AN EXAMPLE OF PUBLIC TRANSPORT MODELLING WITH EMME/2

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To improve, optimise and restructure the public transport system in metropolitan areas on a strategic level, a comprehensive method in regard to public transport modelling has been developed. This method has been successfully implemented in the Durban Metropolitan Area in the year 2000.

The strategic public transport model consists of a combination of several analytical computer programs. The heart of the model is the transport model Emme/2 in use by most of the Metropolitan councils in South Africa. The features of the model are:

- **Matrix building**: a unique method was developed to extract public transport origin – destination (O-D) matrices for rail, bus and minibus taxi passengers from on-board surveys. A method was developed for generating direct O-D trips and removing component rides of transfer trips, which enabled all-modes O-D matrices to be built for selected time periods.
- **Network building**: a computer programme was developed to build a road network based on public transport lines stored as CPTR data in the Durban Public Transport Management Information System. Making use of a taxi OD-matrix and the public transport optimisation model PTOPT, taxi lines were generated.
- **Level of Service indicators**: Emme/2 macros and extensive Excel spreadsheets were developed wherein any specific strategy could be evaluated against an existing situation benchmark. Passenger levels of service criteria such as average fares, waiting and walking times, mode transfers, weighted travel times, annual costs and revenues were incorporated in the spreadsheet after a model run in Emme/2.
- **Converting Emme/2 result into GIS format**: an interface program was developed to convert Emme/2 modelling results into equivalent GIS features. The features were imported into PTMIS, which then became the graphical platform displaying network information, passenger volume bandwidths and other results.

The different modules are user friendly and can easily be customised for other metropolitan areas.

Introduction

In terms of the Moving SA Action Agenda and recent legislation, the public transport system has been identified as one of the key elements that needs to be rectified. The main impetus for this is that the current subsidy levels are clearly not sustainable and the inefficient system that grew over the years now needs to respond to the changes within the country. To improve, optimise and restructure the public transport system in metropolitan areas on a strategic level, a comprehensive method in regard to public transport modelling has been developed.

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The method has been developed as part of the Fundamental Restructuring of Durban Public Transport Task 3: Least Cost Strategy. The strategic public transport model consists of a combination of several analytical computer programs. The heart of the model is the static transport model Emme/2 in use by most of the Metropolitan councils in South Africa.

Conceptually, the Emme/2 model configuration is divided into two separate and complementary streams. Firstly, standalone assignments of separate matrices to each of the main modes rail, taxi and bus, and secondly, one integrated assignment of the total trip matrices (which parallels the combined effects of main mode travel with inter-modal transfers). Figure 1 shows the two streams.

A representative peak hour matrix was used, derived by combining the two early survey periods.

The paper explains the modelling exercise and the difficulties in building the matrix and the network. In this paper the following subjects are not discussed:
- Calibration process
- Development of public transport strategies for Durban
- Results of modelling exercise in Durban.

**Figure 1 : Complementary streams of Emme/2 modelling exercise.**
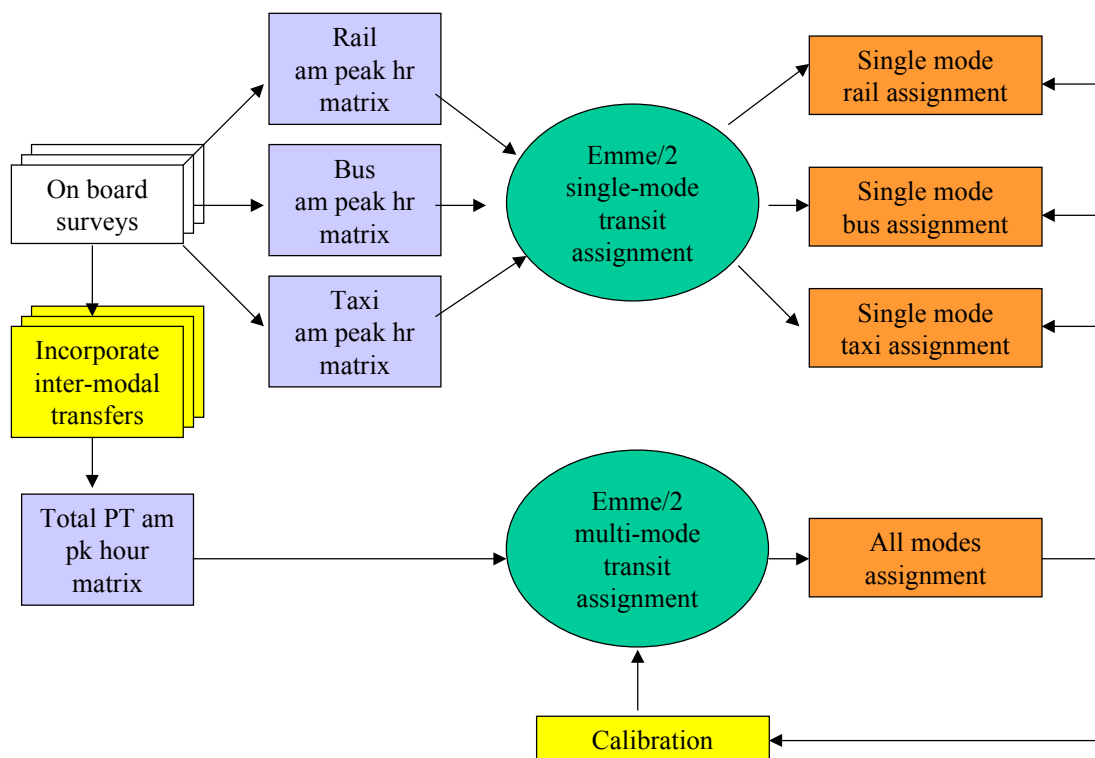
The features, which made the modelling exercise unique, are:
- **Matrix building**: a method was developed to extract public transport origin – destination (O-D) matrices for rail, bus and minibus taxi passengers from on-board surveys. A method was developed for generating direct O-D trips and removing component rides of transfer trips, which enabled all-modes O-D matrices to be built for selected time periods.

- **Network building**: a computer programme was developed to build a road network based on public transport lines stored as CPTR data in the Durban Public Transport Management Information System. Making use of a taxi OD-matrix and the public transport optimisation model PTOPT, taxi lines were generated.
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- **Converting Emme/2 result into GIS format**: an interface program was developed to convert Emme/2 modelling results into equivalent GIS features. The features were imported into PTMIS, which then became the graphical platform displaying network information, passenger volume bandwidths and other results.

The different modules are user friendly and can easily be customised for other metropolitan areas. Figure 2 shows the set-up of the model including some input and output modules.

Figure 2: Set-up and interactions between the different modules.
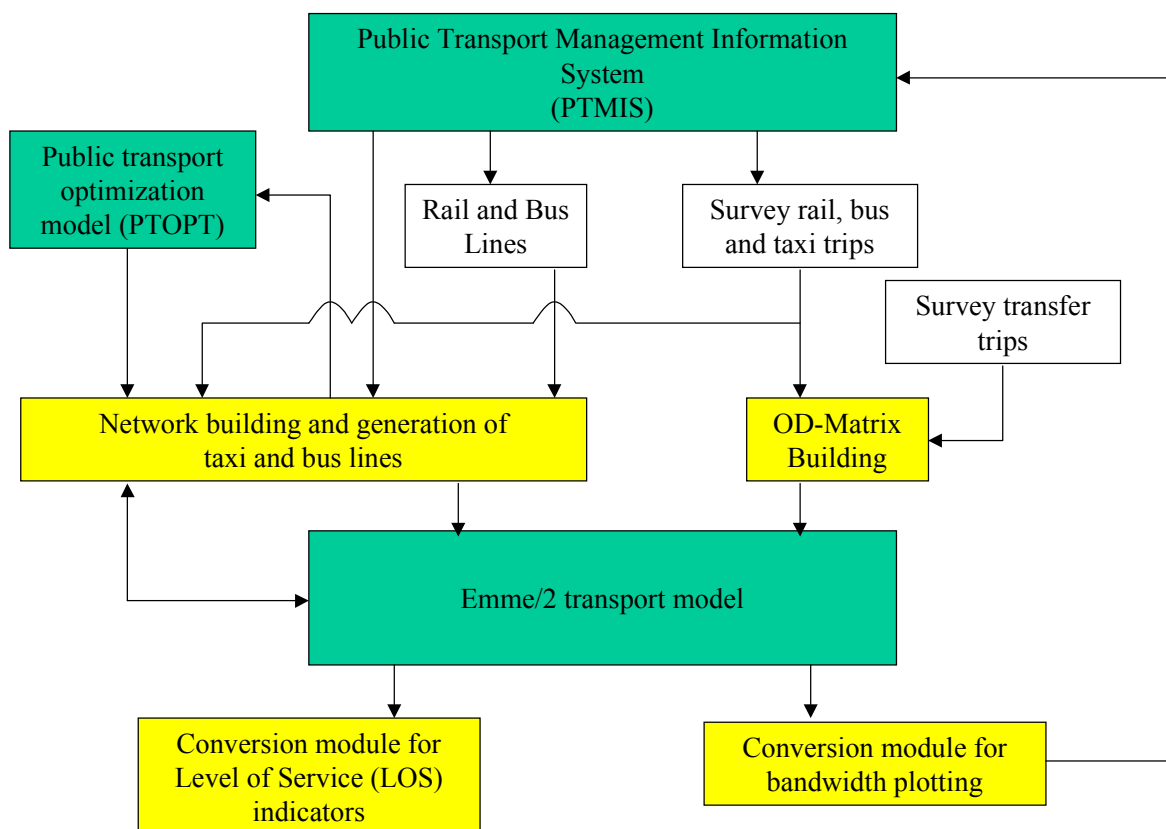
The 4 modules will be reported in separate sections. But first a description of the Public Transport Management Information System (PTMIS) will be given, as PTMIS provided most of the input for the Emme/2 model.

Initially, Stewart Scott developed PTMIS in support of the Durban Metro Fast Track Public Transport Study[1] which was conducted jointly by six consulting firms from May 1998 to June 1999. The intention was to capture and report upon the current public transport records (CPTR), as collected during the course of that investigation. Detailed taxi route and fare information was not available, due to route ownership sensitivities. This will be resolved via a formal and legal *challenge* process, which to date is still in progress. Consequently, route and fare information was limited to rail and bus modes.

PTMIS evolved further to provide a more general platform for storing, analysing and exchanging public transport information. In particular, Stewart Scott was able to extract network and route information from the PTMIS database. De Leuw Cather Emtateni built trip matrices from on-board bus, taxi and rail surveys using DELTRAN programs.

OD Matrix building

The OD surveys were undertaken from 05h00 to 10h00, for three time periods: 05h00 to 07h00, 07h00 to 08h15 and 08h15 to 10h00. In addition to the surveys of each mode, two other surveys were used to derive information on trip transfers: a suburban transfer centres survey in 1999 and a comprehensive interview survey in Durban CBD in 1998. The taxi survey was based on trips from residential areas to work areas, and did not cover Durban CBD or other work area origins. The Durban CBD survey was used therefore to supplement the taxi survey, as well as to analyse transfers.

A client requirement was to use a link to link OD survey rather than zone to zone. This made on-board observation and recording of boarding and alighting locations feasible, but it made for a complex and voluminous OD pattern. The links effectively became zones, and the final tally was 626 (see section about network building).

Data cleaning and building all modes trip matrices for the three time periods with the available data, resizing and incorporating transfer trips while eliminating individual legs of such trips was a lengthy process, which required a number of special purpose programs to be written.

The taxi survey OD data was compiled in such a way that trip origins were imputed to the links leaving a residential area, with no trips on links within such area. This provided a matrix which was too coarse, therefore, the trip origins were redistributed among all the links in each area on the basis of link lengths and knowledge of development patterns.

The trip matrices by mode and the direct transfer matrices were added, and the separate transfer legs were subtracted. The resulting matrices by time period contained several link zone totals with negative values, meaning that the transfer legs outnumbered the trips in the main survey matrices for particular modes in those zones. This applied particularly to taxi trips and to the peri-urban transfers survey.

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[1] Durban Fast Track Public Transport Study: Report on the Assembly of Current Public Transport Records, July 1999

There are four possible causes of this problem:

1)   The peri-urban transfers survey was initially coded coarsely into 77 large areas.   The subsequent requested re-coding into the 75 metro zones may not have been sufficiently accurate.

2)   Taxi trip origin distribution was refined subjectively and this may not have been sufficiently accurate.

3)   Local feeder trips within low income residential areas could have been missed in the taxi survey, but picked up in the transfers interview surveys.

4)   The transfers surveys were resized from 175 to 626 zones on the basis of fine zone OD totals. This inevitably builds in some generality and, additionally, transfer trip distribution may not be proportional to total trip distribution in any zone.

The negative values were set to zero, which increased matrix totals.   The previous totals were assumed to be correct, therefore, the matrices were factored down accordingly. Several specific fine zone ODs were edited to correct obvious errors. Final trip totals are shown in table 3.

Table 1:   Matrix totals

Time	Taxi	Bus	Train	All Modes incl. transfer	Direct transfer CBD	Direct transfer Peri-urban	All modes
05.00-07.00	118.063	41.666	47.146	206.875	8.524	22.740	197.000
07.00-08.15	87.293	48.882	30.483	166.658	11.358	11.432	151.000
0815-10.00	56.073	22.164	12.096	90.333	6.783	8.098	81.000
Total	261.429	112.712	89.725	463.866	26.665	42.270	429.000
Modal split	56%	24%	20%	100%	n.a.	n.a	n.a

To simplify model calibration and for illustrative purposes, a peak hour trip matrix was prepared, composed of 50% of the peak period 05h00 to 08h15, i.e. 174 000 trips.

Network building

The definitions of bus and taxi route sub-sections, as well as the commuter rail right-of-way, as encapsulated in the Public Transport Management Information System (PTMIS), were the primary data sources for the network description. Conversion of such GIS-based information into equivalent traffic zones (or catchment areas), zone connectors, nodes, links, speeds and public transport routes presented a formidable technical challenge to the team, as the data formats were not readily compatible. A series of computer programs was developed to address these conversion difficulties.

Base Network Definition
The GIS route sub-sections perform a dual role: they represent segments of the route system *and* they serve as trip origins and/or destinations. This is in direct contrast to conventional computer models, which normally draw a clear distinction between the trip origins and destinations (OD's) and the transport network. A compromise solution was conceived whereby the 626 road-based sub-sections were treated as catchment "zones", with a width of 500 metres either side of the sub-section centre-lines. Each catchment zone was connected to a point representing the approximate centre of the sub-section. Again, this necessitated the development of software modules able to discern the catchment midpoints by examining the series of GIS co-ordinate points, and still retain the integrity of the GIS sub-section definitions (i.e. in terms of the CPTR requirements).

Modelling constraints (e.g. Emme/2 and DHV limitations on the total number of traffic zones) also imposed additional restrictions on the original definitions of route sub-sections. A large degree of overlap among the sub-sections was necessary to keep the matrix sizes within manageable bounds. From a GIS or visual aspect, this does not represent a problem, but for modelling purposes, such overlaps needed to be "untangled" in order to create unique and separate network links. This again required custom-written software to detect the points of overlap by examining separate series of GIS co-ordinates, and then to place new network nodes at all points of divergence as shown in Figure 3.

Figure 3:   Emme/2 network building from a GIS network.
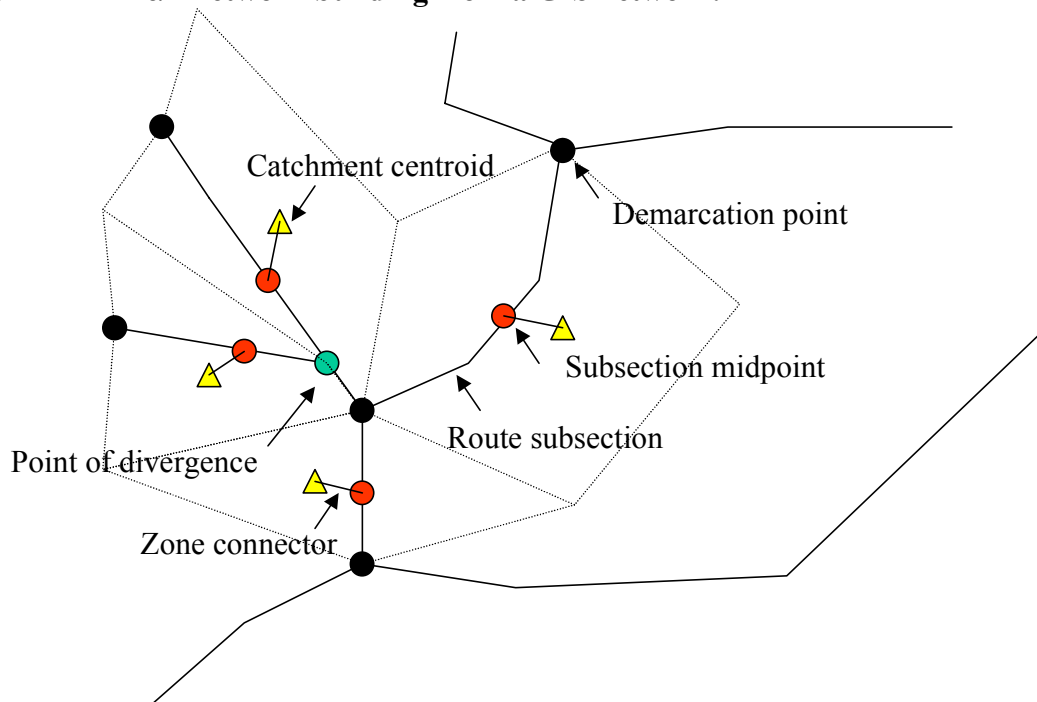
In order to accommodate the 626 centroids in the models, the main (survey demarcation) nodes comprising the sub-section start and end points, needed to be renumbered. With the addition of sub-section midpoints and points of divergence between overlapping sub-sections, a considerable degree of node duplication resulted. These were cleaned up manually. The resultant network links could then be translated into Emme/2 and PTOPT formats, with link distances being calculated from the series of GIS co-ordinates representing each link.

Overall, the base network thus consists essentially of straight lines between original (demarcation) nodes, sub-section midpoints and points of divergence between sub-section overlaps. Additional nodes were introduced to separate links which, due to the straight lines, resulted in visual confusion. Rail links were constructed in a similar fashion by examining the rail GIS co-ordinates, this conversion process requiring far less effort than for the road-based links.

"Dummy" zone connectors were then defined to link the catchment centroids to the sub-section midpoints. Connector distances were defined manually by examining the geographical and land-use characteristics of each specific route sub-section.

Fare and Travel Time Functions.
For the base year calibration, the following modes were defined within the Emme/2 model:
Linear fare functions for each mode were derived using regression analysis, with each function containing a boarding penalty and a distance-based on-vehicle component, as shown in table 2.

Table 2: Fare Functions

Mode	Fare Formula (in Rand)
Rail	0.039 x km + 0.76
Taxi	0.104 x km + 1.232
Bus	0.073 x km + 2.339

The corresponding Emme/2 line travel time functions for each of the three main modes were defined as per table 2, in order to allow tailoring of the various modes to include the effect of km-based fares. Emme/2 uses time (or generalised time) to generate optimal route and mode choice strategies, so these functions are expressed in minutes. They all incorporate nominal time values for the fare, expressed as emme/2 scalar matrices ms1, ms2 and ms3 (e.g. 10 minutes per Rand), which can be manipulated to obtain an optimal calibration of the base year model. The terms in brackets represent the on-vehicle fare component, whereas boarding penalties were incorporated by specifying the constant components in the fare functions (table 2), multiplied by the same time values of the fare, ms1, ms2 and ms3. These values are then stored in the user-defined Emme/2 transit line field, ut1, and incorporated during the integrated transit assignment as a line or mode specific boarding penalty.

Table 3: Mode Travel Time (Fare) Functions

Function	Mode	Format
ft1	Rail	length x 60/Speed + (.039 x length)*ms(1)
ft2	Taxi	Timau/1.25 + (.104 x length)*ms(2)
ft3	Bus	Timau + (.073 x length) *ms(3)

Bus Routes

The PTMIS records distinguish two types of bus routes: those declared by operators as being valid routes and the actual operational routes as determined during on-board surveys. From a modelling point of view, only the surveyed routes are considered to be representative of the current travel demand.

These operational routes were captured into PTMIS in the form of Access tables. Each route was described in terms of sequential main demarcation nodes, hence a further conversion was required to determine the new node number of each demarcation point, or the equivalent emme/2 node, if for some reason the original main node had been eliminated from the network. Additionally, since the sequence of demarcation node numbers described valid sub-sections, it was important to ensure that Emme/2 correctly determined the path along the original street definition of the sub-section. Again, the team had to resort to custom-written software to effect these changes correctly.

These transit lines were then imported into an Emme/2 scenario, and the peak hour bus matrix assigned to the "stand-alone" mode. A total of 818 one-way transit lines was generated in this stand-alone mode, representing 34,047 transit segments (a segment in emme/2 is defined as the unique combination of transit line + link).

Emme/2 level 4 release (the model licence size allocated to Stewart Scott and Durban Metro) can only accommodate 40,000 transit line segments. Hence the model would not be able to handle an integrated transport assignment, with full bus, rail and taxi transit lines, without further simplification. An Emme/2 pruning exercise was then conducted whereby all transit lines which carried less than a maximum line volume of 25 passengers, were "culled" from the set. The matrix was re-assigned, and a workable, reduced set of bus routes, containing 447 one-way bus transit lines

with 19,747 line segments, emerged. Only 900 passengers (2%) were left "stranded" (unassigned). This action immediately pointed to the possibilities of radical pruning of the "dead wood" in the bus system without noticeably affecting the overall level of service, as part of a general strategy.

Rail Routes
These were captured manually directly into an Emme/2 format batch input file, after examining the PTMIS rail timetables.

Taxi Routes
The lack of suitable route data for the mini-bus taxi mode required extensive software development and trial-and-error modelling to derive a representative set of synthetic taxi routes. Two approaches were tried:

- DHV's PTOPT was used to generate optimised routes to match the taxi peak hour trip matrix.
- An Emme/2 route "pruning" macro was developed to reduce a starting set of possible routes to manageable proportions.

Both approaches were capable of generating a reasonable set of taxi routes, each satisfying a different overall objective. The PTOPT method employs rigorous mathematical and linear programming techniques in order to arrive at an end-state that minimises the number of passenger transfers. Upwards of 100,000 possible routes are generated and evaluated, so the total process tends to be quite slow, requiring overnight computer runs.

The Emme/2 pruning macro starts off by generating a much smaller subset of possible routes by only considering OD pairs which would require transport for a minimum of 5 passengers. The resultant 1,797 OD pairs were then converted to one-way lines by providing Emme/2 with the start and end nodes, for automatic path building. By default, Emme/2 would generate shortest distance *paths* between these node pairs. All link distances were temporarily changed to the corresponding link travel times in order to "fool" Emme/2 into building shortest *time* paths, which are more representative of taxi driver behaviour. All such generated routes started off with a 5-minute headway. The peak hour taxi matrix was then assigned to this set of lines and by examining the resultant maximum line volumes, the supply side could be adjusted successively until a convergent end point was obtained.

The second technique gave a quick turn-around, providing a solution in under an hour, so this was used to establish the basic set of synthetic taxi routes, in favour of the more comprehensive PTOPT process. After about 40 iterations of the pruning macro, a resultant set of less than 500 taxi lines (requiring approximately 14,000 line segments) were produced, with the line frequencies adjusted to match the total demand.

Throughout the development of the set of synthetic taxi lines, Emme/2 transit assignments were made to assess visually the taxi travel patterns created by the set of lines. Local knowledge and cordon counts were employed to verify the accuracy of the process, and many network adjustments were made in order to fine-tune the route generation.

Level of service indicators

The ability to measure and compare components is fundamental to any evaluation process. It is also important to apply a consistent yardstick to the process by establishing a suitable benchmark (normally the existing situation) against which different strategies can be compared and the relative

merits of each assessed. The evaluation must also be structured in such a way that impact on the different role players, all of whom have different perspectives, can be estimated fairly accurately.

This section describes the process in creating an evaluation procedure that encompasses the following cornerstones:

- The use of the a.m. peak hour integrated public transport Emme/2 model, which was built specifically for the Task 3 exercise. This model provides the mathematically consistent platform for estimating the transport dynamics of any specific strategy. Each new strategy conceived by the study team would be encoded into Emme/2 format in terms of network, mode, route and fare structures.

- The development of an extensive Excel spreadsheet model, wherein any specific strategy could be evaluated against the base year benchmark. Here, all the various calculations pertaining to passenger levels of service criteria, inclusive of average fares, waiting and walking times, mode transfers, weighted travel times, etc. as well as annual costs and revenues, are performed. The analyses are presented as tables and graphs, sub-divided into 27 geographical areas.

- The creation of a series of custom-written Emme/2 macros designed to extract supplementary information from the model and to process the Emme/2 model results into a format suitable for input into pre-defined Excel spreadsheets, along with a custom-written Excel macro to import the model data into the spreadsheet

Figure 4 illustrates the interaction between the various components of the evaluation procedure framework.

Figure 4 : LOS Procedural framework
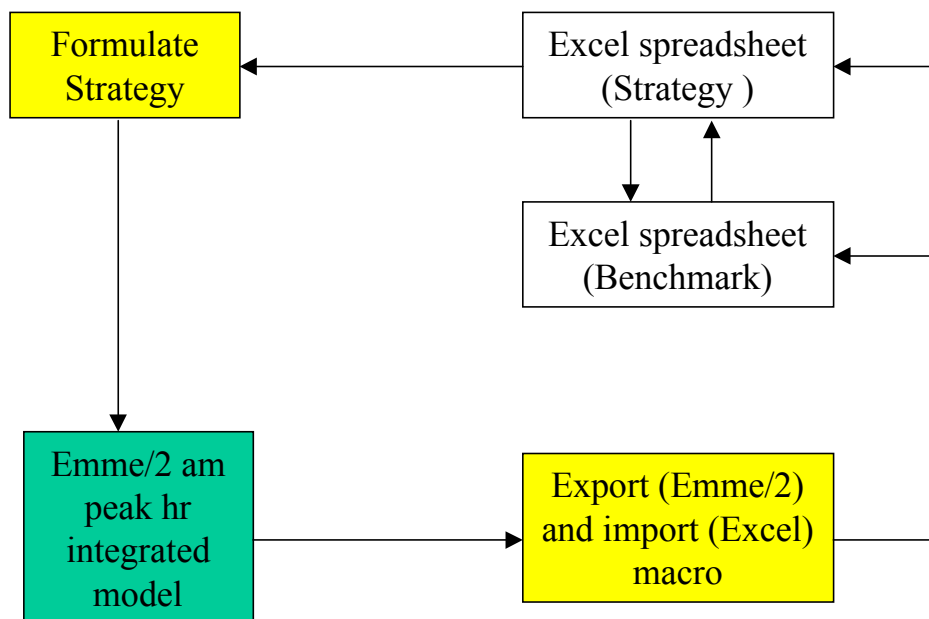
The evaluation process achieves mathematical consistency across all strategies by assigning the same base year am peak hour all-mode matrix to the public transport system corresponding to the strategy under examination. In essence, the basic model run is simplistic in that it comprises a single transit assignment, a relatively trivial Emme/2 process. The complexity is introduced by dividing the analysis into 27 geographical areas and assigning trips originating in each area separately onto the transit network. Since Emme/2's transit assignment does not cater for capacity restraint and/or overcrowding, it follows that individual travel choices will be made independently of the choices made by the other users of the system. Thus, whether one assigns a single origin destination (OD)

trip or the entire matrix, the resulting route choice will be the same in all cases. This has the added benefit that fragmented assignment results will be additive.

Service utilisation (passenger volume to capacity ratios, by route) proved to be one of the trickiest components to quantify in the model runs. The basic premise is that a specific strategy relies upon a target utilisation being achieved for each mode, which unfortunately creates a modelling feed back loop. In order to increase or decrease passenger utilisation on a particular route, the headway must be reduced or increased. This in turn affects the passenger waiting times, which influences the choice of route, thereby attracting fewer or more passengers, which then changes the utilisation. Generally, a number of iterations was necessary to stabilise route supply and demand, for each mode's target utilisation.

Excel Evaluation Spreadsheets
Two types of spreadsheet were defined, one to create, refine and store the benchmark threshold, and the other to undertake the comprehensive analyses of a particular strategy, by creating and storing all the data pertaining to the strategy. The spreadsheet structure, calculations and import macros in the two types are essentially the same, the only difference is that strategy spreadsheets are linked back to the benchmark threshold, in order to draw meaningful graphical comparisons between the two systems. Graphs in the threshold thus show only the benchmark values, whereas in the strategy spreadsheets, bar charts for both the strategy and benchmark are illustrated. Figure 5 shows a screendump of some graphs produced by the LOS-spreadsheet.

Figure 5 : Screendump LOS Spreadsheet
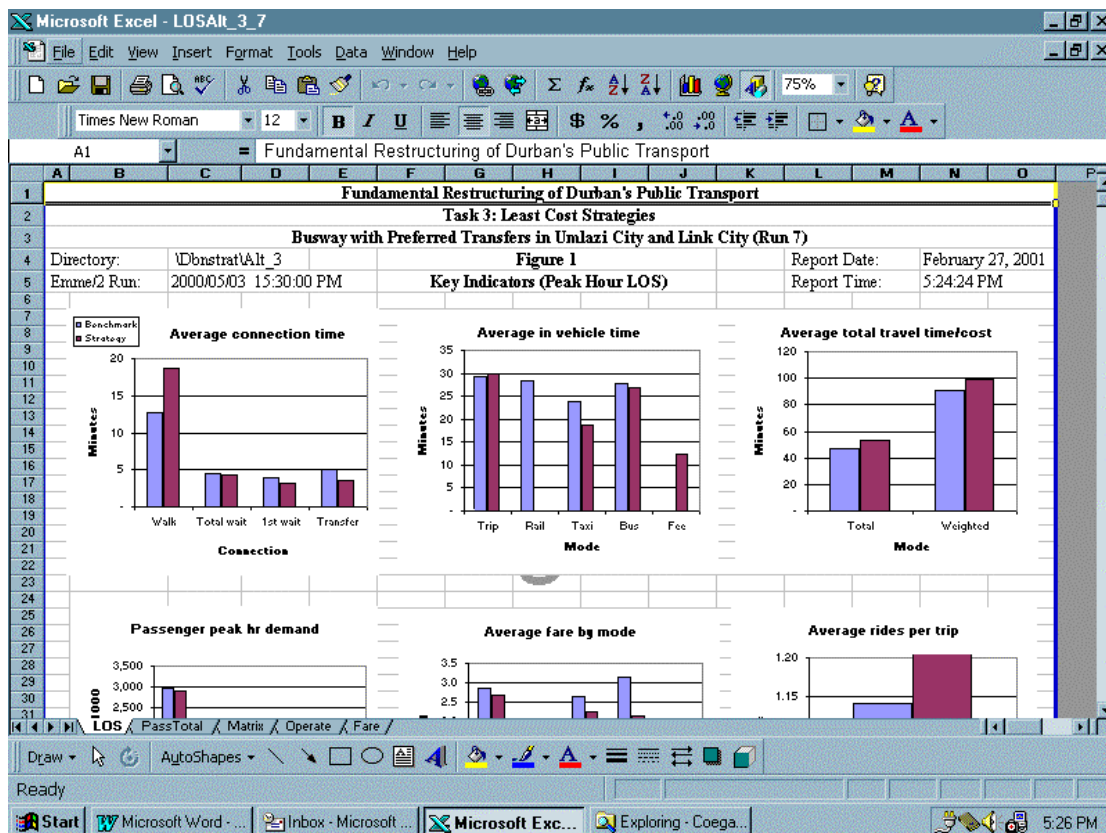
Conversion Emme/2 results into GIS format

The Emme/2 transportation model relies on a somewhat archaic and primitive MSDOS-based graphical interface. Since such outdated techniques are out of step with modern Windows 95/98/2000 graphical capabilities, a series of simple interface programs capable of converting Emme/2 modelling results into equivalent GIS features were developed. These were imported into PTMIS, which then became the graphical platform for displaying network information, passenger volume bandwidths and other results. In February 2001 Stewart Scott will start converting the PTMIS to an ArcView environment. It will be made possible to edit the network and lines in Emme/2 via the graphical interface of Arcview. This will make the management information accessible for multi-users and plotting facilities will increase significantly. Furthermore public transport information, available in the RAS, LTPS, NATIS databases, will be made accessible via PTMIS.

Figure 6 shows an example of a bandwidth plot of a peak hour public transport assignment zoomed in on the Durban CBD

Conclusions and recommendations

The process of using custom written software and emme/2 macros was quite successful. In a relatively short period a complete public transport model was built.

All models are a representation of the real situation on the road. Also this emme/2 public transport model has its limitations. The reliability of the (generated) taxi routes and provided bus routes cannot be addressed for the 100%. But at the end client and consultants agreed with the fact that model produced good results at a strategic level.

It can be concluded that the different modules are user friendly and can easily be customised for the metropolitan areas of Johannesburg, Pretoria and Capetown, but also for cities like Port Elizabeth and East London.

Figure 6: Bandwidth plot of Public Transport Assignment via PTMIS

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He has worked for the DHV Group in the Netherlands, one of the largest consulting engineering companies in Europe, since 1991 and has been involved as a project manager in transportation projects in the Netherlands and other countries in Europe but also in Asia (South Korea, China).

In 1999 he was seconded to Stewart Scott International, South Africa, on a management exchange program. At the moment he is involved in transportation modeling projects in Durban, Pietermaritzburg and Capetown. Mr Nijhout has extensive knowledge of microscopic traffic simulation models like AIMSUN2 and the traditional static transport models like Emme/2 and Questor.