TRANSPORT MODELLING WITH REFERENCE TO THE GAUTENG FREEWAY IMPROVEMENT PROJECT

A Robinson

Pr.Eng. BSc. Civ.Eng (Natal); GDE (Wits) MSAICE MCILT
Trading as ARTranS Consulting

ABSTRACT
Spiralling road construction and maintenance costs combined with the limited funding for the expansion of the road network means that road authorities must justify the need to implement road projects. Traffic/transport models are tools that can provide answers regarding the evaluation of alternative road network improvement options including the analysis of the benefits of a project as well as the potential impact on other parts of the road network. A significant project in this regard is the Gauteng Freeway Improvement Project (GFIP), currently being implemented by the South African National Road Agency Limited (SANRAL). This paper describes noteworthy lessons learned while developing the GFIP transport model with the aim of providing some insight to transport modellers and those who rely on the output from these models what can be expected from them and where the engineer fits into this picture.

1. INTRODUCTION

Road infrastructure construction costs have spiralled over the past decade and the ability of the road authorities to secure funding for road network expansion has become increasingly difficult. Road authorities are faced with having to prioritise improvement schemes and determine what can be done with the available funds and/or finding the means to fund road improvement schemes. A significant project that falls into the latter category is the current Gauteng Freeway Improvement Project (GFIP) currently being implemented by the South African National Road Agency Limited (SANRAL). The development and use of a transport models provided much of the input into the decision making processes in terms of what should be constructed and would it be affordable.

This paper provides a brief description of the various transportation/traffic model types and their uses as well as the potential interaction between them. This is followed by some of the more important elements in the development and use of a strategic transport model, making references to the GFIP work.

Through this experience, it became evident that many transport planning practitioners could benefit from a reminder as to what transport modelling is and does, including the issues relating to the development of traffic models and the reason that it requires engineering input in deciphering the results. The aim of this paper is to put various aspects of transport models into perspective from both the modeller's and client's point of view through the development of the GFIP and other projects.

2. WHAT ARE TRANSPORT/TRAFFIC MODELS

Firstly let us understand what a model is. According to the Oxford Dictionary: Model – "simplified description of a system etc. to assist calculations and predictions" (Oxford University Press, 1976). Secondly, with all the technology and research available to us today and that which has been packaged into the various transport/traffic modelling suites, a traffic/transport model is still a simplified description of the dynamics of a transport system.

When one begins to understand the processes and equations provided in the modelling package’s manuals and compares these to the multitude of thought processes of the model’s subject matter, being the individuals in the general populous making a trip from their origin to their destination, even with the latest technology a transport/traffic model is a simplified description of the system. Having said that, these models are still the tools that are used to capture as much information as possible about current transport trends and use this data to assist in the calculations and prediction as to the “what if’s”.

3. LEVELS OF TRANSPORT/TRAFFIC MODELS

Transport and traffic models come in various forms and each type or level is developed to fulfil a differenct purpose. Each model type requires different levels of information, from gerenalised costs and distribution functions in strategic models to reaction times and decision points in micro simulation models. A brief description of these models is provided below.

Strategic Macro Models

Strategic models are developed for large areas. These are developed using the classical 4-step transport parocesses,

- trip generation,
- distribution
- modal split
- assignment

The models are link based, i.e. do not take into account the effects of intersections, but do take into account congestion. These models should, where possible, form the bases of more detailed modelling work as these models provide a wider area perspective of transport related interventions, i.e. land use development, major road improvement schemes. It should be noted that these models do not contain all roads in the network and are often limited to Class 1, 2 and 3 roads in very large areas and possibly include Class 4 roads in some instances. A strategic model was the basis for the GFIP modelling work and provided input into more detailed models.

Simulation (Meso) Models

The simulation model is a more detailed level within which the operations of intersections can be examined. The modelled areas are generally smaller than strategic models, with a large simulation model being the size of say the Johannesburg CBD and a small model being a few intersections in a small network or corridor. These models can be used to provide more detailed analysis of intersections, including lane configuration and, in some cases, traffic signal optimisation, within a small network or corridor.

Microsimulation Models

Micro simulation models are designed to visually demonstrate how traffic would flow through a system by depicting the interaction between individual vehicles while travelling through a road network. The visual representation of traffic flows provide a means to examine the interaction of traffic and its reaction to changes in the road network being modelled. These models have very good graphic capabilities with the ability to display traffic flow on the roads in a study area in a non-technical manner.

Interaction between model levels

The interaction between a strategic model, a simulation model and a micro simulation model is very useful if known major road improvements are expected to change traffic patterns into and through a local study area. Although it is possible, it is not advisable to combine link based (strategic) and simulation models.

In the GFIP work, output from the strategic model was passed on to the various design consultants as input into meso and micro models. The strategic level output included a base year sub-model comprising a network of the section of freeway and trip matrices of light and heavy vehicles entering and leaving the various interchanges. This approach ensured that the trips enterin and leaving at each section's "ends" corresponded to the the information provided for the next section. In addition to the base year output the strategic model provided trip matrix forecasts based on predicted changes in land use and initial estimates of the freeway improvements.

4. STRATEGIC MODEL DEVELOPMENT

The development of a strategic model can either begin from scratch or be based on a model that has already been developed. The use of an existing model for large areas saves a significant amount of time; since re-creating a large model from scratch could be considered an expensive and time consuming option. This is not to say that models cannot be converted between packages, provided that the modeller understands the processes in both modelling packages and is able to replicate the necessary parameters so that the output in the "translated" model is closely matched to the original model. Getting exactly the same results is virtually impossible because of the differences in the internal operations and inputs between packages.

The section describes the processes used in the development of the GFIP model, highlighting important aspects in the process that are often either overlooked or not given enough attention. These processes include the following:

- The choice of the base model
- Data collection
- The updating and calibration of the modelled road network
- The calibration of trip generation rates
- The calibration of distribution functions
- The choice of assignment algorithm
- The calibration of the base year trip matrices
- The development of model forecasts

Choice of base model

Over the past few decades, strategic transportation models have been developed for most of the metropolitan areas and the PWV (Gauteng) as a region. Due to the time constraints for the development GFIP models, it was necessary to get a running start by using as much previous work as possible. The strategic transport models that were evaluated for use as the base of the GFIP model included the following:

- The Gauteng Transport Study of 2000 (GTS2000) Gauteng provincial model.
- The Super Highways model that was a modification of the GTS2000 developed to test the possibility of tolling provincial roads in the province.
- A combination of the more detailed City of Johannesburg (CoJ) and City of Tshwane (CoT) transport models.

The GTS2000 model was the preferred choice because of the following main advantages:

- It contained the required network coverage and detail.
- The land use information has been updated over the years and is in a format that corresponded to the mode's zone systems.
- The trip distribution functions had been based on household survey data.
- All processes had been documented.

The GTS2000 model was however an Emme/2 model and the GFIP models were to be developed using the SATURN suite. This entailed a conversion process. In addition, the GTS2000 was calibrated to a 2002 base year and did not specifically model heavy vehicles.

Data collection

A significant amount of information was contained within the GTS2000 model. In order to update this model to reflect the base year (2006) traffic conditions, the following data requirements were identified calibrate the model:

- A comprehensive set of travel times on the freeways and provincial "alternative" routes in order to calibrate the modelled road network. This data was obtained from travel time surveys on fourteen routes, each being measured in both directions during the morning peak period.
- A comprehensive set of traffic counts collated from previously acquired data sets and from traffic count surveys undertaken to augment the data set. Traffic counts in models can be problematic if they are not "balanced", i.e. the traffic volumes on two successive sections of freeway travelling in one direction do not add up after subtracting the traffic exiting the off-ramp and adding the traffic entering on the on-ramp at the interchange. It was also found that in existing data sets numerous very different counts were available for the same location. A significant amount of time was spent ensuring that the traffic count data base was balanced for the GFIP model.
- Updated land use was obtained from town planners reflecting the base year situation. This data included residential units by income group, employment by category and floor are for retail in industrial development. The data related to 829 model zones. Furthermore land use forecasts were obtained for the 2010, 2015, 2025 and 2035 design years.

Network development and calibration

The GTS2000 Emme/2 model was converted from into SATURN format (refer to Figure 1). Most of this process is relatively straight forward since the same information is used in both models, i.e. node numbers and coordinates, link lengths, albeit in different formats. The GFIP model network comprises 899 zones, 8136 nodes and 20 670 links. An important aspect of the conversion process was the replication of the volume delay functions so that the traffic speeds are similarly influenced by traffic volumes.

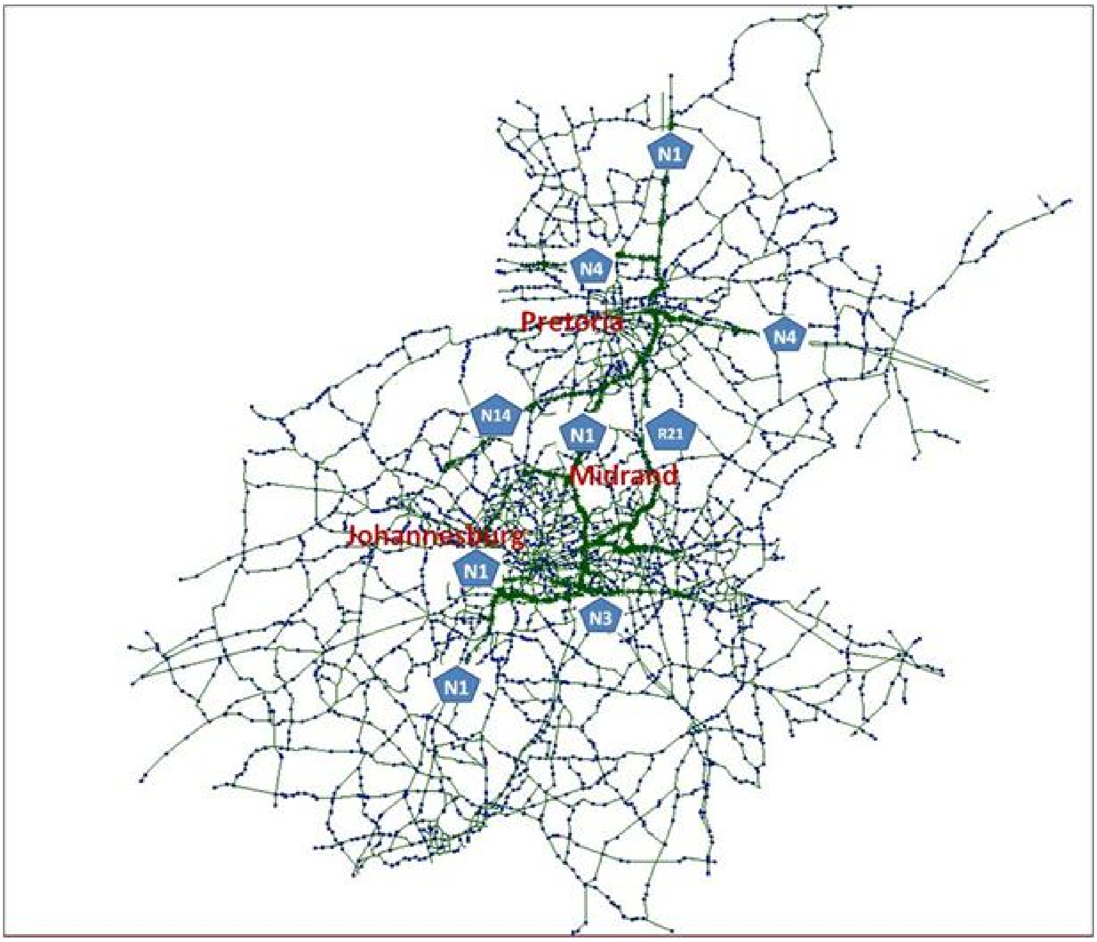

Figure 1: GFIP model network

An extremely important element of the development of any model is to ensure that the network is represented as accurately as possible. This entails a thorough audit of the network. In the conversion of networks from Emme/2 to SATURN, it was found that the SATURN software is more "strict" when it comes to network logic checks and some network errors are highlighted.

The conversion of the volume delay functions is a process of determining the SATURN function parameters that produce the same volume delay curves as the Emme/2 functions. This process is relatively straight forward as shown in the comparison of the two curves in Figure 2, however one must ensure that the functions are applicable to the actual on-street traffic characteristics.

Calibration of the model network also entails a thorough check of the "shortest" or "preferred" routes between origin and destination pairs. This was achieved by plotting a series of routes or "forests" from selected zones to all other zones. An example of one of these forests is shown in Figure 3.

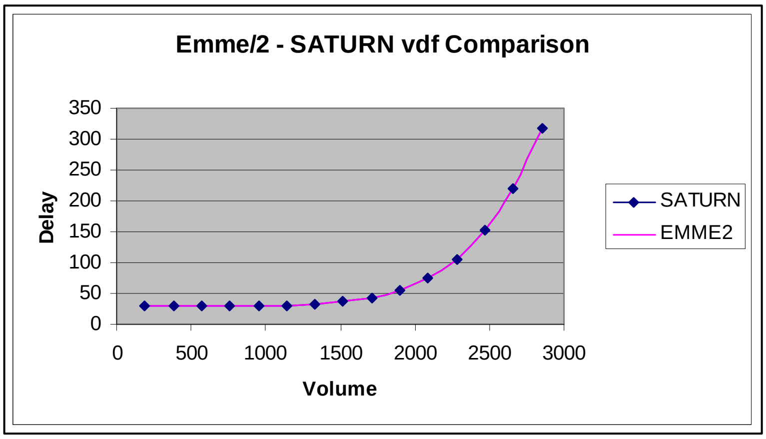

Figure 2: Comparison of volume delay curves

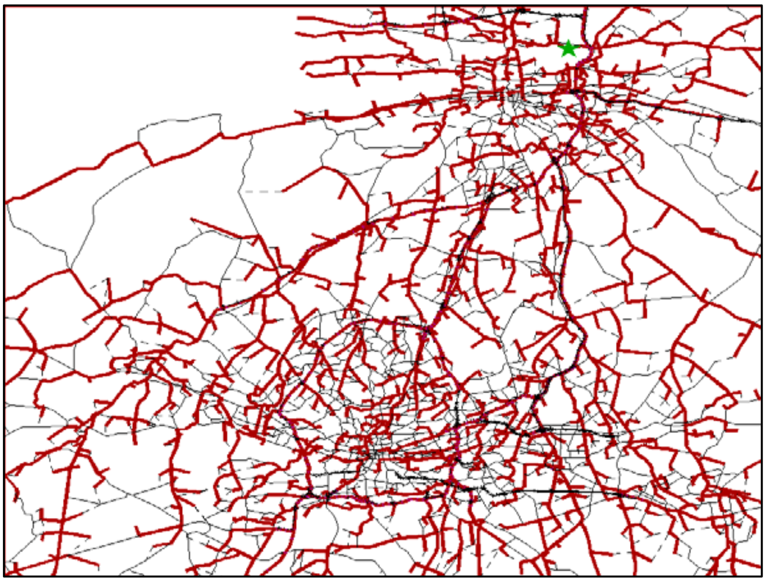

Figure 3: Check forests from zones

In the GFIP model, the volume delay functions were calibrated to match the journey time survey results to an acceptable level of accuracy. This is not a straight forward process, since the first step is to ensure that the modelled journey times are as a result of representative traffic volumes. To accomplish this, a trip matrix was created using matrix estimation based purely on the traffic counts. This process has the ability to irreparably alter the trip distribution within the matrix but can match link volumes reasonably well. The resultant trip matrix was therefore used in the calibration of the volume delay functions and then discarded. The emphasis on this work was to optimise the volume delay functions necessary to represent the different road capacities, free-flow speeds, rate of speed deterioration which best represents road that are also impacted by gradients, interchange merges and weaving etc. Figure 4 shows the calibration results of one of sixty six routes that were surveyed and modelled in the GFIP model. The graphs depict the correlation between the modelled journey times and measured journey times in each direction on the N1 freeway between the Buccleuch and Diepkloof N12 Interchanges. Both directions are modelled with the same volume-delay function, yet the different traffic volumes in each direction result in representative speeds and therefore journey times being modelled.

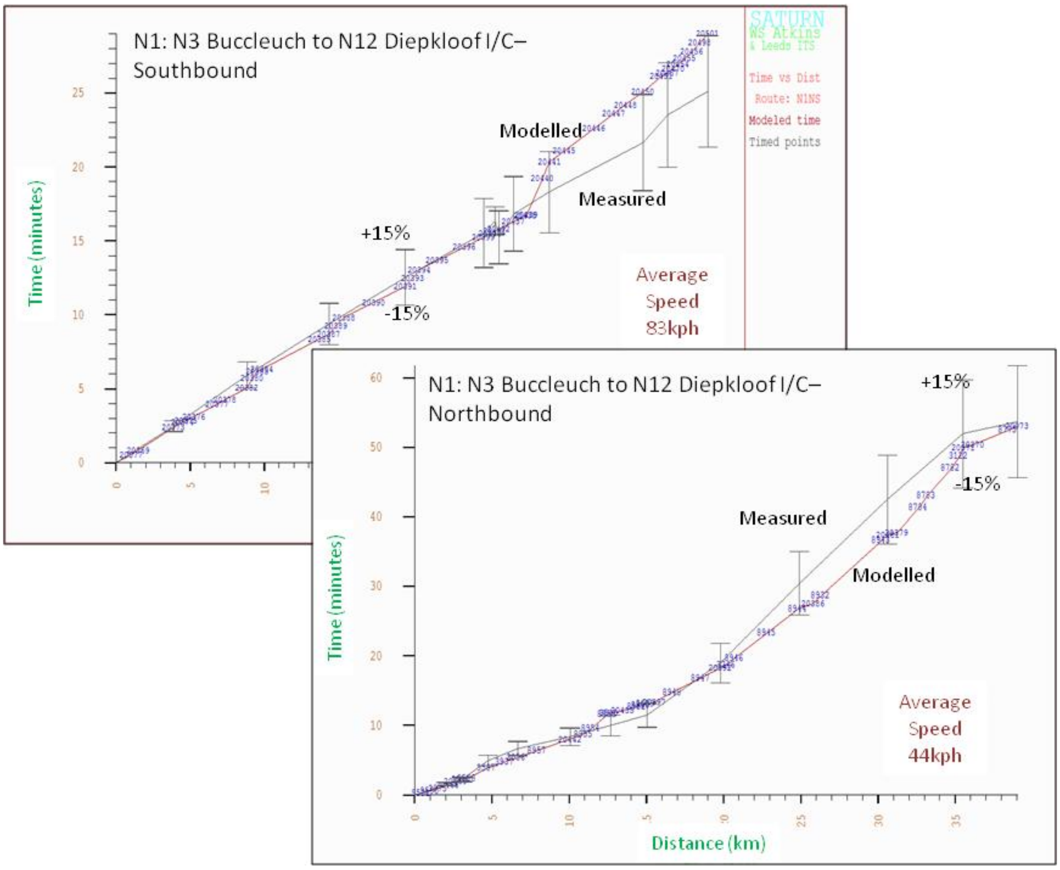

Figure 4: Time/distance calibration of volume delay functions on the N1 between Diepkloof and the N3

These results therefore show that the major road network in the model "reacts" well in terms of calculated speed based on traffic volumes. With this result together with logical routing through the network, the modelled network was deemed fit for use.

<u>Calibration of trip generation rates</u>

The trip generation rates commonly used for traffic impact studies (Department of Transport, 1995) are based on entry/exit counts. In a strategic traffic model, traffic zones should be homogeneous land use types but this is seldom the case mainly because of the size of the zones. As a result it can be expected that the trips generated from/to large zones would be significantly lower than the sum of those measured at the "gates" of all of the developments within the zone. The main reasons for this would be:

- The larger the zone containing mixed land uses, the higher the probability of intra-zonal trips thus reducing the number of trips entering/leaving the zone.
- The commonly used trip generation rates were documented in 1995. It is estimated that the morning and evening peaks have been spreading by 10 to 15 minutes per year. Therefore what used to happen in the peak hour now happens in twp to two and a half hours. Considering that the model is based on an hour, the modelled peak hour's generated trips are a fraction of the manual's figures due to peak spreading.

Through an iterative process comprising adjusting the trips generation rates, trip distribution function, and trip matrices (the latter processes described below), in the GFIP model, it was found that the average trip generation rates entering the rod network from the zones was 37% of the trips that were calculated using the recommended rates as provided in the SA Trip Generation Rate Manual.

Calibration of distribution functions

The semantics involved in the description of the trip distribution function can be quite divers. Essentially it's a function that describes the probability a trip being made in relation to the distance or cost associated with making the trip. From a loaded modelled network, the generalised cost of travel between all OD pairs is calculated and then applying the distribution function to these costs the probability of trips being made between the OD pairs are calculated. These probabilities are then factored up to the zone's trip ends (generations and attractions) to produce the initial base year trip matrix.

In the GFIS model, the initial distribution function was based on those developed for the GTS2000 model, which were derived from household interview data. However no such work has been done in relation to the movement of heavy vehicles. In previous models, the heavy vehicle trip matrix is assumed to be a proportion of the total vehicle matrix. This is fundamentally wrong as trucks do not "commute" from residential areas. In the GFIP model, the heavy vehicle matrix was derived from the land use data pertaining to industrial and retail floor area as well as employment data. Due to the spatial distribution of industrial zones, a distribution function that produced a longer average trip length than for private cars was selected. The total number of heavy vehicle trips was assumed to be equal to the same proportion of heavy vehicles in the traffic counts on the freeways. The heavy vehicle trip ends were distributed amongst the traffic zones in proportion to the size of the industrial and retail components in each zone.

Calibration of the base year trip matrices

The calibration of the base year trip matrices required iterations between the above processes and only then the adjustment of the matrices based on observed traffic counts if necessary. This should be the last step in the process and used to make relatively small "final" adjustments to the trip matrices. This process is heavily reliant on the calibrated network and making sure that as far as possible the correct trips between OD pairs pass through the count locations, i.e. the trip routing is logical. If this is not the case, matrix estimation using traffic counts can have a detrimental affect on the trip distribution in the trip matrices. If multi-user trip matrices are used, i.e. light and heavy user classes, then multi-user class matrix estimation is required. The degree of calibration of a model is often measured in terms of the comparison between the counts and modelled link flows using the GEH statistic and the R^2 value.

In the GFIP model development, prior to using matrix estimation based on counts the model was displaying R^2 values above 80%. An assessment of some of the outliers revealed most of these were because of the position of zone connectors in relation to a traffic count. It must be remembered that very few of the lower order roads are in the modelled network and that all roads leading from an area is often represented by a single zone connector connected to a node (intersection). Therefore any counts located on the approaches to such zone connector can lead to errors where in fact the assignment was quite acceptable. Matrix estimation to traffic counts was therefore used to make relatively slight adjustments to areas of the model were assigned volumes did not match the counts to an acceptable degree of accuracy, due to zone connectors, land use variations or insufficient network detail.

Model validation

Model validation is used to test the robustness of the model. This involves comparing model outputs with data that was not used in the calibration process. An option here would be to not use approximately 20% of the traffic counts in the calibration process and compare the calibrated assigned volumes to these counts to validate the model. In the GFIP model, counts on various sections of freeway were excluded from the calibration process and use for validation purposes.

The choice of assignment algorithm

The assignment algorithm commonly used in modelling packages is the equilibrium assignment. This method assumes that trips would distribute itself on alternative routes in such a way that the cost of travel is the same on all paths used between an origin and destination. An alternative method is the use of a stochastic assignment algorithm. Using this method, trips will only be assigned to routes that are within a specified range of the minimum *perceived cost* between OD pairs (van Vliet, 2008). The distribution of trips between these routes is based on a distribution function (such as a normal distribution) as specified by the modeller.

In addition to these algorithms, there is the option to use an elastic assignment algorithm. This option allows the user to define a rate (or factor) that is applied to the "current" cost of travel between OD pairs that defines "acceptable" travel costs. When the design year demand trip matrix is assigned, trips between OD pairs that would have higher than the "acceptable" trip costs are reduced on the basis that the balance would not travel during the peak hour or use an alternative mode of transport. The result of this process is the creation of a "supply" trip matrix from the demand matrix. An advantage to this assignment algorithm is that it results in more realistic link volumes in the design year forecasts, yet the latent demand is retained in the model such that, if the network is improved and the travel costs reduce, more of the demand matrix is assigned to the network in the modelled hour.

As stated from the outset, models are generally built for a specific purpose. An important output from the GFIP model was to estimate toll revenue from various freeway improvement schemes and toll strategies. As the base year traffic volumes were known, so were the daily flow profiles enabling annual traffic volumes to be estimated. This could then be repeated using the forecast traffic volumes. If, for the design years, only a portion of the demand matrix is assigned, as would be the case of using the elastic assignment algorithm, the daily flow profiles would have changed making it very difficult to convert the resultant modelled hourly flows into annual flows.

The development of model forecasts

The main point of developing a model is to test "what if's" in particular what will happen in some future date when some or other road network improvement is implemented. Traffic growth can be based on an estimated annual growth in demand, which is applied by factoring up an entire matrix. The only problem with this approach is that the trip end growth is the same for a fully developed densely populated area with no room to grow and an agricultural area that currently has few trips but may development into residential estates in the near future. The preferred method for large strategic models is to update the matrix in accordance to predicted changes in land use. Hence the need to calibrate trip generation rates during the model calibration process.

In the GFIP work, since the pre-"matrix estimation" assignments were relatively acceptable and that matrix adjustments based on counts were relatively minor and aimed at taking into account "model quirks" such as zone connector positions or missing lower order roads. The question as to the method of forecasting became one that plagues some modellers.

When forecasting, some parameters are assumed to be fixed with time, for example the trip cost distribution function. This does not mean that one can simply use the design year land use data to calculate new trip ends, apply the probability matrix used to derive the base year "prior" matrix to determine the design year matrix. This would not take into account the "model quirks" ironed out in the final calibration of the base year model. It also does not necessarily mean that one can apply the new trip ends and "Furness" (factor up) the base year matrix, since changes to the network in certain areas would change the trip probability matrix.

In the GFIP modelling work the base year trip cost distribution function was used to derive the trip probability matrix for the various phases of network upgrades. The future trip ends from the predicted land use were use to factor up the probability matrix. So far the same process as for the base year prior matrix. The design year matrices were therefore calculated by subtracting the future matrix, calculated from the probability distribution matrix, from the equivalent base year "prior" matrix (determine from the same processes) and adding these changes to the calibrated base year matrix. This method "retained" changes in the final step of the base year calibration process, i.e. retaining the small adjustments made for the "quirks" in the model.

5. SUMMATION

The development of the GFIP strategic traffic model was a challenge due to the time frame within which the model had to be developed. This made it essential to draw on the work that had been undertaken by other engineers to develop regional strategic models. Without being able to access this good work, it would have been impossible to met the required deadlines. With access to these models and with updated traffic and land use data it was possible produce a reliable and robust strategic traffic model. This model was used to test the various road upgrading schemes for a number of design years.

This work emphasised the importance of spending time on the coding and checking the modelled road network including the calibration of the speed flow relationships. This is not such a straight forward task considering the size of the model, but with the use of a good dose of logic and use of the modelling suites network analysis tools, it is well worth the effort and time.

Acknowledgements

The author wishes to thank the following organisations that were integral in the GFIP project:
The South African National Road Agency Limited for the opportunity to undertake the modelling work and the support given throughout the project, and for the support in the preparation of this paper.
Goba (Pty) Ltd. in join venture with Tolplan (Pty) Ltd, the consultants appointed to undertake the strategic modelling work for the entire project, as well as detailed design of various sections of the current freeway upgrades.

Bibliography

Oxford Dictionary [Book] / auth. Oxford University Press. - Oxford : [s.n.], 1976. - Sixth Edition.

SATURN User Manual [Book] / auth. D van Vliet. - [s.l.] : ITS Leeds, 2008.

South African Trip Generation Rate Manual Second Edition [Book] / auth. Department of Transport. - Pretoria : [s.n.], 1995.