FORECASTING HOUSEHOLD TRANSPORT ENERGY DEMAND IN SOUTH AFRICAN CITIES

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ABSTRACT: The South African built environment is forever changing with implications on the demand for travel related energy demand at a household level. Nonetheless, the development control and development planning practices in the country seldom take into account the implications of changes in the built environment on energy demand. Over time, from a transport perspective, the disregard for transport energy demand implications of land use developments could imply remarkably increased per capita cost of transport and the overall costs of living.

Based on the data available such as household travel surveys and transport models, the paper illustrates how transport energy implications of development proposals can be modelled and forecasted. The City of Johannesburg is used as a case study. In the paper, vehicle kilometres travelled is used as a surrogate measure for transport energy demand.

The paper concludes that development control and development planning practices that aim to minimise the rate of increase of transport costs, for which energy is a significant component, should be central in South African cities. This is achievable through revised design philosophy in Town Planning Schemes, and recognition of the interaction effects of land use developments. The shortcomings of the modelling approach adopted in the case study are discussed as well as some recommendation to address them.

Keywords: Transport energy, transport model, development planning, town planning.

1. INTROCUCTION

Household transport costs in South Africa have over the recent past increased at a rate more than any other household expenditure item (StasSA, 2008). Transport energy from fuel, forms a large component of the transport costs for both private car and public transport trips. For minibus taxis, for example, which carry the largest proportion of public transport trips, fuel costs can be as much as 60% of the operating costs, and consequently a large proportion of the fare paid by passengers (Letebele, Masemola and Mokonyama, 2009). High transport costs also increase the overall cost of living and render the country less competitive, and also increase the vulnerability of large numbers of households to poverty. While it is almost certain that transport costs will forever be on the increase, it is important to ensure that the rate of increase of transport costs is reduced.

Based on the data available such as household travel surveys and transport models, the paper illustrates how transport energy implications of development proposals can be modelled and forecasted. For demonstrative purposes the paper focuses on South African cities and the City of Johannesburg in particular due to data availability. While the focus is on cities, it should nonetheless be noted that South African cities are significant sources of travel demand. For example, while the population in the six metropolitan areas account for a third of the country's population, they account for about half the total number of work trips (Lombard et al., 2007).

Despite the significant contribution of transport energy costs to the overall cost of living, the design of the built environment in South Africa continues to be guided by primitive design guidelines which disregard energy as an important design variable. These guidelines, for example the traffic impact studies guideline (Department of Transport, 2008), which informs municipal development controls, observe past travel behaviour, and on the basis of the observed maximum rate of demand for infrastructure, estimate the design rates. Future design demand for infrastructure is then derived from simply multiplying the rate estimated in the past by the size of the infrastructure being designed. This practise has the effect of perpetuating the historically inefficient built environment, which in South Africa is exacerbated by the inefficient apartheid spatial legacy.

In order to increase the appreciation of the importance of incorporating energy as an input variable in the design of transport systems and infrastructure in the built environment, the paper shows the role of an energy demand sensitive design on the reduction in forecasted energy demand. Since there is a direct correlation between energy demand and travel distance, the paper simply quantifies energy demand in terms of vehicle kilometres travelled in a transport system.

2. THE IMPORTANCE OF LAND USE INTERACTION EFFECTS IN MUNICIPAL DEVELOPMENT PLANNING AND TRAVEL DEMAND MANAGEMENT

Local government in South Africa is mandated by the Constitution to plan and manage the provision of services to communities in a sustainable manner. The services include water, sanitation, electricity and transport. Some of the management instruments used by local government include Integrated Development Plans (IDPs) and Town Planning Schemes. The Spatial Development Frameworks (SDFs) that form part of the IDPs, provide strategic guidance in terms of the desired land use development in municipalities. Town Planning Schemes are used by municipalities to operationally control changes in land use in their areas of jurisdiction. Together with the SDFs, Town Planning Schemes ensure that future land use developments in the municipality are sustainable and predictable.

Town planning schemes usually require traffic impact studies as one of the requirements for any change in land use. These traffic impact studies are aimed at identifying the impact of the development on the road network, in terms of traffic load, and recommending measures to minimise the impact, including increasing the capacity of the road network. In the City of Johannesburg for example, traffic impact studies are required when a proposed development generates more than 275 trips, or when it increases existing daily trips by more than 20% (City of Johannesburg, 2007).

In forecasting the impact of the proposed development on existing transport infrastructure, the Town Planning Schemes usually adopt variation of the estimated parking generation rates and trip generation rates shown in Tables 1 and 2. The rates in Table 1 are used to estimate parking capacity required by the development. For example, general offices require a minimum of 2.5 parking spaces for every 100 m^2 of leasable office area. The rates in Table 2 are used to estimate the number of car trips, as well as person trips, that various developments are likely to generate. For example, cluster housing developments are expected to generate 1.1 car trips per dwelling unit in a peak hour. After the estimation of parking and travel demand, the transport infrastructure is planned to cater for the estimated demand, and where required, the developer pays the municipality monetary contributions for bulk infrastructure provision such as arterial roads. In addition to traffic impact studies, recent legislation, in the form of National Land Transport Act (Act 5 of 2009), require a public transport assessment to be conducted. Nonetheless, complete public transport assessments are seldom undertaken, and to date there are no comprehensive guidelines in the country to guide the formulation of public transport assessments, often with dire consequences, for example, large shopping malls and offices that do not cater for public transport facilities.

Table 1: South African minimum parking standards

Land Use	Land Use -subcategory	Standard
Office	General offices	2.5 spaces/100m^2 Gross Leasable Area
	Banks, building societies and other public trading offices	4 spaces/100m^2 Gross Leasable Area
Business	Neighbourhood shopping centre	7 spaces/100m^2 Gross Leasable Area
	Community shopping centre	6 spaces/100m^2 Gross Leasable Area
	Regional shopping centre	5 spaces/100m^2 Gross Leasable Area
Residential	Dwelling unit of 1 habitable room	1 space/unit
	Dwelling unit of 4 or more habitable rooms	1.5 spaces per unit
Medical	General hospitals	1 space/bed
Educational	Universities	0.4 spaces per student

Short extract from Department of Transport (1985)

Table 2: South African trip generation rates

Land Use	Land Use - subcategory	Standard
Office	General offices: Central Business District	▪ 4.0 person trips per 100 m^2 in the peak hour (75:25 direction split). ▪ 29.1 person trips per day per 100 m^2
	General offices: Suburban	▪ 2.3 car trips per 100m^2 in peak hour (85:15 direction split) ▪ 11 car trips per 100m^2 per day. ▪ 0.6 car trips per employee in the peak hour (85:15 direction split) ▪ 2.8 car trips per employee per day.
Business	General retail Central Business District	▪ 60.0 person trips per 100m^2 midday (50:50 direction split) ▪ 262.1 person trips per day per 100m^2
	Restaurant sit-in	▪ 15.6 car trips per 100m^2 afternoon peak hour (70:30 direction split) ▪ 0.6 car trips per occupied seat midday peak hour (70:30 direction split)
	Shopping centre	▪ 224.5*(Gross Leasable Area)$^{-0.34}$ car trips in weekday afternoon peak hour (50:50 direction split) ▪ 224.5 *(Gross Leasable Area)$^{-0.30}$ car trips in Saturday peak hour (50:50 direction split)
Residential	Low income	▪ 0.5 car trips per dwelling unit in peak hour (65:35 direction split) ▪ 94.2 car trips per 1000 residents in the peak hour (65:35 direction split) ▪ 2.6 car trips per day per dwelling unit. ▪ 927.8 car trips per 1000 residents per day.
	Medium income	▪ 1.1 car trips per dwelling unit in peak hour (75:25 direction split) ▪ 251.0 car trips per 1000 residents in the peak hour (75:25 direction split) ▪ 3.9 car trips per day per dwelling unit. ▪ 1037.0 car trips per 1000 residents per day.
	High income	▪ 1.5 car trips per dwelling unit in peak hour (75:25 direction split)
	Cluster housing	▪ 1.1 car trips per dwelling unit in peak hour (75:25 direction split)

Short extract from Department of Transport (1995)

The rates in Tables 1 and 2 are usually obtained from a wide range of empirical observations of parking and travel demand at pre-existing developments. For example, parking and traffic demand surveys are conducted at selected offices to estimate the total demand within a specific time period, and the demand normalised to measures such as office space or number of employees. It is therefore assumed that the rate so estimated from the different developments is sufficiently representative to allow for infrastructure capacity design for new developments. After a long while, the rates are re-estimated from new surveys.

Municipalities are also legally mandated to produce Integrated Transport Plans (ITPs) which form part of the Integrated Development Plans (IDPs). ITPs basically provide detailed plans for transport within the jurisdiction of the municipality. Furthermore, no transport interventions in the form of transport infrastructure projects or transport services can take place outside the provisions of the ITPs.

In line with the provisions of the Constitution, all the above planning instruments (Town Planning Schemes, IDPs and ITPs) are subject to public consultation before adoption by the municipality.

While the above planning tools in the form of Tables 1 and 2 are useful, they have several shortcomings:

a) Land use developments are evaluated as stand alone components and do not consider the interaction effects between different land uses. The interaction effects have the potential to either increase or reduce estimated demand for infrastructure. Table 3 for example, shows in terms of empirically estimated elasticities that increases in development density, diversification of land use per unit area, connectivity of the road network and increased regional accessibility of developments can reduce vehicle trips and vehicle kilometres, and even more so collectively. By definition, elasticity value shows a percentage change in the output value, when one percent of the input value changes, and negative elasticity indicates indirect proportionality.

Table 3: Built environment elasticities reported from an extensive literature review

Built Environment measure	**Vehicle trips**	**Vehicle km travelled**
Local density ([population +jobs]/area)	-0.05	-0.05
Local diversity (jobs:population balance per area)	-0.03	-0.05
Local design (street network connectedness, sidewalk density, route directedness)	-0.05	-0.03
Regional accessibility (proximity to activity centres in the region)	Not reported	-0.20

Cao (2006)

b) When updated, the rates in Tables 1 and 2 are often increased to cater for increased car ownership and use, and the relative attractiveness of developments. In this way the only alternative adopted is to increase infrastructure capacity without any consideration for demand side measures. In one study, however, it was actually shown that increasing the parking charges to the full cost recovery of providing parking has the potential of reducing private car trips by 10 to 30% (Litman, 2009). From the South African perspective, motorists have traditionally not borne the full costs of car travel. Figure 1 for example (from the 2002 Gauteng household travel survey data) shows that only about 10% of motorists pay for parking at work places and for the rest it is free. However, demand side measures work more effectively when they are part of a more comprehensive mobility strategy.

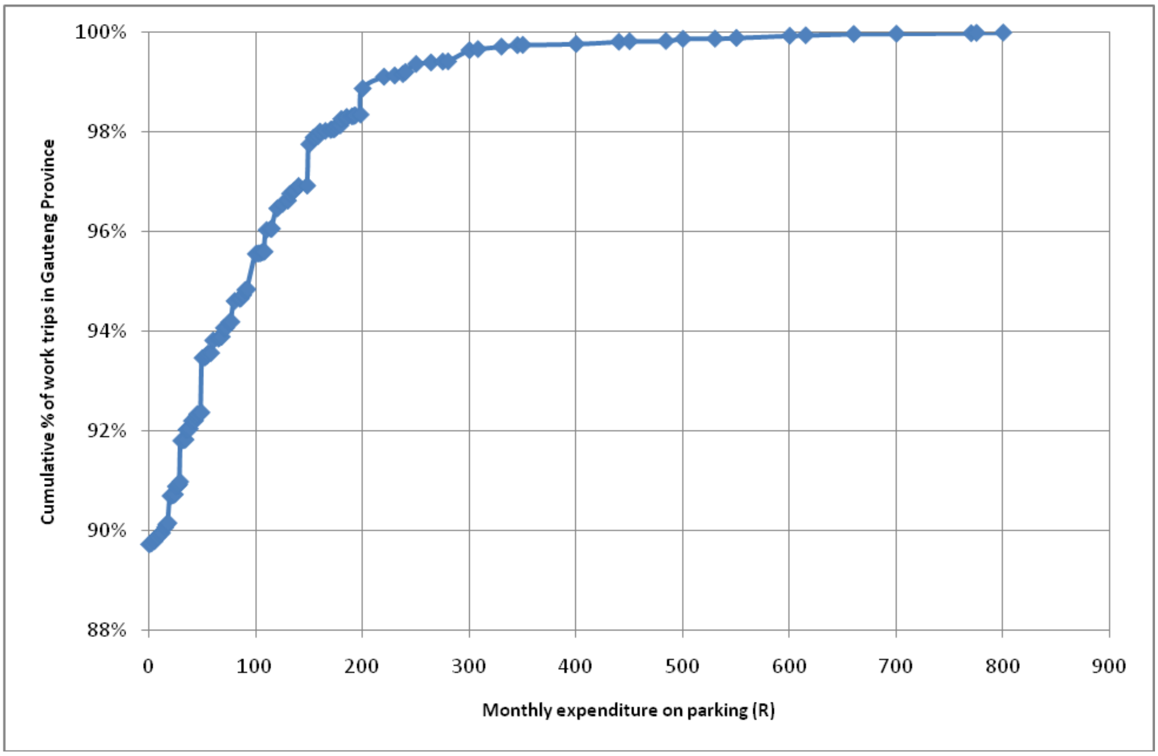

Figure 1: Distribution of monthly expenditure on parking in Gauteng Province for work trips

Indications are that if South African cities continue to apply Town Planning Schemes whose design philosophy was formulated decades before the cost of energy and energy security became a critical planning variable, the legacy of inefficient spatial planning will be perpetuated. Very important at this stage is to ensue that the design philosophy of Town Planning Schemes is revised to respond effectively to future energy challenges. Recognising the need to plan land use as a functionally integrated system, as opposed to isolated pockets of developments, would be a first step to achieving this.

3. FORECASTING THE IMPACT OF DEVELOPMENT PLANS IN SOUTH AFRICAN CITIES: THE CASE OF THE CITY OF JOHANNESBURG

Economically, the City of Johannesburg is of strategic importance to South Africa. It reportedly contributes over 15% to the country's Gross Domestic Product, the highest of all the South African cities. It is therefore important to ensure that the City is functionally competitive, for example in terms of transport costs.

The City's Spatial Development Framework contains development proposals aimed at sustainably restructuring the City, and changes in land use development density is used as one of the strategic interventions. An earlier version of development density proposals is shown in Figure 2, in which 2002 densities, in terms of households per hectare, are juxtaposed against proposed future densities, also in terms of households per hectare. The spatial unit of analysis is the transport zones which were systematically demarcated for the City's transport model. From Figure 2 it is clear that initially the City wanted to substantially increase densities towards the west of the city and in pockets of developments along selected arterial roads. It should however be acknowledged that that the density proposal were subject to a number of practical constraints, for example the ease of interventions in already established areas versus and non-established areas. Nonetheless, the likely future impact of these density proposals on infrastructure that includes water, sanitation, electricity and transport networks needed to be quantified. Even more important was to establish whether the City's transport proposals contained in the Integrated Transport Plan (ITP), such as increased public transport network capacity and other mobility solutions, would be sufficient to respond to the travel demand implications of the density proposals.

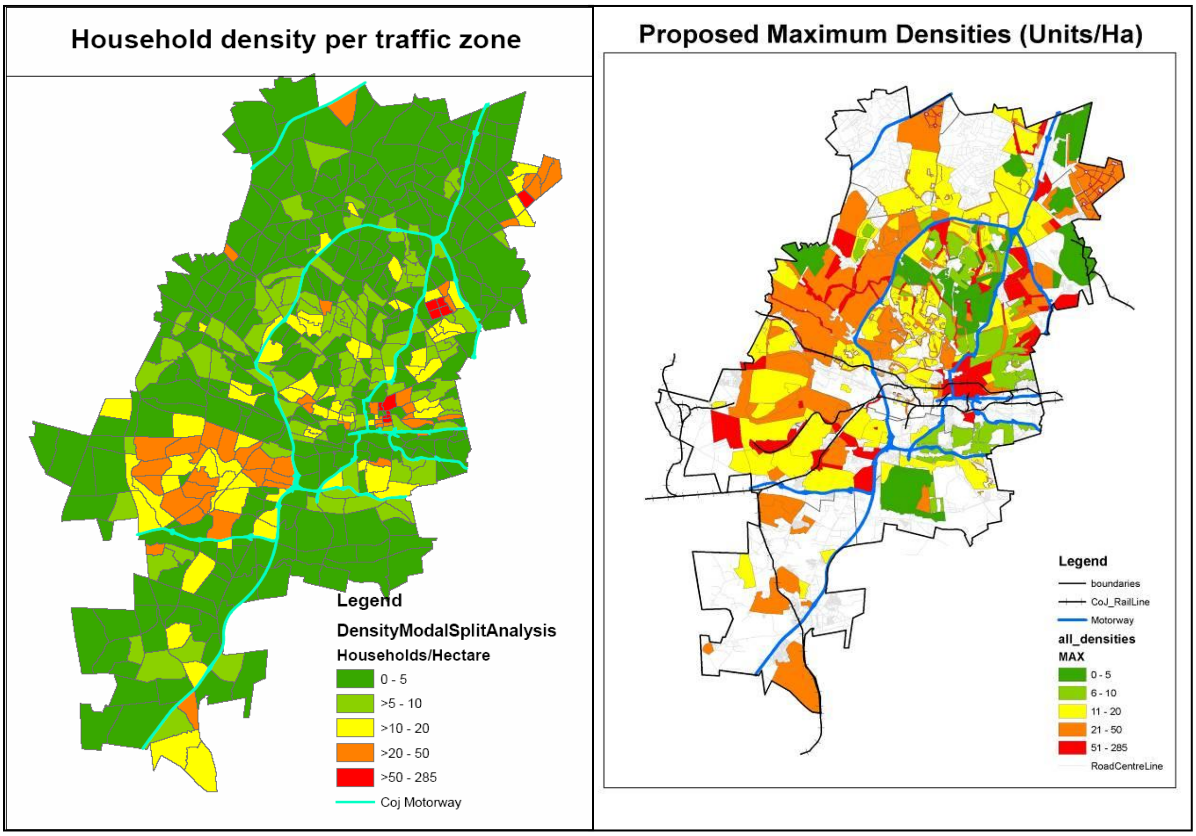

Figure 2: Initial development density proposals in the City of Johannesburg

In order to model the transport implications of the development densities, the City entered into a research agreement with the CSIR. For this, the existing City's transport model was recalibrated using the 2002 Gauteng household travel survey, and validated using observed road traffic counts. The trip generation submodel in particular was re-estimated, examples of which are shown in Tables 4 and 5. Table 4 shows the trip generation rates for work trips per household category, where households are classified in terms of the number of employed persons, household income and the number of cars per household. The table then provides the average number of person trips per mode of transport (non-motorised, private car and public transport) per household. For example, a household with 1 employed person, in the R7000+ monthly income category, with 1 car makes on average 0.0291, 0.7233, and 0.0243 non-motorised, private car and public transport person trips respectively. These rates are then multiplied by the corresponding number of households in each transport zone in order to estimate the number of person trips per zone, and in the case of Table 4 to estimate work trips. Table 5 on the other hand is a product of regression analysis of land use data, and estimates the number of work-based person trips attracted to a transport zone given the number of formal and informal job opportunities. Once the trip ends (total number of trips per zone) are estimated, the pre-existing trip distribution matrix (a matrix showing the number of trip between any two zones) per trip purpose is adjusted. Future travel demand per zone is estimated by forecasting the number of households per zone and the changes in land use per zone, which were estimated from the development density proposals and the Spatial Development Framework.

Table 4: Category-based person trip production rates per person for work trips for the City of Johannesburg transport model

Employed persons per household	Household income (R)	0 car per hh	1 car per hh	2+ car per hh	0 car per hh	1 car per hh	2+ car per hh	0 car per hh	1 car per hh	2+ car per hh
		Non-motorised	Non-motorised	Non-motorised	Private car	Private car	Private car	Public transport	Public transport	Public transport
0	0-699	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000
1	700 - 1999	0.0022	0.0102	0.0000	0.0000	0.0000	0.0000	0.0022	0.0000	0.0000
0	1999 - 6999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0	7000+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0-699	0.3548	0.1875	0.0000	0.0206	0.3125	1.0000	0.4370	0.2500	0.0000
1	700 - 1999	0.1831	0.0753	0.0741	0.0300	0.4032	0.5556	0.6775	0.3602	0.1852
1	1999 - 6999	0.1265	0.0595	0.0402	0.0804	0.5758	0.6897	0.7157	0.2131	0.1092
1	7000+	0.1228	0.0291	0.0064	0.2281	0.7233	0.7395	0.5263	0.0243	0.0161
2+	0-699	1.0000	0.2500	0.0000	0.0000	1.0000	2.0000	0.4839	0.5000	1.0000
2+	700 - 1999	0.5340	0.2889	0.0000	0.0388	0.6222	1.2857	1.2006	0.6889	0.2857
2+	1999 - 6999	0.2586	0.0965	0.0909	0.1136	0.7066	1.2626	1.5022	0.8417	0.3030
2+	7000+	0.2443	0.1408	0.0229	0.3511	0.9965	1.4811	1.4885	0.4718	0.0687

Table 5: Regression based person trip attraction rates for the City of Johannesburg transport model

Description	Non-Motor	Private	Public
Trips per formal job opportunity	0.0288	0.2607	0.3543
Trips per Informal job opportunity	0.2483	0.1570	0.4243

The results of the modelling exercise for the base year scenario are summarised in Table 6. For each scenario (2002, 2010 and 2020) the table provides the estimated performance of the road network. The road network itself is divided into categories that relate to road classes, road ownership as well as road link of strategic importance for public transport. For example, the baseline scenario show that in the base year there are estimated 2 701 973 peak hour vehicle kilometres on the City of Johannesburg owned roads, translating into 52 760 peak hour vehicle hours, roadway volume to capacity ratio of 0.391 and an average speed of 51km/h. In 2010 and 2010 the performance of the road network is shown to deteriorate remarkably.

Table 7 shows the results of the modelling exercise in which the impact of different transport interventions were assessed, but shown only for City owned roads. The interventions shown in Table 7 are: (i) increased diversion of trips from car within 1 km of BRT network to BRT services once the entire BRT network is completed, (ii) impact trip diversions to Gautrain based on the projected station-to-station train service demand, (iii) the introduction of a freeway tolling scheme by the South African National Roads Agency, and (iv) the use of park and ride facilities for trips destined to high density areas. The following results can be observed from Table 7:

- The impact of BRT on roadway congestion becomes notable at high diversion levels between 30 and 40%.
- Gautrain has negligible impact on the road network performance.
- The tolling scheme tends to worsen the overall performance of the road network due to trip diversions from freeways to other roads.
- Park and ride facilities also have a negligible impact on the road network performance.

Overall, it was shown that development densities as proposed needed to be revised in order to increase the effectiveness of the transport interventions. More appropriate locations for increased densities were identified, which had the least impact on the road network performance.

Goyns (2008) shows that, on average, a private car in the City of Johannesburg makes 21 900km per annum. Crudely, this implies that peak hour vehicle kilometres on the City of Johannesburg road network make up about 5% of daily kilometres. Annually therefore, private car trips could be making as much as 32.9 billion vehicle kilometres. If the same ratio of peak hour to daily kilometres is maintained, the vehicle kilometres double very 8 years from the 2002 baseline, with direct implications on energy demand.

Table 6: Results of the baseline –do nothing scenario

ANALYSIS ELEMENT	ROAD NETWORK ELEMENT	Base year (2002)				2010 scenario				2020 scenario			
		Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)	Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)	Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)
Road Network Hierarchy	Class 1 roads	1 338 748	18 203	0.554	74	1 645 917	39 210	0.723	42	2 097 308	166 077	0.962	13
	Class 2 roads	1 626 264	39 297	0.628	41	2 331 803	91 393	0.904	26	3 436 487	387 814	1.325	9
Strategic Public Transport Network (SPTN-Now BRT network)	Entire SPTN	1 160 702	29 229	0.688	40	1 601 273	64 240	0.950	25	2 309 496	265 513	1.369	9
	North South Flagship route	121 666	2 528	0.789	48	166 310	7 644	1.103	22	240 612	42 898	1.582	6
	2010 Public Transport Routes Network	132 296	2 817	0.700	47	182 962	8 442	1.008	22	265 881	45 644	1.494	6
Road Ownership	National	1 041 566	14 227	0.803	73	1 250 092	29 717	0.742	42	1 573 820	131 709	0.956	12
	Provincial	694 049	18 915	0.681	37	961 619	37 651	0.928	26	1 432 619	143 410	1.362	10
	City of Johannesburg	2 701 973	52 760	0.391	51	4 040 070	127 852	0.623	32	6 216 416	540 202	0.999	12
Entire modelled network		4 956 036	92 291	0.418	54	6 908 924	207 061	0.642	33	10 095 022	851 250	1.009	12

Table 7: Performance of some of the selected City of Johannesburg transport interventions

Measured interventions	2002				2010 scenario				2020 scenario			
	Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)	Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)	Total veh km travelled (km)	Total travel time (hours)	Average v/c ratio	Average speed (km/h)
Baseline: Do nothing for the City owned Roads	2,701,973.00	52,760.00	0.39	51.00	4,040,070.00	127,852.00	0.62	32.00	6,216,416.00	540,202.00	1.00	12.00
10% diversion to BRT	-3%	-7%	-4%	4%	-3%	-9%	-4%	6%	-3%	-8%	-2%	0%
20% diversion to BRT	-6%	-12%	-7%	8%	-6%	-16%	-8%	9%	-6%	-15%	-6%	8%
30% diversion to BRT	-9%	-17%	-11%	10%	-9%	-21%	-11%	13%	-9%	-25%	-10%	17%
40% diversion to BRT	-11%	-21%	-14%	12%	-12%	-27%	-14%	19%	-11%	-32%	-13%	25%
50% diversion to BRT	-14%	-24%	-17%	14%	-15%	-31%	-18%	22%	-15%	-40%	-16%	33%
60% diversion to BRT	-16%	-27%	-20%	16%	-17%	-35%	-21%	28%	-17%	-44%	-19%	42%
Gautrain implementation	0%	0%	-1%	0%	-1%	-2%	-1%	0%	0%	-2%	0%	0%
South Africa Roads Agency Freeway tolling scheme	4%	6%	3%	-2%	57%	331%	64%	-66%	49%	416%	56%	-75%
10% diversion to park & ride	0%	-1%	0%	2%	0%	-1%	-1%	0%	0%	-1%	1%	0%
20% diversion to park & ride	0%	-1%	-1%	2%	0%	-2%	-1%	0%	1%	2%	1%	-8%
30% diversion to park & ride	0%	-1%	-1%	0%	-1%	-2%	-1%	0%	0%	-3%	0%	0%
40% diversion to park & ride	-1%	-1%	-1%	0%	-1%	-4%	-1%	3%	0%	-2%	0%	0%
50% diversion to park & ride	-1%	-2%	-1%	2%	-1%	-3%	-1%	0%	-1%	-4%	-1%	0%
60% diversion to park & ride	-1%	-2%	-2%	2%	-1%	-4%	-1%	3%	-1%	-6%	0%	0%
70% diversion to park & ride	-1%	-2%	-2%	2%	-1%	-5%	-2%	3%	-1%	-5%	-1%	0%
80% diversion to park & ride	-2%	-3%	-2%	2%	-2%	-6%	-2%	3%	-1%	-5%	-1%	0%

4. SHORTCOMINGS OF THE FORECASTING TECHNIQUES IN THE CITY OF JOHANNESBURG MODEL

While the transport model indeed provided useful results and insights, it is not without shortcomings some of which are:

- Trip distribution is likely to change over time because of the movement of households as well as changes in trip length distribution. This in turn affects the trip distribution matrix used in the model. Correcting this shortcoming requires additional trip distribution surveys to re-estimate the trip distribution model.
- People alter their travel behaviour as a result of changes in road network conditions, for example change in mode of transport, destination and time of travel. Venter and Mokonyama (2009) show that these effects can be significant.
- The feedback loop emanating from demand elasticity of the generalised costs of transport, for example fuel costs, is not comprehensively taken into account.

5. CONCLUSIONS

The paper uses the City of Johannesburg as a case study for forecasting transport energy demand implications of development planning interventions. It is shown that land use interaction effects are important and need to be incorporated in the design of Town Planning Schemes in order to design more sustainable built environment. The paper also shows that it is possible to quantitatively model the long term implication of development planning proposal. This was demonstrated through the application of a transport model to assess the impact of development proposals contained in the City of Johannesburg Spatial Development Framework, as well as the extent to which the City's transport proposals can adequately respond to resulting travel demand challenges in terms of road network performance. From a correlation between vehicle kilometres travelled and fuel consumption, the energy demand can be estimated.

The modelling process is not without shortcomings, and these can be addressed in future through improved modelling techniques and low cost data collection techniques to obtain time series data for continuously re-estimating the models.

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