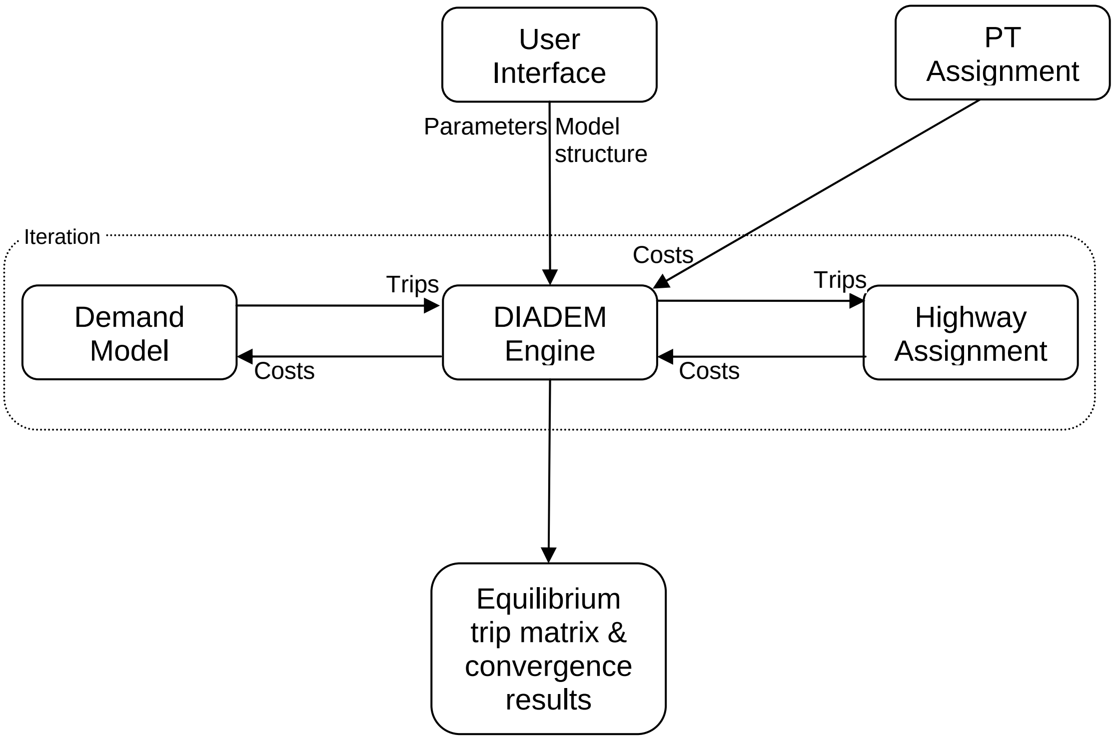

Figure 2. DIADEM software structure.

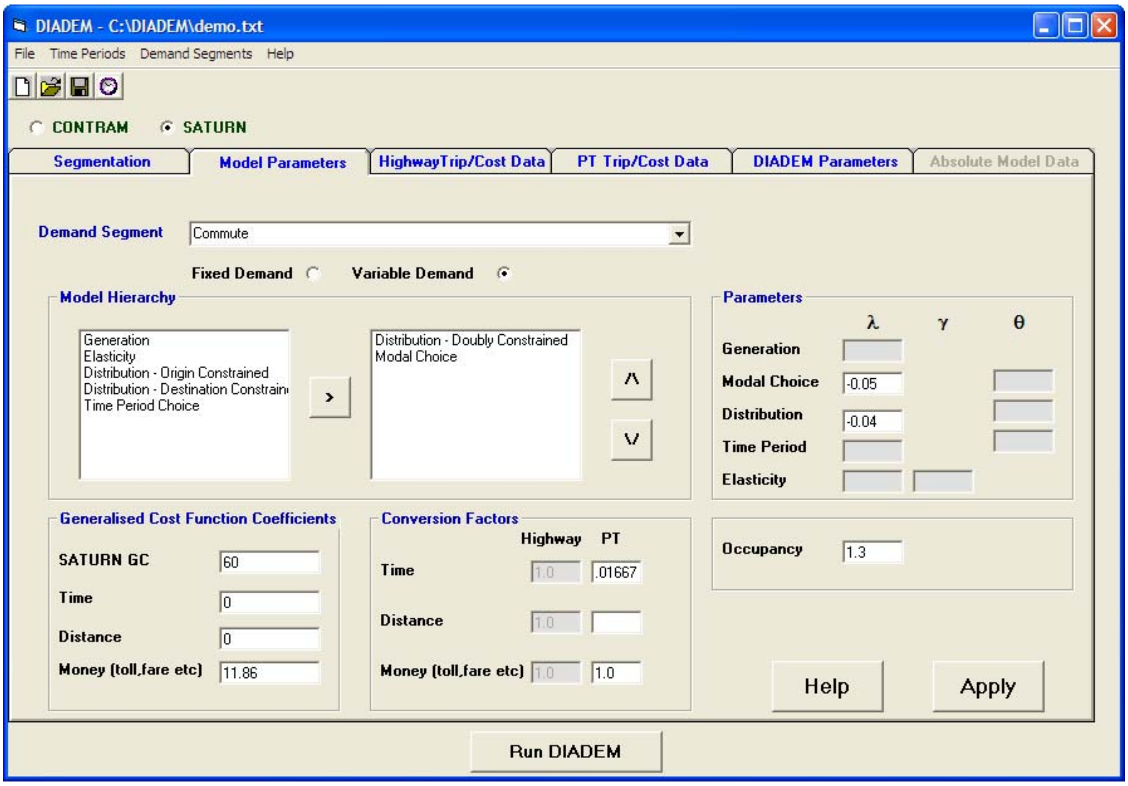

Figure 3. Example input screen.

4. THE IMPORTANCE OF CONVERGENCE

Scheme appraisal using DIADEM would typically involve running the program to find the equilibrium point for the do minimum (DM) scenario (i.e. *without* the scheme) and then running it a second time to find the do something (DS) scenario (i.e. *with* the scheme) equilibrium point. This would be done for at least two modelled years (typically scheme opening year and 15 years later). For the economic part of the appraisal cost and trip matrices from each run of DIADEM would be passed to TUBA for the calculation of user benefits.

As discussed earlier, the equilibrium point cannot be calculated exactly. However, if the estimated point is too far from the true equilibrium then there is a risk of significant errors in the calculation of user benefits. This is illustrated in Figure 4 (here the impact of the scheme is represented by a shift in the supply curve). The economic benefits from the true equilibria for the DM and DS scenarios are given by the area within the dashed line. The benefits calculated using crude approximations are given by the area within the dotted line. Clearly the two are very different, illustrating that poor convergence in demand/supply can lead to very large errors in economic benefits

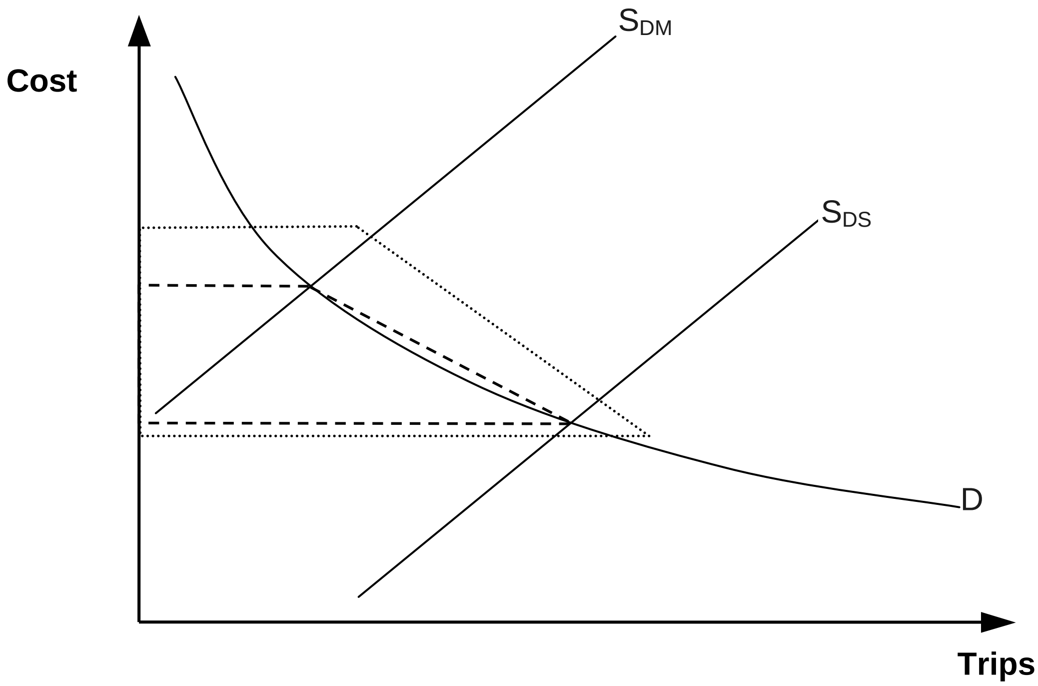

Figure 4. Errors in economic benefits from poor convergence.

The key convergence criterion recommended in WebTAG, and reported by DIADEM, is the relative demand/supply gap. This is given by the following formula:

$$\frac{\sum_{ijctm} C(X_{ijctm}) \left| D(C(X_{ijctm})) - X_{ijctm} \right|}{\sum_{ijctm} C(X_{ijctm}) X_{ijctm}} \times 100\%$$

where

X_{ijctm}	is the current estimate of travel demand
$C(X_{ijctm})$	is the generalised cost obtained by assigning that matrix
$D(C(X_{ijctm}))$	is the output from the demand model, using the costs $C(X_{ijctm})$ as input
ijctm	represents origin *i*, destination *j*, demand segment/user class *c*, time period *t* and mode *m*

The numerator of this expression for a very simple example is shown graphically by the shaded area in Figure 5. The current estimate of demand *X* is assigned to obtain costs C(X). These costs are passed to the demand model to obtain the demand D(C(X)).

The shaded area is then divided by total costs in the system. If *X* reaches the equilibrium point then the gap value will be zero.

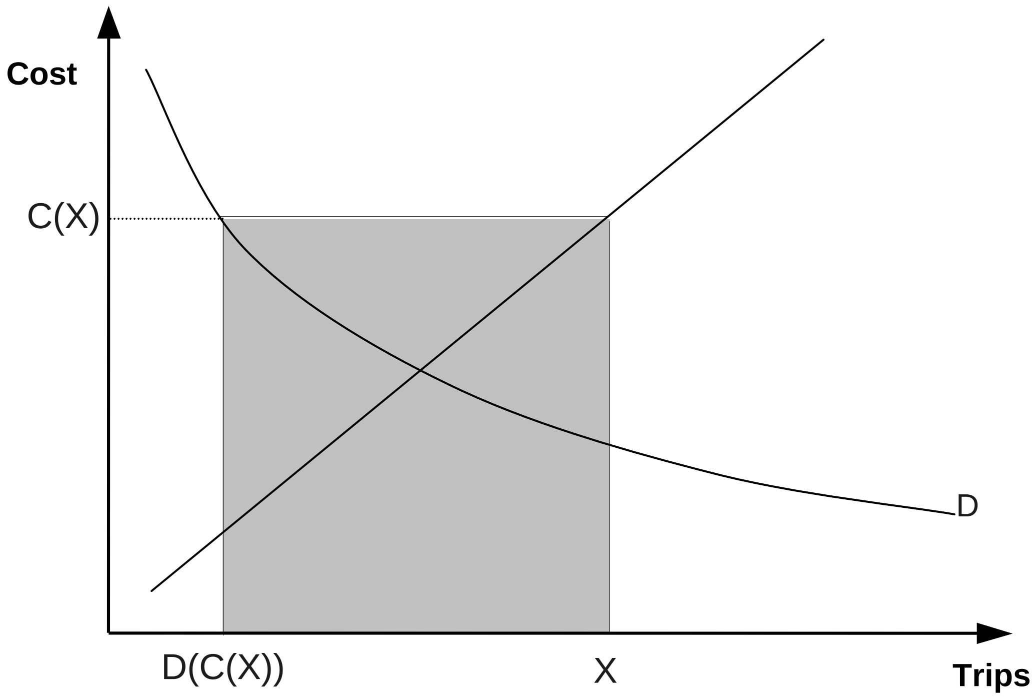

Figure 5. Monitoring convergence.

Figure 6 shows an example of how lack of convergence can lead to errors in the calculation of user economic benefits. The DM scenario has converged extremely well (gap of about 0.02%); the DS scenario has been run in DIADEM for a variety of levels of convergence. It can be seen that convergence affects the magnitude and the sign of the benefits quite significantly.

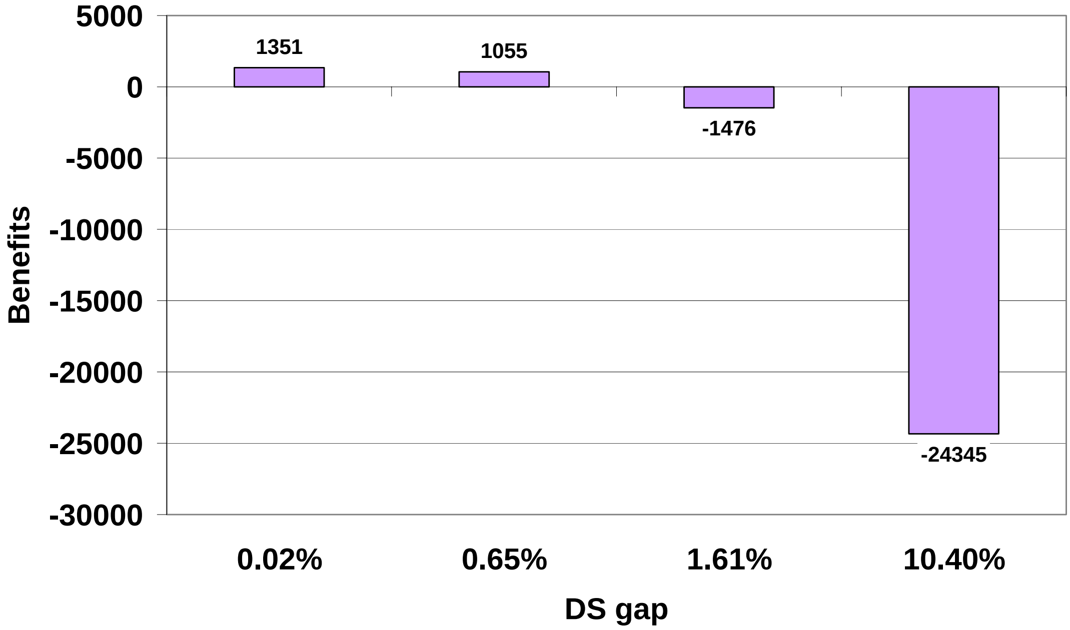

Figure 6. Effect of convergence on economic benefit calculation.

WebTAG relates the required level of convergence to the scale of scheme benefits. Put simply, the robust appraisal of small schemes in large networks requires better convergence (i.e. a smaller relative gap) than for large schemes is small networks.

5. SUMMARY

The Department for Transport has issued new on advice on variable demand modelling on their Transport Analysis Guidance site, WebTAG. The advice replaces existing Departmental guidance on Induced Traffic Appraisal (in DMRB 12.2.2) and extends the types of scheme for which the effects of variable demand on scheme benefits and the level of induced traffic has to be estimated quantitatively.

Linked to this advice is new software called DIADEM. This allows users to set up multi-stage variable demand models relatively simply and provides a mechanism for achieving convergence between supply and demand. It currently works with CONTRAM and SATURN traffic assignment models.

6. REFERENCES

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