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Travel Demand Management – modelling techniques

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Abstract:

Constraints on capital investment into new road infrastructure and changing community demands are continuing to influence transport planning methods for resolving congestion problems. Conventional methods that aim to improve the supply of the road network are gradually yielding to techniques which optimize existing infrastructure through methods of improved management and planning. Transport demand models provide the planner with a useful tool to assist in their decision making process, but traditionally they have lacked in their ability to analyse the influence of Travel Demand Management (TDM) strategies. A suite of models that can perform accurate network modelling procedures with the ability to analyse a wide range of TDM measures is required. This paper will discuss techniques that are being developed as part of a TDM modelling suite and in particular, concentrate upon the decision-making characteristics of the traveller associated with modal and route choice.

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Background

As metropolitan regions throughout the world experience continual expansion, the transport infrastructure designed to cater for the transport needs of the community also experience increases in pressure to perform adequately. When this system fails to provide for the community, demands can exceed network supplies resulting in traffic congestion and related problems that subsequently require some form of resolution.

As a result of Commonwealth and State Government constraints upon levels of capital investment into new road infrastructure, emphasis has shifted away from conventional techniques of tackling road congestion problems. Traditional methods of resolving the problem have generally involved altering the supply network in the affected region. This procedure is one which is not only costly, but can have follow on effects such as shifting the problem to another location and inducing traffic to areas with an increased capacity. Attention is now directed toward attempting to optimise existing infrastructure through methods of improved management and planning. This approach is often referred to as Travel Demand Management (TDM), and differs from other methods in that it concentrates on user demands placed upon the transport system rather than the supply provided by the network itself. It is recognised by the Institute of Engineers Australia (IE Aust), that TDM has the potential to reduce the direct cost of major infrastructure as well as indirect costs associated with the quality of life (IE Aust 1996). The IE Aust encourages engineers to consider TDM in the development and improvement of transport systems.

Incorporating TDM techniques into the everyday use of the transport system is a process involving the development of policies and management strategies through transport planning. In accomplishing this, there exists a need to model the network and the effects that such strategies would have upon it. It has been found that traditional transport demand modelling procedures lack in their ability to perform this type of modelling as they find difficulty in keeping up with changing community demands (Taylor, 1996).

This paper presents the structure of a travel forecasting model which can perform network modelling procedures and has the ability to include parameters relating to a wide range of policy measures. The model is directed toward use by the transport planner for sketch planning purposes and to investigate the effects of strategies upon the network before their implementation.

The Classic Four Stage Modelling Process

The classic four stage modelling process is presently relied upon as an accurate method of forecasting travel demand within urban regions worldwide and is also utilised within popular macroscopic transport models such as TransCAD, TRIPS and EMME 2. It has long been generally accepted as a reliable forecasting procedure and is versatile in relation to its transferability between cities and transportation systems of various size and configuration.

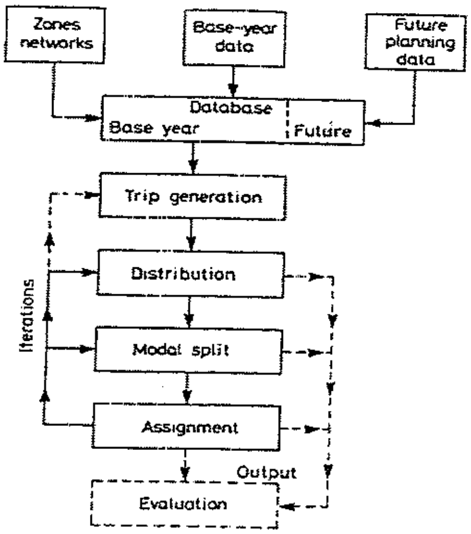

Figure 1 The Classic Four Stage Planning Model

The classic four stage planning model, as depicted in figure 1 has the ability to predict the levels of demand for the transport network, through the sequential execution of the algorithm. Initially, demographic data relating to the population and economic activity is used to predict the transport demands created throughout the network in terms of trip numbers. The mode by which these trips are made is determined and then the trips are allocated to the transport network itself, completing the modelling process.

Although the classic four stage model can accurately predict levels of demand on transport networks, it remains inadequate in providing for influences on the nature of the demand for travel. The demands placed upon the network are due largely to decisions made by individuals relating to:

- Behavioral patterns of the individual affecting their reasons for travel;
- Travel choices affecting the time periods when people travel;
- The selected mode for the journey/s to be made;
- The nature of surrounding urban structure.

Such aspects of an individual's behavior are often represented in the forecasting process by mathematical means including discrete choice and probability functions in a variety of forms. Although the conventional representation of behavioral patterns suffices for traditional requirements of such a model, they are often inapt in modelling the intervention to modify travel decisions for more desirable transport, social, economic and environmental objectives.

Major deficiencies are present in classic four stage forecast model when the timing of trips is required as part of the modelling process Originally, the model was only intended to provide the user with forecasts of 24-hour flow levels on the network. In order to obtain peak hour flows, this flow count is often scaled (perhaps 10 percent of the 24-hour flow) which places limits on the model's abilities. The need to introduce a method of trip timing into the modelling procedure, particularly for TDM analysis purposes, has become apparent.

Travel Demand Management Techniques

There exist a large number of possible techniques that could be used to implement TDM related policies, however when the issue of practicality is raised this becomes dramatically reduced. Travel demand management strategies aim to affect community travel demands through the utilisation of different methods and processes. Common to all of these management strategies is the aim of reducing unfavorable impacts of travel and to provide an effective and efficient transport system. Travel demand management is broadly reliant upon incentives, disincentives, education campaigns and planning measures to achieve their goals of modifying travel decisions.

Table 1 Travel Demand Management Strategies

DEMAND Measures	SUPPLY Measures:
Land use / Zoning Strategies	**Traffic Management Strategies**
Land usage and Zoning policy	Traffic signal priority
Precinct structure and land use mix	Network capacity alterations
Regulatory and Administrative Procedures	**Preferential Treatment**
Parking controls	Transit, HOV or Toll lane
Trip reduction ordinances (TRO's)	Freight vehicle priorities
Travel distance ordinances (TDO's)	
Vehicle restriction zones	**Public Transport Strategies**
Flexible work schedules	Public Transport improvements
Carpool programs	Park & Ride facilities
	Local community collector buses
Economic and Finance Based Strategies	**Freight Strategies**
Road or congestion pricing	Decentralised freight distribution centres
Parking pricing	
Mode selection incentives	
Providing Traveller Information	
Traveller information	
Tele-commuting	

TDM techniques can be categorised into those that focus upon the supply of the transport network infrastructure and others that seek to address the demands placed upon it by the users. A range of TDM technique examples are listed in table 1.

Strategies that aim to manage the travel demand for the wider community will seek to encompass several of these measures as part of the transport planning process. Those which are well structured will have short-term and long-term visions for increasing the transport network efficiency (IE Aust, 1996).

Recent Theoretical Developments

In recent years, much research has been conducted into the development of a modelling system that can effectively represent techniques for TDM, often involving a restructuring of traditional modelling algorithms. This is mainly because such models have also been adapted to utilise state of the art technologies, intensive information databases and to exploit developments in travel behavioral theories which have occurred over the past two decades. An example of such work is the Sequenced Activity - Mobility System or SAMS (Spear, 1996). As can be observed in figure 2, the SAMS has the ability to incorporate TDM and transportation control measures (TCM's) within the planning process of the model.

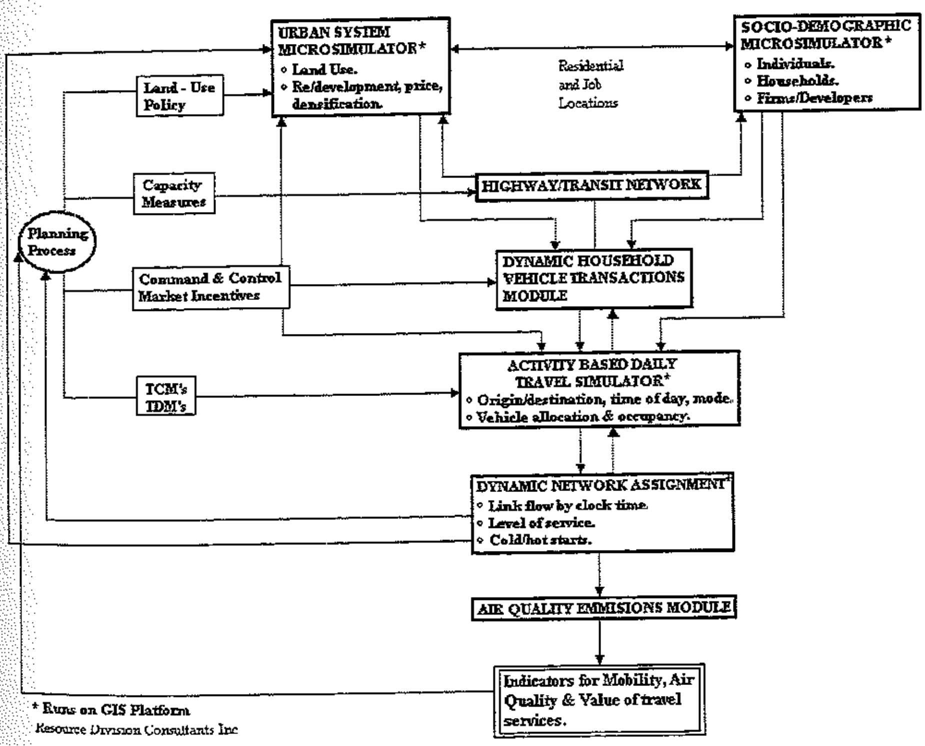

Figure 2 The Sequenced Activity - Mobility System (SAMS)

Other examples of new forecasting processes exist (Spear, 1996), however practical limitations arise in the implementation of new developments in transportation planning techniques. Often a theory that is developed and is unique in composition will require the support of specifically designed software for execution. This software development can have its own associated problems which require resolution and as a result, the practical implementation of developed theories can be a resource intensive process. Even once a new theory is presented in a practical form there may be a high level of expertise required for operation of the modelling software. A transport planner who may only seek the "sketch planning" level of detail from a model may not find it feasible to operate a highly detailed network model such as SAMS in order to obtain results.

Adaptation of the Classic Four Stage Model

An alternative approach posing itself to transport planners wishing to participate in TDM planning is to accommodate the effects of TDM strategies within a conventional modelling method. At first glance, the traditional four step modelling procedure can be perceived as inflexible in the procedures utilised in modelling, but this is not necessarily the case. Although each stage must be undertaken in an ordered fashion there exist many methods for achieving the aims of each level of the four stage algorithmic process. In addition to this, much research has been conducted with the intention of investigating deficiencies in traditional theories and addressing these with proposed alterations or new methodologies for the task. The inclusion of trip timing is important for the evaluation of TDM methodologies and it is possible to accommodate this also. The following discussion is directed at the analysis of the four stages of the classical forecasting procedure and to investigate possibilities for TDM incorporation

Trip Generation

The classic four stage forecast model begins with the process of generating trip origins and destinations for all journeys to be made within a specified time period on the transport system. The journeys produced and attracted within the network may be for a variety of purposes such as work, education, shopping and recreation. It is usual practice to divide the network in question up into sub-regions or zones, where information relating zonal characteristics is aggregated from household attributes and socio-economic activity. It is from this aggregated data that the amount of trip productions and attractions are forecast for the zone

Results from this stage of the forecasting procedure are heavily dependent upon the nature of the social and demographic information inputted. The type and amount of information collected relating to characteristics of the population and land use for the study region play an important role in the accuracy of predictions made. These predictions relate to decisions made concerning the individuals' need to generate out of home trips for various purposes.

It is therefore important that TDM techniques applying to the trip generation phase have an association with the potential traveller's need to create a journey. Travel management within trip generation can influence the essential need to create a journey and the subsequent impact that it would have upon the network. For instance, if the task of shopping or work can be carried out from the placed of residence then the need to physically travel out of the home can be eliminated.

Within this model stage, the production of trips (O), from each network zone (i), for all purposes (p), and person type (n) is usually accomplished with the use of a linear regression technique with the basic form:

$$O_{ipn} = x_{1i}.\alpha_{1np} + x_{2i}.\alpha_{2np} + \ldots \quad (1)$$

The α values are coefficients estimated by linear regression and the zonal descriptor variables x, represent relevant characteristics of the zone. Other models that can perform the task of trip generation include category analysis and trip rate models, and although they utilise similar input data, they are not discussed here.

When equation (1) is applied to the production of trips from the zones within the network, the zonal descriptor variables can relate to attributes including:

- Number of occupants and possible hierarchy within households;
- Employment details of household members;
- Education status of household members;
- Car ownership levels of households and
- Accessibility factors.

Trips attracted to the zones are generated with a similar regression model, but in this case the zonal descriptors are related to land use characteristics and the economic activity within a zone such as:

- Employment types and respective quantities;
- Education types and respective quantities;
- Details on retail outlets;
- Accessibility factors;
- Parking costs and restrictions and
- Other socio-economic details of relevance.

Descriptors that are relevant to TDM techniques may be included as part of the trip generation process with use of existing or especially dedicated zonal descriptor parameters and an associated calibration coefficients. For example, an accessibility zonal descriptor may be influenced by introduced TDM techniques, and such an influence may alter the value of this parameter and hence the number of modelled trips attracted to the zone. Network zones can therefore hold properties relating to TDM initiatives, which may affect the trip generation rates. TDM zonal descriptors may largely apply to the characteristics that lead to the *attraction* of trips to a zone, but depending upon the input information, could also affect car ownership levels or accessibility parameters of trip *production*.

To demonstrate this method, take the example of telecommuting for work purposes. Telecommuting involves performing tasks (normally undertaken at the workplace), within the home or a more convenient location. In the case of telecommuting from the home, the need for a worker to physically travel to the workplace can be eliminated, effectively removing the person trip from the model (ITE 1993). If a zone has levels of activity (such as work, education and shopping) transferred to telecommuting then the zonal descriptor relating to a telecommuting TDM technique could reflect this. Such a descriptor may represent zonal levels of employment or educational enrolments through which telecommuting could be practiced. With a correctly calibrated model it would therefore be possible to model different scenarios relating to the possibilities of conducting activities from home.

Other techniques that could have incorporation as zonal descriptor variables relating to trip attraction may include freight decentralisation strategies, park and ride facilities and parking controls.

Trip Distribution

Following the generation of network trip ends the model shall then need to establish a pattern of travel for the study area. This is done by the distribution of trips among destinations, resulting in the construction of a trip matrix that represents person trips created for the entire network.

In the process of selecting his/her destination it is assumed by the model that the traveller would like to minimise the generalised costs associated with the journey (Ortuzar and Willumsen, 1994). Costs incurred can be related to the time taken for the journey, the fuel used in travelling, parking charges, tolls and so on. It is therefore important that a trip distribution model be able to incorporate these and other possible costs that may come as a result of a TDM scheme. With a cost sensitive distribution model, the travellers' response to system constraints and deterrences can be represented.

Singly and doubly constrained gravity models are a popular methods of distributing trips in the classical forecasting model with many research developments to support it including calibration techniques and software. They are also appropriate techniques to be used in a TDM modelling method as they include the influence of travel costs over the distribution pattern. The doubly constrained gravity model has the following general form:

$$T_{ij} = (A_i O_i).(B_j D_j).f(C_{ij}) \qquad (2)$$

Trips between zones i and j, (T_{ij}) are derived from productions (O_i) and attractions (D_j), their corresponding coefficients (A_i and B_j), and from the cost function ($f(C_{ij})$). The cost function represents the travellers' response to costs incurred when making a network journey. In this case it is represented by the combined exponential and power function (3), as this gives a similar representation of a typical urban population of travellers responding to journey travel costs.

$$f(C_{ij}) = C_{ij}^{n}.e^{(-\beta C_{ij})} \qquad (3)$$

Figure 3 represents the nature of the gravity model's response (when generating motorised trips) to trip costs when equation (3) is utilised. Initially it generates fewer short trips that incur a cost (maybe walking is preferred), followed by a large number of medium length trips and then fewer high cost trips (Ortuzar and Willumsen, 1994).

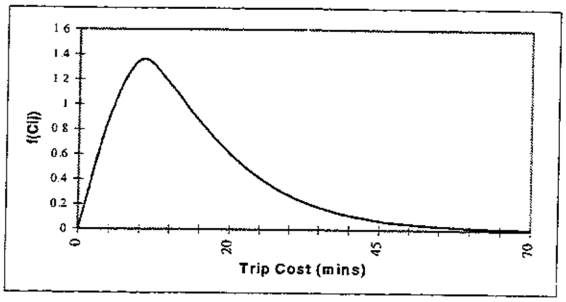

Figure 3 General shape of a combined cost function.

It is within the cost factor C_{ij}, that the combination of costs in travelling from origin to destination can be incorporated. These may include the following:

- In vehicle travel time;
- In vehicle travel distance;
- Public transport fares and waiting times;
- Road user charges;
- Environmental factors, including health risks;

Demand management techniques that have an application within the distribution modelling may be represented within the cost factor and (depending on the trip purpose), will have varying levels of response. A road-user charge is an example of a parameter that may represent the effects of a TDM technique on trip distribution.

Modal Split

At this stage, the model has estimated a pattern of travel between origin and destination zones throughout the network but has not yet determined by what means the travellers will make these journeys. Modal splitting distributes all person trips between available travel modes in preparation for the assignment to the network.

Policies that aim to reduce the demand made on the transport network often aim at accomplishing a modal shift from the network users. This involves influencing the decision made by the trip maker at the point of evaluation of the available modes. The travellers' mutually exclusive selection is greatly dependent upon the modal attributes and how attractive they appear to the traveller for his/her journey. If a TDM technique is to have an effect on the share of person trips attracted to each modal type it should attempt to alter the characteristics which appeal to the user.

The hierarchical or nested logit model provides a suitable structure to represent the travellers' decision in modal choice. In addition to this it will allow the inclusion of a range of properties which affect the attractiveness or utility of each mode. This is an important factor when TDM parameters are to be represented for the purpose of evaluation by the traveller.

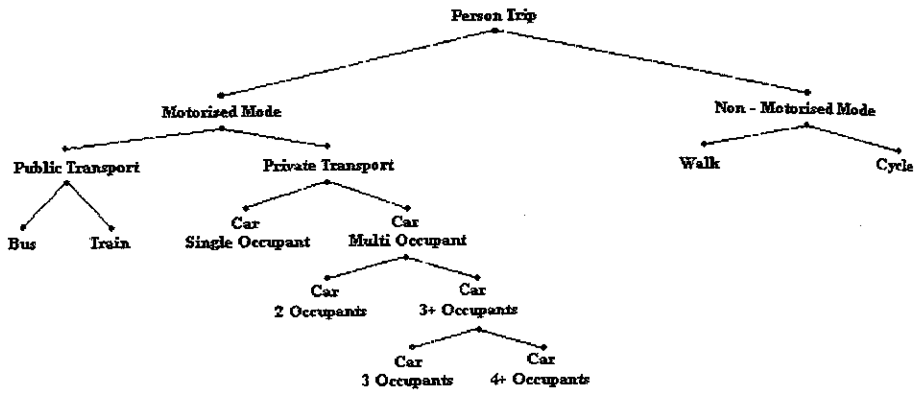

Figure 4 The Nested logit model

Figure 4 displays an example of a nested logit model that provides the traveller with a range of mode options to select. Each mode present in the model has an associated utility function that represents attributes of the mode in question. Utilities for all modes are included within a multinominal logit equation that determines the probability of the mode being selected. This particular example is structured as sequence of binary choices, as compared to one which would require a single choice to be made from a set of greater than two alternatives. When the model is configured in such a manner, problems associated with the independence of irrelevant alternatives property of the multinominal logit model are avoided (Oppenheim, 1995).

The utility of the alternatives is represented in the resulting modal choice, hence it is possible to incorporate TDM parameters within the utility functions used in the modelled decision making process. Parameters that are included will affect the overall attractiveness of the mode with consequent effects on its share of trips.

An application of the hierarchical mode choice model is that associated with the inclusion of a high occupancy vehicle (HOV) lane within the network. This technique has been successfully used in the Unites States to model the use of a HOV lane on the Shirley Highway in Washington DC, (US Department of Transportation, 1994). The aim of the modelling process was to distinguish between vehicles that could utilise the HOV priority lanes, for later selective treatment in the assignment process.

It was determined that specific characteristics of the population would influence the decision of users to utilise a HOV mode of travel, which in this instance included buses, vans and private vehicles with four or more occupants. The variables utilised in determining the HOV utility functions related to:

- Presence of preferential parking for carpooled vehicles;
- Flexible workhours offered at workplace;
- Possible time savings in using HOV lane and
- Number of employees at workplace.

The population of trip makers was then subjected to the model and potential HOV patrons identified for later assignment to the HOV lanes.

Assignment

The assignment of trips to the network is the process by which the population's transport requirements are provided for by the transport infrastructure itself. Trips between origins and destinations by all modes must be accomplished within the defined practical and physical limitations of the supporting infrastructure, effectively establishing a problem of supply and demand.

Within the previous stages of the forecasting model community demands have been well established apart from the determination of routes to be taken throughout the network. Route selection is a decision that is heavily reliant upon the properties of the network itself, along with the need for the traveller to fulfil his or her own objectives usually associated with the minimisation of travel costs. The selection of a route to accomplish this is sensitive to network costs and resulting flow distributions shall reflect this. To influence the modelled route selection decision made by the traveller for the purpose of TDM the assignment procedure should include parameters that represent imposed network costs.

To undertake the assignment of trips to the network and allow the flows of vehicles upon the transport links, the model utilises a method based on Wardrop's first and second principles and Jewell's principle of traffic network equilibrium (Taylor, 1997)

Under Wardrop's first principle, journey times on all routes between an origin and a destination are equal and shall be less than times experienced on any other route when the equilibrium point is reached. This is a result of each individual driver seeking to optimise his or her own travel time, independent of the behaviour of other drivers. Wardrop's second principle however seeks to obtain a minimisation of the travel task in terms of a system wide result of minimum total travel time (vehicle hours of travel). Under this principle, a high degree of cooperation is required between drivers, with drivers sacrificing individual travel time gains for the sake of overall system optimisation.

Jewell's principle may be seen as a generalisation of the two Wardrop principles. This principle states that the travel task should be accomplished in a fashion as to optimise some economic objective. This may involve an individual or system wide travel time minimisation (as with Wardrop's first and second principles), or some other objective which may involve the minimisation of fuels used or pollutants emitted.

From this we can obtain a family of equilibrium assignment models as described by Taylor (1997) which represent various policy strategies for the network. An example of this is the equilibrium objective function relating to the Leeds model of cordon zone pricing (May *et al* 1996).

Initially, the cordon zone is defined within the network, effectively dividing the links into three categories:

- Links (w) which lie wholly within a possible road pricing zone;
- Links (l) which cross the cordon line;
- Links (e) which remain wholly outside of the road pricing zone and do not cross the cordon.

The model is then represented by the objective function

$$Z = \min\left\{\sum_{e}\int_{0}^{q(e)} c_e(x)dx + \sum_{l}\left[\int_{0}^{q(l)} c_l(x)dx + q(l)m_l\right] + \sum_{w}\int_{0}^{q(w)} c_w(x)dx\right\} \qquad (4)$$

The objective function used here refers to a congestion function (c) which is the relationship between the amount of traffic using a network element and the travel time and delay incurred on that element. One form of the congestion function is the modified Davidson function (Tisato et al 1991), which exists as

$$c = c_0\left(1 + J\frac{q}{C-q}\right) \qquad x < x_0 \qquad (5)$$

$$c = c_0\left(1 + J\frac{x_0}{1-x_0} + J\frac{x-x_0}{(1-x_0)^2}\right) \qquad x \geq x_0 \qquad (6)$$

where q represents flow volumes, x is the volume capacity ratio, x_0 is a user selected proportion (usually between 0.85 and 0.95) and J is an environmental parameter reflecting road type, design standard and abutting land use development. The parameter c_0 is the zero flow travel time.

A type of congestion function presenting itself as an alternative to the Davidson function is a time dependent congestion definition such as that derived by Akcelick (1991). A function that is time dependent may be more accurate than the modified

Davidson function and, depending upon the application of the equilibrium assignment and the TDM measure under assessment, may indeed replace it.

Of most importance to the modelling of a cordon pricing scheme is the inclusion of the fixed charge (m_i). As the objective function seeks a solution according to the Wardrop or Jewell principles, it will assign traffic to the network with consideration of this road pricing element. The result is a flow pattern recognises the influence of cordon pricing and distributed the network demands accordingly.

Forecast Model Summary

It should be noted that the model described here concentrates it's resources on the modal splitting and assignment stages of the algorithm. The reason for this is the importance of higher occupancy vehicle modes and traffic route selection in reducing congestion problems within the network. Although decisions made by the population associated with trip generation and distribution have an influence over resulting network flow patterns, most TDM techniques are heavily reliant upon providing incentives and disincentives for the traveller. These have proven to be greater in benefit and flexibility when directed at properties of the vehicle fleet (eg. public transport properties), and the road network (eg. road pricing schemes). Management techniques that seek to spread the high levels of demand placed on the network during peak periods are also of great importance in alleviating congestion problems. The traffic assignment model described by Matsui and Fujita (1996) focuses upon time-elastic travel demand and fits closely with the family of equilibrium assignment model described previously.

It is also important to note that due care should be taken when the model seeks to address multiple issues associated with TDM. Although management techniques can display particular results when modelled individually, the combination of several TDM strategies may cause erroneous results. This is because when used in combination TDM techniques may have the effect of supporting or neutralising one another. This is an issue that is beyond the scope of this paper and requires further investigation.

As technological advances elevate the processing ability of personal computers and make available less resource intensive data collection methods, the field of transport modelling stands to benefit greatly. It will be possible for transport planners to perform modeling tasks at lower cost, and with greater levels of ease and accuracy. Initiatives like the Travel Model Improvement Program (TMIP) in the United States seek to overcome barriers between theory development and practical implementation with the use of these new technologies (TMIP 1998).

Conclusions

As the need to utilise TDM strategies within transport networks is becoming realised worldwide, transport planners require appropriate evaluation tools for analysis. This presents the transport planner with a need for a computer model with TDM modelling capabilities. Progressively, research into this problem is providing theories to undertake detailed modelling of network behaviour and include TDM, but limitations exist in the practical application of many of these. The classic four stage model produces forecasts of traffic volumes on road networks and is widely used and accepted by transport planners, especially for use in sketch planning. In this paper it has been demonstrated that it is possible to incorporate parameters in the classic four stage model for the purpose of TDM technique analysis and evaluation. Methods for the incorporation of parameters to allow the evaluation of TDM strategies are presented along with a description of how they undertake the task.

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