Supporting Densification through the Planning and Implementation of Road Infrastructure in the South African Context

K. Govender, M. Sinclair

***Abstract*—**This paper demonstrates a proof of concept whereby shorter trips and land use densification can be promoted through an alternative approach to planning and implementation of road infrastructure in the South African context. It briefly discusses how the development of the Compact City concept relies on a combination of promoting shorter trips and densification through a change in focus in road infrastructure provision. The methodology developed in this paper uses a traffic model to test the impact of synthesized deterrence functions on congestion locations in the road network through the assignment of traffic on the study network. The results from this study demonstrate that intelligent planning of road infrastructure can indeed promote reduced urban sprawl, increased residential density and mixed-use areas which are supported by an efficient public transport system; and reduced dependence on the freeway network with a fixed road infrastructure budget. The study has resonance for all cities where urban sprawl is seemingly unstoppable.

***Keywords*—**Compact cities, densification, road infrastructure planning, transportation modeling.

I. Introduction

PLANNING and implementation of road infrastructure projects, controlling urban sprawl, developing compact city layouts, balancing jobs and housing opportunities – these have all been on-going concerns for transportation planners world-wide. These elements are inter-dependent and form some of the principles of creating a compact city and, with on-going refinements, can eventually be the key to achieving "The Future City".

While much of the debates and visualization around future cities are occurring in the developed world, it is the developing world that consistently faces growing crises of sprawl and the inevitable social inequalities that come along with it. As a result, the urban poor are largely spatially marginalized and spend significant proportions of their income and time commuting between their places of residence and work. This has the undesirable consequence of their home environments themselves leaving a lot to be desired in terms of the impact on family life and access to amenities, services and local employment opportunities.

South Africa is no newcomer to urban sprawl; in all of its metropolitan areas, sprawl continues apace. Right now the two major cities of Pretoria and Johannesburg are growing closer and closer, and look certain to become a single metropole in the near future unless sprawl can be contained. However, to effect the change needed to reduce or even stop sprawl would arguably be impossible without significant financial investment and a redirection in urban planning principles.

This study considers the objective of promoting densification through a more pragmatic angle, which is to look at whether an environment supporting urban densification can be promoted by changing our ways of investing in transport infrastructure in the future. This approach to transport planning moves away from the age-old philosophy of building roads such that private vehicles and freeways are prioritized. Instead, this approach focuses on investing more intelligently in local route development, as well as in public transport and non-motorized transport (NMT). The idea here is that the changes that we need to make to curtail sprawl can be brought about very easily through a revision of how transport budgets are spent in the future. The study firstly determines the deterrence function for the base year strategic transport model, based on information in the latest available land use and traffic data provided by the South African National Roads Agency Limited (SANRAL), and then generates various synthesized deterrence functions to test their effect on trip lengths and route choice on the Gauteng Freeway Improvement Project (GFIP) model's road network.

The objective and nature of this research project is unique because it approaches the planning and implementation of road infrastructure from a different viewpoint. This study focuses on investigating an approach to the planning and implementation of road infrastructure such that densification is encouraged, and indeed becomes inevitable. This places transportation planning in a key area of influence over the shape of cities in the future.

II. The Problem of Sprawl in an International Context

Urban sprawl is described as unrestricted growth in housing, commercial developments and road infrastructure with minimal consideration of future urban planning [1]. Sprawl is directly proportional to the distance away from the city boundary. This means that sprawl increases as the distance from the city center increases. There are social and environmental consequences of sprawl in cities and towns which include longer home-work and work-home distances travelled by commuters and larger road infrastructure required to link residential areas to the central business district (CBD) [2]. Characteristics of urban sprawl also include pockets of low-density residential areas spread outwards from the CBD

K. Govender and M. Sinclair are with the Civil Engineering Department, University of Stellenbosch, Stellenbosch, CO 7602 South Africa (e-mail: govenderkerisha93@gmail.com, msinclair@sun.ac.za).

of cities and towns, single use zoning and relies heavily on the use of private vehicles for transportation to and from places of work and leisure [1]. In summary, urban sprawl is the decentralization, discontinuity and segregation of residents. Reference [2] further explains that a key factor contributing to the increase in urban sprawl over the years is the cost of land and property. Market trends from across the world indicate that the price of property increases towards the CBD. This in turn contributes to the segregation of commuters according to their level of income.

Urban sprawl has a number of negative consequences. The main consequence, which this research project addresses, is the high cost of transportation (infrastructure, maintenance and generalized cost in terms of travel time and distance travelled). Another consequence of sprawl is the high costs of providing services such as sewerage, electricity and water to households far from the city center or other highly densified areas [3]. Social costs associated with sprawl and the marginalization of the urban poor, especially in the developing world, are well documented. Equally well documented are the growing concerns related to environmental damage from air, light and noise pollution.

New thinking about cities suggests that it makes more sense to concentrate households in areas which are near to city centers and other densified places which contain places of work and access to medical care, educational facilities and other amenities. Planning city layouts such that urban sprawl is limited will allow for services and road infrastructure to be provided to residents in a more economical manner. An added bonus of reducing urban sprawl and creating a more compact city layout would be that public transport becomes more accessible to residents and commuters. Subsidies for the provision of public transport service and infrastructure become easier to provide due to trips being shorter than those in an environment that has increased urban sprawl.

Literature suggests that transportation planning should focus on reducing sprawl by limiting the distance of developments (residential zones) from city centers. In theory, through the limitation of sprawl, an environment which supports and encourages densification would be created. An additional benefit of a densified environment is that the average trip lengths between zones will be shorter. The combination of shorter trip lengths between zones and a densified environment supports the implementation of public transport [2].

III. Urban Spatial Planning in South Africa

The evidence of poor spatial planning in South Africa can be seen in the urban infrastructure. The consequence of this poor spatial planning is the following:

- Imbalance in access to available public transport services;
- Poor connectivity between suburbs, cities and towns; and
- Increased trip lengths for home-work trips.

The public transport infrastructure in Gauteng was never designed to accommodate all income groups (low, middle and high) effectively.

Urban sprawl continues to increase in South Africa despite the acknowledgement of its consequences [16]. The reason can be partly based on the apartheid spatial planning of cities and towns in South Africa; i.e. white (high-income) residents were located in suburbs close to city centers, other race residents were only allowed to reside, and eventually buy, property on the city peripheries. Since the end of apartheid in South Africa, new urban developments have followed this trend. Now, low income earners do not have adequate funds to cover both transport and housing costs and therefore seek lower priced housing either on the urban periphery or away from the urban periphery. This means that they are doubly burdened with high transportation costs and limited public transport options [10]. In the South African context, the available public transport services are mini-bus taxis and a limited supply of buses.

The cost of implementing public transport in Gauteng is exceptionally high due to low urban densities and high urban sprawl. Due to the sprawl layout of cities and areas in Gauteng, a formal transport service has not been financially feasible.

The consequence of urban sprawl in South Africa can be summarized as follows [4]:

- Inefficient use of urban land;
- Rural encroachment;
- Dependence on private vehicles;
- Traffic congestion on mobility routes as well as the second order road network; and
- An expensive public transport system.

When considering the consequences and effects that urban sprawl has had on South Africans, it can be concluded that urban sprawl has impacted negatively on their quality of life.

IV. The Concept of a Compact City

There has been rapid urbanization occurring in many areas throughout the world. Approaches to revive inner cities, such that the ever-increasing population and their corresponding transportation needs are accommodated for, are constantly being reviewed by transportation planners and policy makers [11]. As a result, methods of modifying the “modern day city” are being scrutinized. In the past, the basis for planning urban and road infrastructure was “private vehicle” induced mobility [11]. The dominant influence of private vehicles has created accessibility for people residing in farther distances. This has led to the creation of a low-density urban environment (sprawl) and has left those without private vehicles - or access to an affordable public transport service - stranded. Policy makers have recently taken a new approach to the planning of urban and road infrastructure; that being focusing on access to transportation (public transport) and the distribution of network capital [11]. These factors in turn result in social exclusion of those living further away from cities and employment centers.

The prime focus of urban development centers around using public transport and walkable (pedestrian friendly) cities in an effective manner [11].

The concepts of ‘New Urbanism’ and the ‘Compact City’ have emerged as suitable answers in modifying low density and private vehicle driven urban and road infrastructure, and environments, to achieve the following characteristics:

- Cities and towns with mixed urban densities;
- Neighborhoods which are well connected;
- Mixed used and diversity;
- Increased densities of cities and towns; and
- Improved quality of life for all income groups through reducing social exclusion of income groups.

The topics of New Urbanism and the Compact City are fairly new in the South African context with limited applications in existence. Some examples include *Century City* in Cape Town and *Melrose Arch* in Gauteng. However, it is to be noted that these developments are targeted at high income earners and exclude the lower- and middle-income groups. Therefore, these developments operate in isolation to the transportation network and urban infrastructure around them.

The capabilities and extents of changes required to urban and road infrastructure, such that the concepts of New Urbanism and the Compact City can be implemented, need to be understood. A compact city has the following characteristics:

- Promotes working and living in places which have high densities of living and working spaces;
- Has pedestrian friendly streets;
- Arranges residential areas and work spaces such that they are located within walking distances of each other;
- Has an affordable and efficient public transport service and the necessary pedestrian facilities to cater for the movement of people for work or leisure needs;
- Incorporates a spatial layout that is conducive to and promotes shorter distance trips; and
- Has a spatial layout which encourages densification and mixed land use.

A compatible relationship exists between the level of compactness of a city and its public transport systems [11]. High density urban layouts promote the success of public transport services, reduce the dependency on private vehicles and improve the walkability of a city. The combination of these aspects therefore contributes to a sustainable transport strategy for urban growth in the future [11].

V. The Impact of Transport Planning on Urban Density

A. The Relationship between Density and Trip Length

Research published by [12] suggests that commuters residing in areas with a lower population density and a lower proportion of mixed land use travel longer distances than those residing in areas with higher population densities and higher proportions of mixed land use. Trip lengths have proved to be consistently low in inner city networks (city layouts) which have high densities and mixed land use. Longer trip lengths have been found to be consistent in neighborhoods and suburbs with low densities [11].

The concept of *activity intensity* can be defined as combining population density and job density as both ends of a trip needs to attain high density levels to significantly affect travel behavior. Of course, in order to achieve a workable high density within a city an effective public transport system is an essential component.

Not all parts of a city are of equal population or activity density. *Articulated density* is explained as a method of strategically distributing the population density over a metropolitan area with regards to the proximity to public transport or transit-oriented development [2].

B. Public Transport Systems

The density of an urban city or region affects the number of passengers that are able to use a public transport service [2]. User ridership of a public transport service is primarily dependent on accessibility to the public transport system. The accessibility of the public transport system is derived from the generalized cost as well as how close the user is located to a public transport facility [2]. It is crucial to remember that all public transport users are also pedestrians. Hence, the spacing and location of public transport facilities must be based on the maximum distance that a pedestrian is willing to walk to get to the relevant facility. The maximum distance (proximity) defines the effective catchment area which has the highest probability of user's utilizing the public transport stops or facility [2]. This means that most public transport users will prefer to live and or work within the collective catchment area of a public transport facility. At the same time, the number of users who are most likely to use the public transport service is fundamentally dependent on the density of the urban development or city [2]. The threshold ridership is based on the financial cost of the operation of the service - provided that user costs are kept constant [2]. A high quality and efficient public transport system will have a high ridership threshold [2]. For a public transport service to be of a high quality and good viability it must have a ridership threshold which equals the number of users [2]. This can be explained using the example of a subway system. An expensive subway system with a high ridership threshold will require an equally high urban density to be viable.

C. Infrastructure Requirements

The gross population densities of cities, combined with supporting urban infrastructure, are key components in creating a viable and efficient public transport system.

A study of 24 Global Cities compiled by [5] provides a comprehensive review of various transportation systems in selected countries. It led to the publication of an implementation guide for public transport in 2019, which includes methods to make public transport a more attractive option in cities. Table I summarizes the infrastructure requirements for a viable and efficient public transport system as proposed by this guide.

Overall, the research around densification at an international level has shown that:

- Gross population densities of cities play a key role in the viability and efficiency of its public transport system;
- High frequency short trips play a key role in the viability and affordability of a public transport system; and

- Densified urban cities provide a conducive environment for public transport systems. An added benefit of densified urban cities is that they provide a "walkable" environment for people thereby promoting the use of public transport facilities and discouraging private vehicles. The densified and walkable environment makes the use of private vehicles unnecessary, expensive and inconvenient. This in turn reduces congestion levels within and around cities.
- Specific infrastructural requirements are associated with densification, including effective public transport and safe transit areas.

TABLE I
INFRASTRUCTURE REQUIREMENTS FOR VIABLE AND EFFICIENT PUBLIC TRANSPORT SYSTEMS [5], [13]

Infrastructure Requirement	Example of Successful Implementation
Users must have easy access to public transport facilities.	Singapore, Hong Kong, Madrid
Bus Routes must be optimized to reduce overlap of routes and improve coverage of the city area.	Houston (United States of America). Reduction in trip overlap increased ridership by 7%.
Location of regular bus stops for improved access.	Barcelona has bus stops spaced at a maximum of 350 m. Seattle has a year 2040 strategy to position 73% of households within 800 m of frequent transit routes.
Reduce spatial bias by reclaiming road space for public transport for the following infrastructure: • Dedicated bus lanes; • Improved facilities for waiting areas; and • Improved transit terminals	• Hong Kong • Singapore • Madrid • Paris • London • New York

The challenge in the South African context is to understand how densification can be achieved without massive urban redevelopment programs or indeed massive public investment.

D. Integrated Transportation and Land Use Models

Integrated transportation and land use models are used as a method of representing the reaction (interaction) cycle of transportation and land use in a network [6]. According to multiple sources [2], [6]-[10], [17], and [14], areas (including neighborhoods) which are more accessible are seen as being more desirable regarding choice of location than those seen as less accessible. The choice of location and transportation are interdependent [6]. To explain this simply, when households or companies change their location to be in suburbs then the existing trip distribution will change to reflect the change in origins and destinations in the area/network [15]. The change in the distribution of trips will in turn affect the level of congestion experienced on links, between origins and destinations. The relationship and inter-dependency between transport and land use in an area, which affects the behavior of the model, is not a new concept. However, many transportation planners/modelers have ignored this relationship in their models [6].

Strategic transport models developed on the basis of integrating transport and land use produce more realistic results than those produced by models which only consider transport and not land use [6]. Strategic transport models integrating transport and land use are useful in modeling and analyzing different scenarios. The effects on trip distribution, congestion and travel times as a result of re-zoning and densification of areas in the network can be tested [15]. This enables decision makers to select the most suitable, financially affordable and economically viable options for projects.

E. The Four-Step Modelling Process

The four step modelling process is the conventional method used to forecast travel volumes and travel behavior. This modelling process involves completing four steps. The stages of the four-step travel demand forecasting (4S-TDF) modeling process are as follows; trip generation, trip distribution, modal split and trip assignment, as shown in Fig. 1.

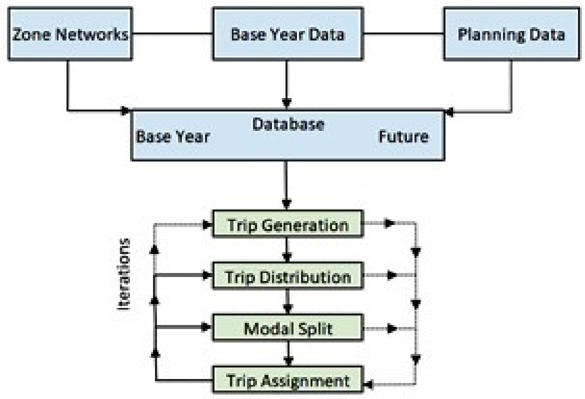

Fig. 1 The Four-Step Model

While the four step model considers the four key variables useful in determining travel demand, it is still faced with criticism. For example, [18] noted: "In general, the traditional 4S-TDF procedure takes on a top-down approach, from the decision to travel, to destination and mode choice, up to ending with the route choice. Consequently, each level is treated separately and sequentially". Also, within each of the four stages, there are limitations. For example, within the stage 'Trip Generation', some examples of limitations include: The factors responsible for generating trips are typically limited to household or household attributes, and ignore mode attributes; a number of listed trip purposes are limited to between 6 and 8 specific purposes when there are myriad differences between trips that may fall under one large category (e.g. shopping); the use of linear regression to determine trip generation is normally associated with description, not prediction, and so on [19], [18].

In our attempt to model travel demand differently, a decision was made to move away from the four-step model to a model that was capable of being more accurate, relying more directly on actual data than on broad generalizations. It was decided to develop a strategic transport model using the Simulation and Assignment of Traffic in Urban Road Networks (SATURN) modeling software. The SATURN software was selected due to availability of the software and the authors' competency level in usage of the software package.

The calibration of the traffic assignment on the network played a crucial role in developing a distance-deterrence function. The GFIP data for 2018 were provided by the South African National Roads Agency and formed the basis for the model.

Each of the following categories of data was calibrated extensively to ensure the highest levels of accuracy:

- Road network data (road link lengths, number of lanes, operating and free flow speeds);
- Travel time survey data;
- Land use data;
- Trip generation rates related to land use; and
- Traffic counts (including specifically details of freeway sections between interchanges; interchange ramps; between interchange on- and off-ramps on the freeway, on the approach roads and between interchange terminals).

Calibrations involved comparing the modelled and observed traffic flows and making corrections where necessary. For example, with the traffic flow data, due to the high scatter in data points, the low B and R^2 values and the high GEH values, the traffic flows were calibrated over the course of approximately 4000 iterations. The results of the final calibration of the traffic flows are presented in Fig. 2. The B and R^2 values for the comparison of the modeled and observed traffic flows were ultimately 1.029 and 0.9492 respectively. This indicates as good fit between the modeled and observed traffic flows.

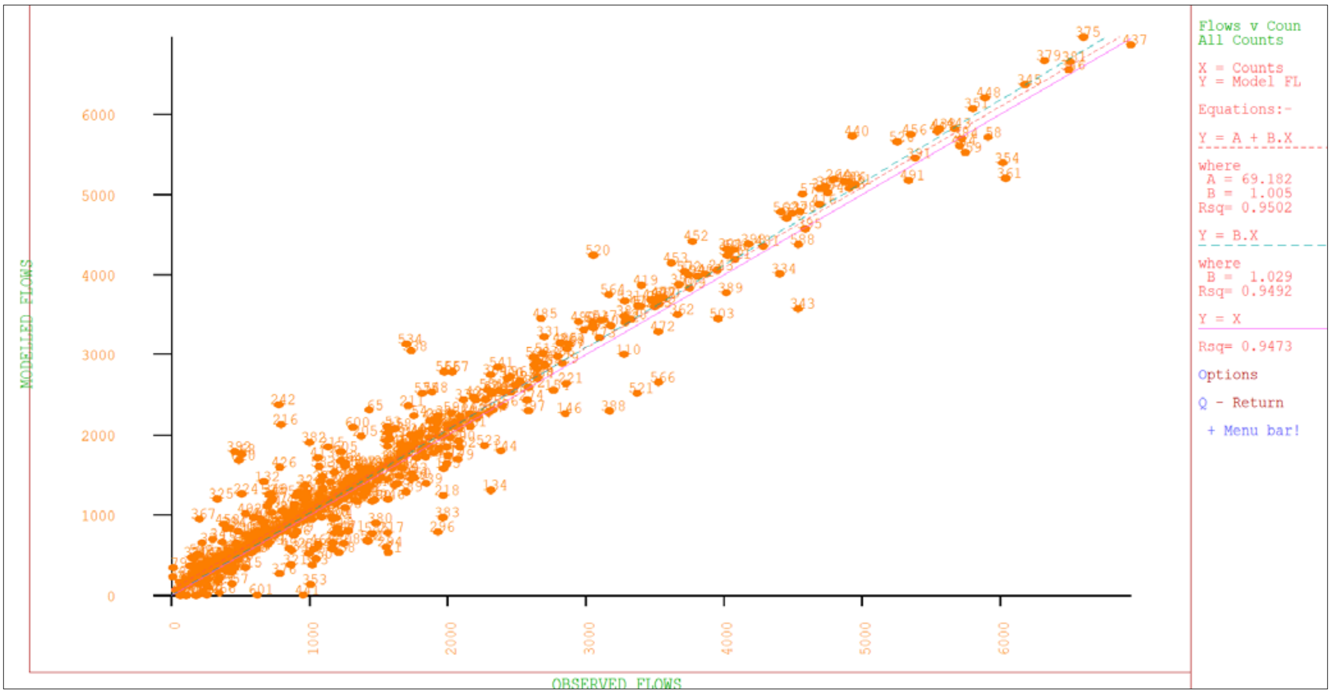

Fig. 2 Calibrated traffic flows

VI. Estimation of a Deterrence Function

The estimation of the parameters in the distance-deterrence function for trips on the study area was completed through an extensive curve matching process. The purpose of the curve matching process was to determine the form of the distance-deterrence function best suited to represent the trip distribution and trip lengths on the study network for the base year. The curve matching process was completed for two of the three forms of the distance-deterrence function. The forms of the distance-deterrence function are as follows:

a) The Exponential Function: $f(C_{ij}) = n * e^{(-\beta C_{ij})}$

b) The Power Function: $f(C_{ij}) = n * C_{ij}^{-n}$

c) The Combined Function: $f(C_{ij}) = n * C_{ij}^{n} e^{-\beta C_{ij}}$

C_{ij} is the term known as generalized cost expressed in distance, time or a combination of both [15]. C_{ij} has a direct influence on trip distribution on a network [15]. The parameters n and β are constants.

The estimated values of the parameters in the corresponding distance-deterrence function forms are as follows:

- The Exponential Function: $f(C_{ij}) = 1.592 * e^{(-0.08C_{ij})}$
- The Combined Function: $f(C_{ij}) = 0.0444 * C_{ij}^{1} e^{-0.133C_{ij}})$

The results of the curve matching process indicated that the exponential function form of the distance-deterrence function best illustrated the trip distribution and trip lengths on the study network (the GFIP network).

VII. Effect of Beta in the Distance-Deterrence Function on Average Trip Length on the Study Network

A set of distance-deterrence functions was estimated using different beta values. The average trip lengths resulting from the assignment of trips using the different synthesized distance-deterrence functions are summarized in Table II. The results indicate that the relationship between the beta value in the distance-deterrence function and the average trip length on the study network is as follows: As the value of beta is increased, the average trip length travelled by a vehicle is shown to decrease.

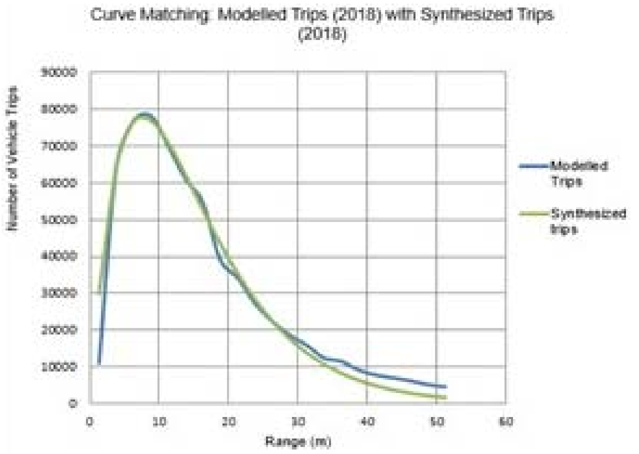

Fig. 3 Curve Matching using the Combined Function Form

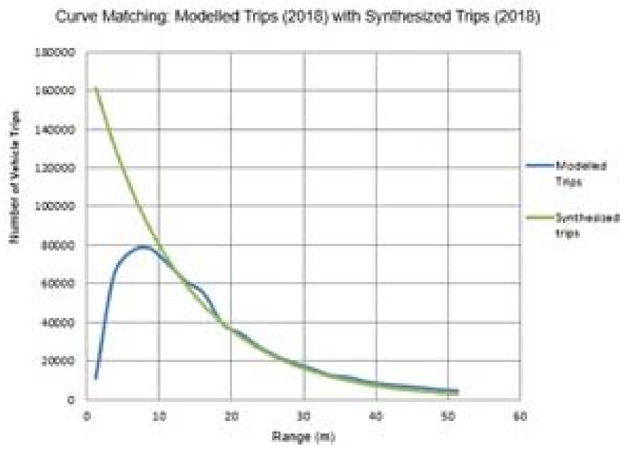

Fig. 4 Curve Matching using the Exponential Function Form

TABLE II
AVERAGE TRIP LENGTHS PER BETA VALUE FOR THE DESIGN YEAR (2038)

Test Case	Average Trip Length (km)	Beta Value
Scenario 1: Do-Nothing Scenario	16	0.08
Scenario 2: Decrease Average Trip Length by 10%	14.4	0.140
Scenario 3: Decrease Average Trip Length by 20%	12.8	0.170
Scenario 4: Decrease Average Trip Length by 10%	11.2	0.22
Scenario 5: Decrease Average Trip Length by 40%	9.6	0.24

VIII. IMPACT OF TRIP REDUCTION ON SPRAWL

The model was run to depict trip reduction lengths of 10%, 20%, 30% and 40% by 2038. Overall, the optimum model was found to be the reduction in trip lengths by 40%. Here the following was found:

- There is an expected reduction in congestion levels on both the freeways and second order roads close to both CBDs, indicating that people, in this scenario, are now moving closer towards both the Pretoria and Johannesburg CBDs.
- The red bands highlight the road infrastructure that will require capacity improvements/upgrades by 2038. This will result in a smaller budget being required for road infrastructure upgrades to support travel demands compared with the previous scenarios.
- This results in reduced average trip lengths, reduced delays in trips and higher savings in terms of generalized cost values (cost of travel per km + value of time spent per driver).
- A 40% reduction in the average trip length travelled on the network may be sufficient to support densification or create an environment which is conducive to the implementation of a viable, affordable and efficient public transport system.

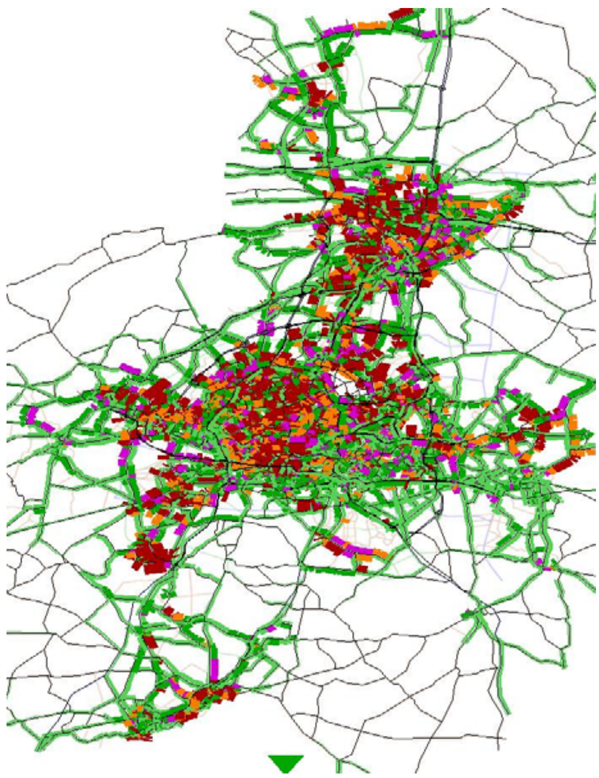

Fig. 5 Trip Distribution and Congestion Levels for Design Year (2038): 40% Reduction in Trip Lengths

A 40% reduction in the average trip length travelled on the network may be sufficient in supporting densification or creating an environment conducive to the implementation of a viable, affordable and efficient public transport system. Developing a method to achieve the reduction in average trip lengths was the next challenge. After more analysis it was determined that the reductions in trip lengths would be most likely achieved through investing in the second order road infrastructure, and not in the freeways which have been shown to increase sprawl.

IX. Achieving Shorter Trips: Practical Implications

In an ideal world, a 40% reduction in average trip lengths would be achievable in a single upgrade project. However, in a more realistic situation, achieving a 40% reduction in average trip lengths would need to be implemented through smaller projects. A pilot project scenario was tested to determine the total travel time based on improving the capacity of the freeways and second order roads (in separate alternatives) by 10%. 12 road infrastructure improvement alternatives were developed as instruments to achieving shorter trip lengths. These were modeled and tested against each other as well as against the Do-Nothing scenario. The accompanying discussions are applicable to both the base and design years since a similar trend has been indicated.

The results presented in Table III represent the total travel time for all light vehicles on the GFIP network during a typical peak hour. The typical peak hour used for this study was from 7am to 8am. The total travel time is presented for each improvement alternative tested for both the base and design years.

TABLE III
Total Travel Time for All light Vehicles (Hours) on the GFIP Network

Road Infrastructure Improvement Alternative Proposed	Total Travel Time for all Light Vehicles (hours)	
	2018	2038
The Do-Nothing Scenario	284 756	2 433 667
Assignment of OD matrix (for a 10% reduction in average trip lengths) on the unchanged Network	217 500	1 546 394
Assignment of unchanged OD matrix to improved network: Improved capacity on freeways	276 036	2 269 367
Assignment of OD matrix (for a 10% reduction in average trip lengths) on improved network: Improved capacity on freeways	214 435	1 474 355
Assignment of unchanged OD matrix to improved network: Improved capacity on second order roads	268 164	2 150 574
Assignment of OD matrix (for a 10% reduction in average trip lengths) on improved network: Improved capacity on second order roads	206 504	1 378 218

TABLE IV
Comparison of Improvement Alternatives vs the Do-Nothing Alternative

Road Infrastructure Improvement Alternative Proposed	Difference in Total Travel Time (hours) of Improved Alternative against the Do-Nothing Alternative	
	2018	2038
Assignment of OD matrix (for a 10% reduction in average trip lengths) on the unchanged Network	67 255	887 273
Assignment of unchanged OD matrix to improved network: Improved capacity on freeways	8 720	164 300
Assignment of OD matrix (for a 10% reduction in average trip lengths) on improved network: Improved capacity on freeways	70 321	959 312
Assignment of unchanged OD matrix to improved network: Improved capacity on second order roads	16 592	283 093
Assignment of OD matrix (for a 10% reduction in average trip lengths) on improved network: Improved capacity on second order roads	78 252	1 055 449

The results for the total travel time for all light vehicles for each improvement alternative tested were then compared with that of the Do-Nothing alternative. The purpose of this was to determine which improvement alternative had the biggest saving in terms of total travel time on the network. The results of the comparison of total travel times for each improvement alternative against the Do-Nothing alternative are summarized in Table IV.

The results indicate that the road infrastructure improvement where the capacity of the second order roads is improved by 10% and drivers make shorter trips (i.e. the environment is such that shorter trips are encouraged) has the biggest saving in terms of total travel time for all light vehicles on the GFIP network. This is applicable for both the base and design years.

The second highest saving in terms of total travel time for all light vehicles on the network was for the alternative where the capacity of the freeways is increased by 10% and drivers make shorter trips. Even though this alternative produces the second highest total travel time saving, it is not recommended. The reason for this is that increasing the capacity of the freeways may address the issue of congestion and mobility for longer trips, but it does not contribute to reducing and controlling sprawl, supporting densification and working towards changing the approach of transportation planning in the future. Increasing the capacity of freeways encourages longer trip lengths and also encourages people living far away from city centers which in turn results in an increase in urban sprawl. This alternative does not contribute towards supporting densification, the compact city concept, the future city concept or towards creating an environment which is conducive for the implementation and operation of a public transport system.

The third highest saving in terms of total travel time for all light vehicles on the network was for the alternative where drivers make shorter trips. To fully understand the effect of shorter trips on the total travel time, the result for this alternative must be compared with that of the previous alternative discussed. That is, by increasing the capacity on freeways by 10% as well as drivers making shorter trips a travel time saving of 70 321 hours was achieved. By drivers simply making shorter trips (10% shorter than the current average trip length on the GFIP network), a total travel time saving of 67 255 hours was obtained. There is a difference of 3066 hours between the two alternatives. However, an upgrade to the capacity of the freeways, and creating a more densified environment, will cost more than simply encouraging drivers to make shorter trips by living closer to places of work. This can be achieved through creating a more densified environment and implementation of policies focused on increasing the gross-population densities of cities. In the long term, creating an environment which promotes shorter trips should cost less than continuously expanding the freeways which is accompanied by high maintenance costs.

The fourth highest saving in terms of total travel time for all light vehicles on the network was for the alternative whereby the capacity of the second order road network was increased by 10%. This is realistic since currently majority, if not all, of the second order roads are operating at capacity. This is one of the prime reasons for congestion in Pretoria. This also justifies the need for capacity improvements required on the second order roads in Gauteng. This will assist with reducing the delays and congestion linking from the second order roads onto the freeways in the GFIP network.

The alternative with the lowest saving in total travel time is that of increasing the capacity of the freeways by 10%. This makes sense and is a true reflection of what is happening currently on the GFIP network. The GFIP network is almost operating at capacity and having second order roads which are in dire need of capacity improvements only makes things worse in terms of delays and increased travel times. In short, congested second order roads are linking onto an almost congested freeway. There is simply nowhere for traffic to move.

X. Conclusion

It is concluded that the proof of concept applied in supporting densification through the planning and implementation of road infrastructure in the South African context works. It is evident that the current approach used in road infrastructure planning and implementation needs to be improved and adapted to meet the needs of the new era of professionals. We need to move towards "The Compact City" and "The Future City". Continuous expansion of freeways is not always the most economical solution and the spending of road infrastructure budgets should be based on a holistic benefit (societal and mobility) and not primarily on congestion alleviation. The existing public transport system in South Africa is not yet synchronized with the spatial planning in the country. Before we can hope to have a public transport system which is viable, affordable and efficient, we need to improve the existing spatial planning in South Africa and adopt a fresh and innovative approach for future spatial planning. We can control sprawl and driver behavior by simply controlling the environment concerned. It is time for something new.

References

[1] Britannica (2019). Urban Sprawl. Available from https://www.britannica.com/topic/urban-sprawl (Accessed 09 September 2019).

[2] Cooke, S. and Behrens, R. (2014). A Comparative Empirical Analysis of the Relationship between Public Transport and Land Use Characteristics. Paper presented at 33rd Annual Southern African Transport Conference. Pretoria, South Africa, 7-10 July 2014. Cape Town: Department of Civil Engineering at the University of Cape Town.

[3] Sieg, S M. and Landre, M. (1991). The Measurement of Residential Sprawl in The Johannesburg Metropolitan Area. S.l, p 3-9.

[4] Yusuf, MP. and Allopi, D. (2010). The Impact of Urban Sprawl on the Inhabitants of the eThekwini Municipality and the Provision of Infrastructure. Paper presented at 29th Annual Southern African Transport Conference. Pretoria, South Africa, 16-19 August 2010. Durban: Durban University of Technology, pp 415-424.

[5] McKinsey & Company (2018). Elements of success: Urban transportation systems of 24 global cities. (no publication details given).

[6] National Cooperative Highway Research Program (NCHRP) (2018) Integrated Transportation and Land Use Models. Washington DC.

[7] Bertaud, A 2003, The Spatial Organization of Cities: Deliberate Outcome or Unforeseen Consequence?, World Development Report 2003: Dynamic Development in a Sustainable World, World Bank.

[8] Levinson, DM 1998, 'Accessibility and the Journey to Work', Journey of Transport Geography, vol. 6, no. 1, pp. 11-21

[9] Cervero, R 1989, 'Jobs-Housing Balancing and Regional Mobility', Journal of the American Planning Association, vol. 55, no. 2, pp. 136-150.

[10] Lin, D., Allan, A. and Cui, J. (2013). Does Polycentric Urban Spatial Development Lead to Less Commuting: A Perspective of Jobs-housing Balance. Paper presented at 49th ISOCARP Congress. Australia, 1-4 October 2013. Australia: Universities of South Australia and Griffith University, pp 1-10.

[11] Varma, GR. (2017). A Study on New Urbanism and Compact City and their Influence on Urban Mobility. Paper presented at 2nd IEEE International Conference on Intelligent Transportation Engineering. Singapore, 1-3 September 2017. United States of America: Transportation Systems and Design, Art Center College of Design, pp 250-253.

[12] Holz-Rau, C., Sceiner J. and Sicks, K. (2013), 'Travel Distances in daily travel and long-distance travel: what role is played by urban form?', Environment and Planning, vol. 46, pp. 488-507.

[13] C40 Knowledge hub (2019). How to make public transport an attractive option in your city. Available from https://www.c40knowledgehub.org/s/article/How-to-make-public-transport-an-attractive-option-in-your-city?language=en_US (Accessed 20 September 2019).

[14] Frank, LD & Pivo, G 1994, An Analysis of Relationships Between Urban Form (Density, Mix, and Jobs: Housing Balance) and Travel Behaviour (Mode Choice, Trip Generation, Trip Length, and Travel Time), Washington State Transportation Center (TRAC), University of Washington, Seattle.

[15] Ortúzar, J., & Willumsen, L. (2011). Modelling Transport, Fourth Edition. Wiley.

[16] Simpson, Z., McKay, T., Patel, N., Sithole, A., van den Berg, R. and Chipp, K. 2014, Past and Present Travel Patterns in the Gauteng City Region, University of Johannesburg.

[17] Litman, T, Victoria Transport Policy Institute (2019). Evaluating Transportation Land Use Impacts. Available from https://scholar.google.co.za/scholar?q=evaluating+transportation+land+use+impacts+site:http://www.vtpi.org&hl=en&as_sdt=0&as_vis=1&oi=scholart (Accessed 22 March 2019).

[18] Mladenovic, Milos & Trifunovic, Aleksandar. (2014). The Shortcomings of the Conventional Four Step Travel Demand Forecasting Process. Journal of Road and Traffic Engineering.

[19] N. Oppenheim, (1995). Urban travel demand modeling: from individual choices to general equilibrium: John Wiley and Sons.