

# UPTRANS: AN INCREMENTAL TRANSPORT MODEL WITH FEEDBACK FOR QUICK-RESPONSE STRATEGY EVALUATION

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## ABSTRACT

The paper describes the development of a prototype transport model to be used for high-level evaluation of a potentially large number of alternative land use-transport scenarios. It uses advanced logit modelling to capture travel behaviour change in a more theoretically tractable manner than the conventional four-step method. The model is designed specifically for fast implementation, with limited calibration needs, to assess a wide range of strategies including transport investment, land use strategies, and management interventions such as high occupancy vehicle lanes or road pricing. A prototype application of the UPTrans model as part of a demonstrative urban and regional growth modelling exercise for the Gauteng Global City Region is described.

## 1. INTRODUCTION

The four-step sequential approach to transport modelling has consistently drawn criticism over the last four decades. In particular, its application in developing countries for strategic and tactical transport planning purposes has been criticised on the following grounds:

- Despite theoretical advances in the field, aggregate models used in practice lack behavioural sophistication, including an ability to adequately capture behavioural feedback effects, land use-transport linkages, time-of-day shifts, and vehicle occupancy shifts (e.g. Behrens, 2004; TRB, 2007)
- Conventional models are data and skills intensive, making them costly and time consuming to implement (TRB, 2007)
- The manner in which transport models are used within the urban transportation planning process is mismatched with the dynamics of developing societies, and leads to over-emphasis of car-based solutions to the neglect of public transport, non-motorised and management options (e.g. Dimitriou, 1990).

These shortcomings, it has been argued, render existing models inadequate in addressing the key transport planning challenges faced in South Africa (Kane & Behrens, 2002).

This paper attempts at improving on especially the first two points raised above. Taking for granted that mathematical models are and will remain useful for assessing the

complex options and strategies available to urban and transport planners, we describe the features of an improved modelling approach that incorporates several of the theoretical advances made in discrete choice modelling to capture behaviour in a more theoretically tractable manner. The model is designed specifically for fast implementation, with limited calibration needs, to be used primarily for high-level evaluation of a potentially large number of alternative land use-transport scenarios within a short period of time. A wide range of strategies can be assessed, including transport investment, land use strategies, and management interventions such as high occupancy vehicle lanes. Outputs are provided in the form of spatially disaggregated performance indicators of the transport-land use system in order to judge the level of service and user cost or opportunities enjoyed by specific user groups.

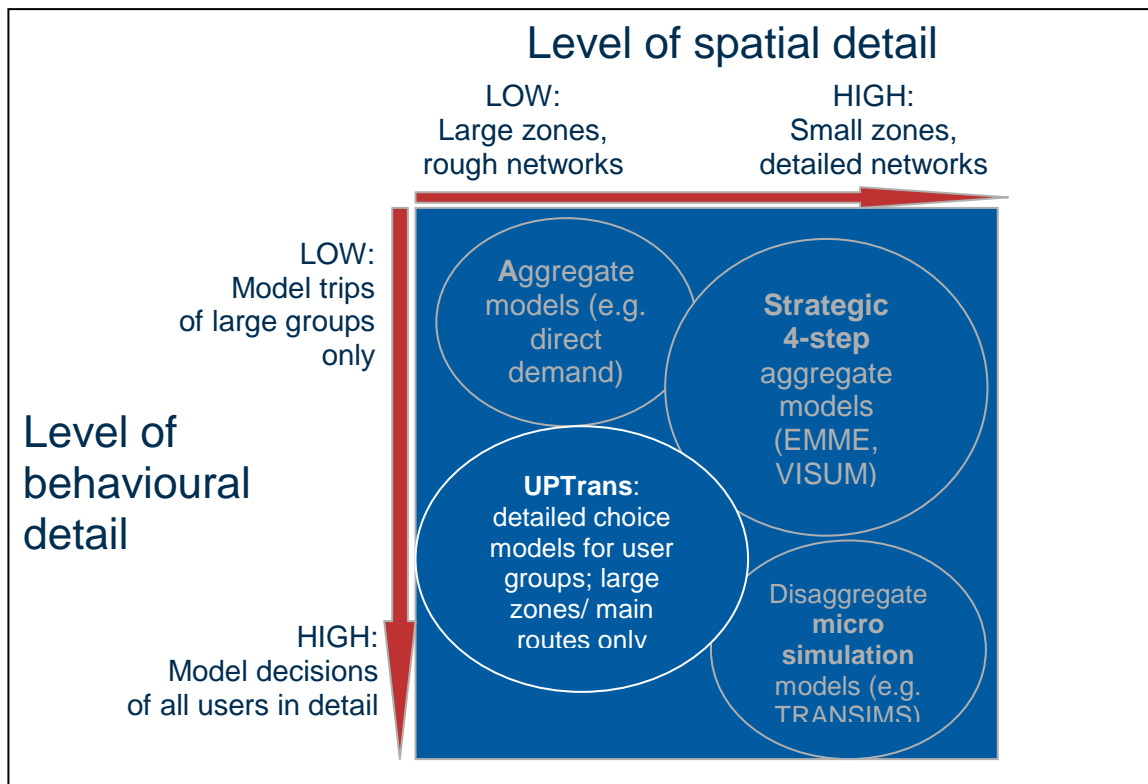
The paper starts by describing the main features of the modelling approach, and, in brief, its theoretical basis. To give a sense of the actual abilities and limitations of the model, the next section describes a prototype application of the UPTrans model as part of a demonstrative urban and regional growth modelling exercise, the Integrated Planning, Development and Modelling Project, implemented by the CSIR in 2008 on behalf of the Department of Science and Technology for the Gauteng Global City Region.

## 2. KEY MODEL CHARACTERISTICS

The UPTrans model is similar in structure and theoretical approach to the START model developed in the 1990s by the MVA Consultancy in the United Kingdom (Roberts & Simmonds, 1997) and successfully applied in the UK and Brazil for strategic urban transport policy development (Bates et al., 1991). However it has been adapted to accommodate the data constraints and key policy questions faced in South Africa.

Key characteristics of the modelling approach are as follows:

1. Travel behaviour is treated in a relatively detailed manner, with **simultaneous prediction** of changes in:
  - trip frequency (i.e. number of trips),
  - choice of destination,
  - choice of mode,
  - choice of vehicle occupancy, and
  - time of day (peak vs off-peak)through the use of an incremental nested logit model. Theoretically, the approach is superior to the conventional sequential four-step models, as these do not necessarily contain any feedback or balancing between the steps.
2. Quick implementation is achieved by using a relatively **low level of spatial disaggregation**, using larger zones than the typical transport model (see Figure 1). This cuts down on the amount of pre-processing needed and the time needed to prepare inputs for new scenarios to be evaluated. The transport network can similarly be represented at a coarse scale, including only major roads or public transport links within and between zones. This is in line with the strategic, rather than project-specific, nature of the tool.
3. To ensure behavioural relevance the model relies on a **high level of demand disaggregation**, i.e. the population is finely divided into person type segments, each segment potentially behaving differently from the others. For instance, using three employment classes (scholars, workers, other), three income classes, and car-owning vs non-car-owning households, 18 segments of people may be considered. Trips are further disaggregated by purpose (work, education, other).

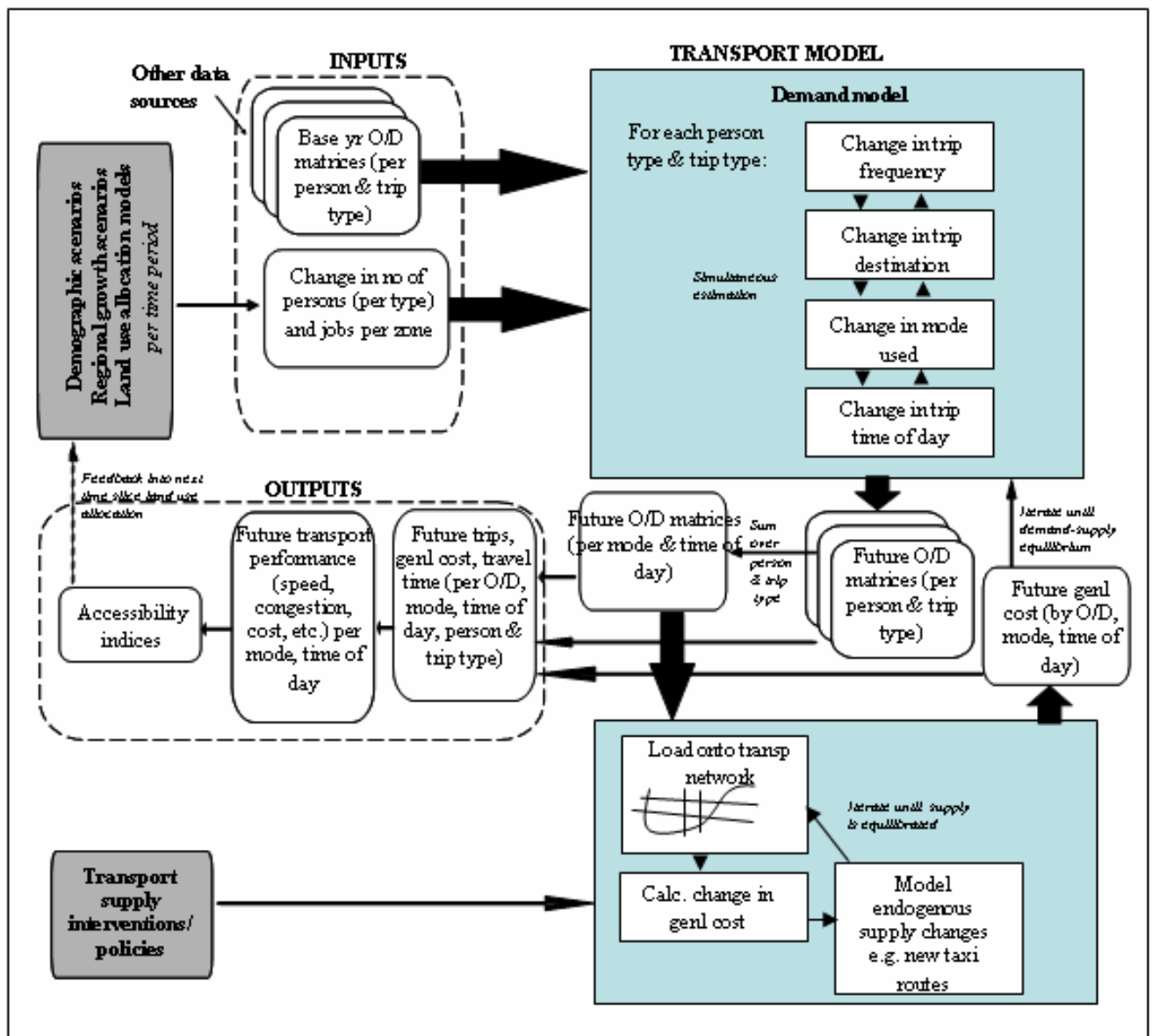


**FIGURE 1 UPTrans in relation to other modelling approaches**

4. The model is capable of including **feedback between demand and supply**, enabling the crucial impacts of supply interventions on trip frequencies, trip destinations, mode use, time of day choice, route choice, and congestion levels to be predicted. (Although the literature suggests that the loss in prediction accuracy resulting from the model's spatial coarseness should be largely offset by its increased behavioural richness and feedback properties (Roberts & Simmonds, 1997), this has not yet been confirmed for the local case.)
5. Changes in behaviour are driven by a **small number of behavioural coefficients**, which are obtained by drawing upon a wide range of previous research (both local and international). This is in line with the model's strategic approach, which avoids *"being limited by the availability of local data and by what could be done in the time available"* (Roberts & Simmonds, 1997: 380)".
6. The model is **incremental**, meaning that it takes the current (base year) population, land use and travel patterns as a starting point, and then models the *incremental* changes that would result over the modelling period(s) as a result of transport interventions and demographic/economic change. This avoids the need for calibrating a base-year model, which is very time-consuming, but reduces the accuracy of the model's simulation capabilities over time horizons of longer than, say, 15 years, when the impacts of unforeseen structural shifts in behaviour and technology might become significant.
7. UPTrans is currently implemented on proprietary software (the **EMME transport modelling platform**), in order to draw on the software's strong transport-specific subroutines, but does not necessarily require strong spatial analysis capabilities.

### 3. MODEL STRUCTURE AND THEORETICAL BASIS

The overall structure of the transport model is illustrated in Figure 2. Input data is supplied in the form of base year origin-destination (O/D) matrices, differentiated by



**FIGURE 2 Diagrammatic outline of transport model components**

person type, trip type, and time of day (e.g. peak period and off-peak). For each forecast year, zonal changes in the number of persons (per type) and activities (such as jobs) are supplied by an external demographic/land use simulator. These changes are converted to a base-line increase or decrease in trip ends per zone using fixed trip rates obtained from previous studies. The base year O/D matrices are adjusted accordingly, in essence to reflect what “theoretical” trip patterns would look like if land-use and demographic changes took place without any change in the generalised cost of transport.

The heart of the model is the demand and supply modules, where the impacts of behavioural changes that occur between the base and any given horizon year are estimated. The demand model estimates changes in each O/D matrix as a result of changes in trip frequencies, destinations, modes, or times of day. This is accomplished through the use of an incremental nested logit model, a disaggregate choice model that endogenises the linkages between the four choice dimensions mentioned above (for the mathematics of the incremental nested logit model, see Bates et al., 1987).

Changes in the demand model are driven by two sets of factors: changes in the generalised costs of travel, and a set of behavioural coefficients used in the utility functions. The generalised costs of travel reflect the travel time, travel cost, and mode-specific effects for a trip between a particular origin and destination zone, by a given mode, at a specific time of day. Changes in the generalised cost matrices are passed to the demand model from the supply model (described below). Generalised costs change as a result of endogenous effects (i.e. congestion), and exogenous interventions that can be specified by the modeller (e.g. changes to the fare or access time of a mode). The demand model thus estimates, in an internally consistent way, how groups of travellers adjust their travel behaviour in response to the changes in generalised travel costs they face.

The behavioural coefficients are identical to the scale parameters that are usually found in the utility functions of logit choice models, and reflect the sensitivity of travellers to changes in the travel time, travel cost, and mode characteristics of the alternatives they face. As different behavioural coefficients may be used for each person type, trip purpose, and time of day, the behavioural response can be fitted to the observed elasticities of different user groups. For instance, if low-income people are more sensitive to changes in travel cost than travel time, or if persons travelling to work are more likely to adjust their mode than their trip timing, this can be captured through the use of different coefficients. The model is thus specified in an extremely flexible manner.

The demand model interacts with the supply model, where the changes in generalised travel costs are estimated as a result of congestion effects, based on user equilibrium principles. The model has the ability to endogenously determine other relevant supply effects, such as adjusting the frequency of minibus-taxi services according to the demand on a route, but this feedback effect has not yet been implemented. The supply model outputs changes in equilibrium generalised costs, at O/D matrix level, by mode and by time of day. This data is fed back to the demand model, which in turn estimates changes to the O/D matrices. Iteration between the supply and demand models continue until equilibrium is achieved.

For the zoning and network size described below, the model converged to equilibrium within 20 minutes for a large metropolitan area, on a standard computer.

Once demand-supply equilibrium has been reached, the results can be aggregated according to person types, trip types, times of day, or modes used, and displayed using standard GIS or transport modelling software. Because the O/D matrices for different user types are kept separate throughout, various measures of accessibility, affordability, or mobility can easily be calculated. If the land use/demographic allocation model has the capability of incorporating such indices in future year forecasts, the land development impacts of changes in transport performance or accessibility can be modelled, thus completing the loop between transport and land use modelling.

## **4. PROTOTYPE APPLICATION TO GAUTENG GLOBAL CITY REGION**

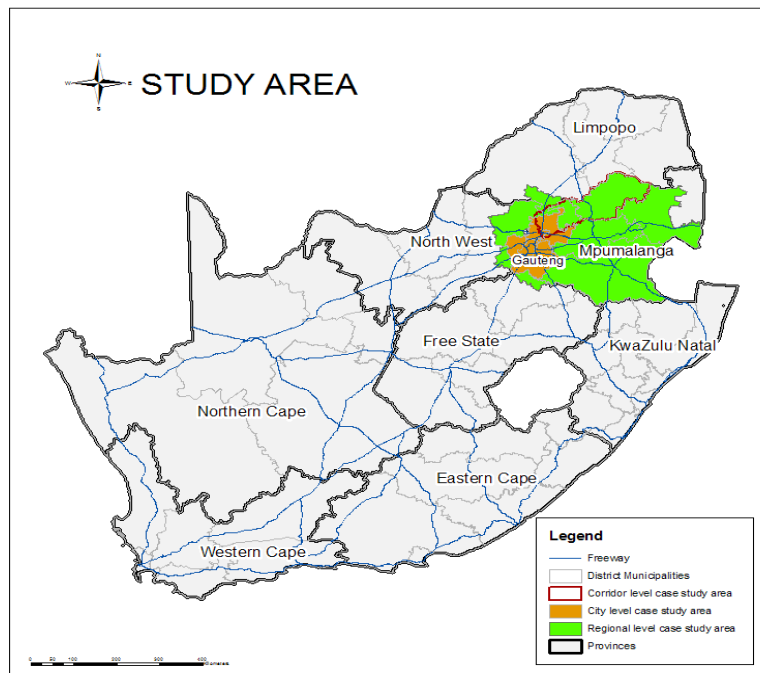
### **4.1 Background**

The UPTrans transport model was implemented as a part of the Integrated Planning Development and Modelling project, undertaken for the Department of Science and Technology (DST), by the CSIR Built Environment as lead agency, in collaboration with

the Human Sciences Research Council, the Universities of Johannesburg and Pretoria, and a number of external specialist contractors. The overall purpose was to use technology to enhance the quality of integrated spatial and infrastructure planning in South Africa to improve evidence-driven planning at the local and provincial levels. The outcome included the development of a web-based, demonstrator Toolkit for Integrated Planning (TIP), with a simulator component to enable the prediction of settlement growth patterns and the evaluation of the impacts of alternative planning decisions for a range of scenarios (DST, 2008).

## 4.2 Model set-up

**4.2.1 Study area and zoning system:** The study area was selected to include a range of South African settlement typologies, from dense urban to displaced rural. The transport model focused on the larger Gauteng City Region (GCR) area, which included Gauteng plus adjacent areas with functional economic and infrastructure linkages (Figure 3). Adjacent areas included the Moloto Road corridor to the north-east of Pretoria; districts in northern Free State (including Sasolburg) and western Mpumalanga; and up to the Rustenburg area to the north-west of Gauteng in North West Province.



**FIGURE 3 Study area of TIP prototype application**

The zoning system included a total of 119 zones (including 8 external zones). Zones are much larger than those used by typical strategic transport demand models – the Gauteng Transport Study (GTS) model, by comparison, has about 830 zones – but are not as large as the analysis zones used by the National Household Travel Survey (NHTS). Zones correspond more or less to districts (in rural areas) or to subplaces (in cities).

**4.2.2 Transport networks:** The base year transport network from the GTS was used to reflect the as-is network of roads and public transport routes in Gauteng (for 2001). Additional coding extended the network into peripheral areas of Greater Gauteng. The road network was at a finer level of detail than what is required (or even optimal) for this strategic level of modelling. The use of relatively large zones is thought to have led to

underestimation of some intrazonal travel times, as well as travel times through major bottlenecks, necessitating some manual adjustments to be made.

*4.2.3 Base year origin-destination matrices:* Peak period base year (2001) transport demand was obtained from the updated GTS transport model. For areas outside of the GTS model, base year demand data was obtained from the NHTS dataset of 2003. Since the NHTS only provides detailed zone-to-zone information on home-to-work and home-to-education trips, only these trip purposes were included for the additional zones.

The demand model also required off-peak travel demand matrices. As these were not available for Gauteng, they had to be synthesised for this prototype application. Synthetic off-peak matrices were obtained by examining a data set with 24-hour trip information, collected in 2004 in the Nelson Mandela Metropolitan Area (NMMM, 2004). By calculating peak and off-peak trip rates for various person type and trip type combinations, and applying these to similar categories in the Gauteng model, off-peak matrices were estimated. The off-peak matrices were calibrated relative to off-peak vehicle counts on major roads to ensure they were at least reasonable.

*4.2.4 Segmentation of user groups:* The demand model disaggregated demand into ten categories consisting of:

- Three income group categories:
  - Low income = under R2000 per household per month
  - Medium income = R2000 to R7000 per household per month
  - High income = above R7000 per household per month
- Three trip purposes (home-to-work, home-to-education, home-to-other); and
- A category for all non-home-based trips (regardless of income of the tripmaker)

The demand matrices were also disaggregated by each of the modes modelled (car, Gautrain (where applicable), bus, taxi, and rail). Changes in car occupancy were not explicitly modelled but the model makes provision for simulating switching between single occupant and high-occupant car modes.

*4.2.5 Behavioural coefficients:* The behavioural coefficients (elasticities) for the different demand segments were obtained from an extensive review of previous South African choice model studies (using both revealed and stated preference data), coefficients and values-of-time used in existing models, and international travel behaviour literature. No formal calibration was carried out, but coefficients observed internationally had to be reduced somewhat to reflect the relatively lower sensitivity to changes in trip costs and travel times observed among some segments of South African tripmakers.

#### 4.3 Scenarios explored

The scenarios considered for this prototype application were selected to be broadly indicative of alternative growth and development paths for the GCR region, and not intended to be strict forecasts. This is in line with the purpose of TIP as a tool for assessing the impacts of various development interventions that may be directionally different – it is thus a strategic comparative tool rather than a predictive one. As this was an exploratory exercise to test the abilities of the model framework, much further fine-tuning, expansion, and (possibly) optimisation of the scenarios would be needed before substantive policy recommendations could be made.

An external regional growth simulator was developed to model the likely movement of economically active population across the region, including the effects of in-migration from elsewhere in South Africa, internal migration, and endogenous demographic growth (see DST (2008) for further description of the methodology and data sources). Two broad scenarios, varying essentially in terms of the weight given to “corridor development” (i.e. development within high accessibility transport corridors), were explored iteratively with the growth simulator and the transport simulator:

- **Trend scenario: Business as usual** - The scenario assumes the direction of development is embedded and difficult to shift, due to: a) strong influence by the market and preferences of different social groups and economic sectors, and b) misalignment of competing and overlapping public sector plans and strategies.
- **Corridor-led scenario: NSDP principles** - The effect of a combination of high fuel prices, increased long-distance interaction costs and greater equalisation of unemployment rates, results in a reduction of oscillating migration/ long distance commuting, and increased urbanisation focused on the areas with relatively higher employment rates (especially the main metro and functional regions). Effective public transport investments, including first-phase Bus Rapid Transit (BRT) in Johannesburg and Tshwane, and densification around high-access nodes, feature in this scenario.

A more detailed description of the alternative scenarios is given in table 1. The base year was 2001, the horizon year 2014, and interim modelling years 2007 and 2010.

**TABLE 1 Description of the alternative scenarios**

<b>2014 scenario choices</b>	<b>Trend scenario</b>	<b>Corridor-led scenario (NSDP principles)</b>
Subsidised housing quantum (how much)	Current supply rates	Current supply rates
Subsidised housing form (of what)	Low density, single dwelling on single stand delivery predominates	BNG housing forms and densities – higher proportion of higher density residential forms
Subsidised housing locality (where)	Subsidised housing supplied predominantly in place of need: in and around existing low income residential areas. Often greenfields development on peripheries	Converge subsidised housing delivery towards places of economic potential – directed more towards higher access areas, e.g. Midrand; Moloto corridor; well-located/suitable land in dense city contexts
Transport response	Mobility-driven (status quo): current road network, no freeway upgrades; no new PT investment	Access-driven: BRT deployed along first-phase networks in COJ & CTMM; Gautrain completed
Non-subsidised housing	Trend/adjacent localities and growth rates	Higher densities & mixed use in more accessible locations, around Gautrain stations, and emerging densifying nodes
Non-residential development	Trend/adjacent localities and growth rates	High intensity development in more accessible locations, around Gautrain stations, and emerging densifying nodes

NSDP=National Spatial Development Perspective; BNG=Breaking New Ground; COJ=City of Johannesburg; CTMM=City of Tshwane Metropolitan Municipality; PT=Public Transport

#### 4.4 Indicative results

4.4.1 *Impact of regional growth on travel behaviour and congestion:* Table 2 indicates that Gauteng’s transport network will have to accommodate significantly increased



travel volumes over the 2001-2014 period. The corridor-focused scenario leads to a lower overall growth in vehicular trips as compared to the trend scenario. The corridor-driven scenario favours public transport, which grows faster than the car mode, as a result of its higher accessibility when housing is directed towards corridors served by buses, taxis and rail.

What is striking, though, is the relatively modest impact of the corridor-led scenario on the popularity of the car. This finding is confirmed when we look at mode choice results in more detail. Figure 4a indicates that by 2014 mode splits are projected to change very little from their 2001 levels, under either scenario. This is entirely consistent with both the close proximity of the forecast horizon and the limited extent of the Gautrain and BRT network coverage.

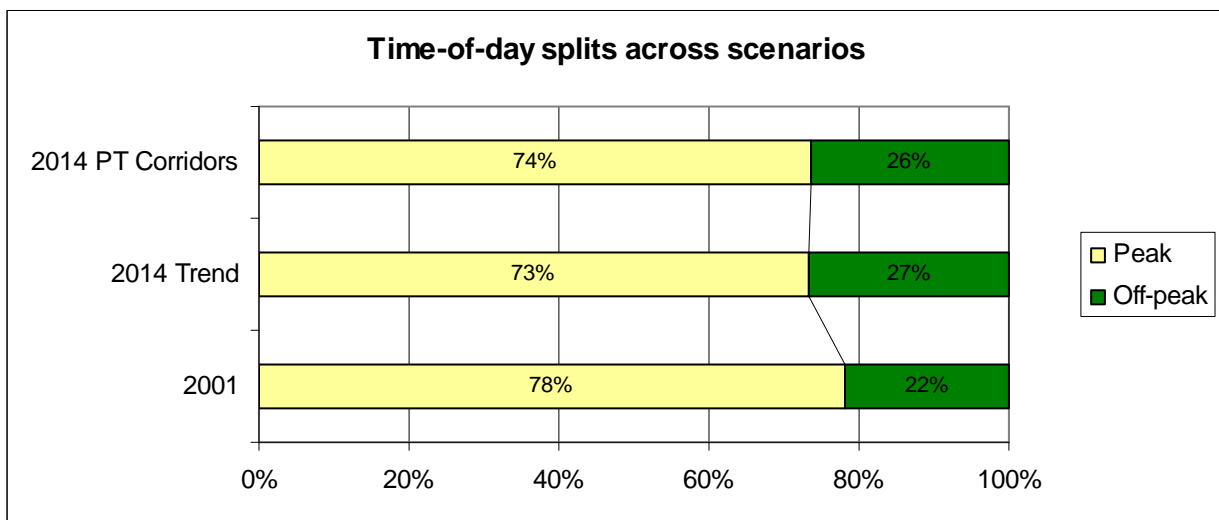
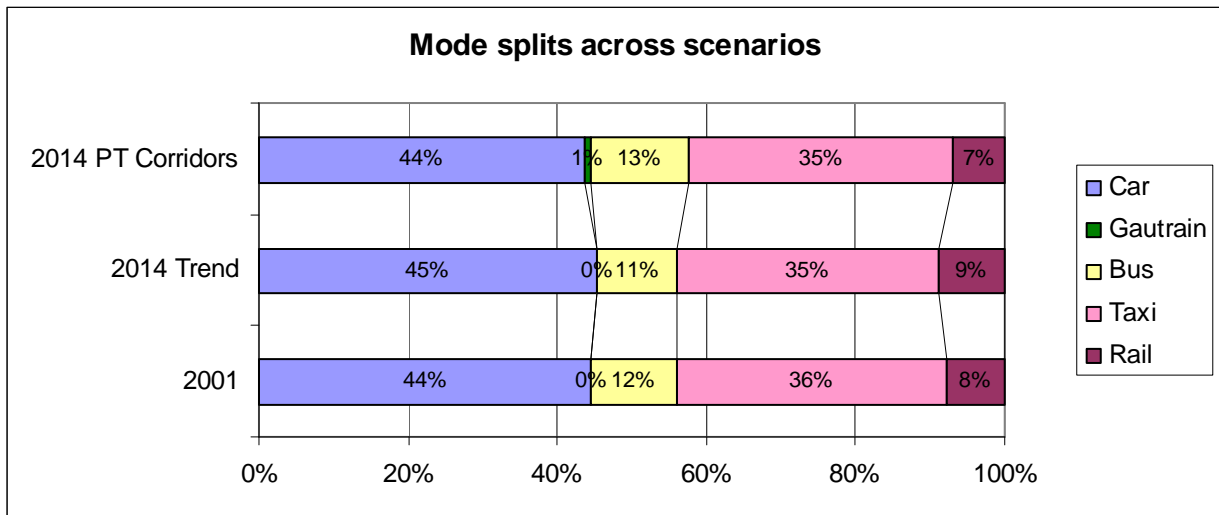
Road congestion will as a result increase significantly. Car travel times for high income users grow by 30% on average with no new transport investment, from an average of 23 minutes to 30 minutes per one-way trip (Table 3). Investing in public transport and urban densification may limit congestion growth to keep corresponding travel times to around 26 minutes.

However, given the drastic growth in traffic indicated above, the growth in congestion is less than what may be expected, as a consequence of the adaptive behaviour allowed by the model – people switch routes, destinations and time of day in response to rising travel times. The most significant behavioural response is switching of trips from the peak to the off-peak period (Figure 4b). The percentage of (one-way) trips made in the peak period declines from 78% in the base year to 73%-74% in 2014, mostly as a result of non-work, non-school trips that are shifted out of the increasingly congested peak periods. This departure time shift cannot be predicted by any of the standard travel demand models in use, leading to a likely overprediction of the growth in road congestion levels.

4.4.2 *Discerning equity impacts:* Table 3 allows comparison of the aggregate travel times and costs across different income groups. Low income persons spend, on average, more than twice as much time travelling as high-income persons (by motorised means), but pay lower fares per trip. This reflects the higher use of public transport among low income travellers. Medium income travellers seem to be in some senses worst off – their average travel times are towards the higher end due to their higher use of public transport modes, but their average trip costs are also high due to their long

**TABLE 2 Simulated growth in daily person-trips**

	Scenario			
	Base yr	2007 Trend scenario	2014 Trend scenario	2014 Corridor scenario
Total person-trips				
Car	4,044,130	4,990,974	6,484,606	5,929,778
Gautrain	0	0	0	98,506
Public Transport	5,067,448	6,387,808	7,861,640	7,550,676
% growth from base yr				
Car	--	23.4%	60.3%	46.6%
Public Transport	--	26.1%	55.1%	49.0%



**FIGURE 4a & b Simulated mode split and time-of-day choice results**

travel distances and greater use of cars. It may be that medium income residents (who comprise about a quarter of travellers in the model) are deserving of more attention in strategy formulation.

**4.4.3 Discerning spatial impacts:** Figure 5 shows how the UPTrans results might be interrogated to discern broad spatial trends – in this case to identify areas that will benefit more from a consolidated growth/transport strategy, compared to the trend scenario. It plots the difference in average work travel times for residents of each zone, between the two scenarios for 2014. The map indicates that the corridor strategy is likely to provide the biggest benefits to residents in areas that have ultra-long commutes at present, such as in the commuter-"homeland" areas of North-West and along the Moloto corridor. By reducing the number of residents settling in inaccessible places travel time growth is kept lower than it would otherwise be. Interestingly, areas directly inside the priority corridors, which are supported by faster BRT services like along the Tshwane-Rosslyn-Mabopane axis, do not on average gain from a drop in travel times, presumably because local congestion increases in these areas (more densely settled than under the trend scenario), are off-set against long-distance speed gains. Areas of Gauteng that benefit from the corridor scenario include Soweto, parts of Ekurhuleni and the West-Rand.

**TABLE 3 Simulated travel time and cost by income group and mode used**

	Scenario			
	Base yr	2007	2014	2014
		Trend scenario	Trend scenario	Corridor scenario
Average trip time (mins)				
Low Inc - PT	74.79	75.01	76.61	77.90
High Inc - Car	22.75	24.35	29.58	26.28
Low Inc - All modes	67.68	67.43	68.21	68.89
Med Inc - All modes	51.65	51.77	54.20	53.12
High Inc - All modes	27.46	28.92	34.07	31.48
Average trip cost (R/trip)				
Low Inc - All modes	4.70	4.68	4.81	5.11
Med Inc - All modes	6.19	6.10	6.20	6.17
High Inc - All modes	6.12	6.17	6.48	6.57

## 5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the UPTrans incremental transport model seems to hold potential for expanding the set of modelling tools available for strategic land use-transport policy evaluation. It requires less calibration and coding than conventional models, by relying on behavioural models and coefficients obtained from previous research, but requires base year origin-destination matrices at a finer level of disaggregation. Conceptually the model is able to capture a wider set of behavioural shifts in response to changing land use and demographic patterns, congestion growth, and transport-related strategies or interventions – including changes in the choice of destination, mode, and most importantly, time-of-day of trips. Initial results reported here indicated the extent to which people’s adaptability in terms of their travel behaviour serves to mitigate the severe congestion growth that is typically assumed to accompany urban growth.

The model’s reliance on utility-maximising choice model theory (as robust as it is), within the supply-demand equilibrium framework, makes it a second-generation model. It does not possess the conceptual-behavioural superiority of activity-based micro-simulators, but neither does it have their large data and calibration requirements. The model is thus suited for quick-response, high-level strategic evaluation over short to medium time horizons rather than project-level or long-term assessments.

Particular limitations of the prototype Gauteng City Region version include:

- No freight flows or forecasting are included due to a lack of data
- Off-peak base year travel demand had to be simulated using travel behaviour data from elsewhere in South Africa – an imperfect substitute for real off-peak data. Better 24-hour travel diary data is needed to improve the simulation of time-of-day effects in response to, for example, Travel Demand Management initiatives.
- No walking or bicycling trips were included, as the focus for now was only on motorised modes. Accurate data on non-motorised transport demand remains hard to get, and little is known about the behavioural aspects (e.g. mode

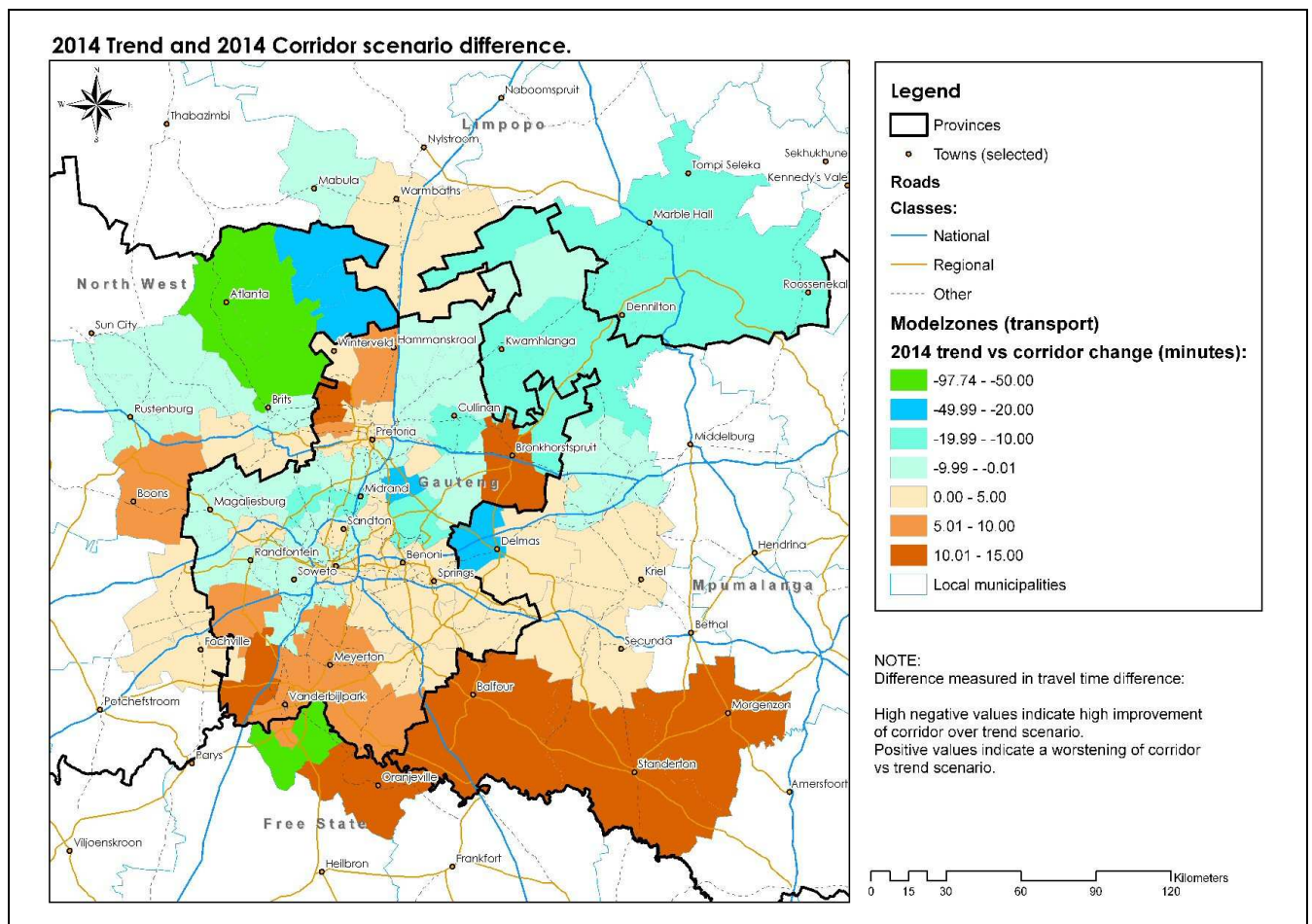


FIGURE 5 Travel time differences by zone between 2014 scenarios

switching) when walking is an option.

- Modal definitions considered only the main mode (car, Gautrain, bus, rail, taxi) and no detailed modelling was undertaken of feeder or secondary modes.
- The model did not implement occupancy shift as a behavioural adaptation, but assumed a constant vehicle occupancy of 1.24 persons per private vehicle. Methodologically this is easy to correct once better occupancy data is included.
- Behavioural coefficients used in the demand model assume that user groups respond in a constant and predictable way to changes in underlying generalised travel costs. Further work is needed to refine the values used for different user groups and at different points in time.
- The supply model uses the existing GTS transport network. It should ideally be able to estimate interzonal travel times and distances without having to rely on a coded network for trip assignment, in order to be more quickly implementable in study areas without pre-existing network data. The estimation of representative aggregate networks for strategic evaluation is the topic of ongoing research.
- The model structure makes provision for feedback between land use and transport model components by feeding weighted travel time estimates for intermediate model years to the land use model, where it can be used to account for accessibility effects on land use development in ensuing years. However this feature was not yet available at the time of prototype implementation.

The prototype transport model is still under development. Improvements are likely to be implemented as a part of further DST-funded roll-out of the TIP programme.

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