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# TECHNICAL REPORT

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## Cost Damping in Travel Demand Models

Report of a study for the  
Department for Transport

Andrew Daly

Prepared for the UK Department for Transport

The research described in this report was prepared for the UK Department for Transport.

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# Summary

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## Introduction

The Department for Transport maintains Guidance for those concerned with predicting traffic flows, on the internet site [www.webtag.org.uk](http://www.webtag.org.uk). In particular Unit 3.10 (on Variable Demand Modelling) describes the modelling procedures that are recommended. Unit 3.10 and this report focus on personal travel – that is, freight movements are not considered.

To summarise, the modelling procedures represent travel as being movements between pairs of zones defined in the area of study and are based on the representation of the impedance to travel between two zones. Impedance or generalised time – WebTAG calls it ‘generalised cost’ – is measured in minutes of travel time, with cost converted to time units by dividing by a ‘value of time’ and additional weighting given to travel components such as walking, waiting or time spent in crowded circumstances. When used in the models, generalised time is multiplied by a parameter (called lambda), which represents the marginal sensitivity of behaviour to each minute of travel.

The aim of the present study is to help the Department to improve its Guidance concerning the specification of these lambda parameters. The study is organised in two Tasks:

- Task A: to answer eight Questions relating to key issues which were previously unanswered concerning the Guidance that ought to be given on the lambdas (see text box); and
- Task B: to prepare new Guidance on the basis of the findings of Task A.

### Text Box: The eight DfT questions for this study

The Department wishes to know:

1. How the requirements for realism testing in WebTAG are addressed in practice;
2. Whether there are any cost damping mechanisms in use in the UK or elsewhere other than those listed in the Brief;
3. How widely each mechanism is used a) in the UK and b) elsewhere;
4. How effective are these mechanisms in addressing requirements for realism testing?
5. What are the other practical advantages and disadvantages of each mechanism?
6. What are the theoretical basis and empirical evidence for each of these mechanisms?
7. If the scope for realism testing should be broadened, and, if so in what way?
8. What methods are available for implementing realism testing in models used for major scheme appraisal and how does this compare with the methods that have been adopted?

Task A is itself broken down into three Work Packages (WP):

WP1: to answer the Questions (1, 4, 5 and 8) which relate to issues concerning the testing of models and the adjustment of lambdas to give more realistic models;

WP2: to answer the Questions (2, 3 and 6) which relate to the ways in which the lambdas should vary within a model – in particular how they should be adjusted by ‘Cost Damping’; and

WP3: to answer Question 7 which asks how realism testing should be broadened and how the tests should be specified.

The present document forms the final report of WP2 of Task A; that is, it answers Questions 2, 3 and 6 which relate specifically to Cost Damping.

The context of the present report is given by the following definition of Cost Damping, slightly amended from the Department’s original Brief for this work.

*The ‘standard’ modelling approach, as recommended in WebTAG Unit 3.10, assumes a model in which a) generalised cost is linear in its components (time, money costs and so on) and b) lambda parameters are constant throughout. However, the Department is aware that some models include additional elements or different structures that have the effect of reducing the model sensitivity with increasing distance. These mechanisms are what we mean by ‘cost damping’.<sup>1</sup>*

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<sup>1</sup> By ‘constant’ here is meant that the parameters do not vary as a function of time or cost. Different lambda values would generally be used for different travel purposes and for different aspects of behaviour, such as mode or destination choice. When mode choice is ‘above’ destination choice in the hierarchy, it is also possible to define separate lambda values by mode for modelling destination choice.

The following sections of the Summary give brief answers to the three Cost Damping questions and draw conclusions and recommendations which are intended to support the development of new Guidance. The technical discussions on which these answers and conclusions and recommendations are based are presented in the following chapters of the report.

- Chapter 1 reports correspondence with international experts which has supported the parts of the answers to Questions 2 and 3 relating to the use of cost damping outside the UK. (The corresponding information within the UK was collected for Work Package 1.)
- Chapter 2 is a revised version of a paper presented at the 2008 European Transport Conference in The Netherlands. This Chapter gives the basis for answering Question 6.
- Chapter 3 summarises the microeconomic theory against which recommendations for cost damping mechanisms might be tested

### **Answers to the Cost Damping questions**

The context in which these questions are asked is that models are being used to forecast matrices of trips or tours (origin-destination or production-attraction) by predicting some or all of travellers' choices of frequency, mode, destination and time of travel. The models are expected to make their predictions by calculating an impedance of travel for each of the alternatives which can be expressed in minutes of travel time; this measure can probably best be called generalised time. The models are of the nested logit type.

In fact, this approach seems to be almost universally used, both in the UK and elsewhere, although some models would require to be slightly reformulated to fit this paradigm. This uniformity means that information from a wide range of sources can be used to answer the questions.

#### **QUESTION 2: What are the cost damping mechanisms in use in the UK and elsewhere?**

In the UK, the following cost damping mechanisms are used<sup>2</sup>:

- A. damping generalised time by a power of distance;
- B. increasing the value of time by a function of distance;
- C. log cost formulation;
- D. addition of constants that depend on distance;
- F. origin-destination-specific scaling of generalised time;
- G. power function of generalised time;

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<sup>2</sup> The labelling of the mechanisms A, B etc. relates to that used in Chapter 2, specifically in Table 1. More detailed explanations of each of the mechanisms are given in that chapter.

H. detailed segmentation by purpose, e.g. distinguishing 10-20 purposes.

We cannot claim that our survey is exhaustive, but it is unlikely that there are other mechanisms that are used in a significant number of studies.

Outside the UK, our survey has necessarily been much more limited in scope and it is very likely that mechanisms have been missed. It is notable that most of the mechanisms used in the UK are *not* used in other countries; in fact, only mechanism C is known to be used in exactly comparable form both inside and outside the UK. The following mechanisms have been found in foreign studies:

- C. log cost formulation;
- E(a) Box-Tukey<sup>3</sup> transformations applied to the generalised time;
- E(b) Box-Tukey transformations applied to components of the generalised time.

It should be noted that mechanism C is actually a special case of mechanism E(b) and G is a special case of E(a). Mechanisms A and F are closely related in practice. Moreover mechanisms D and H are not strictly cost damping mechanisms at all, although they have some features that relate to cost damping; they are not discussed further in any detail.

**QUESTION 3: How widely is each mechanism used a) in the UK; and b) elsewhere?**

By far the most common mechanism in use in the UK is A from the list above, which is used by different consultants in several large-scale studies. Mechanisms B and C appear to be used in a small number of studies each; B is sometimes used in conjunction with A. Mechanism D is, to our knowledge, used only in the National Transport Model. Mechanism F is provided in the DIADEM software, but we know of only one application that has used it, and that a rather limited one. Mechanism G is used in only one study. Mechanism H has been reported as in use, but we do not know where.

RAND Europe has used mechanism C in a number of studies outside the UK. Mechanism E(b) appears to be used rather seldom, primarily in work by Marc Gaudry, and E(a) has been seen in only one study (Swiss National Model). In general it appears that cost damping is more prevalent in the UK than elsewhere.

**QUESTION 6: What are the theoretical basis and empirical evidence for each of these mechanisms?**

The *empirical evidence* for requiring cost damping is very strong. It may be summarised as follows.

- Modelling studies, in the UK and elsewhere that test for cost damping at the time that the models are estimated almost always find that specifications with cost damping are significantly and substantially better than undamped formulations.
- Practical modelling studies in the UK often find that they are not able to obtain reasonable forecasting behaviour in the models – in particular, reasonable

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<sup>3</sup> The better-known Box-Cox transformation is actually a special form of the more general Box-Tukey transformation. Both of these transformations are explained in detail in Table 1, Chapter 2.

elasticities – without cost damping, but that the use of cost damping allows reasonable models to be obtained.

- Value-of-time studies in the transport sector most often find that the value of travel time in money terms increases with the length of the trip, usually concluding that this effect is due to a decline in the marginal impact of money cost, rather than an increase in the marginal impact of time.

The strength of the evidence comes from the large number and overwhelming proportion of studies that make these findings.

It should be noted that almost all of the tests that have been made assume that the modelling scale does not vary with trip length – that is, that the impact of one unit of impedance on choice proportions is constant; this restriction is inherent in the logit formulation used for practical modelling. In more sophisticated work, when that assumption is abandoned and models other than nested logit may be used, different results can be obtained. However it should be noted that current models that allow varying model scale are both experimental and very computer-intensive, so that their use in practical studies would not currently be feasible.

While the question is posed to require empirical evidence for each of the tests separately, we have found no evidence that would allow discrimination between the power of the mechanisms. Study teams typically select one mechanism *a priori*, show that it is better than having no mechanism, and continue with their work. There is strong empirical evidence<sup>4</sup> that the value of time increases with trip length, so that cost damping mechanisms that permit this change are to be preferred to those that do not. This effect apart, the large body of empirical evidence justifies the use of cost damping in general but does not indicate that one mechanism is better than another.

The *theoretical basis* is a more complicated issue.

If the models are viewed as microeconomic constructs, there exists a body of theory against which they may be judged. A summary of that theory is given in Chapter 3, which concludes that there is almost no economic theory to support or reject cost damping.

If however the models are viewed more generally as derived from an unspecified theory of behaviour, then several points may be made which allow us to test the mechanisms for their general reasonableness.

- Mechanisms involving a distance variable, such as A and B (and possibly D and F) are difficult to justify because the role of the distance variable and its impacts on cost and time sensitivity are not clear; therefore the assumption that its impact in the future will remain unchanged, not subject to influence by policy or exogenous changes, is questionable.
- The ‘kilometrage test’, which requires that a model should predict a decline in the total kilometrage driven when the cost per kilometre increases uniformly, can be used to test the reasonableness of models. This test allows the rejection of several model forms, including (in principle) those that are not smooth.

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<sup>4</sup> See the literature reviewed in Chapter 2.

- The evidence that value of time increases with trip length is very strong, so mechanisms that do not allow that effect (A, D, E(a), F and G) are inferior in this respect to mechanisms that do allow this effect (B, C, E(b) and possibly H). In the latter group of mechanisms the sensitivity with respect to cost should decline more rapidly than the sensitivity with respect to time, which may not decline at all (and cannot in B and C).
- Taking all the preceding considerations together, the only mechanism of those listed that meets all the requirements is the Box-Tukey transformation of components, E(b). Mechanism C does not allow variation in the influence of time and allows only the most extreme decline in the influence of cost.
- However, models that use ‘mixed’ mechanisms – that is, linear combinations of different functional forms, in particular mixed log and linear forms, can also meet all the requirements while not imposing the complications of a power transformation such as the Box-Tukey.
- It is better from the viewpoint of explaining behaviour and of justifying the model that is being used, that cost damping should be included in model estimation, not added afterwards in an attempt to obtain realistic elasticities but abandoning fit to the original data – for example, to observed trip lengths.

These tests and conclusions are explained in more detail in Chapter 2.

It is clear that cost damping is an intrinsic aspect of how people respond to cost and time in making travel choices. Therefore, calibrating models that exclude cost damping will simply obtain incorrect parameters – for example, for sensitivity. Applying cost damping subsequently cannot give a correct result, because the parameters used initially will not take account of the subsequent adjustment. The correct approach is to calibrate the models *with* cost damping in the first place. If parameters are being taken from other regions – e.g. via WebTAG – those imported parameters should be estimated with account taken of cost damping; for example, the parameters in WebTAG should be estimated taking account of the impact of cost damping.

## Conclusions and Recommendations

The conclusions and recommendations emerging from this work may be stated as follows.

**Cost Damping is used more widely in the UK than abroad.** In the UK, damping is primarily performed by scaling generalised time by a power of distance, sometimes also adjusting the value of time; a number of other mechanisms including log cost are also used. In other countries, log cost and Box-Tukey transformations are used; it is quite likely that other forms are used also but these have not been revealed by our limited search. Foreign governments take differing views to non-linear scaling such as cost damping, some (e.g. US) being suspicious, others (e.g. France) being apparently strongly in favour.

**Empirically, the evidence for cost damping is very strong,** given the nested logit framework used in most practical models. This evidence comes from

- modelling studies where the effect has been tested,
- the need to introduce cost damping to achieve realistic elasticities and (

- c) value-of-time studies, which show that damping operates more strongly on cost than on time.

**There is little empirical evidence that indicates that one cost damping mechanism should be preferred to another**, except that mechanisms which permit values of time to increase with trip length are to be preferred to those that do not.

**Microeconomic theory can be used to give a basis for discrete choice models** of the type used for travel demand modelling. However, no indications can be drawn from this theory concerning the propriety of cost damping.

**While microeconomic theory does not rule out the use of model parameters that vary with distance, there is a risk that the effects of time and money variables could be biased** if distance is included as an explicit variable. However, the methods for assessing these risks fall outside the scope of the current work. Moreover, the empirical evidence on the following issues does not rule out

- generalised cost parameters that vary with distance;
- non-linear functions of some components, such as log costs;
- linear combinations of functions of this nature.

**Other theoretical considerations than microeconomics can be used to support various forms of cost damping.** These include the following.

- The use of a distance variable is questionable, since there is no behavioural basis and consequently no case that the effect of distance will remain constant over time.
- The use of transformations of individual variables, rather than of the overall generalised time function, is to be preferred, as this allows the value of time to increase with trip length.
- Box-Tukey or power functions can be applied to the variables comprising generalised time or to the whole function; in either case these functions should have exponents less than 1 to give the required damping effect. The exponent used on time should be greater than that on cost to allow the value of time to increase with trip length.
- A *kilometrage test* has been devised, which requires that the total kilometrage driven should decrease when the marginal cost per kilometre increases uniformly. This test can be used to derive limits on the degree of cost damping that is acceptable:
  - power functions should have exponents not less than zero;
  - a pure log cost function does not give a change in the kilometrage when the marginal cost changes and therefore forms the limit of acceptability; however, the small addition to cost that is often made before the log is taken means that the function gives a small decrease in kilometrage when cost increases;
  - exponential functions are not acceptable;

- ‘kinks’ in functions are in principle not acceptable, but this may not be important in practice.
- ‘Mixtures’, i.e. linear combinations with positive coefficients, of functions that are acceptable with respect to these tests are themselves acceptable and these functions can be used to simplify practical estimation work, when power functions are awkward.

**When nested logit models are used, cost damping is part of our current best understanding of traveller behaviour** and it would be expected that it would be incorporated in models.

**Cost damping should be part of the initial set-up of a model to be estimated** and should not be introduced solely as a means of achieving realistic elasticities.

These recommendations represent the current state of knowledge as it has been assessed for the present study. It is to be hoped that further research and practical work will allow continual improvement to modelling Guidance and practice.