Modelling variable demand using microsimulation

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Microsimulation is increasingly being applied to larger networks to model major transport interventions and to provide forecasts for scheme appraisal. This has highlighted a need for a variable demand modelling (VDM) capability for use with microsimulation that meets the requirements of Department for Transport (DfT) WebTAG guidance. The methodology described in this paper represents what is probably the first application of S-Paramics microsimulation in conjunction with VDM. The procedures were developed in response to a Brief issued by Wiltshire Council to assess the demand for parking and public transport associated with development scenarios in the town of Chippenham.

INTRODUCTION

A Brief was issued by Wiltshire Council to assess the demand for parking and public transport associated with development scenarios in the town of Chippenham. The approach undertaken provides a basis for retro-fitting an existing S-Paramics highways model for VDM and public transport assignment capability. It contains a number of innovative features including an interface between S-Paramics and the DfT programme DIADEM, a procedure to model time period choice and a Public Transport (PT) assignment model that allocates bus trips to individual services based on bus travel times derived by S-Paramics. This ensures that bus journey times reflect the interaction with other vehicles on the highway network, something not normally achieved in conventional PT assignment models.

As the approach utilises an existing validated S-Paramics highway model, it provides a cost effective solution to model variable demand. It also could provide a blueprint for extending other highways-based S-Paramics models to provide a multi-modal capability.

VARIABLE DEMAND MODELLING – THE CHALLENGE FOR MICROSIMULATION

VDM is a process used to predict changes in travel demand arising from a change in travel costs, for example, resulting from new infrastructure or by increasing levels of congestion over time.

VDM methods are required to assess larger scale transport schemes that result in changes in travel costs and are almost exclusively undertaken using wider area models that typically employ deterministic equilibrium modelling techniques.

While microsimulation has, for some time, been applied for area-wide modelling, the absence of any mechanism for undertaking VDM means that the application of microsimulation for scheme appraisal has been restricted to smaller schemes where the impact on travel costs is small.

It is widely acknowledged that microsimulation has played an important part in restoring credibility and accuracy to the modelling process and has provided a powerful tool for scheme design. The challenge is to unlock the potential of microsimulation for wider application to encompass variable demand and multi-modal functionality.

Figure 1: Chippenham Model Study Area

REQUIREMENTS FOR CHIPPENHAM

A multi-modal model was required to assess the impacts of development scenarios for Chippenham in Wiltshire, with a specific focus on parking and public transport proposals. It was envisaged that this would be developed as an extension to an existing S-Paramics model that had already been used to assess the operation of the highway network.

In 2010 Wiltshire Council appointed SIAS Limited (SIAS) and PFA Consulting to extend the existing model to provide variable demand and multi-modal modelling capability. It was determined that the study area should be based on the 2008 model network with an extension north to include the junction of M4/A350 (J17). The study area network is illustrated in Figure 1.

The modelling framework was required to meet the following objectives:

- To provide a VDM capability that takes account of all behavioural responses, including mode choice between car and bus
- To provide an assignment of bus trips in order to assess flows of bus passengers, including boarding and alighting totals
- To conform to Department for Transport (DfT) guidance relating to VDM and Public Transport Assignment as set out in WebTAG

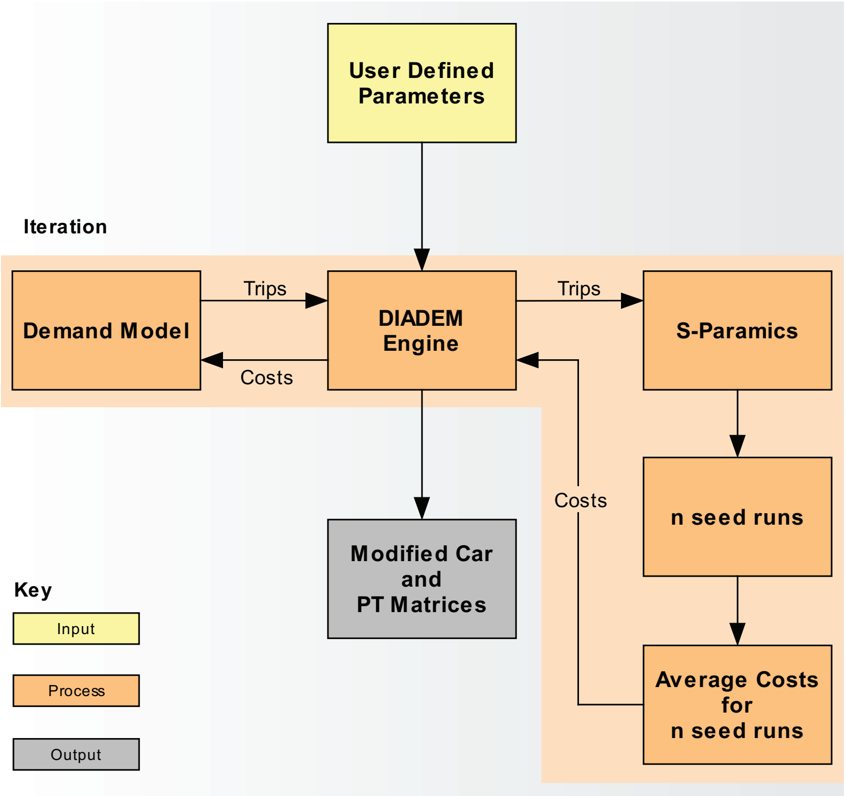
The VDM framework developed for the project represented the culmination of research and development that had been undertaken by SIAS to support earlier projects. The various components are described in the following section.

COMPONENTS OF MODELLING FRAMEWORK

There are three main components of the modelling framework that comprise:

- A procedure to model Variable Demand
- A method that takes account of trip re-timing due to changes in travel time
- A procedure to assign public transport trips that uses travel times from S-Paramics

Figure 2 : Operation of DIADEM



Variable Demand Model

The approach to modelling variable demand is based on the application of the DfT's program DIADEM. Developed in parallel to DfT guidance on VDM as detailed in WebTAG, DIADEM provides a fully adjustable hierarchy of demand mechanisms through the following behavioural responses:

- Trip frequency
- Mode choice
- Trip re-distribution
- Departure time choice – using a macro time period choice procedure that models time shift between discrete time periods

The demand model in DIADEM is an incremental hierarchical logit model that predicts the probability that an individual will pick a particular alternative when faced with a choice between a number of options. The incremental model works by adjusting an input reference demand matrix according to changes between forecast travel costs and input reference travel costs, eg between a Base Year and a future year forecast.

The rationale for adopting DIADEM is that it operates in conjunction with highway assignment modelling packages and undertakes variable demand modelling as a single process. It provides a means of building on the existing S-Paramics model, minimising the requirement for new data collection and the need to develop and calibrate separate models for mode choice and trip distribution.

DIADEM was developed to interface with the highway assignment software SATURN and Contram. In 2009 an interface was developed by SIAS to enable DIADEM to be applied in conjunction with S-Paramics, representing the first application of variable demand modelling using microsimulation. It is expected that the interface with S-Paramics will be included in a future version of DIADEM to be released through the DfT.

DIADEM is run iteratively whereby costs are passed from the assignment model into the DIADEM demand model. For each iteration of DIADEM a number of runs of S-Paramics are carried out and costs are averaged before being passed to DIADEM. The user defines the behavioural responses and order in the hierarchy, their application to the various trip purpose matrices and the parameter values that determine the elasticities. The operation of DIADEM is illustrated in Figure 2.

As DIADEM was developed in accordance with DfT advice, it fully satisfies the guidelines on variable demand modelling as set out in Section 3.10.4 of WebTAG.

A significant strength of the S-Paramics/DIADEM approach is that bus journey times are obtained directly from the microsimulation model. This means the bus journey times fully reflect the interaction between buses and other vehicles on the same network that includes, for example, the impact of congestion on bus journey times. As a consequence, the relative costs for car and bus journey times that are input to DIADEM are not only accurately modelled but fully consistent since they will be derived from a single model.

While DIADEM only considers choice between car and a single public transport mode, it is well suited for application to Chippenham where the requirement is to assess mode choice between car and bus as the primary public transport mode. Rail was not included as this only provided a viable route choice for longer distance trips ie with origins or destinations external to Chippenham.

Micro Time Period Choice

Time period choice occurs when travellers change their time of travel, choosing to travel either earlier or later to avoid congestion. It is recognised as one of the most significant responses to increasing congestion, yet is rarely modelled.

In modelling terms, a distinction is made between macro and micro time period choice. Macro time period choice is where trips are re-allocated from one modelled time period to another. Micro time period choice is based on smaller time shifts within a given time period, eg retiming of a journey, say 10min earlier, in order to maintain the desired destination arrival time.

DIADEM provides a mechanism to model macro time period choice, but this does not take into account the more detailed time shifting in the modelled time period.

S-Paramics lends itself readily to the adoption of a micro time period choice approach, as trip departure times are represented through the demand profiles that determine the release of vehicles over the modelled time period. This behavioural response is particularly important as networks become increasingly congested and trip re-timing results in the so called 'peak spreading' effect.

The procedure to apply micro time period choice in microsimulation was developed by SIAS in 2009 and has been applied on various projects where the application of growth would have otherwise resulted in 'unrealistic' levels of congestion. The procedure utilises the two DfT approved methods for modelling micro time period choice;

1. The Application of Peak Spreading, Design Manual for Road and Bridges (DMRB) Volume 12, Section 2, Part 1, Appendix F
2. Heterogeneous Arrival and Departure times based on Equilibrium Scheduling theory (HADES), as described in HADES B Final Report (Mott MacDonald, Feb. 2005)

The procedure is applied iteratively and results in modified flow profiles that take account of the shift in departure times. The effect of applying a micro time choice methodology is shown in Figure 3, which demonstrates the change in flow profile for a modelled PM peak period. The resulting changes in modelled journey times based on assigning the modified profile is illustrated in Figure 4.

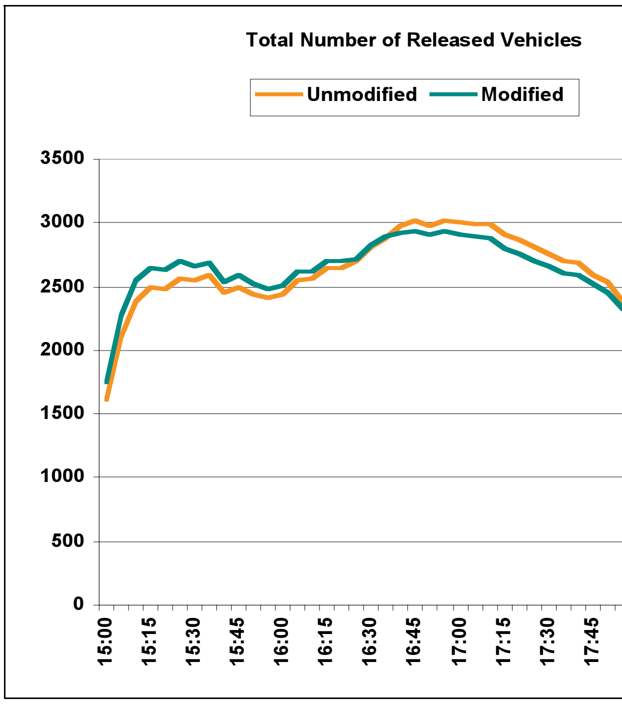


Figure 3 : Time Period Choice – Flow Profiles

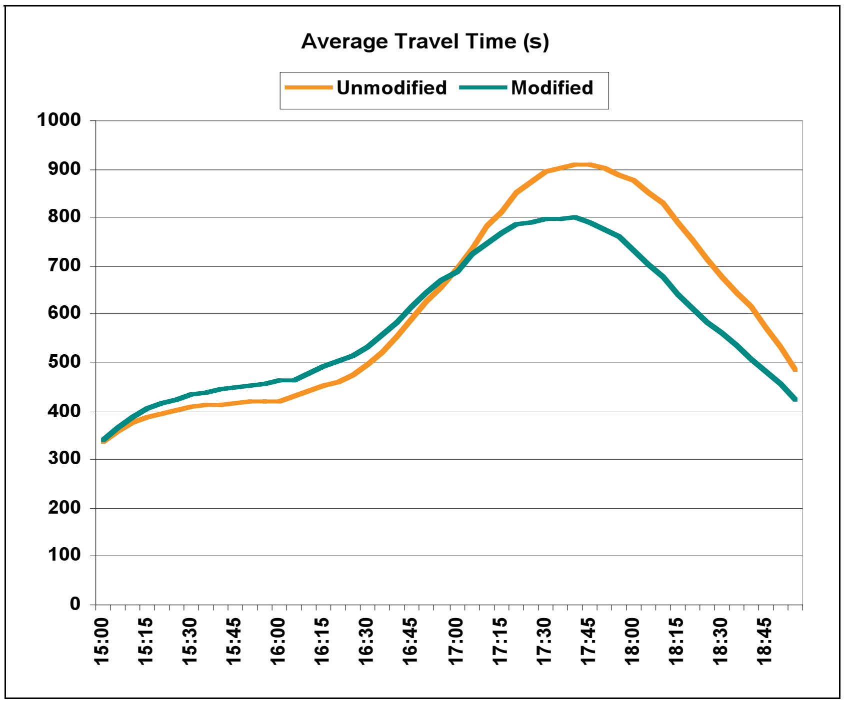


Figure 4: Time Period Choice – Modelled Journey Times

Public Transport Assignment Model

Two requirements were identified for modelling public transport in Chippenham as follows:

1. A detailed representation of bus journey times to derive the relative cost of travel between private and road based public transport for input to the demand model
2. An assignment of bus passenger trips to the available choice of bus routes and services between zones in the study area to derive passenger flows and boardings/alightings.

In S-Paramics, buses are allocated to fixed routes with the departures from the terminal points specified in accordance with the scheduled timetables. Buses are modelled in the same way as other vehicles, so bus journey times in S-Paramics take account of the interaction with other vehicles including the delays and congestion encountered on route.

To ensure that all components of the bus journey were included, procedures for estimating walk, wait and interchange times in S-Paramics were also developed so these could be added to the 'in bus' journey time.

In a multimodal context, the relative cost of travel between private and public transport is the key determinant for mode choice in the demand model. As S-Paramics provides a very accurate calculation of travel costs for separate modes at different periods of the day, it is suited probably better than any other modelling system, to provide robust relative cost estimates for input to the demand model.

The PT assignment procedure was developed as a visual basic application linked to S-Paramics. It assigns bus trips to services/routes and outputs passenger flows on links, using the bus journey times output from S-Paramics.

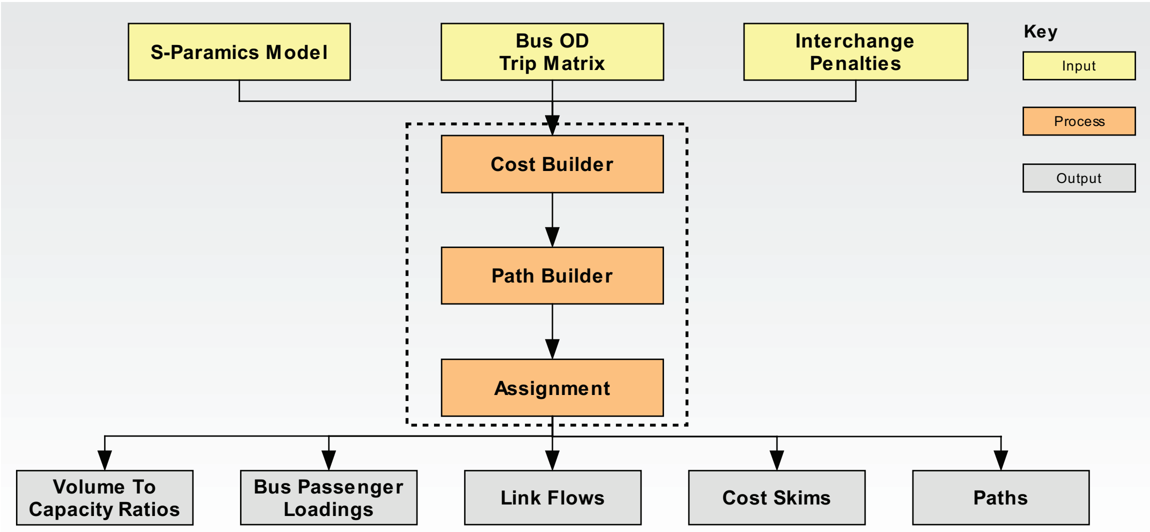


Figure 5: Structure of Public Transport Assignment Model

The structure of the PT assignment model is illustrated in Figure 5.

The bus trip times from S-Paramics that include walk, wait and interchange time as well as in-bus time, are used to build paths in accordance with WebTAG guidance. The bus passenger demand matrix is then assigned to the bus network via a logit model formulation using either a frequency-only or frequency-and-cost based assignment method. The output includes an analysis of PT flows by link, boardings and alightings by bus stop, volume to capacity ratios and service taken between OD pairs. The procedure is fully compliant with WebTAG.

DEVELOPMENT OF VDM MODEL FRAMEWORK

The main stages in the development of the VDM platform for application in Chippenham are illustrated in Figure 6.

The starting point for the process was the 2008 base model for Chippenham that included the highway network and trip matrix. The key stages are described below.

Stage 1: Prepare S-Paramics Base Network

The existing S-Paramics base network was modified to facilitate the modelling of two additional components of travel costs. These were:

1. Car parking charges
2. Walk time and interchange time for public transport users

Car parking charges were included through the allocation of tolls at the entrance to each car park. These tolls are included in the zone to zone costs that are required by DIADEM.

For modelling mode choice, DIADEM requires the costs of travelling by public transport for every Origin-Destination pair that is served by the public transport option. The cost components include walk time, wait time and interchange time (for journeys requiring more than one bus) and in-vehicle time.

In-vehicle time was derived from the S-Paramics model from an analysis of bus travel times on a bus stop to bus stop basis. Wait time for each route was estimated as half the headway.

Walk time was calculated as the crow-fly distance between a zone centroid and the associated bus stop(s) converted to time using an average walk speed. This required that each bus stop be allocated to model zones that represent the catchment area served by the stop.

Transfer times between buses were derived by defining interchange points on the network by grouping bus stops serving more than one service into a 'terminal'. A 'transfer

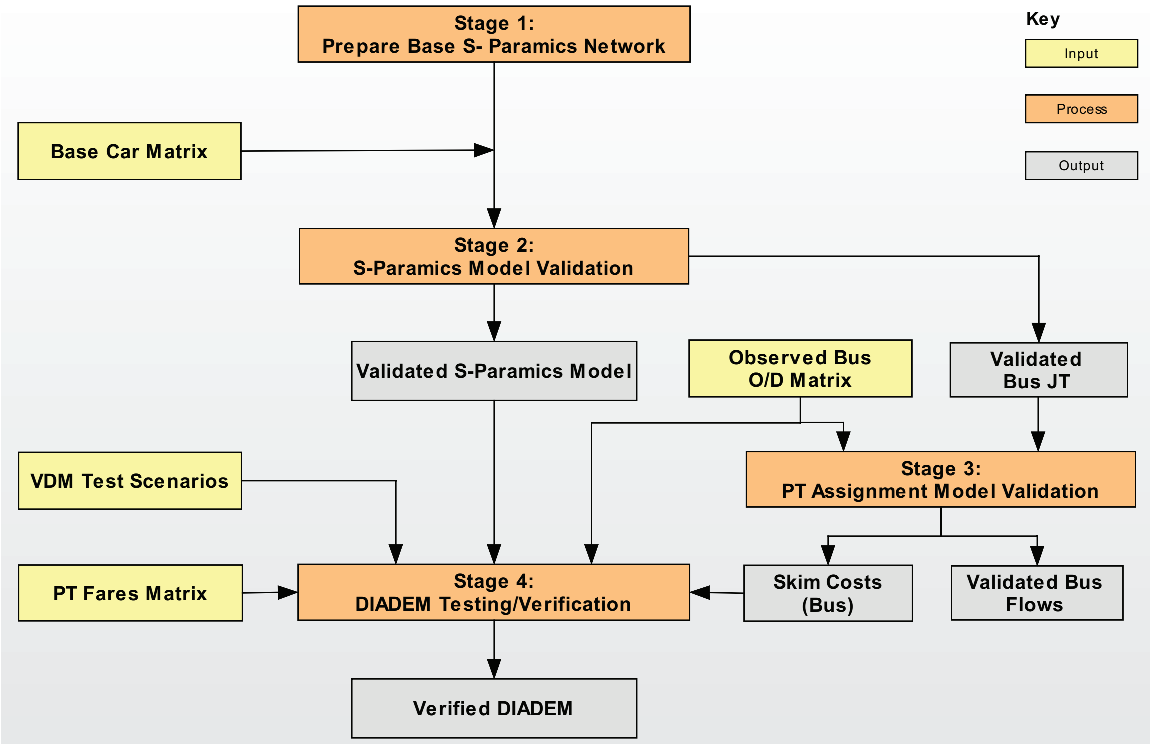


Figure 6: Development of Variable Demand Modelling (VDM) Framework

cost' was then allocated that reflected the additional time for those bus journeys requiring an interchange.

Stage 2: Revalidation of S-Paramics Base Model

The original Chippenham model was developed using S-Paramics 2007.1. The use of the model in conjunction with DIADEM required upgrading to version 2010.1 in order to output skim costs to DIADEM. Adoption of version 2010.1 required that the model be revalidated.

Comparison of the base year flows and journey times revealed little change compared to the original validated base model.

Stage 3: Public Transport Assignment Model Validation

The PT assignment model uses the bus journey times generated by the S-Paramics microsimulation model to generate the cost of travelling by public transport for each Origin to Destination (OD) pair, and assigns the observed bus passenger trip matrix through a logit model based formulation, based on the difference in cost between acceptable paths.

Validation of the PT assignment model was carried out by assigning a matrix of bus passenger trips that was developed from surveys undertaken in June 2010. The resulting modelled passenger flows were validated against observed passenger flows that were obtained from bus passenger counts also carried out in June 2010.

The assignment model also outputs a skim cost matrix of zone to zone bus journey times that is required by DIADEM.

Stage 4: DIADEM Verification

The procedure used to verify whether DIADEM is producing plausible results when applied to a particular model is known as 'realism testing'.

This is carried out by changing the various components of travel costs and times and checking that the overall demand response (elasticities) are within acceptable ranges in accordance with guidance set out in Section 1.6 of Unit 3.10.4 of WebTAG.

Verification of the DIADEM model for Chippenham was carried out using the two prescribed 'realism tests', the first involving a reduction in bus fares by 50% the second involving an increase in car fuel costs of 20%.

The 'realism tests' involved running DIADEM using the following inputs as identified in Figure 6:

1. Observed trip matrix of bus journeys
2. A matrix of bus fares
3. Cost matrix for bus trips (from the PT assignment model)
4. Cost matrix for car trips (from the S-Paramics model)

The results of the 'realism test' are presented in Table 1.

Table 1 shows that demand elasticities for the tests undertaken for the fuel costs and the bus fares lie within the specified range for the AM peak and inter-peak trips. Therefore the DIADEM model was considered to be verified.

Micro Time Period Choice

The micro time period choice procedure did not specifically form part of the development of the VDM framework for Chippenham. The micro time choice procedure represented an earlier development that had been applied in other projects, specifically to model trip retiming in response to increasing levels of congestion. It was decided that this should be adopted for Chippenham for modelling future conditions where congestion is likely to be a significant issue.

Realism Test 1 – Decrease PT Fares by 50%	AM Peak	Inter Peak
No of PT trips before change in cost	606	1192
No of PT trips after change in cost	713	1428
Increase in PT trips	18%	20%
Demand elasticity predicted by model	**-0.23**	**-0.26**
Target Elasticity	**-0.2 to -0.4**	**0.2 to -0.4**

Realism Test 2 – Increase fuel costs by 20%	AM Peak	Inter Peak
Total car km travelled before change in cost	73,413	59,784
Total car km travelled after change in cost	69,829	56,656
Reduction of car km travelled	-5%	-5%
Demand elasticity predicted by model	**-0.27**	**-0.29**
Target elasticity	**-0.25 to -0.35**	**-0.25 to -0.35**

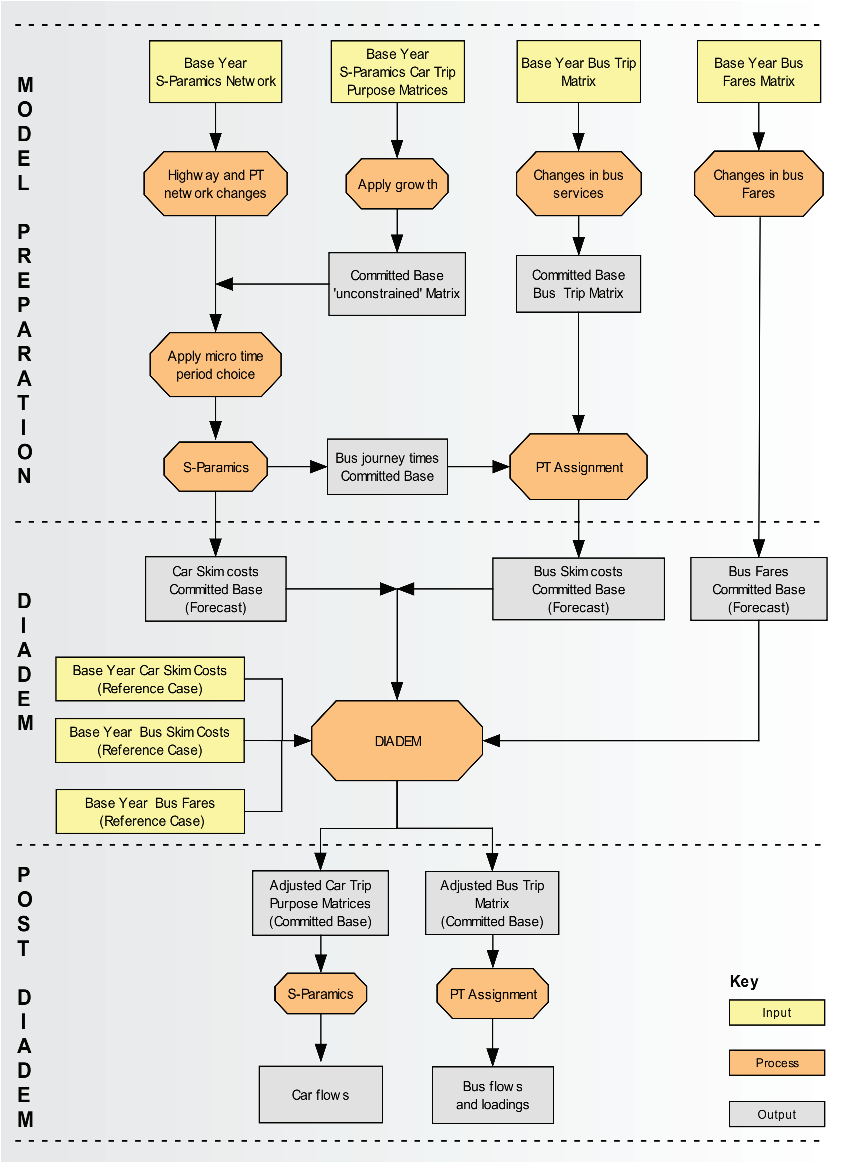
Table 1 : DIADEM Verification Tests

It is acknowledged that the micro time period choice procedure is extremely difficult to calibrate/validate. This is primarily due to the absence of detailed local traffic data that would be needed to both identify and quantify the effects of trip-retiming over the long term.

MODEL APPLICATION FOR FORECASTING

The modelling framework provides a method for assessing the variable demand responses between two scenarios. DIADEM uses an incremental hierarchical logit model that provides the main mechanism to adjust a

Figure 7 : Model Application to Develop Future Year Committed Base Forecast



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demand matrix according to changes between forecast travel costs and input reference case travel costs.

This section describes how the Variable Demand procedures are applied to calculate the change in demand based on changes in travel costs between the Base Year Model and a Future Year containing committed or proposed network improvements, termed the 'Committed Base'. In DIADEM, the former is referred to as the 'Reference Case' and the later the 'Forecast'.

The procedure for developing a future year Committed Base forecast is illustrated in Figure 7.

The procedure can be broken down into three stages:

1. Model preparation
2. DIADEM
3. Post DIADEM

Stage 1: Model Preparation

S-Paramics

The Committed Base S-Paramics network is developed by adding all planned highway network improvements and proposed changes to bus services and frequencies. Changes to car parking charges are also included by adjusting the toll at car park entry.

The Base Year car trip purpose matrices are growthed to the forecast year, taking account of any committed developments in the study area to create demand matrices for the Committed Base.

The micro time period choice procedure is applied at this stage if required. This should be applied in cases where traffic growth is likely to lead to high levels of congestion.

The new demand matrices are assigned to the network to produce an 'unmodified' Committed Base forecast, using the modified demand profiles for the trip matrices if the micro time period choice has been applied. This assignment provides the costs for the car trip purpose matrices for input to DIADEM.

PT Assignment

The base Bus matrix is modified to include any planned changes to bus routes or service frequencies and fares matrix adjusted to take account of any proposed changes to the fares structure. A PT assignment is then carried out by assigning the new bus matrix using the journey times output from the S-Paramics model run. The zone to zone skimmed costs from the PT model will provide the bus costs for input to DIADEM.

Stage 2: DIADEM

DIADEM provides the mechanism to adjust a demand matrix according to changes between the Forecast travel costs and input Reference Case travel costs. These costs can be related to the inputs to DIADEM that are shown in Figure 7 and are identified as follows:

- Reference Case Costs for Car trip purposes
  The skimmed costs derived from the Base Year S-Paramics model
- Reference Case Costs for Bus Trips
  The skimmed costs derived from the Base PT assignment
- Reference Case Bus Fares
  Obtained from the Base Year Fares Matrix
- Forecast Costs for Car trip purposes
  The skimmed costs derived from the Committed Base S-Paramics model following application of time-period choice
- Forecast Costs for Bus Trips
  The skimmed costs derived from the Committed Base PT assignment
- Forecast Bus Fares
  Obtained from the Committed Base Fares Matrix

Prior to running DIADEM consideration will need to be given to the behavioural responses to be modelled, the hierarchy to be applied and parameters used to control the demand responses. In cases where DIADEM is being used to support a business case that requires DfT approval, the procedures set out in WebTAG unit 3.10.4 will need to be observed.

Stage 3: Post DIADEM

DIADEM outputs modified purpose matrices for Car trips and for bus trips. The Car matrices are assigned in a further run of S-Paramics to produce forecast flows for the Committed Base. The bus trip matrices are assigned the PT model utilising the journey times output from S-Paramics to provide forecasts of passenger flows and boardings and alightings.

Do-Something Forecast

The procedure may also be applied to assess the change in demand resulting from implementation of a transport scheme or strategy, ie 'Do-Something' scenario. In this case the Committed Base would be used as the 'Reference Case' and the Do-Something the 'Forecast'. The procedure would be used to calculate the change in demand based upon the difference in travel costs between the Do-Something and Committed Base.

SUMMARY

This paper describes the development and application of a variable demand and multi-modelling framework that has been designed to operate in conjunction with microsimulation.

The methodology that represents the culmination of research and development carried out for earlier projects, has been applied on a recent project commissioned by Wiltshire Council to extend an existing S-Paramics model of Chippenham to provide a multi-modal capability that conforms to WebTAG. The basis of the approach is an interface between the DfT program DIADEM and S-Paramics that undertakes variable demand modelling as a single process. This has the advantage of maximising the utility of the existing model, minimising the requirement for new data collection and the need to develop and calibrate separate models for mode choice and trip distribution.

Allied to the VDM capability, a PT assignment model has also been developed that interfaces with S-Paramics and utilises bus journey times generated by the S-Paramics model to build journey paths. The bus journey times from S-Paramics include all components of the bus journey time including walk time, wait time in addition to in-bus time. By using S-Paramics bus journey times reflect the interaction with other vehicles on the highway network which is not normally achieved in conventional public transport assignment models. It means that the relative travel times between bus and car journeys can be predicted much more reliably. This is an important element when predicting mode transfer.

The capability to undertake variable demand represents a significant development in microsimulation modelling. The methodology also provides a blue-print for retro-fitting other microsimulation models with a capability to model variable demand. Significantly, by building on existing models it provides a highly cost effective means of developing a multi-modal framework and opens up opportunities for wider application.

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