# OPTIMISING SETTLEMENT LOCATIONS: LAND-USE/TRANSPORT MODELLING IN CAPE TOWN

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## ABSTRACT

Urban sprawl is a major characteristic of spatial developments in South African cities. Housing is continuously being located at the periphery of cities. Conversely, this spatial configuration has high implications for the level of transportation demand. In order to create compact cities, sustainable and environmentally sound urban land use and transport systems, integrated land use and transport planning is required.

There remains an unresolved debate within the South African literature of the use of optimisation models (tools), which seek to jointly solve for both travel activity patterns and urban activity allocations. Urban land use and transportation planning ought to be a highly interactive and a consensus-building process. Therefore models should be placed within spatially explicit decision support aids taking advantage of the latest geographic information systems to open up the process to land use and transport planners.

The current debate in South Africa is focused on how and where new housing developments should be developed. However, there isn't a land use-planning tool, which tries to predict the consequence of land use planning on the transport system at a local level.

Spurred on by this interest the University of Cape Town is currently developing a land use model to help local governments in South Africa to integrate land use and transport planning. The model's inputs consist of socio-economic data and network information and it calculates number of trips, kilometres and destinations.

## 1. INTRODUCTION

The idea that models of land use and transportation might contribute to more rational urban planning was born in the 1950s in the context of Detroit and Chicago Transportation studies in the United States of America. These models were thought to be a major technological breakthrough that would revolutionalise the practice of urban planning and policy making (Wagener, 1994). Since their inception the attitude towards planning has changed facilitating a widespread production of even more sophisticated models over the years for several cities particularly in the developed countries. At first they were introduced with the aim of solving land use and transportation questions and later with the goal of addressing a wider range of urban problems (Torrens, 2000).

This paper aims at enhancing policy makers' ability to evaluate the unforeseeable impact of new residential developments on road traffic. The ultimate purpose is to design an efficient tool, which can advise planners to base settlement planning on impacts on travel behaviour within a city.

A prototype of this settlement-planning tool is currently being developed for the city of Cape Town in South Africa with some preliminary testing to establish the validity of the model.

As a first step in this paper the need for a land use transportation model in Cape Town is introduced, followed by a description of land use and transport models in general. The procedure undertaken to develop the model itself is described in section 4. An overview concerning implementation of the model to two sample zones is covered in section 5 together with the results produced by the model. Section 6 gives a comparison of the two scenarios. The paper closes giving a discussion of further research needs speculating on the most promising avenues to further improvement and diffusion of this kind of model.

## 2. PROBLEM DESCRIPTION

The growing demand for better coordination of metropolitan land use and transportation planning has led to the need for new analytical tools to examine the potential impacts of settlement investment and policies. There is a pressing need for models, particularly for the developing countries, that answer 'what if' questions about the land use and transport systems and address important policy concerns of relevance to both planners and the public. To also provide answers and information to decision-makers on planned development and management of transport infrastructure.

There are some planning tools used by developed countries that have been very useful in predicting consequences of land use planning on the transport system at a local level. A good example of such a tool is WOLOCAS developed in Netherlands in the 1990s (Van Nes, 2002). However, these models cannot be adopted in their present form and used in South Africa due to different socio-economic and environmental contexts.

One of the challenges that developing countries face today is that urban growth is so rapid that it is threatening the viability of the mobility systems. Therefore, in order to bring about sustainable reductions in urban traffic volumes significant changes are necessary in the way in which households engage in daily activity travels. Such changes are likely to be in the way we organise and use traffic generating and attracting land within cities through the use of integrated and land use models.

The intention of this paper is to provide a model that can adequately and practically support the analysis of a diversity of relevant issues, impacts and policies.

Our aims are to develop a model that should:

- Operate at a specific geographic scale, that is, transport zones/census tracts in an area in order to provide a treatment of space that is sufficiently disaggregated for policy guidance.
- Provide an integrated representation of the land use, transport and economic components.
- Should be activity based in order to be sufficiently behavioural in the representation of system responses to different policy inputs
- Must be affordable in terms of both time and money resource requirements.

## 3. INTEGRATED LAND USE TRANSPORT MODELLING

Urban modelling emerged in response to a need for educated forecasts of the future pattern of urban systems, as well as a means by which hypotheses, theories and projects relating to cities could be tested.

According to Torrens (2000) land use-transportation models (LUTM) are a particular class of models used to simulate how land use and transportation systems interact and operate (Torrens, 2000). Policies, projects and ideas about the city are difficult to experiment with.

As such LUTM are used:

- in the management of urban systems to facilitate long range planning,
- to simulate the potential outcomes of decisions affecting the city, and
- as a laboratory for testing ideas and hypotheses relating to urban systems

The land use component denotes a range of land uses such as residential, industrial and commercial. This paper concentrates on the residential use with industrial and commercial uses incorporated as fixed input data. The land use system (residential) as an input into the transportation model is used to estimate the location, volume of potential trips and the trips pattern associated with individuals needs to perform activities. It is generally concerned with factors generating economic activities, which are correlated with transportation requirements. For instance, by using a set of economic activity variables, such as population, household types (car ownership and income levels) it becomes possible to calculate the generation and attraction of passenger or person trips. Once this procedure has been resolved, the data is feed into the transport calculation model using the four-step model.

3.1 The Four-Step Model

Basically the transport system is simulated via the four-step model. The four-step model, is a sequential model which constitutes of four steps as follows:

Trip generation ⇒ Trip distribution ⇒ Modal split ⇒ Trip assignment.

- *Trip Generation* – concerned with the prediction of the amount of trips produced by and attracted to each zone.
- *Trip Distribution* – concerned with the prediction of where the trips will go
- *Modal-split* – concerned with the type of mode used to make those trips. Therefore, the model would predict the amount of trips made for each mode.
- *Trip Assignment* – concerned with predicting the routes used by the trips from a given origin to a given destination by a particular mode (Ortuzar & Willumsen, 1994).

3.2 GIS in land use-transportation modelling

Decision support systems help improve the class of decision-making. Technology exists today that enables us to perform visually stunning and richly detailed simulations of urban environments in a manner that renders an ease of interaction and understanding that is not currently present in many models (You & Kim, 1999). As such the model is developed using Geographical Information Systems (GIS) tools with a function to depict and evaluate the broad effects on the traffic and transport system of major residential developments in a city. The GIS serves as a tool to represent and model the land use impacts as well as being a user interface. It is used to prepare data for input to the land use transportation model and to display the results. The next section will give an overview of the design and development of the model itself.

## 4. PROCEDURE UNDERTAKEN

During the development of the model the following steps were undertaken:

4.1 Step 1: Production of model parameters

The trip generation data was drawn from a research document produced by Van Nes (2002).

Van Nes' contribution in the formation of the prototype planning tool was to adjust socio-economic data from an existing household based travel data in order to produce production parameters of the model. The data originated from an activity based household travel survey in the CMC by Behrens (2000) comprising of 204 households (Van Nes, 2002). The results obtained in the document were further used to obtain the parameters for the new settlements in the trip generation stage. The study identified different population groups, trip purposes and travel modes for use as inputs by the model.

Table 1. Identified population groups, purposes and modes.

| **Population groups** | **Trip Purposes** | **Travel Modes** |
|---|---|---|
| 1.Employed, with car, high income | 1. Work | 1.Car driver |
| 2.Employed, with car, middle/low income | 2. Education | 2.Car passenger |
| 3.Employed, without car, high/middle income | 3. Shopping | 3. Public transport |
| 4.Employed, without car, low income | 4. Serve passenger | 4. Slow & other modes |
| 5.Unemployed, with car | 5. Other | |
| 6.Unemployed, without car, high income | | |
| 7.Unemployed, without car, middle income | | |
| 8. nemployed, without car, low income | | |

It is assumed that each of these groups exhibits uniform decision behaviour, its own mobility pattern in their purpose of travel and modes they travel in to these respective purposes.

Table 2. Production parameters.

| **Matrix for mean number of trips per person/day** | | | | | |
|---|---|---|---|---|---|
| **Purpose**<br><br>**Group** | **1** | **2** | **3** | **4** | **5** |
| **1** | 1.9 | 0.1 | 0.3 | 0.1 | 0.6 |
| **2** | 1.4 | 0.2 | 0.2 | 0.2 | 0.6 |
| **3** | 1.8 | 0.0 | 0.2 | 0.0 | 0.4 |
| **4** | 1.5 | 0.0 | 0.1 | 0.0 | 0.6 |
| **5** | 0.1 | 0.4 | 1.1 | 0.1 | 1.3 |
| **5** | 0.1 | 1.5 | 0.3 | 0.1 | 0.5 |
| **6** | 0.0 | 0.9 | 0.4 | 0.0 | 0.8 |
| **8** | 0.1 | 0.5 | 0.1 | 0.0 | 1.0 |

| **Matrix for the mean number of trip kilometres per person per day** | | | | | |
|---|---|---|---|---|---|
| **Purpose**<br><br>**Group** | **1** | **2** | **3** | **4** | **5** |
| **1** | 15.4 | 10.7 | 7.3 | 3.3 | 11.1 |
| **2** | 22.8 | 18.3 | 10.2 | 14.5 | 14.2 |
| **3** | 18.0 | 0.0 | 5.6 | 10.0 | 10.0 |
| **4** | 19.0 | 0.0 | 11.0 | 0.0 | 10.6 |
| **5** | 6.0 | 18.1 | 9.4 | 4.0 | 10.3 |
| **6** | 13.3 | 8.0 | 9.0 | 15.0 | 9.3 |
| **7** | 1.0 | 4.0 | 7.0 | 0.3 | 5.0 |
| **8** | 7.2 | 9.0 | 4.8 | 0.3 | 9.0 |

Using these groups the following production parameters for the model were computed:

- mean number of trips per person per population group per motive,
- mean number of kilometres per trip per population group per motive, and
- mode distribution for each population group and each motive (see Table 3)

4.2 Step 2: The Calculation Model

The calculation of the transport model is a modified version of the traditional four-step model. Instead of the four steps the model only includes the first three steps without the trip assignment and with a different sequence of steps as follows:

Trip generation ⇒ Modal split ⇒ Trip distribution ⇒ Number of trips, Kilometres per purpose and mode

4.2.1 Trip generation stage
The objective of this stage is to define the magnitude of total daily (24 hour period) travel in the model system, at the household and zonal levels, for various trip purposes, population groups and modal groups. The trips produced in the new settlement are calculated per purpose and population group based on the size of the settlement, composition of the inhabitants and mobility patterns of the population groups. Trip generation has two components, that is, productions and attractions. Already there are trip attractions for all the zones from the CMC data. Therefore this stage will only be entirely based on calculating the trip productions pertaining to the origin zone ( the new settlement to be built) and influence factors and variables such as number of houses, workers per household, percentage of people with car, percentage of people per income group have to be computed.

4.2.2 Modal-split stage
Based on the data from Van Nes (2002), illustrating the distribution of modes per population group per purpose, it was possible to produce matrices showing the total number of trips per mode and purpose. However, for the purposes of this paper only two examples are given for population group 1 and 7.

Table 3. Total trip frequencies for each mode per population group per purpose.

| **Group 1** | | | | | |
|---|---|---|---|---|---|
| **Mode** | **Purposes** | | | | |
| | **1** | **2** | **3** | **4** | **5** |
| **Car driver** | 58 | 5 | 10 | 2 | 17 |
| **Car passenger** | 7 | 0 | 0 | 0 | 4 |
| **Public transport** | 5 | 0 | 0 | 0 | 0 |
| **Slow & other** | 3 | 0 | 0 | 0 | 0 |
| **Total** | **73** | **5** | **10** | **2** | **21** |

| **Group 7** | | | | | |
|---|---|---|---|---|---|
| **Mode** | **Purposes** | | | | |
| | **1** | **2** | **3** | **4** | **5** |
| **Car driver** | 0 | 0 | 0 | 0 | 0 |
| **Car passenger** | 0 | 12 | 4 | 0 | 26 |
| **Public transport** | 0 | 18 | 10 | 0 | 4 |
| **Slow & other** | 5 | 68 | 27 | 2 | 61 |
| **Total** | **5** | **98** | **41** | **2** | **91** |

4.2.3 Trip distribution stage
The trip distribution stage is carried out for each purpose and mode separately. Trip distribution is essentially a destination choice model and generates a trip matrix for each trip purpose per mode utilised in the previous stages as a function of activity system attributes and network attributes (distances) [Ortuzar & Willumsen, 1994]. It relies on a conventional gravity model where flows from one settlement to another are calculated. The gravity model is based on the "fact that the number of trips between two zones is proportional to the magnitudes of each zone and inversely proportional to the distance between the two zones" (ITE, 1991).

$$I_{ij} = (O_i * A_j * f(D_{ij})) / [\mathrm{Sum} (A_k * f(D_{ij}))]$$

$I_{ij}$ = Is the number of trips going from i to j
$O_i$ = is the number of trips originating from zone i
$A_j$ = is the measure of attractiveness of zone j
$d_{ij}$ =measure of spatial separation of zones i &j

In this model, distance between zone centroids was used as the measure of spatial separation of zones. Zone trip attractions are one of the parameters used in the calculation model and are extracted from the CMC data plus additional surveys done to get the attractions for education and shopping by Goncalves, 2002. They serve primarily to scale the subsequent destination choice (trip distribution) problem and provide a measure of relative attractiveness for various trip purposes as a function of socio-economic and demographic variables.

## 5. CAPE TOWN CASE STUDY

For a number of years now the City of Cape Town has been pursuing an ambitious program of improving their transportation and land use systems through the MSDF (See Figure 1). This program of improvement has included development of corridors, nodes, urban edge and urban moss. In addition the government housing subsidy scheme is running parallel to these developments. Unfortunately planners have limited ability to visualise alternative settlement location schemes or the impacts associated with these location policies. Thus planners are often not able to give highest quality advice to the city regarding places to locate houses in a sustainable way.

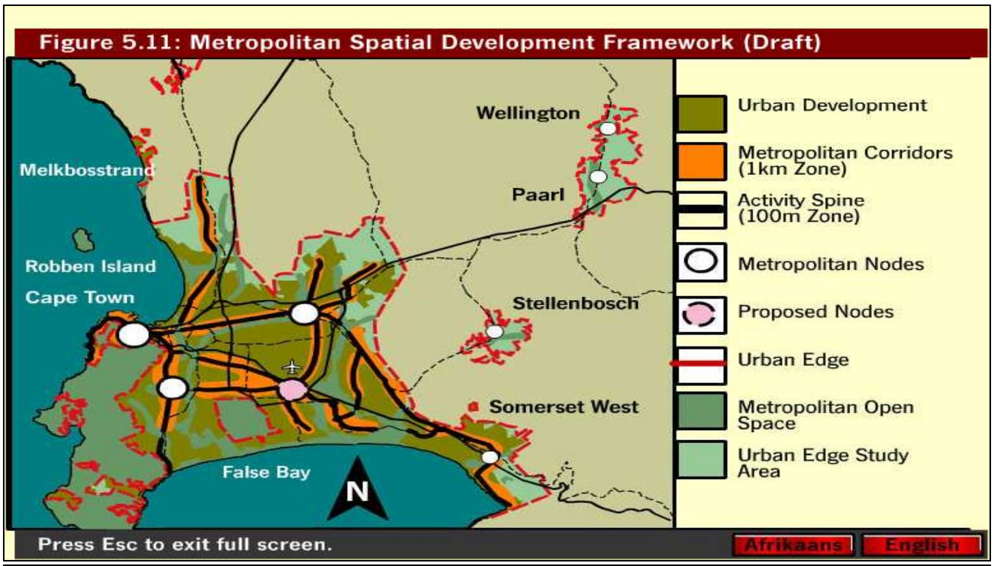
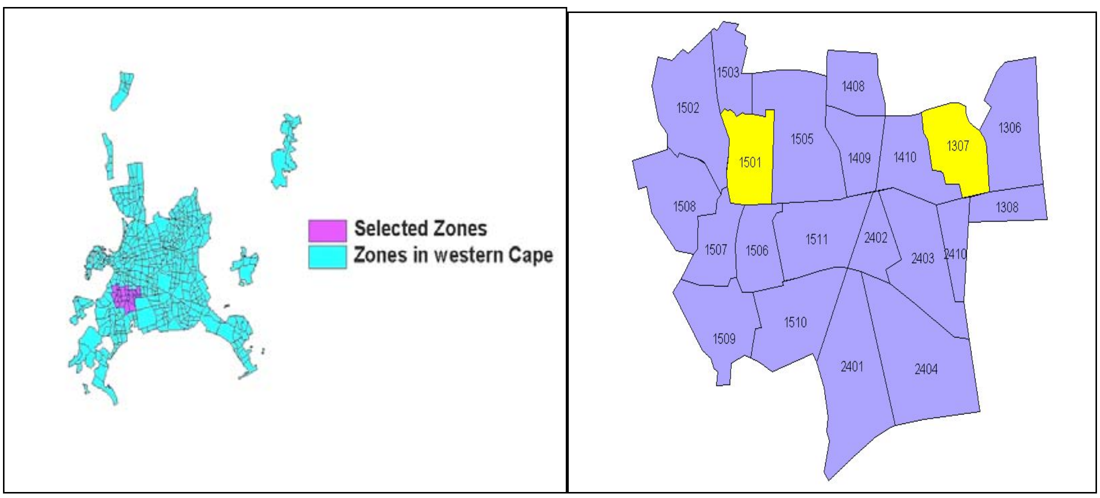



Figure 1. MSDF concepts (CMC, 1996).




a) b)

Figure 2. a) Selected zones used by the model, and b) selected zones for the development of a new settlement.

The central debate on this paper is that land use does affect travel behaviour and that policies should thus be partly based on the expected transport impacts given by the model. The model is intended to cover the entire city of Cape Town. However, due to data constraints the prototype model only concentrates on 21 transport zones within the city (Figure 2).

5.1 Scenarios for Cape Town

Two zones were chosen for use as examples in the model, that is Kenilworth Central (Zone 1501) and Hanover Park West (Zone 1307) [Figure 2]. For the purposes of this paper it was decided to build 600 houses for the new settlements. The number of houses is a variable in the model. The same variables (number of households and percentage of people with car) in the CMC data for the respective zones are used as representative variables for the new settlements (Table 4). These variables are subject to change by decision makers depending on what they prefer to built.

Table 4. Input variables for the two new settlements.

| **Scenario 1 (Kenilworth Central)** | | **Scenario 2 (Hanover Park west)** | |
|---|---|---|---|
| # of Houses | 600 | # of Houses | 600 |
| Average # of people/household | 2.1 | Average # of people/household | 4.89 |
| Total Population | 1260 | Total Population | 2934 |
| Average # of workers /household | 1.62 | Average # of workers /household | 1.6 |
| % of people with car | 0.61 | % of people with car | 0.69 |
| % of people with high income | 0.2571 | % of people with high income | 0.228 |
| % of people with middle income | 0.4308 | % of people with middle income | 0.4192 |
| % of people with low income | 0.3121 | % of people with low income | 0.3528 |

Using these variables the following number of people per population group were calculated:

Table 5. Total number of people per population group for each scenario.

| **Scenario 1 (Kenilworth Central)** | | **Scenario 2 (Hanover Park west)** | |
|---|---|---|---|
| **Population group** | **# of people** | **Population group** | **# of people** |
| 1. Employed, with car, high income | 152 | 1. Employed, with car, high income | 151 |
| 2. Employed, with car, middle/low income | 440 | 2. Employed, with car, middle/low income | 511 |
| 3. Employed, without car, high/middle income | 261 | 3. Employed, without car, high/middle income | 193 |
| 4. Employed, without car, low income | 118 | 4. Employed, without car, low income | 105 |
| 5. Unemployed, with car | 176 | 5. Unemployed, with car | 1362 |
| 6. Unemployed, without car, high income | 29 | 6. Unemployed, without car, high income | 140 |
| 7. Unemployed, without car, middle income | 48 | 7. Unemployed, without car, middle income | 257 |
| 8. Unemployed, without car, low income | 35 | 8. Unemployed, without car, low income | 216 |
| **TOTAL** | **1260** | **TOTAL** | **2934** |

5.2 Results for Kenilworth Central

The information in Tables 4 and 5 served to compute the number of trips produced by the new settlements. Figure 3 presents the total number of trips calculated per population group per purpose by the model for the new settlement in Kenilworth. As illustrated in Figure 3, in total, the amount of trips generated by this new settlement is 3249 trips. Therefore there are about 2.6 trips per person or around 5 trips made per household per day. The results indicate that population group 2, that is, those who are employed, have car and are middle/high income, produces most of the trips.

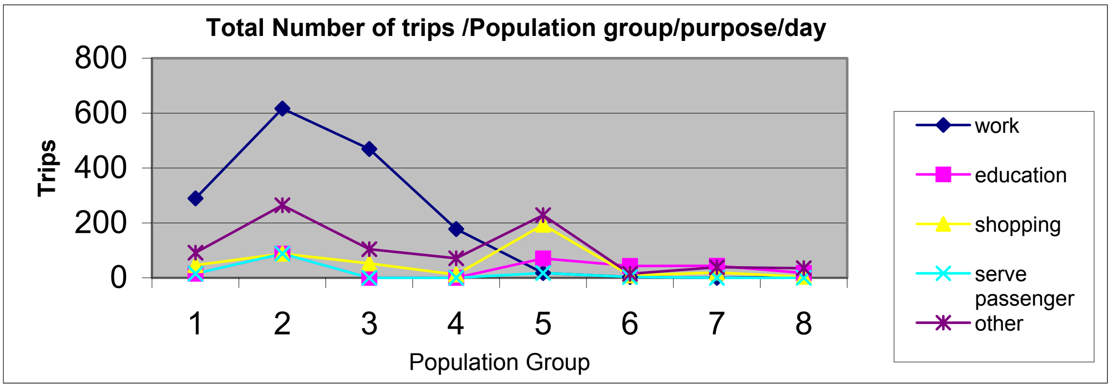



Figure 3. Total estimated trips per population group per purpose for Kenilworth Central.

Based on the calculations from Table 3 the total amount of trips /purpose/mode/day (modal split) are estimated as shown in Figure 4. It is noticeable in Figure 4 that cars make up most of the trips for every purpose, particularly for work purposes.

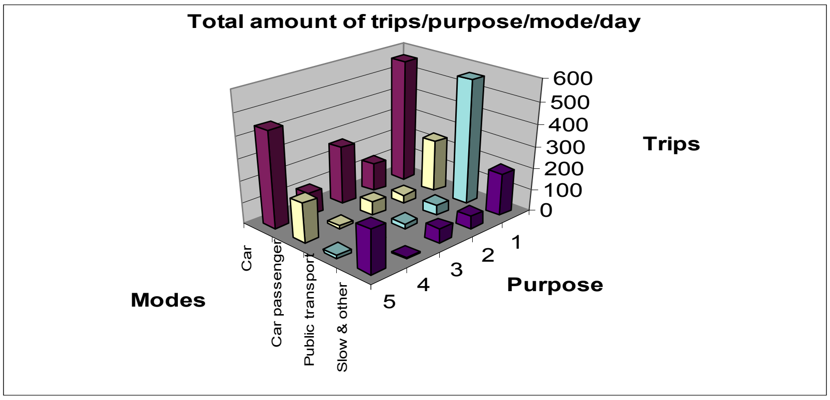



Figure 4. Total estimated trips per purpose per mode for Kenilworth Central.

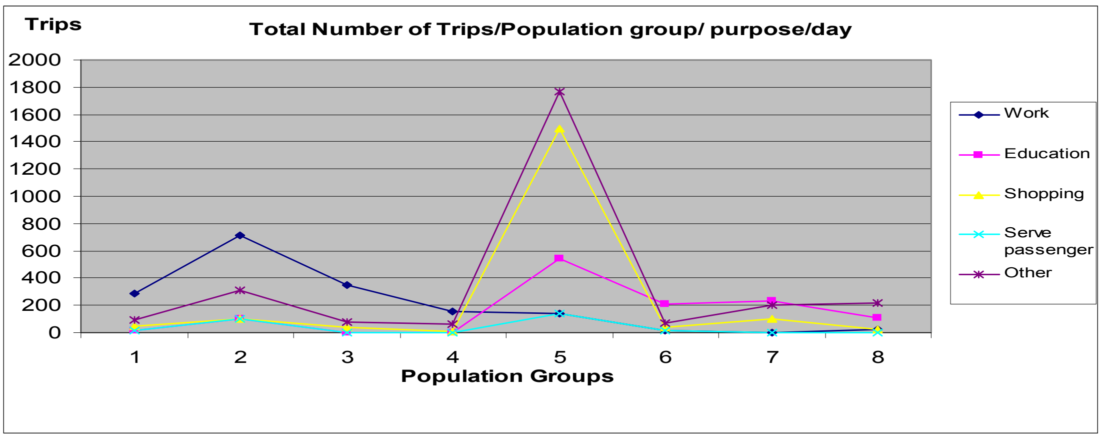



Figure 5. Total estimated trips produced per population group/ purpose for Hanover Park West.

5.3 Results for Hanover Park West

A second scenario was conducted and for comparison purposes it was decided to place the second settlement in Hanover Park East. The same procedure undertaken for scenario 1 (Kenilworth Central) was followed. Using information from Tables 4 and 5 the total number of trips per population group/purpose/day were estimated for Hanover Park West (Figure 5).

The new settlement in Hanover Park West will generate a total of 7817 trips resulting in 2.7 trips per person daily and around 13 trips per household. Figure 6 provides the modal split.

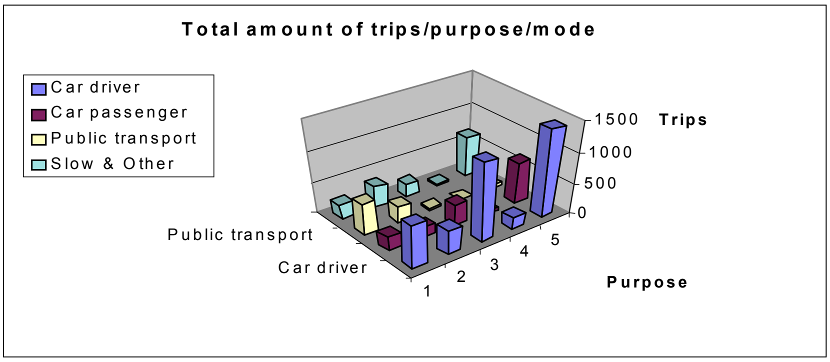



Figure 6. Total estimated trips per purpose per mode for Hanover Park West.

Figure 6 shows that most of the trips are done using the car, mostly as car driver (3971 trips) and secondly as car passenger (1466 trips).

## 6. COMPARISON OF THE TWO SCENARIO SETTLEMENTS

Figure 7 demonstrates the type of results obtained from the analysis of the two different settlements. It shows the total number of kilometres per person per mode.

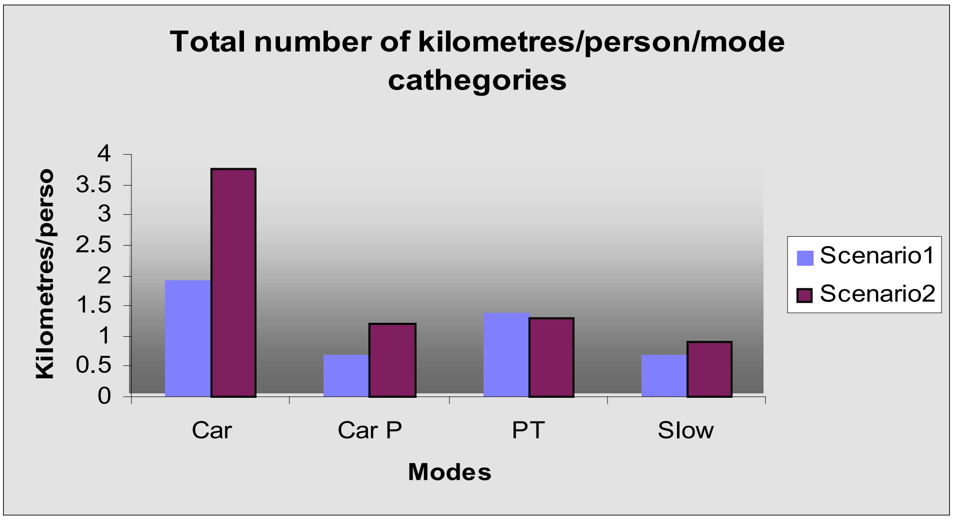



Figure 7. Total estimated trip kilometres/person per mode for scenario 1 and 2.

The model provides results of trips to be produced for different scenarios. It is evident in figure 7 that Scenario 2 (Hanover Park West) produces more trip kilometres per person than Scenario 1 (Kenilworth Central) for almost all modes. The model is basically ensuring that zones are not filled beyond capacity of the transportation system. Therefore planners can choose scenarios, which minimise trips and kilometres travelled and that encourage use of public transport to ensure that mobility rates are compatible with sustainable developments.

In this case it will be environmentally and economically wiser to build in Kenilworth since it is more central and not on the periphery where Hanover Park West is located. This brings us back to the point noted earlier that housing or rather new settlements, should not be built on the periphery of cities as it has major impacts on the existing transport systems.

The GIS programme used to perform the tasks was Arcview version 3.2a. The GIS is able to display the results for the trip distribution as the total number of trips distributed to the different zones and the total number of kilometres. Figure 8 shows the comparison between the two scenarios using GIS.

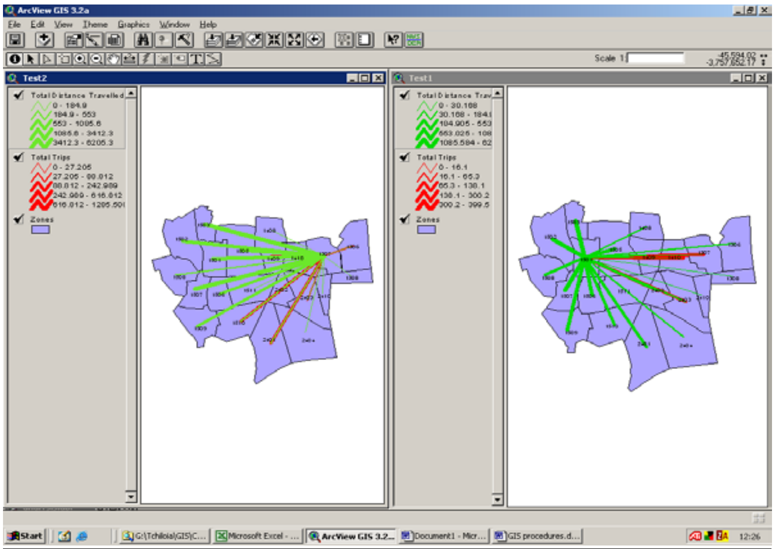


Figure 8. Comparison between the two scenarios using GIS.

Therefore the model provides the total number of trips and kilometres, per mode per purpose distributed over to the different zones from the new settlements.

This analysis and visual presentation together with additional information about the city makes it possible for the planner to answer a series of questions such as:

- In which areas is congestion more likely to occur?
- Which areas are served by public transport, are there facilities available?
- If I build a settlement here for that % of people without car, where are they going to go for education? Will I have to build another road? Insert a bus route here? Build another school?
- How will it impact in the overall region?
- How are the different types of travel flows distributed?

The main objective of a planner should be to minimise the need to travel, total number of car kilometres and to maximise the use of public transport by making people less dependent on private cars. Having the model at hand, the planner is able to make informed decisions in settlement (housing) planning and development.

## 7. CONCLUSIONS

It is important to monitor mobility changes due to development of new settlements so that people's behaviour can be understood. With this understanding it is then possible to provide better settlement planning and manage transport infrastructure for the future. Decisions and planning can be improved to allow settlement locations to be optimised and served in terms of transport infrastructure and services. The prototype has proven the possibilities of integrated land use transport models.

The procedure presented here admittedly suffers from some limitations. The production parameters for the prototype were produced from a limited database of an activity based household travel survey in Cape Town. Ideally the data should have had more than **385** household instead of 204 household used. Therefore in order to produce a good model there is need for more accurate data to upgrade the existing prototype. The importance of empirical research becomes clear should future case studies be developed.

There are several remaining tasks. The gravity model approach used in the trip distribution stage of the model assumes that the choice of destination of trips produced is dependent on distance alone, whereas such an assumption is too general to simulate the complicated urban systems. The distance used between cells, is not the exact amount of kilometeres travelled by the individuals. Therefore, more research should be conducted to discover other variables such as travel times and costs that also influence an urban traveller's behaviour. Moreover, further research is needed for shopping and education trip attraction as the quality of data input determines the quality and reliability of the output.

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**Biography**

Lindiwe Molai graduated with a Bsc Honours in Rural and Urban Planning, majoring in Transport planning and management, at the University of Zimbabwe in August 2000. She worked for the Ministry of Lands and Agriculture as a Land Officer responsible for Land Suitability and Resettlement Planning for one year. In 2002 she joined the Ministry of Local Government and Public works as a Junior Town Planner in the department of Physical Planning for three months before moving to South Africa in May 2002. On moving to South Africa she started her Master of Philosophy in Urban Transport Studies at the University of Cape Town as a full time student. Her current research interests are Urban transport policy, planning and management, Transport modelling and Urban Planning and Management.