A RELOOK AT RESIDENTIAL TRIP GENERATION VARIABLES

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ABSTRACT
Income forms the basis for the differentiation of residential trip generation rates in South Africa. In the last ten to fifteen years this country has experienced sweeping political and socio-economic changes; with the result that income categories as described in the South African Trip Generation Rates (1995) have become difficult to apply. This situation is proving to be a source of frustration and contention for developers, traffic engineers and the local authorities alike. A review of the current trip generation rates as well as the methodology used to establish trip rates is called for. The purpose of the paper is to investigate alternative independent variables to define residential trip generation in middle and higher income areas, and to develop a method that can be applied in practice. Based on the literature and practical experience with traffic impact studies, the following independent variables were selected for investigation:

- Size of development in number of units.
- Density of development in units per hectare.
- Size of units in square meters or number of bedrooms

Trip generation surveys were undertaken at 55 locations in Johannesburg and Ekurhuleni. The independent variable that performed the best as a predictor of residential trip rates is Density of development. The weighted average method of establishing trip rates is applied, and appropriate trip rates are provided. Compared to the rates published in the South African Trip Generation Rates (1995) and other relevant sources available in South Africa, average trip rates appear to have declined, necessitating a more in-depth relook at trip generation rates and procedures used in traffic impacts studies.

INTRODUCTION
Income forms the basis for the differentiation of residential trip generation rates in South Africa. The South African Trip Generation Rates document (South African Department of Transportation, 1995) recommends peak hour trip rates of 0.5 trips per dwelling unit for low income areas, 1.1 trips per dwelling unit for middle income areas, 1.5 trips for high income areas and 1.1 trips for cluster housing.

South Africa has experienced major political and socio-economic changes in the last 15 years, including the emergence of a black middle class. Characteristics of residential areas have changed as crime and the need for improved security resulted in the development of security complexes on a large scale.
Many of the changes are discussed and statistically presented in documents such as the State of the Environment South Africa Report (Department of Environmental Affairs and Tourism, 2005), the State of the Cites Report 2006 (Department of Provincial and Local Government), as well as the National Household Travel Survey (Department of Transport, 2006).

As a result of these changes income categories have become more difficult to define, added to which, information on income is highly sensitive and confidential. This situation is proving to be a source of frustration and contention for developers, traffic engineers and the local authorities alike. To developers a small difference in a trip rate may significantly change the resulting transportation decisions and financial commitment. To the local authority it is vital to have access to a realistic trip rate to establish the true impact of the development on the road network, as well as to establish a fair and accurate method for the levying of bulk service contributions.

Issues of legal responsibility and technical robustness, coupled with criticism of its apparent orientation towards car-based development (e.g. Shoup, 2002; Van Rensburg & Van As, 2004), have lead to efforts to update the Traffic Impact Assessment (TIA) methodology used in Gauteng. Despite the fact that the new methodology allocates bulk services contributions based on a combination of trips and trip lengths, it remains the case that trip rates are for the time being the foundation of traffic impact studies and the basis upon which developers' contributions are calculated nationally.

The objectives of the paper are therefore to:

- Review the current method of determining residential trip generation rates in South Africa.
- Investigate which alternative independent variable based on development characteristics is most suitable for determining residential trip generation rates, by applying the methods described in the Institute of Transportation Engineers Trip Generation document (Trip Generation, 7th Edition,2004)
- Recommend a method that can be used to establish residential trip generation rates in practice.

The focus of the paper is on residential trip generation in the middle and higher income areas. It is also likely that socio-economic changes have led to a growing trip generation in the low income areas, which must not be neglected or underestimated, but such areas were not included in the present study.

THE CURRENT METHOD OF DETERMINING RESIDENTIAL TRIP GENERATION

The South African Trip Generation Rates document (South African Department of Transportation, 1995) identifies some of the factors that influence residential trip generation as household size, vehicle ownership, workers per unit, availability of public transport and the annual income of residents. Acknowledging that most of the socio-economic factors are difficult and costly to measure in practice, it uses only income levels as an indicator of trip generation rates. The document recommends peak hour trip rates of 0.5 trips per dwelling unit for low income areas, 1.1 trips per dwelling unit for middle income areas, 1.5 trips for high income areas and 1.1 trips for cluster housing.

The income of residents is mainly used for a general classification of residential areas into trip generation categories. No attempt was made in the document to attach monetary values to the categories, presumably as they would change over time. This makes it rather difficult to apply in practice, and subjects the estimation of trip generation to the subjective and controvertible judgment of the practitioner. In addition, more precise income data for an individual development (intended or existing) are difficult to obtain or estimate due to privacy concerns.

The document gives both the average and 75th percentile values for trip generation. Local authorities can decide which rate they would prefer to use. The 75th percentile is recommended for the following reasons:

- The use of the average peak hour trip rates as design values appears impractical; given the limited number of data points, as well the wide scatter of observed values and the occurrence of outliers.
- When analysis of levels of service is performed on urban facilities, the peak 15 minutes of the peak hour is always considered to provide for the worst case scenario. The use of only the average trip generation rate would be contradicting.
- The use of the 75th percentile is considered as being more equitable for both the road authority and the community when bulk service contributions of developers are calculated. Summary sheets are presented in the document showing the average and recommended trip rates, as well as the number of studies, range, and standard deviations.

VARIABLES INFLUENCING RESIDENTIAL TRIP GENERATION

As an alternative to the use of income as an indicator of residential trip generation rates, the following potential independent variables based on development characteristics are investigated:

- Size of development in number of units.
- Density of development in units per hectare.
- Size of units in square meter or number of bedrooms. {this independent variable was analyzed as percentage (%) of three or more bedroom units in a development}

Size of development in number of units

It is hypothesized that the higher the income of a household or individual the greater the tendency to live in smaller developments at lower densities with large residential units; as opposed to households with lower income living in large high density developments with small residential units such as flats. This theory does not always hold true due to the recent emergence of Golfing Estates and Security Estates that have a large number of units in them. It is also true that examples of high density- high income flats do exist in certain residential areas in Johannesburg such as Sandton and Randburg.

Density of development

It is hypothesized that the higher the income of a household or individual, the greater the tendency to live in a larger unit with more private space in a lower density development; as opposed to a household or individual with a lower income living in a smaller unit, with less private space, in a higher density development. This theory is best observed when one compares a high density block of flats with a low density Golfing Estate.

Number of bedrooms

The number of bedrooms is directly linked to the size of the unit and can be logically linked to the income of the residents. The greater the number of bedrooms in a unit; the greater the size of the unit; the greater the size of the unit, the higher the bond repayment or the rent; the higher the bond repayment or rent, the higher the income of the household. The number of bedrooms in a unit may also give an indication of the number of workers, the number of drivers, household size and the number of school children. It is hypothesized therefore, that the higher the income of a household, the greater the number of bedrooms in the household unit, and the higher the trip rate.

It is also hypothesized that the higher the percentage of three and more bedroom units in a development the higher the trip rate of that development. Conversely the higher the percentage of single bedroom units in a development the lower the trip rate of that development. This hypothesis was tested by analyzing the percentage of three and more bedroom units in a development.

It is contended that these independent variables do influence the trip generation of residential sites in a logical way as required by the ITE, but can also be logically linked to the socio-economic factors described in the official South African Trip Generation Rates document. Unlike the socio-economic factors described in the current document however, information on these independent variables is readily available as part of the town planning process. Development density in particular plays a major part in every town planning scheme in South Africa as well as in the Regional Spatial Development Frameworks.

DATA COLLECTION AND ANALYSIS METHODOLOGY

The methods and principles prescribed by the ITE (Trip Generation, ITE, 7th Edition, 2004) form the basis for the key actions carried out in the research project, including the selection of independent variables, the definition of independent variable categories, the determination of the number of sites to be surveyed, the physical conducting of the traffic surveys and the final data analysis.

The two data analysis methods applied in the report are weighted average trip rate and linear regression analysis. The weighted average trip rate methodology was applied to discrete categories while simple and multiple regression analysis was applied to identify continuous relationships.

The data sample is based on surveys conducted at 55 residential sites in twenty suburbs across Ekurhuleni and Johannesburg. The distribution of surveyed sites is shown in **Table1.** The sites were selected semi-randomly to ensure that the full range of development types was identified. A development type is defined by the combination of size (in terms of the number of units) and the density (units per hectare). Nine types were defined, based on three size (small, medium, large) and three density (low, medium, high) categories. In each of the nine types, a minimum of four sites were identified. The ITE prescribes between 3 and 5 surveys to be done.

Table 1: Distribution of sites surveyed

The following steps were followed:

1. After identification of suitable survey sites, information on the size of the development, the density of the development, the number of bedrooms, and the proportion of one, two, three and more bedroom units was determined from the developer or community representatives.

2. Traffic surveys were conducted at each chosen site during the average weekday, for the AM and PM peak periods.

3. Traffic data was analyzed to determine trip rates for the AM and PM peak hour as well as the AM and PM peak two hours for each development.

NO	LOCATION	INCOME AREA	NUMBER OF SURVEYS
1	ALOE RIDGE - COJ	M	1
2	AMAROSA- COJ	H	1
3	BEDFORDVIEW - EKURHULENI	H	7
4	DOUGLASDALE - COJ	M/H	3
5	EDENGLEN – EKURHULENI	M/H	5
6	EDENVALE– EKURHULENI	M	1
7	HELDERKRUIN - COJ	M/H	2
8	HONEYDEW MANOR - COJ	M/H	3
9	HONEYDEW RIDGE - COJ	M/H	4
10	HURLEYVALE - EKURHULENI	M	3
11	MARLANDS - EKURHULENI	M	7
12	MOGALE CITY	M/H	1
13	PAULSHOF - COJ	M/H	3
14	PRIMROSE HILL – EKURHULENI	M	2
15	RUIMSIG - COJ	H	1
16	SEBENZA - EKURHULENI	M	2
17	WILGEHEUWEL	M/H	5
18	WILLOWBROOK	M/H	2
19	WITFIELD - EKURHULENI	M	1
20	WOODMERE - EKURHULENI	M	1
	TOTAL		**55**

4. Data analysis was carried out using the weighted average trip rate methodology as well as simple and multiple linear regression. The objective of the analysis was to identify the independent variable, or combination of variables, that produced the most stable relationships and the highest coefficients of determination (R^2). The ITE prescribes the use of the weighted average when discrete categories or classes are used, and regression analysis when continuous relationships need to be established. Comparisons were made between the one hour and two hour peak periods. Statistical tests (t-test and F-test) were performed to confirm the statistical significance of the relationships derived.

5. The results of the data analysis were summarized and compared to existing and relevant data available in South Africa.

The results of the analysis are discussed in the next section.

RESULTS OF THE DATA ANALYSIS

The results of the data analysis can be summarized as follows:

1. All three alternative independent variables affect residential trip generation in significant and expected ways, thus confirming the hypotheses stated above:

- Trip rates decrease as density of development increases.
- Trip rates decrease as the size of development increases.
- Trip rates increase as the percentage (%) of three or more bedrooms in a development increases.

The results for the simple linear regressions are given in **Table 2** below. The significance of all three relationships are evident from the significant t- and F-statistics. However, the coefficients of determination (R^2) are lower than the minimum R^2 of at least 0.75 prescribed by the ITE for an acceptable regression equation for trip generation. Despite the low R^2 values, the models make intuitive sense and the coefficients have the correct signs.

Table 2: Summary of linear simple regression analysis

DESCRIPTION		ONE HOUR		
		AM	PM	PEAK
DENSITY				
	EQUATION	y = -0.00353x + 0.8666	y = -0.00444x + 1.0211	y = -0.00398x + 0.9439
	R^2	0.2127	0.1983	0.1938
	F(statistic)	14.326 (>1.94)	13.112(>1.94)	25.962(>1.59)
UNITS				
	EQUATION	Y = -0.00102X + 0.796405	y = -0.00115X + 0.9217	y = -0.00109x + 0.8590
	R^2	0.102	0.0760	0.0824
	F(statistic)	6.044 (>1.94)	4.363 (>1.94)	9.703 (>1.59)
% 3 BEDROOMS				
	EQUATION	y = 0.003065x + 0.5543	y = 0.003996x + 0.6213	y = 0.003531x + 0.5876
	R^2	0.2538	0.2543	0.2408
	F(statistic)	18.035 (>1.94)	18.08 (>1.94)	34.255 (>1.59)

2. The data displays a non-linear relationship, which is the clearest in the case of the density vs trip rate relationship shown in **Figure 1**. Trip rates at very low densities are higher than what would be suggested by a simple linear relationship, indicating that trip generation rates could increase drastically for sprawling development types. The converse is that trip generation would tend towards some asymptotic value as densities grow. This non-linear relationship was confirmed by non-linear simple regressions that were performed, testing power, logarithmic, and polynomial functional forms. The power and logarithmic forms produced improved R^2 values than the linear equations mentioned above, but the polynomial form did not perform as well as it forced the relationship to have an illogical inflection point.

It is furthermore clear that the data display heteroschedasticity, as the variance of the observed trip rates are much higher for lower values of all three independent variables, than for higher values (see for example **Figure1**). Although this does not invalidate the significance of the relationships between the trip rate and the independent variables that have been derived, it decreases the confidence in any application of the regression equations in a *predictive* mode.

3. Of the three independent variables, Density of development is the most suitable of the independent variables for the following reasons:

- Density provided the highest R^2 values overall when Power Functions and Logarithmic Functions were used to fit curves to the data**. (Table 3)**

- From a practical perspective information on development density is readily available in comparison with information on development size or the % three bedrooms, as most town planning schemes prescribe development density.
- Density of development indirectly describes some of the socio-economic factors that influence trip rate, and conforms to much previous empirical research that has shown the importance of density in determining mode choice, trip lengths, and other aspects of travel behaviour.

Table 3: Summary of non-linear regression analysis for density of development

FUNCTION	ONE HOUR R2			TWO HOURS R2		
	AM	PM	PEAK	AM	PM	PEAK
LOGARITHMIC FUNTION	0.4135	0.3248	0.3430	0.4579	0.3808	0.3822
POWER FUNCTION	0.4019	0.3588	0.3644	0.4370	0.4191	0.4008

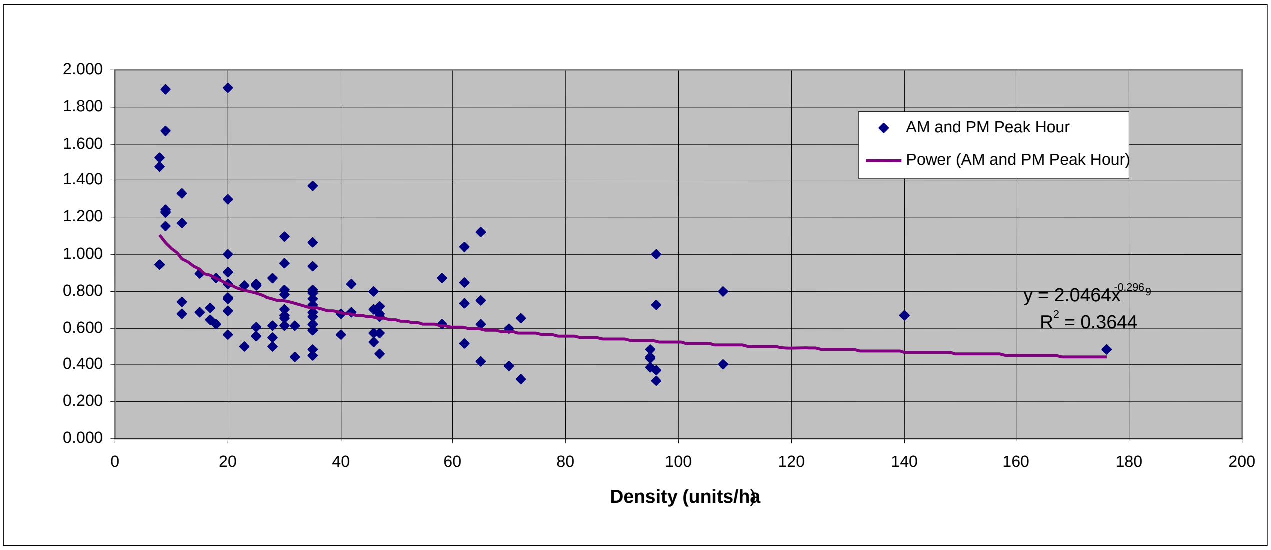

Fig 1: Density – am & pm peak hour trip rate (power function)

4. A multiple linear regression was also performed to determine the effects of each of the three independent variables, controlling for the others. The model also combined the AM and PM peak hour data, and attempted to identify the effect of the time of day by introducing a PM peak dummy variable. The results are shown in **Table 4** below.

All variables are significantly different from zero at the 95% significance level, and have the expected signs. This indicates that density, size of development, and the size of units each has independent effects on the trip rate that are not accounted for by the other variables. By implication, if information is available on all three of the independent variables for a particular residential area, they could all be used in this model to improve the accuracy of the trip generation forecast. In general, it suggests that trip rate models might benefit from including a larger number of descriptive variables, provided these are easily and accurately obtainable.

Table 4: Results of multiple linear regression analysis

VARIABLE	ONE HOUR R2	
	COEFFICIENT	**t STATISTIC**
Constant	**0.767**	**9.49**
Density of development	**-0.00223**	**-2.52**
Number of units	**-0.000924**	**-3.12**
% of 3+ bedroom units	**0.00225**	**3.18**
PM dummy (1 if PM)	**0.115**	**2.45**
	R^2 = 0.368	**F stat = 15.33 (p=0.00)**

5. Of further significance is that the afternoon (PM) trip generation rates are found to be higher, on average, than during the morning. In the table above, the PM dummy variable is positive and significantly different from zero, and indicates that the average household makes 0.115 more trips in the afternoon peak than in the morning, everything else being equal. This is contrary to conventional wisdom that holds that morning peak hours tend to be more peaked, or the current SA trip generation rates approach which takes the two peaks as being equal. This issue is important as the choice of design hour affects the capacity enhancements needed for access to new developments. Further studies are needed in this issue.

6. In light of the problems with non-linearities and heteroschedasticity in the data, the use of the weighted average trip rate methodology was also investigated. The method determines average trip rates for discrete categories of the independent variables, instead of a continuous relationship. The weighted average trip rate methodology is prescribed by the ITE and has also been adopted for the Revised South African Trip Generation Rates, 2007.

The results of the weighted average trip rate analysis for the three discrete density and units categories are indicated in **Tables 5** and **Table 6.** The cut-off points between the density and units categories were selected manually to maximize the apparent difference between the dependent variables in each category. T-tests were used to confirm the significance of the differences in the average trip rates so obtained across categories.

Table 5: Summary of weighted average trip generation rates for density categories

DENSITY CATEGORY		ONE HOUR (Trips per Unit)			TWO HOURS (Trips per Unit)		
		AM	**PM**	**PEAK**	**AM**	**PM**	**PEAK**
High	Density>40	0.49	0.61	**0.55**	0.84	1.03	**0.94**
Medium	20<= density=< 40	0.64	0.75	**0.69**	1.06	1.31	**1.19**
Low	Density <20	0.90	0.97	**0.94**	1.57	1.73	**1.65**
WEIGHTED AVERAGE		**0.63**	**0.74**	**0.69**	**1.08**	**1.28**	**1.18**

Table 6: Summary of weighted average trip generation rates for units categories

UNITS CATEGORY		ONE HOUR (Trips per Unit)			TWO HOURS (Trips per Unit)		
		AM	**PM**	**PEAK**	**AM**	**PM**	**PEAK**
Large	Units>100	0.62	0.71	**0.66**	1.07	1.23	**1.15**
Medium	10 <=units<= 100	0.72	0.86	**0.79**	1.16	1.49	**1.33**
Small	Units<10	0.82	1.10	**0.96**	1.31	1.62	**1.46**
WEIGHTED AVERAGE		**0.64**	**0.75**	**0.69**	**1.09**	**1.31**	**1.20**

The data for the Density Categories is presented schematically in **Fig 2**.

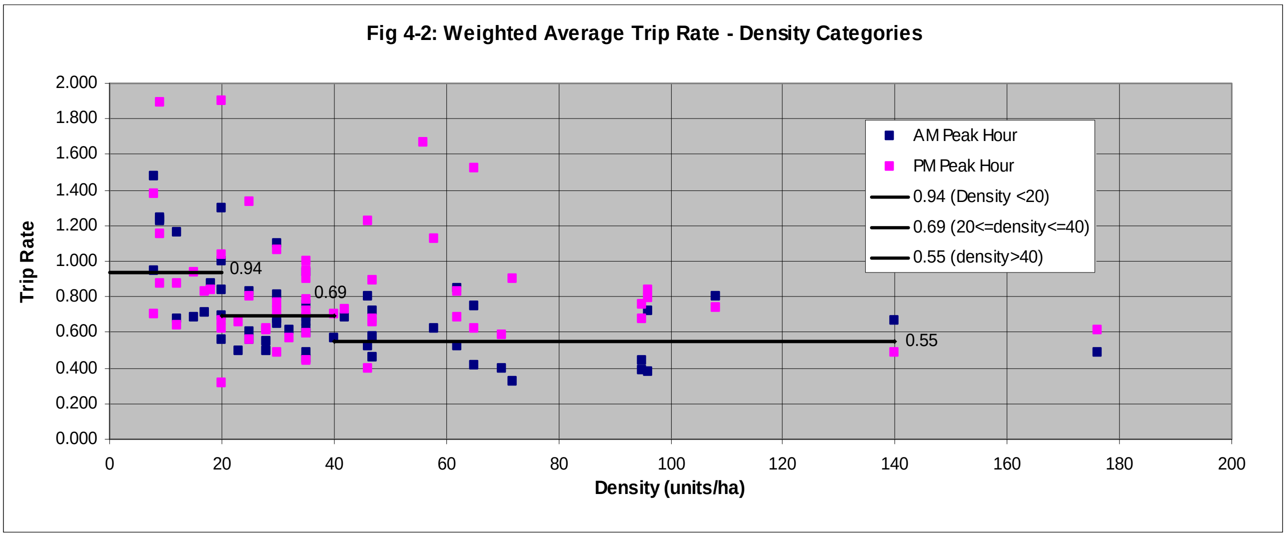

Fig 2: Weighted average trip rate – density categories

The trip rates for the two hour peak period are typically 70% to 80% higher than trip rates for the peak hour; this indicates a high degree of peak spreading. Due to the small increase in the coefficient of determination (R^2) when comparing the two-hour peak period with the peak hour period, it is concluded that use of the two hour rate does not offer particular benefits over use of the conventional one hour rate.

Weighted average peak hour trip rates (combining AM and PM peak data) are strongly related to the development density. A decrease in trip rate of approximately 40% was observed from low to medium density, and a decrease of approximately 30% was observed from medium to high density.

COMPARISON WITH TRIP RATES FROM OTHER SOURCES

The weighted average trip rates calculated for the density categories were compared with residential trip rates in the following documents and presented in **Table 7**:

- South African Trip Generation Rates, 2nd Edition, June 1995
- Proposed Revised South African Trip Generation Rates, Draft Report, 2007
- Trip Generation, ITE, 7th Edition, 2004

It is confirmed that the trip rates presented in ITE (7th Edition, 2004), as well as the Revised South African Rates (2007), are based on weighted average values, while the trip rates presented in the official South African Trip Generation Rates (1995) are based on 75th percentile values. This is due to the relatively small number of developments surveyed in 1995, as well as the wide scatter of observed values.

The official South African Trip Generation Rates provides both the average and 75th percentile values for trip generation, giving local authorities the choice as to which rate they would prefer to use. Therefore, for a more realistic comparison to be made, the average values provided in the official South African rates must be compared to the weighted average values provided in the existing sources and in the research project.

Table 7: Comparison of the estimated weighted average peak hour trip rates (density) with other relevant rates currently used in South Africa.

OFFICIAL SOUTH AFRICAN RATES- 1995		PROPOSED REVISED SOUTH AFRICAN RATES 2007		ITE (7th Edition 2004)		RESEARCH PROJECT CATEGORIES RATES	
CATEGORY	**RATE** Trips per unit	**CATEGORY**	**RATE** Trips per unit	**CATEGORY**	**RATE** Trips per unit	**CATEGORY**	**RATE** Trips per unit
RES.HOUSES HIGH INCOME AREA (75th percentile) (Average)	**1.5** **1.3**	SINGLE DWELLING HOUSE HIGH VEHICLE OWNERSHIP	**1.09 AM** **0.78 PM**	SINGLE FAMILY DETATCHED HOUSE	**0.77 AM** **1.02 PM**	**LOW DENSITY**	**0.90 AM** **0.97 PM**
RES.HOUSES MIDDLE INCOME AREA (75th percentile) (Average)	**1.1** **1.0**	SINGLE DWELLING HOUSE HIGH VEHICLE OWNERSHIP	**1.09 AM** **0.78 PM**	SINGLE FAMILY DETATCHED HOUSE	**0.77 AM** **1.02 PM**	**LOW DENSITY**	**0.90 AM** **0.97 PM**
CLUSTER HOUSING (75th percentile) (Average)	**1.1** **0.9**	TOWNHOUSE HIGH VEHICLE OWNERSHIP	**0.87 AM** **0.87 PM**	LUXURY CONDO	**0.65 AM** **0.65 PM**	**MEDIUM DENSITY**	**0.64 AM** **0.75 PM**
CLUSTER HOUSING (75th percentile) (Average)	**1.1** **0.9**	APARTMENT HIGH VEHICLE OWNERSHIP	**0.68 AM** **0.66 PM**	LOW RISE APARTMENT	**0.51 AM** **0.62 PM**	**HIGH DENSITY**	**0.49 AM** **0.61 PM**
		RETIREMENT VILLAGE	**0.32 AM** **0.37 PM**	SENIOR ADULT HOUSING DETATCHED	**0.31 AM** **0.35 PM**	**HIGH DENSITY**	**0.49 AM** **0.61 PM**

From the data shown in **Table 7** it would appear that trip rates have decreased since 1995. Reasons for this decrease could include:

- **Peak Spreading due to increased congestion.** As the road network has become more congested over the years, residents leave home earlier and return home later to try to avoid points of congestion. Trips are spread out over a longer time period resulting in lower trip rates.
- **Increased number of mixed land-use developments.** Increased densification has brought about an increase in the number of mixed land-use developments which have resulted in the reduction of trips as well as the length of trips that residents need to make. (eg. Neighborhood shopping centre with a gym, restaurant, post office, pub and supermarket).
- **Increased vehicle occupancy.** Increased urban densification, road network congestion and the higher petrol price has resulted in an increase in the formation of “lift clubs” and “ride - share” schemes.
- **Increased use of Public Transport.** Though the South African public transport system leaves a great deal to be desired in comparison with other countries around the world,

increased congestion and the high petrol price has forced many motorists to re-evaluate public transport.

Further research is required to fully investigate the effects of congestion and densification on trip rates.

CONCLUSIONS AND RECOMMENDATIONS

1. Density of development is recommended as the single most appropriate independent variable to be used to describe residential trip generation. The application of Weighted Average Trip Rate methodology to the three discrete density categories resulted in the peak hour trip rates shown in **Table 5** above.

2. The afternoon (PM) trip rates are up to 25% higher than the corresponding morning (AM) rates. This is a significant difference that warrants further investigation to understand how peaking across different times of the day is changing. In the meantime, the use of one average rate for both peak hours is recommended to maximize the statistical validity of the average trip rate estimate.

3. From a practical perspective, and in view of the low coefficient of determination (R^2) values obtained from regression analysis, it is also recommended that the Weighted Average Trip Rates methodology based on discrete density categories, as opposed to the use of continuous curves, is adopted for the estimation of residential trip rates. Trip rate values based on discrete categories will serve to simplify the conducting of traffic impact assessments and transportation planning, as well as the calculation of bulk service contributions by the local authority.

4. The average trip rates estimated here for typical residential developments in Gauteng are lower than the corresponding rates recommended by previous documents commonly used for traffic impact assessments. It suggests that travel behaviour in South Africa continues to change in ways which could impact the accuracy and effectiveness of transport planning efforts if practices are not updated and revised. A data base modeled on the system used by the ITE should be established in South Africa. Transportation professionals, local authorities and developers should be encouraged to submit trip rate data to build the data base, this would result in the estimation of more accurate and realistic trip rates.

5. The work reported here suffers from the same problems affecting previous studies, insofar as it remains very difficult to determine empirically the effects of new policy initiatives such as improved public transport services on trip generation, due to the difficulty of observing its impacts in practice. This constrains our ability to adequately anticipate and plan for the traffic impacts (especially its benefits in terms of traffic reduction) of public transport investments. In order to move the practice of traffic impact assessment towards a more policy sensitive state, further research on the following is required:

- The effects of traffic congestion on trip rates.
- The effects of densification and mixed land-use on trip rates.
- The difference between AM and PM peak hour trip rates.
- The impact of public transport on trip rates.
- The use of discrete categories as opposed to continuous curves.
- Trip generation in low income areas

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