Variable demand traffic modelling: **introducing realities**

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BACKGROUND

In most urban areas the demand for road space has increased to a point where the traffic demand during peak periods far exceeds the available road capacity, or supply, resulting in congestion. The higher the levels of congestion, the longer it takes to reach one's destination. This gets to the point where road users make certain decisions regarding their travel plans, such as to start their trips earlier or later to miss the peak periods, which results in peak spreading. Prior to the upgrading of the Gauteng freeways it was recorded that the peak period (this being the period where the freeways were running at their maximum capacity) was extending by 15 minutes every year.

Traffic and transport modelling in South Africa generally continues to use the standard trip assignment algorithms, and modellers attempt to mitigate the effects of congestion in their base models by modelling the 'supply' conditions through factoring the input trip generation rates or adjusting the trip matrices to 'supply' traffic counts. As a result the latent traffic demands are excluded from the base traffic models.

AIMS AND OBJECTIVES

The aim of this article is to examine the use of ***variable demand*** traffic modelling techniques with the objective of demonstrating how this approach can be used to introduce another element of reality into traffic modelling outputs. This is achieved by retaining the traffic demand in the model, with the outputs reflecting the effects of congestion and producing results that the road network can accommodate.

Based upon this examination, an approach to traffic modelling is proposed which, if approved by planning authorities, could lead the way to providing more comprehensive and reliable outputs for transport and infrastructure planning.

BACKGROUND ISSUES

Transport and traffic modelling is a tool used for the planning of roads and public transport systems, as it is used to predict traffic volumes and traffic patterns based on 'what if' scenarios. Models are developed at different levels of complexity, from macro-models, where one models traffic over relatively large areas, to micro-simulation models that animate traffic movements through a smaller part of the road network. They reflect a specific time of the day, usually an hour during the peak period.

Transport modelling has been used extensively in South Africa to test various road planning and development schemes. In undertaking the modelling, the generally accepted four-step model process is adopted, this being:

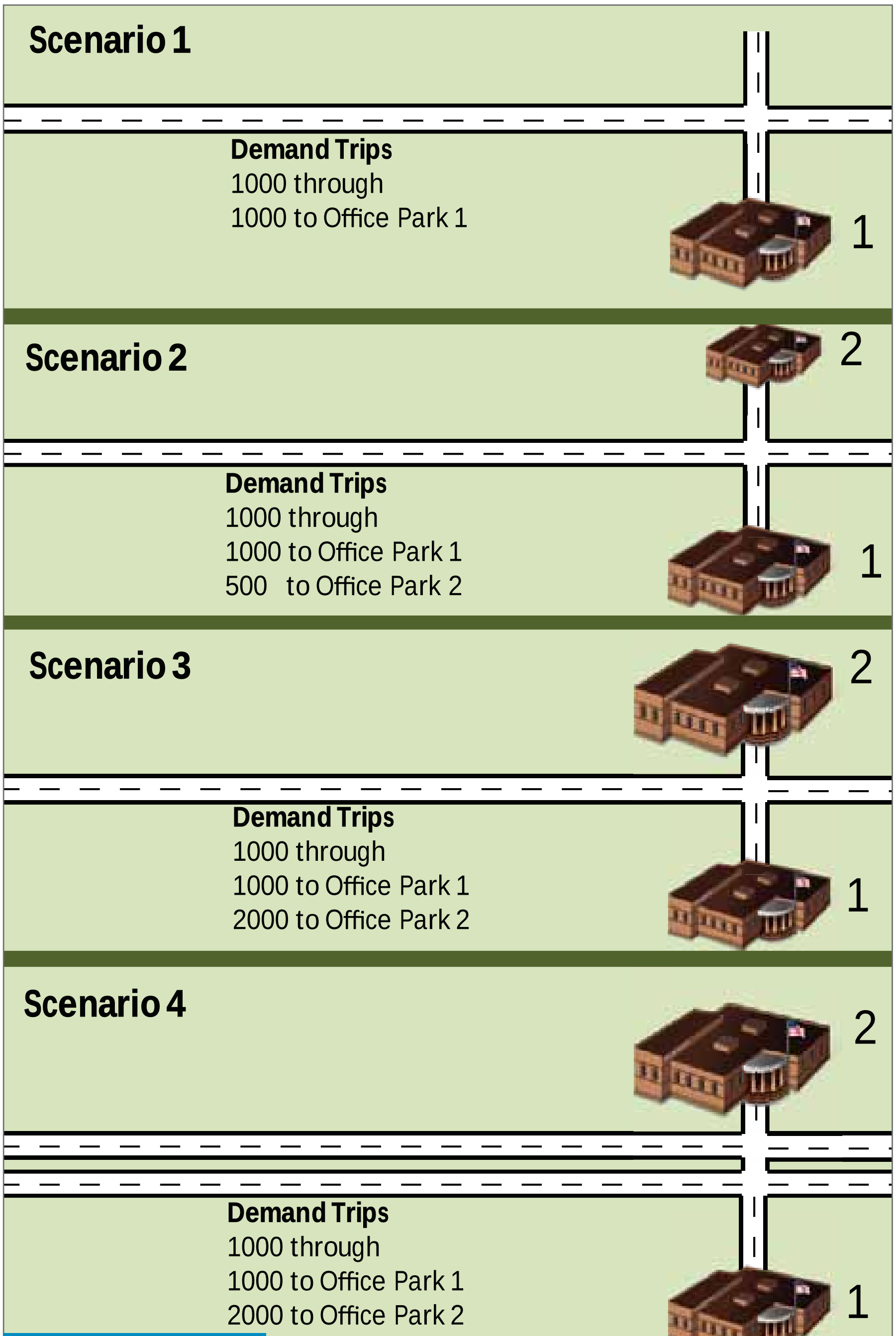

Figure 1: Scenarios evaluated

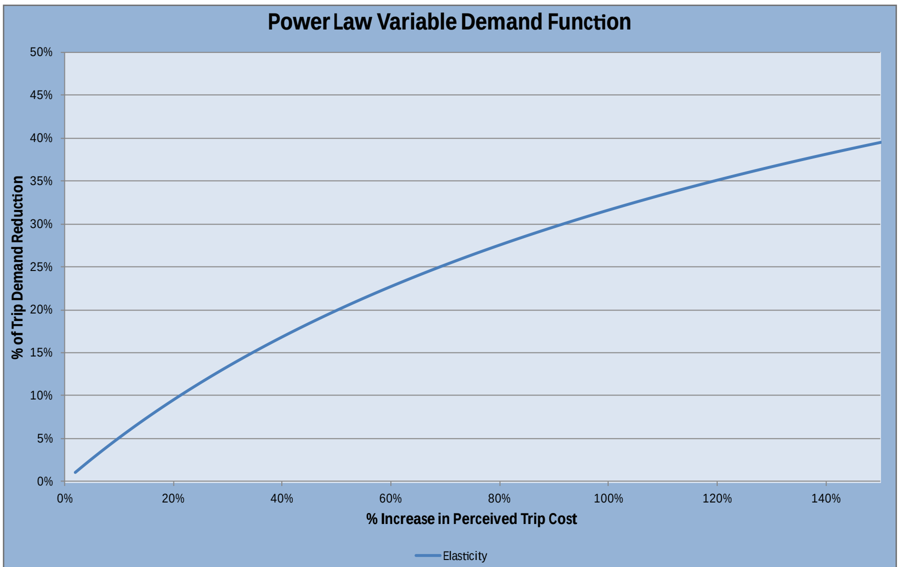

Figure 2: Power law variable demand function

- Trip generation – where land use data and trip generation data, e.g. that contained in the South African Trip Generation Rate Manual (SATGRM)[i], is used to determine the quantum of trips generated by, and attracted to various development types.
- Trip distribution – this being derived usually from information obtained from surveys and thereafter through the calibration of a trip distribution function.
- Modal split – this being derived from undertaking generalised cost comparisons between private and public trip making, the availability of public transport supply and car ownership levels.
- Trip assignment – determined through the model assignment algorithms, which ultimately assign the public transport passengers and private vehicles onto the modelled networks.

During the development of the base year model, the assigned flows on the network are normally calibrated to reflect measured traffic volumes, thus ensuring that the base year model 'robustly' reflects current traffic flows during the modelled hour.

The problem with the above calibration process is that on congested road networks one is not modelling the actual traffic demand, but rather only the 'supply' demand which the road network can supply/accommodate. The difference between the actual and 'supply' demands is often referred to as the latent demand. The fact that the latent demand is 'calibrated out' of base year models is obviously problematic, since the modelled demands are being underestimated. This problem gets carried forward, in that models predicting the traffic demands in future years will inherent this shortcoming. The implications of excluding the latent demand can be extensive, say in under-estimating future urban freeway requirements.

VARIABLE DEMAND MODELS

As congestion levels increase, trips take longer and the perceived 'generalised' cost of the trip increases. Standard models assign trip matrices onto the road network irrespective of these individual changes in travel cost. The variable demand model utilises the principle that there is an elasticity between travel cost during the modelled period and travel demand, i.e. as the perceived cost of a trip during the modelled hour increases, individuals change their trip-making patterns, for example, by:

- Travelling at an alternative time, outside the peak hour (modelled hour)
- Embarking in ride-sharing schemes
- Using an alternative mode of transport, i.e. using public transport

The elastic demand function can take a variety of forms, and different functions and function parameters would be different for various trip types (trip purpose) and vehicle types. It is not within the scope of this article to determine which function would be most applicable to South African conditions; however, these functions include the following[ii]:

- Logit (incremental form)
- Power law or constant elasticity
- Exponential
- Elastic exponential
- Nested logit
- Shared logit

The use of variable demand models is a requirement of the Highway Agency of the Department of Transport (UK). This was introduced in 2006 through the issuing of the Transport Analysis Guidance (TAG).[iii iv v]

MODEL EVALUATION DESCRIPTION

To demonstrate the issues around current transport model assignment techniques, and in order to compare these results with those obtained from using variable demand assignments, a simple hypothetical situation was modelled. This network comprised a heavily trafficked arterial road, representing a congested road network, along which commercial developments take place. The results from this model, in terms of the volume/capacity (V/C) ratios and trip generation rates, demonstrate the different outputs attained from the two traffic modelling approaches.

Four scenarios are examined where traffic travels from the west on an arterial, either through to the east or to office parks on the eastern end of the road. Figure 1 depicts these scenarios. The demand trips to the office park are assumed to be based on the SATGRM, assuming a trip generation rate of 2.2 trips per 100 m^2 of Gross Leasable Area (GLA). The scenarios in more detail are as follows:

- Scenario 1: A single carriageway two-lane road with a capacity of 1 800 vehicles per hour (in one direction), with a demand of 1 000 through trips and 1 000 trips to Office Park 1 during the peak hour.
- Scenario 2: Scenario 1 but adding Office Park 2 with a peak hour demand of 500 trips.
- Scenario 3: Scenario 2 but with Office Park 2 having a peak hour demand of 2 000 trips.
- Scenario 4: Scenario 3 but with an improved road with a one-way capacity of 3 600 vehicles per hour.

The standard models assume current modelling practices and the variable demand models use the power law form of the variable demand function, which takes the form:

$$T_{ij} = T^0_{ij}.(c/c^0)^p$$

Where:

T = the number of trips travelling between an origin i and destination j

T^0 = the number of demand trips

c = the perceived cost of travel assuming demand conditions

c^0 = the perceived cost of travel assuming free-flow conditions

p = a user defined constant

In order to determine p, it was assumed that, should the perceived cost of travel between the origin i and destination j increase by 50%, actual demand would reduce by 20% during the modelled hour, i.e. as a result of a change in the time of travel or a suppression of trips by way of ride-sharing or a change in mode.

Using the power law formula, the relationship between the increase in perceived travel cost and the reduction in the trip demand during the modelled period is shown in Figure 2.

Pertinent results from the modelling of the four scenarios are provided in Table 1.

DISCUSSION OF RESULTS

The demand model results are as one would expect, in that the traffic that is assigned to the road network 'manages' to arrive at their destinations during the modelled hour. In the case of Scenarios 2 and 3, this results in V/C

Table 1 Model results

Model type	Scenario	1	2	3	4
Standard model	Trips assigned	2000	2500	4000	4000
	V/C ratio	1.11	1.39	2.22	1.11
	Trips past the office developments	1000	1000	1000	1000
	Trips to Office Park 1	1000	1000	1000	1000
	Trips to Office Park 2		500	2000	2000
	Trip generation rate to Office Park 1	2.2	2.2	2.2	2.2
	Trip generation rate to Office Park 2	2.2	2.2	2.2	2.2
Variable demand model	Trips assigned	1716	2004	2880	3443
	V/C ratio	0.95	1.11	1.60	0.96
	Trips past the office developments	858	801	720	866
	Trips to Office Park 1	858	802	722	865
	Trips to Office Park 2		402	1438	1713
	Trip generation rate to Office Park 1	1.89	1.76	1.59	1.90
	Trip generation rate to Office Park 2		1.77	1.58	1.88

ratios of 1.39 and 2.22 respectively. The consequences of these results are:

- The road requires upgrading under all scenarios.
- The intersection that would need to be designed to provide access to the office parks would be significantly over-designed, because in reality the resultant traffic volumes cannot actually reach the intersection within the modelled hour.
- The upgrading of the road reduces the V/C ratio of the road to the same level as Scenario 1, as expected.

The variable demand model results provide a more realistic outcome in terms of predicted traffic volumes. These results highlight the following:

- The maximum V/C ratio in Scenario 3 reduces from 2.22 to 1.60, which still provides the indication that the road requires upgrading.
- Traffic to the three destinations (the end of the road and the office parks) must share the available road space and hence the 'supply' traffic flows for each destination reduce.
- The variable demand trip generation rates to the office parks reduce due to the need to share the available road capacity.
- Increasing the road capacity allows more traffic to access the office parks during the modelled hour, hence the trip generation rate increases.

Further to the above, the difference between the trips assigned in the standard model and the variable demand model provides an indication of the demand for alternative modes of transport during the modelled period.

The variable demand model results negate the trend whereby modellers use observed entry/exit traffic counts at similar developments in the area as the trip generation rates for their traffic impact studies. This practice means that the input trip generation rates for proposed developments are reduced to the 'supply' trip generation rates based on the limited capacity of the surrounding road network. Adding this to a model that has been calibrated to 'supply' traffic counts removes any latent demand from the model. As a result no reasonable results would be obtained by increasing road capacity in the area which, as demonstrated using the variable demand model, would increase trip generation rates and the amount of traffic travelling through the modelled area.

CONCLUSIONS

The comparison of fixed demand versus variable demand traffic modelling, albeit using a simple example, and noting the problems associated with trying to produce a supply model using a fixed demand model, reveals a number of issues, these being:

- True demand models will overestimate traffic flows on the road network.
- Calibrating a fixed demand model to 'supply' traffic counts and using measured trip generation rates from developments with congested access roads completely remove any latent demand from the traffic model. As a result, the traffic projections on any major road upgrades will be underestimated.
- Using variable demand assignment algorithms enables the modeller to use SATGRM rates for the proposed development and retain latent demand from congested upstream conditions. Such latent traffic demand would be 'released' onto the road network in the event of road network capacity.
- The model used for this demonstration is simplistic, but the theory demonstrated does apply to much larger models, including models comprising large congested networks.
- The demonstration model used one of the available variable demand functions calibrated to an assumed relationship between the increase in cost and reduction in demand. This function may not necessarily be the most appropriate for local (South African) conditions and hence further research in this regard is required.
- Using the variable demand modelling process, and results from these models, the design of accesses to developments would be more appropriate as they would be in line with the traffic volumes that can physically get to them as opposed to being over-designed.
- The properties of variable demand models can be used to provide a compromise between authorities and developers in the determination of trip generation rates for proposed developments.
- The results presented here show the benefits of variable demand models in that they assign actual demand trip matrices and produce assignments that are closer to the supply capacity of the road network. On-going research is being undertaken to determine the most appropriate variable demand function that should be adopted to represent South African conditions.

RECOMMENDATIONS

Variable demand models retain latent traffic demand in the input trip matrices and are able to assign this latent demand in the evaluation of road improvement schemes. Road schemes that improve traffic distribution, as opposed to merely shifting traffic problems or providing road capacity that cannot be accessed, will be highlighted. It is therefore recommended that planning authorities pursue the use of variable demand model algorithms in the prioritisation of road infrastructure schemes.

Due to the potential benefits of using variable demand modelling techniques, it is recommended that the South African transport authorities consider specifying the use of variable demand models in large traffic impact assessments where proposed developments generate over say 1 000 vehicle trips per hour. In regard to the debate between developers and authorities with respect to trip generation rates and road construction requirements, it is suggested that:

- Developers pay bulk contributions based on the number of trips calculated using the SATGM for the future upgrading of the road network.
- Development access upgrades are based on supply traffic volumes, preventing the need to build unnecessary infrastructure that traffic would not fully utilise due to congested upstream conditions.
- Bulk contributions be used for road upgrades, which include the upgrading of intersections when sufficient funding has been collected.

In order to promote the use of variable demand modelling, it is recommended that South African authorities promote further research into the use of variable demand modelling algorithms, the appropriate functions that should be used and the calibrating of these to local conditions.

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