URBAN PLANNING APPROACH FOR IMPROVEMENT OF ROAD SAFETY IN SUBURBAN ARTERIAL ROADS OF BLOEMFONTEIN CITY, SOUTH AFRICA

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ABSTRACT

According to the Road Traffic Management Corporation (RTMC) of South Africa, a large number of accidents involving motor vehicles occur annually on the arterial roads passing through the suburban residential areas of the cities of South Africa. This problem warrants planning and design interventions for the reduction of vehicular accidents and the consequent improvement of road safety on these city roads. Based on this premise, an investigation was conducted to explore the major causes of vehicular accidents, and to develop a set of urban planning and design guidelines to reduce vehicular accidents in suburban arterial roads of a city and to improve the road safety appreciably. The investigation was conducted by considering the suburban areas of Bloemfontein city of Free State, South Africa as the study area. A survey research methodology was followed for this purpose, and data was collected from both primary and secondary sources. Sample surveys were conducted in four different suburban areas of the city to collect primary data and to acquire firsthand information for understanding the scenario at grassroots level. The surveys included household surveys, in order to understand the demographic, socio-economic, and perceptual infrastructural conditions of the study area and their influence on vehicular accidents; road geometrical design parameter surveys; and traffic surveys to understand the road geometry and traffic-related scenarios in the city. In addition, structured statistical data was collected from secondary sources, such as published and unpublished literature and a range of other documents. The data collected was analysed statistically to find the major control parameters influencing vehicular accidents in the suburban arterial roads, and to establish relationships between vehicular accidents and the major control parameters. Based on the analyses, a theoretical linear multiple regression model establishing relationships between the vehicular accidents as the dependent variable and vehicular traffic-related variables (speed of vehicles and average daily traffic), road geometry design variables (road width and median width), and spatial variables (land use and land form in the form of the number of access points from residential areas to arterial routes), was developed to observe the number of accidents under varied simulated scenarios. The simulated model results were employed to develop various policy scenarios to reduce accidents and to improve road safety in the study area. The investigation revealed that, under the composite scenario of the reduction of number of accesses from residential areas to arterial roads, speed, and average daily traffic along with the increase of road width and median width, the occurrence of vehicular accidents in the arterial roads of suburban areas of the city would be reduced and road safety would be improved significantly. It was also observed that residential areas with limited vehicular access from residential areas to arterial roads would have fewer vehicular accidents than residential areas having unrestricted access. Consequently, the number of access points from residential areas to arterial roads in suburban areas of the city would need to be limited, depending on the functions and land use of the area, to improve road safety.

Key words: Vehicular accidents, Suburban areas, Arterial roads, Road safety, Land use

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own independent work and that this dissertation, or any part thereof, has not previously been submitted by anyone or myself to another institution in order to obtain a degree.

Signature

02/08/2013

Date

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1. CHAPTER 1 INTRODUCTION AND RESEARCH DESIGN

1.1 INTRODUCTION

In recent years, South Africa has experienced rapid urbanisation. This enhanced urbanisation process in South Africa may be seen in the transformation of small towns into medium cities and of medium cities into large cities or metropolitan areas with a proliferation of various urban functions, especially service activities. The increase in urban functions including service activities has created a higher demand for intra-city vehicular movement. The increased demand for intra-city vehicular movement, conjoined with a progressive economy, the easy availability of finance, higher living standards, and the aspirations of individuals, has brought about the phenomenon of a one man-one car system in most of the country's urban areas. However, as in many other developing countries, a number of South African cities are experiencing a change from almost single modes of travel in self-driven cars to a multimodal system with the gradual introduction of public transportation by buses, the increase in two wheelers, and goods vehicles, in addition to the predominance of individual-driven cars. At the same time, there is also a transformation in city structures and urban form in the wake of the establishment of a number of suburbs.

The popular choice of living in the suburbs has led to the creation of a complex road network system and the location of important public, civic, and commercial functions adjacent to nodal points, such as road junctions and squares with paradoxically higher vehicular movement in these locations. As an example, of the estimated population of 2.0 million in Pretoria (National Capital of South Africa), the 3.2 million population of Johannesburg (the largest city serving as the financial capital of the country), and the 3.4 million combined population of other major cities like Durban and Cape Town, the majority of the population live in the suburbs of these respective cities (Statistics South Africa, 2006). Of the populations living in the suburbs, about 45.61 per cent consist of the male working population and 45.10 per cent consist of the female working population, the majority of whom use private cars on roads for daily commuting from their residences to their work places and other allied functions and vice versa (Statistics South Africa, 2006). Similarly, out of the estimated 0.85 million residents of Bloemfontein city, the study area of this investigation, about 42.93 per cent of the male working population and 37.05 per cent of the female working population use individual or shared vehicles in order to travel to their work places, schools, and other locations of the city to discharge their daily responsibilities.

This higher intra-city movement of people has led to complex road network systems in the suburbs of the cities. As a consequence of all these urban functional requirements, as well as the transportation and vehicular movement processes in such progressive and rapidly-growing cities, higher accident risks have been created, not only on the primary thoroughfares (arterial) of the cities, but also in the road links and junctions in the suburbs. This is corroborated by the findings of the Road Traffic Management Corporation of South Africa (RTMC, 2008) that there were 11 577 major crashes reported in South Africa during a period of only one year from 1 April 2007 to 31 March 2008. The RTMC also indicated that, in South Africa over the past few years, motorcars were the leading vehicle types for driver, passenger, and pedestrian accidents, followed by Light Driven Vehicles (LDVs), and motorcycles respectively. It was noted that a sizeable portion of the accidents occurred on the suburban arterial roads or at nodal points like junctions. The major types of accidents occurring in such locations included mainly pedestrian, hit-and-run, and overtaking-related accidents, as well as failure to stop or yield, unsafe turning manoeuvres, poor visibility, insufficient following distance between vehicles, speed, traffic volume, the number of access streets, and general human/driver behavioural factors. With many suburbs adapting a mixed land use development (combining residential areas, commercial functions, civic functions, etc.), commuters' travel patterns and movement within the residential areas have increased. It was also observed that vehicle movement increased in a city when mixed land uses increased, with more commuters visiting a residential area or suburb for multiple purposes (commercial, industrial, civic functions, etc.). The enhanced vehicular movement consequent upon the rise of urban function development increases the daily or yearly occurrence of accidents within a suburb. Similarly, the number of accessibility points to residential areas from suburban arterial/sub-arterial roads and vice versa may create more conflict points, and, with the increase in the number of vehicular movements, together with the increase in accessible points, the possibility of vehicular accidents increases in the suburban roads. Thus, urban form, urban pattern, urban functions, and consequent land use have an influence on the generation of the type and volume of vehicular traffic in the suburban areas of a city and the consequent accidents in such locations. This situation calls for an investigation to explore the causes of vehicular road accidents in suburban arterial roads of cities of South Africa, and to develop plausible policy measures to reduce vehicular accidents and improve road safety in the suburban areas of cities of South Africa.

1.2 PROBLEM STATEMENT

With the increase in urbanisation in South Africa, it has been estimated that more than half of the total population of the country lives in urban areas (SA Statistics, 2011). The majority of this urban population prefers to live in suburban areas and commute every day to different parts of the urban areas for their daily functions, such as work, education, civic activities, entertainment, etc. However, in the absence of structured and reliable public transportation systems in most of the cities of the country, the majority of the people travel in their own vehicles, especially cars or light motor vehicles (LMVs), leading to high volumes of traffic in the suburban arterial roads of the cities. In addition, there has been an increase in the use of motorcycles in cities, thus adding to already complex traffic scenarios. Consequently, a large number of accidents is also experienced on such suburban arterial roads.

The popular choice of living in suburban areas away from the city centre or areas with major urban functions, together with daily communication by individual vehicles and the consequent high traffic volumes on the suburban arterial roads, make suburban arterial roads vulnerable to the increasing occurrence of vehicular traffic accidents. Despite the various transportation and traffic-related measures taken by city authorities, the occurrence of vehicular accidents is on the rise. This poses a major concern for traffic safety in the cities, particularly in the suburban areas. Therefore, there is a need to understand the causes of vehicular accidents as well as the various safety measures which could help to reduce traffic accidents and improve road safety.

For this purpose, the city of Bloemfontein city in the Free State province was considered as the study area, as it is one of the important cities of South Africa having similar morphological and demographic characteristics to other cities in South Africa. It has also not escaped the burgeoning problem of increased traffic volume and the consequent accidents. It has been estimated that, on average, about 4000 vehicular traffic accidents occur every year in the suburban areas of the city, of which more than 5% result in fatalities. Most of these accidents occur on the suburban arterial roads. Thus, this investigation explores the various causes of vehicular accidents in the suburban arterial roads of the city as well as the development of plausible policy guidelines, based on urban planning approach, in order to reduce the number of vehicular accidents and, consequently, to improve road safety in the city.

1.3 PURPOSE OF STUDY

1.3.1 Research aims of the study

The main aim of this study is to evolve a set of planning and design guidelines in order to improve road safety and reduce vehicular traffic accidents in the suburban residential areas of Bloemfontein city, South Africa. For this purpose, the shortcomings in urban planning and design aspects of the city are linked to road safety and addressed accordingly. It is also needed to explore the most influential causes of the vehicular traffic accidents in the suburban arterial roads of the study area, the influence of various urban functions and land uses, as well as vehicular traffic and road geometry parameters on the occurrence of number of accidents. Also, to establish an appropriate multiple regression model, based on the most influential parameters that would assist in the prediction of vehicular traffic accidents on the arterial roads of the suburbs of the study area.

1.3.2 Objectives of the study

For the purposes mentioned above (section 1.2.1), a set of objectives was framed. The objectives of this investigation are:

- To assess the existing traffic and related accident scenarios in suburban areas of the study area.
- To assess the relationship between traffic accidents and spatial parameters, including land use and urban form in the study area.
- To establish the major control parameters influencing traffic accidents in the study area.
- To establish a suitable multiple regressions model and predict the number of accidents in the study area under different simulated scenarios.
- To develop a set of plausible strategic, urban planning, and design guidelines for safe vehicular movement and the reduction of accidents in the suburban areas of the study area.

1.4 HYPOTHESIS

A plausible hypothesis based on the analytical work, and to be tested in the present investigation, may be expressed thus: that residential areas with limited access to suburban arterial thoroughfares will have fewer traffic accidents than residential areas having unrestricted access to such roads. Thus, the reduction of the number of access points from the residential areas to suburban arterial roads and vice versa on a more demanding arterial route (thoroughfare) will reduce the number of traffic accidents.

1.5 SCOPE OF THE STUDY

The scope of the investigation is limited to developing a strategy and a set of urban planning and design guidelines to reduce the vehicle-related accidents in the arterial roads of suburban areas in the city of Bloemfontein, South Africa by considering the road geometry as well as the traffic and spatial parameters of the city’s suburbs. The investigation was conducted by considering selected suburbs in the city and by collecting data through sample surveys. The investigator hopes that, if the recommendations of the present investigation are implemented according to the proposed guidelines, vehicular accidents in the suburban arterial roads of Bloemfontein will be reduced, and road safety will be improved.

1.6 RESEARCH DESIGN

The research design of the study is represented in Figure 1-1. The figure outlines the methodology which was followed to conduct this investigation.

1.6.1 Methodology of the study

This investigation followed the systematic and step-wise methodology presented in Figure 1.1. The various steps followed in the investigation were the identification of problems and the formulation of objectives followed by the collection of data, analysis and identification of major control parameters influencing vehicular traffic accidents, the development of models, the validation of the model, forecasting, simulation, the drawing of inferences, policy analysis, and the development of a set of policy guidelines and recommendations.

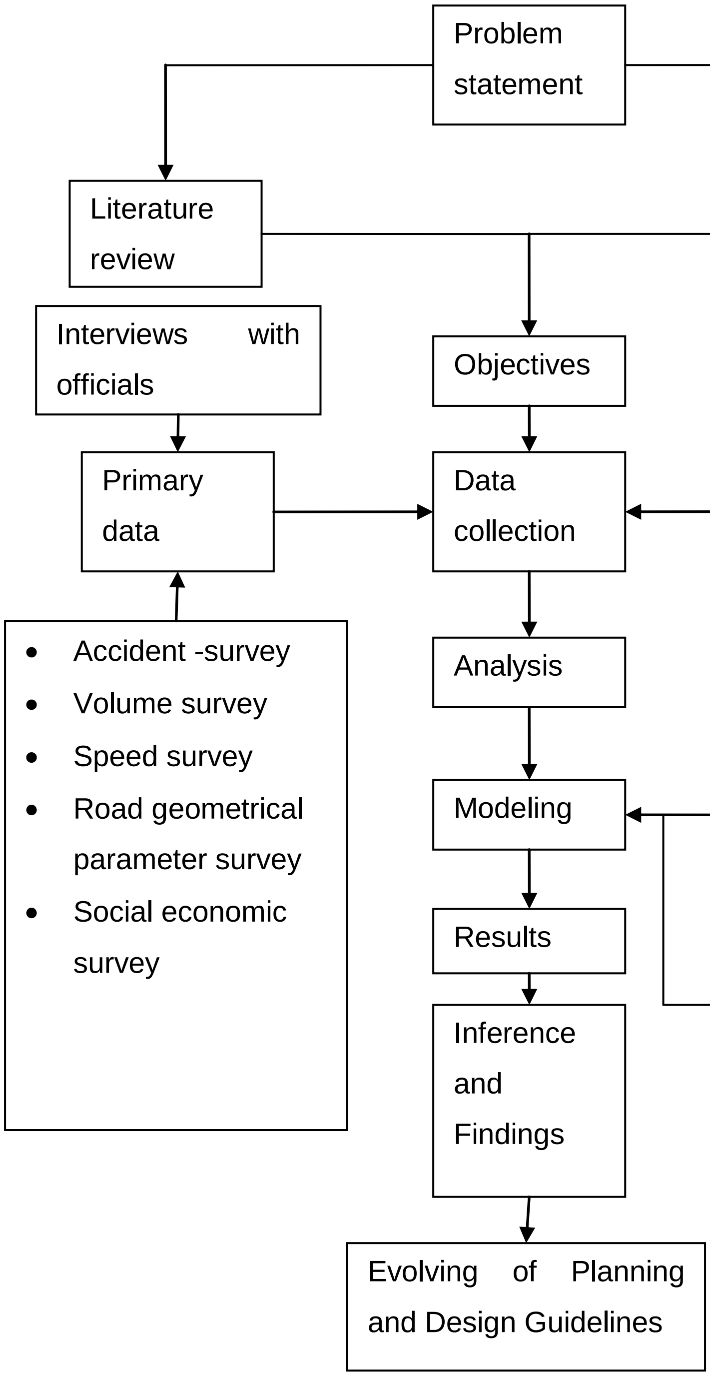

Figure 1-1: Methodology outline of the study

1.6.2 Data Collection

Two types of data, primary and secondary, have been collected and employed in this investigation.

1.6.2.1 Primary Data

Primary data was collected by means of direct household surveys, physical surveys of geometrical parameters of roads, and traffic surveys (such as speed surveys and traffic volume surveys) in order to obtain first-hand information. The collection of data from primary sources was essential because structured and up-to-date statistical data of important parameters relating to socio-economic conditions, traffic conditions, and traffic accidents were not available for the study area. Further, the development of strategies and policy guidelines for the reduction of road vehicular traffic accidents and the enhancement of road safety requires an in-depth understanding of various parameters influencing road traffic accidents in the study area.

Selection of sites for survey

Several selection criteria were used to identify suitable residential areas (suburbs) within Bloemfontein city according to the theoretical framework of the study and which were aligned to the objectives, problem statement, and research questions. Figure 1-2 displays a full map of the city of Bloemfontein with all its suburbs, as does Annexure B.

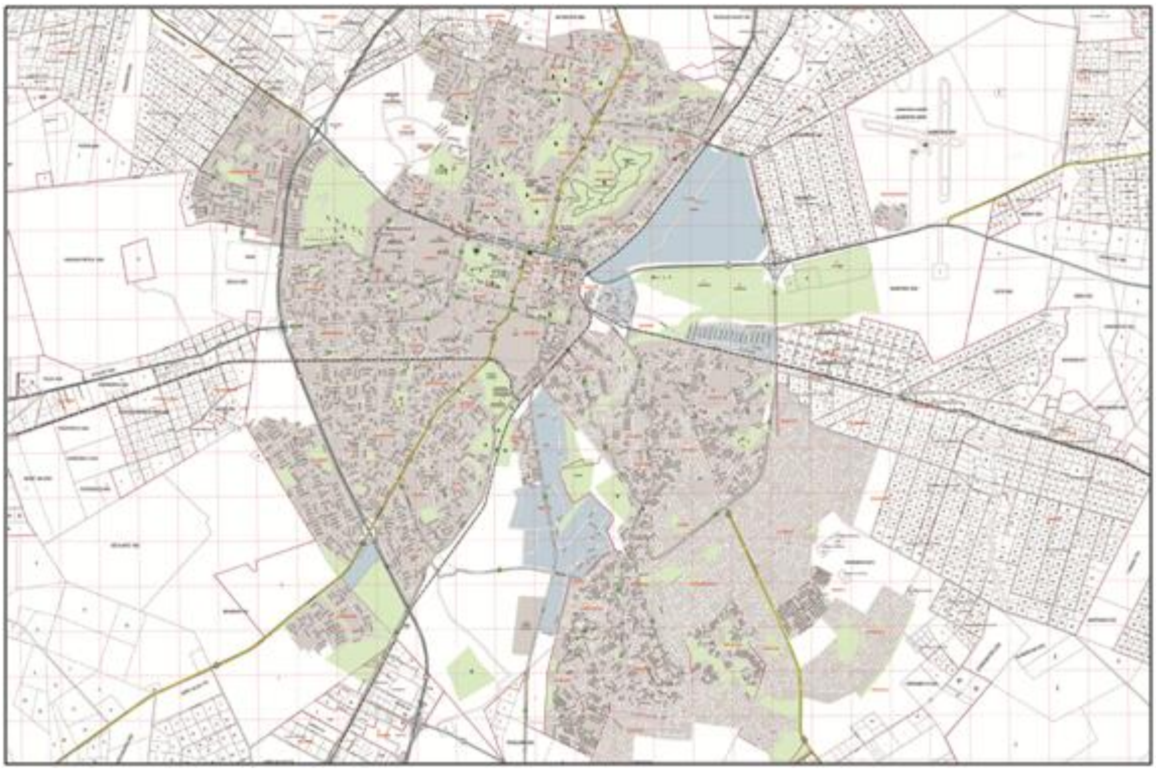

Figure 1-2: Full map of the city of Bloemfontein including all suburbs (Google Earth)

Bloemfontein city comprises 26 suburban residential areas. Table 1-1 and Figure 1-3 present various suburban areas of the city and their accessibility (Figure 1-3 illustrates the selected residential suburban areas of Bloemfontein city through a colour coding system (yellow = thoroughfare suburbs; blue = limited access suburbs). Of these twenty six suburbs, four important suburbs representing the city were chosen for survey purposes. The suburbs were selected on the basis of a set of selection criteria such as population, vehicle ownership, the importance of the area, accessibility, the complexity of the road network and the location of thoroughfares inside the residential area, the availability of major urban functions, number of accidents, etc. The selected suburban areas are Fichardtpark, Pellissier, Universitas, and Langenhovenpark, which are located on the southern, south-western, and western parts of the city. In addition to residential areas, these areas are highly populated, with relatively higher levels of urban commercial and civic functions, such as market complexes, schools and universities, hospitals, and entertainment areas, all of which require higher vehicular movement. Further, these four suburban areas represent diverse types of accessibility, such as limited access areas like Langenhovenpark and Pellissier, and thoroughfare access areas like Universitas and Fichardtpark linking each other and other parts of the city.

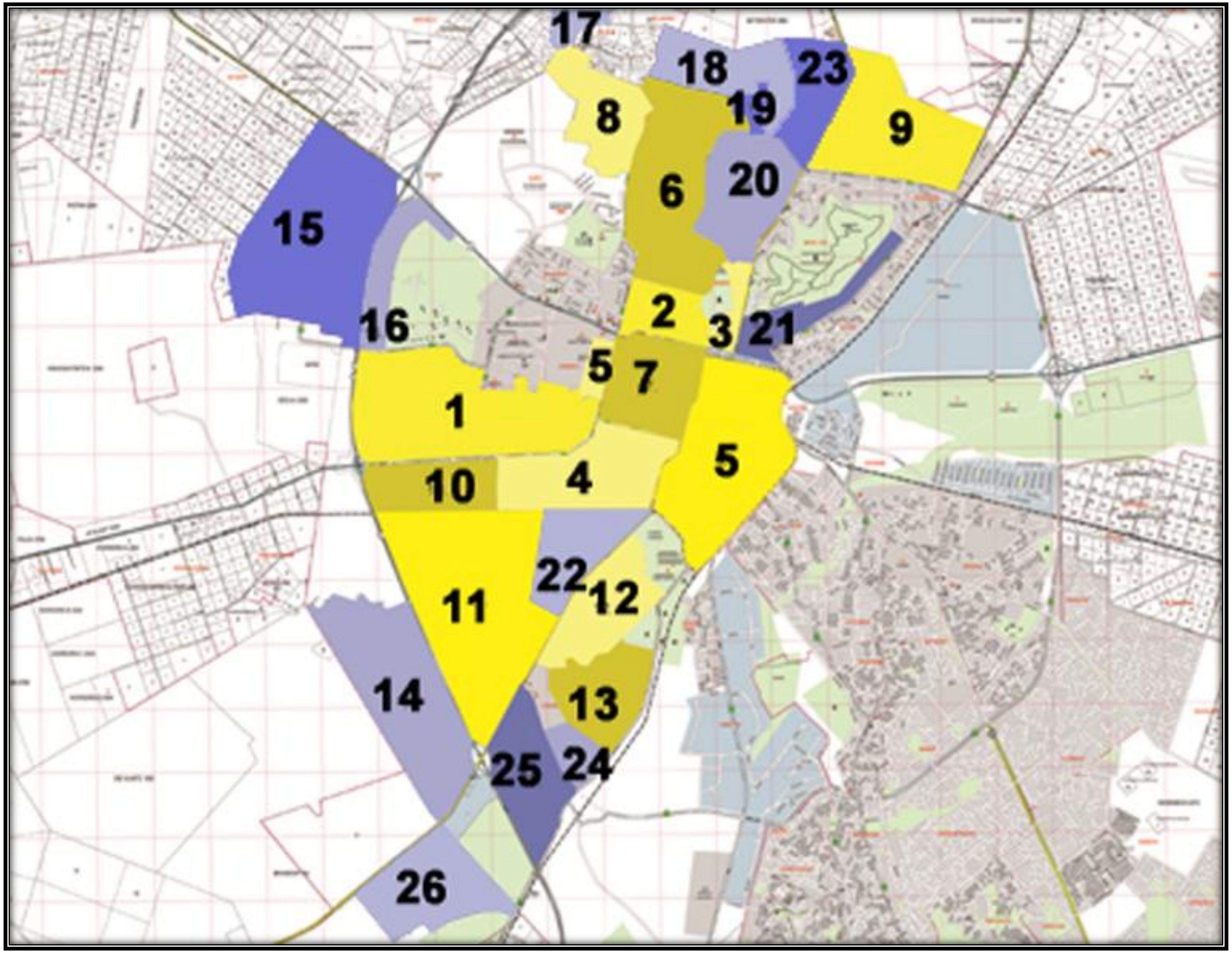

Figure 1-3: Residential suburbs of Bloemfontein

Table 1-1: Limited access suburbs and thoroughfare suburbs in Bloemfontein City

Thoroughfare Suburbs	**Limited Access Suburbs**
1. Universitas	14. Pellissier
2. Westdene	15. Langenhovenpark
3. Arboretum	16. Universitas-Ridge
4. Wilgehof	17. Woodlands
5. Park West	18. Pentagon Park
6. Dan Pienaar	19. Kiepersol
7. Willows	20. Waverley
8. Heuwelsig	21. Navalsig
9. Bayswater	22. Hospital Park
10. Gardenia Park	23. Helicon Heights
11. Fichardtpark	24. Fleurdal
12. General de Wet	25. Fauna
13. Uitsig	26. Lourier Park

In addition, while selecting the survey areas, care was taken to ensure that the selected areas presented a good blend of homogeneity and diversity in their characters and their inter-linkage to one another. Accordingly, the survey area have two groups of residential suburbs, each group consists of a thoroughfare suburb and a limited access suburb, which are linked to each other directly by a road link (For example, Group 1: Universitas and Langenhovenpark). Furthermore, these two groups of suburbs are also linked to each other by a road link. In this case, while Universitas and Langenhovenpark form Group 1, Fichardtpark and Pellissier form Group 2. Both suburb groups are linked by a major road link known as Stals Road. The inter-linkage between the two groups of suburbs and the detailed internal road network of these suburban areas are indicated in Figure 1-4 while Figure 1-5 magnifies the route that links the two groups of residential suburbs.

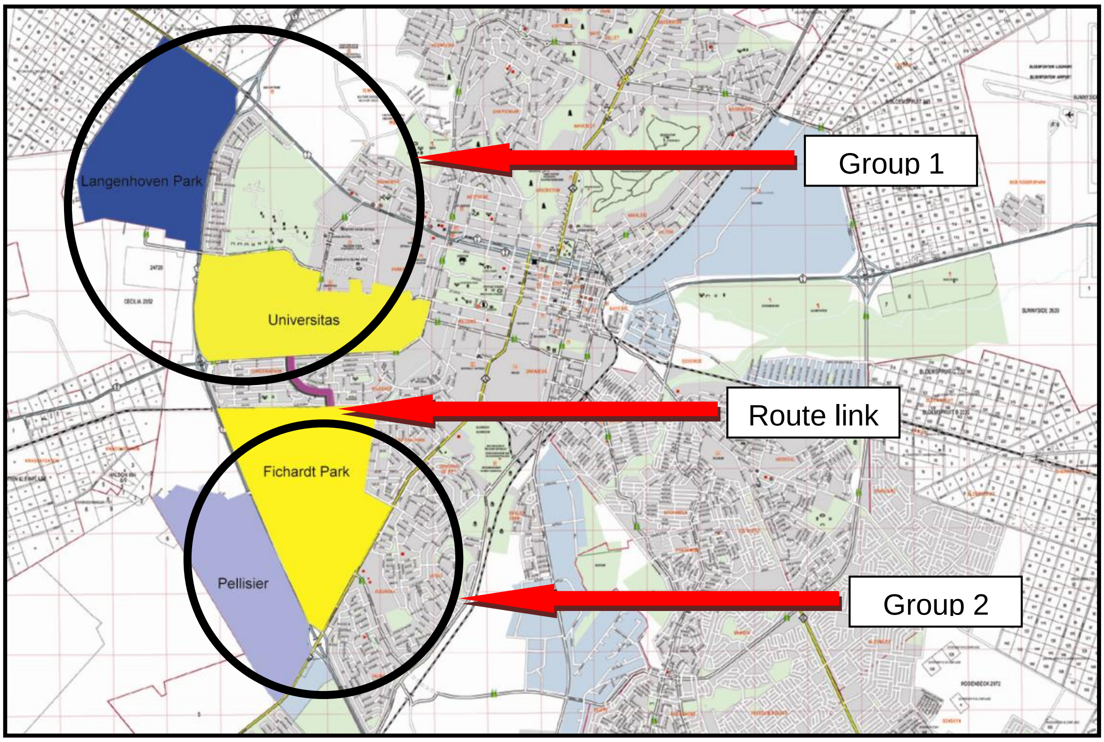

Figure 1-4: Selected residential areas

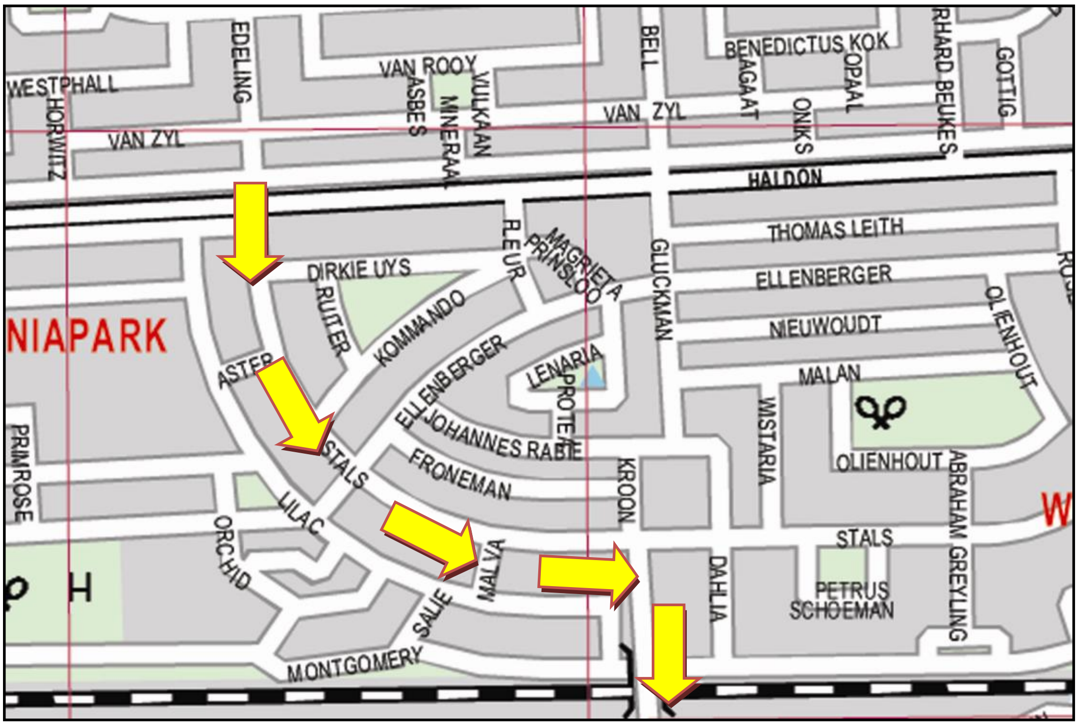

Figure 1-5: Internal road network and inter-linkage between selected residential suburban areas

All the surveys, including the household survey, the traffic surveys, and the road geometrical parameter surveys, were conducted in these selected suburban areas.

1.6.2.1.1 Household Surveys

To conduct the household surveys, the investigator collected a list of households available in the selected suburbs. A total of one hundred and twenty households were selected for the survey, with the number of households varying between 25 and 35 in each suburb selected for the survey. The survey was conducted by employing a systematic stratified random sampling process, using pretested survey schedules comprising various parameters relating to demographic, socio-economic, infrastructural, vehicular, and vehicular traffic accidents. The demographic and socio-economic parameters included population, general age, employment age, academic qualifications, gender, income level, occupations, and dwelling type (owner or tenant) of the residents. Vehicle-related parameters included types of vehicles, number of vehicles used to commute per day, the number of commuting trips per vehicle, the average distance travelled per vehicle per month, etc. Traffic-accident-related parameters included the suburbs in which the residents were involved in or witnessed accidents, the types of accidents, and the severity of accidents. The residents were also required to provide a reason for the traffic accidents; the seven options included (1) user-related causes, (2) vehicle-related causes, (3) road-related causes, (4) junction-related causes, (5) environment-related causes, (6) urban form and land use-related causes, and (7) pedestrian-related causes as well as what type of vehicles were involved in the accidents, the type and condition of road in which the accidents occurred, and the time of day at which the accident occurred.

1.6.2.1.2 Road geometrical parameters survey

Data pertaining to physical road geometrical parameters were collected at the road sections identified for this purpose. The road sections and junctions where relatively greater numbers of accidents with higher severity had occurred were chosen for this survey. The various existing road-geometry-related parameters measured at each road section were: road traffic system (one way or two ways), road width, number of lanes, the width of each lane as well as the total width of all lanes heading in one direction, the presence of service lanes, gradient, curvature, shoulder width, sight distance, the type of kerbing, median width, the type of road surfacing, etc.

1.6.2.1.3 Speed survey

Speed survey (Spot speed) data were collected at the road sections, which were identified for road geometry survey by employing standard templates for the purpose. The data was collected by conducting a survey for one week which includes five week days and two weekends for 16 hours a day, i.e. from 6.00 a.m. to 10 p.m. continuously. The other periods of the day were not considered because of the very meager volume of traffic observed during the pilot survey. The survey was conducted in parallel at all the selected road sections.

1.6.2.1.4 Traffic volume survey

Traffic volume surveys were conducted (Figure 1-6) at five intersections in the four identified suburbs as well as at fourteen road sections identified earlier for the survey in order to investigate the volume of traffic and their implications in vehicular traffic accidents in each area. The selection of these intersections was based on the criteria of their importance in the traffic movement, such as type of intersection, the number of legs of the intersection, the intersections which serve as links from one suburb to another, and intersections identified as high accident areas in the traffic accident data collection. The intersections selected for the traffic volume surveys were (1) Paul Kruger Drive roundabout, (2) Haldon Road, Stals Road, and Edeling Street, (3) Haldon Road, Gardenia Avenue, and Van Schalkwyk Street, (4) M14 (Totius Street), Wynand Mouton Drive, and De Bruyn Street, and (5) Eric Rosendorf and Benade Drive (Figure 1-6). These intersections differ from one another in their characteristics: (1) Paul Kruger Drive is a three-legged roundabout, (2) Haldon Road, Stals Road, and Edeling Street is a four-legged signalised junction, (3) Haldon Road, Gardenia Avenue, and Van Schalkwyk Street is a four-legged junction, (4) M14 (Totius Street), Wynand Mouton Drive, and De Bruyn Street) is a three-legged signalised junction, and (5) Eric Rosendorf and Benade Drive is a large three-legged T-junction. The traffic volume surveys on road sections were done on the survey's selected routes with high accident occurrences. The traffic volume surveys were also conducted by using a standard template which includes various modes of vehicles, such as motorcycles, delivery vehicles, buses, taxis, and other vehicles, entering a specific intersection or road section per hour as well as the direction of the traffic flow, number of vehicles, etc.

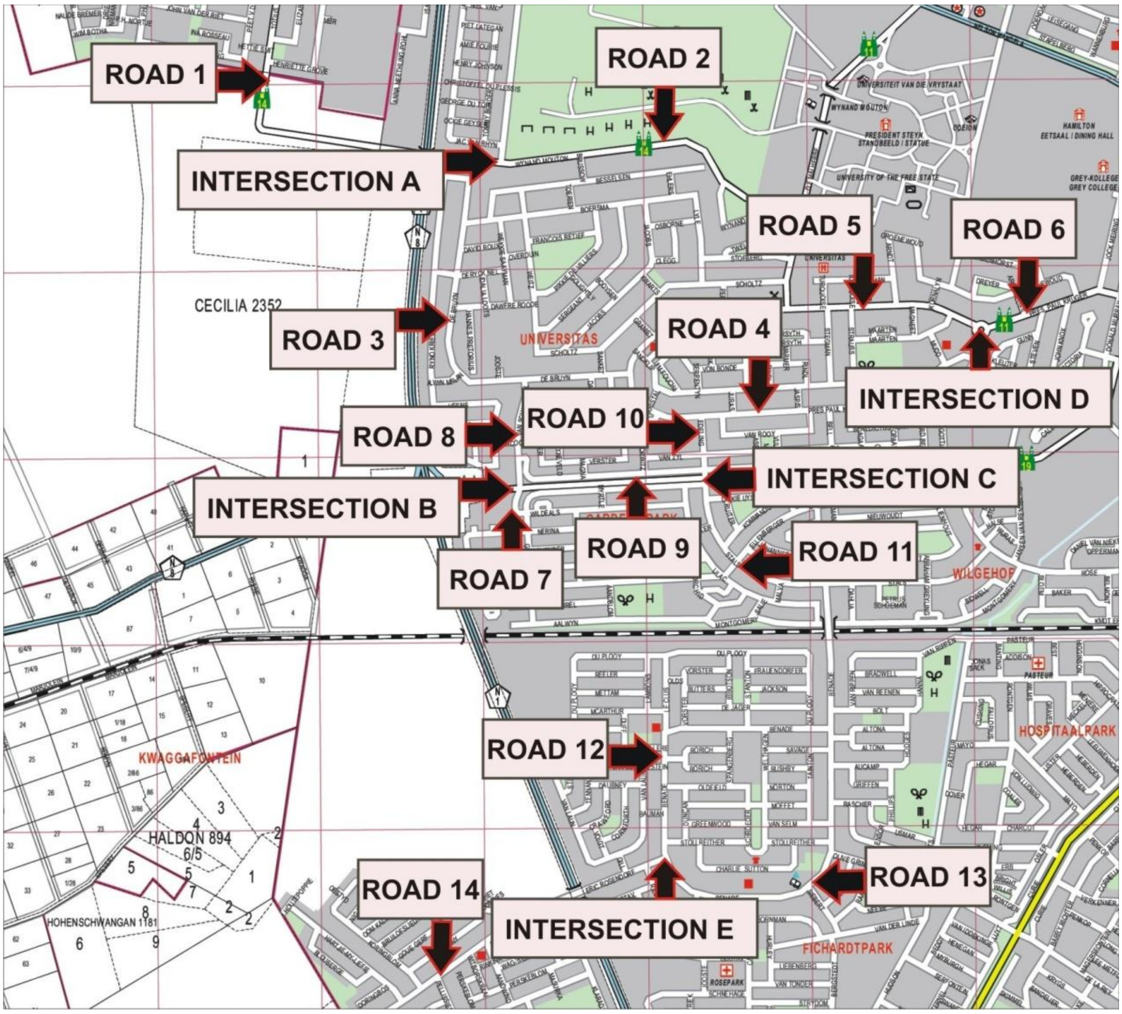

Figure 1-6: Sites of traffic volume surveys

In addition to the above, discussions with police and traffic officials were conducted through a semi-structured interview process.

1.6.2.2 The significance of data collected

The significance of the data is that it is linked to the specific objective(s) of the investigation. The traffic volume surveys, speed surveys, and the measurement of the geometric parameters are essential to understand the existing scenarios and their implications for traffic movements and vehicular traffic accidents in the study area. Socio-economic data collected through household surveys provided a socio-economic and demographic background of the residents in the study area. Discussions with police and traffic officials provided insight to the traffic scenarios and the consequent vehicular accidents in the study area.

1.6.2.3 Secondary Sources of Data

Secondary data pertaining to this study were collected from various sources, such as published and unpublished literature and documents available at various levels, including the study area level as well as the provincial and national levels. The various data that were collected included demographic data, as well as traffic and vehicular accident data from the year 2005 to the year 2011. These data were employed, together with the primary data, to develop theoretical simulation models to analyse the causes of traffic accidents and their implications for reducing vehicular traffic accidents.

1.6.2.3.1 Accident surveys

Accident data were collected to identify the road sections with the highest traffic accident rates in the four selected suburban areas, the types of accidents, the frequency of accidents and their related causes, the severity of accidents, etc. These data were collected from the various records available at the police stations located in the selected suburbs, namely, the Fichardtpark, Universitas, Pellissier, and Bainsvlei Police Stations. The information that was collected with permission from the respective authorities, included the year in which the accident occurred, the time of the accident, the street names where the accident happened, the types of accidents, the severity of the accidents, etc.

The data collected were compiled into a coded spread sheet from the traffic accident registers available at these police stations from the year 2005 to the year 2011. The data before the year 2005 could not be accessed and gathered.

1.7 DATA ANALYSES

After compilation, the data were checked for completeness and correctness, and errors or bias in the returns were eliminated by crosschecking, and subsequently, carefully transferred into excel code sheets and then to a computer for analysis. The analysis is done by employing various tools and techniques, described below.

1.8 ANALYTICAL TOOLS AND TECHNIQUES

1.8.1 Analytical Tools

Relevant analytical tools, including code sheets and software (SPSS, EXCELL, etc.) were used for data processing, analysis, and modelling.

1.8.2 Analytical Techniques

Relevant statistical techniques, such as tabulation, correlation, significance tests, and multiple regression, etc., were employed, according to the requirements of the present investigation.

1.9 MODELLING

A statistical multiple regression model was developed and employed to understand the traffic scenario, the influence of major control parameters on occurrence of the number of vehicular accidents, and the development of plausible policy scenarios for evolving planning and design guidelines for the reduction of accidents in the study area.

1.9.1 Validation of model

The multiple regression model was validated to understand the reliability of the model for future prediction.

1.9.2 Forecasting

The developed and validated model was employed to project accident rates in different scenarios, based on variations of various major control parameters, such as volume of traffic, speed, lane width, accessibility to arterial roads, median width, etc.

1.9.3 Application of the model

Alternate plausible simulated scenarios were developed by employing the model for arriving at different feasible policy decisions.

1.10 RESULTS AND DISCUSSION

The results from all types of analysis, in the literature review, the primary household survey, the road geometrical parameter survey, the accident survey, and the simulated model results have been discussed in detail to arrive at plausible findings.

1.11 INFERENCES

Plausible inferences were drawn for developing a set of feasible policies.

1.12 STRATEGIES AND RECOMMENDATIONS

A set of policy guidelines has been prepared and recommended, based on the results, discussions, and inferences of this investigation, for the reduction of vehicular accidents and the enhancement of road safety in the study area.

1.13 LIMITATIONS

One of the limitations of this study is that it cannot be generalised because the findings of the study are applicable only to the specific scope of study, and thus need further investigation. In addition, the investigator could survey only 120 households for various reasons, namely:

- Time limit (M.Tech research is time-based)
- The limited availability of manpower for conducting the survey (the researcher himself) conducted the investigation at grassroots level because it yields more advantages)
- The survey was conducted during the daytime and evenings only

In addition, one of the major limitations of this investigation is the limited availability of secondary data pertaining to the study area.

1.14 CHAPTER SCHEME

Chapter 1: This chapter consists of an introduction, the statement of problems, and objectives, the scope, concept, research methods, and limitations of the research.

Chapter 2: This chapter consists of the literature review.

Chapter 3: This chapter focuses on the study area profile with respect to the background of the study area, demographic profile, social functions, basic infrastructure, transportation, and traffic management systems.

Chapter 4: This chapter consists of the data analysis results and discussions.

Chapter 5: This chapter contains the findings, the discussion, policy recommendations and the conclusion.

2. CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Every commuter has the right to select his/her choice of travel mode and route. The selection of a route or mode of travel by an individual in an urban area depends on various factors, such as the location of the urban functions, the purpose of the trip, the physical distance and time relationship, the road and traffic conditions, ease of driving and movement, etc. On the other hand, the selection of a route or mode of travel by an individual also has an influence on the traffic distribution of a selected area generally. This whole process of movement and route selection may alter or fix a route for a commuter’s daily commuting and may influence the occurrence of vehicular accidents. If a road is over-occupied, it generally leads to the occurrence of vehicular traffic accidents when the road has not been designed to carry a high volume of traffic. Therefore, the road user may decide to use a road with a lower traffic volume to avoid any delays and accidents. However, if these roads are not appropriately designed according to required road characteristics and if the urban functions in or around those roads are not appropriately planned, then vehicular accidents may also occur. It is essential, therefore, to understand the various factors causing vehicular accidents in an urban area. Further, it is necessary to understand the methods/models that need to be employed to predict the occurrence of vehicular accidents and the various intended solutions available to reduce such accidents on urban roads and advance safe movement in the urban areas.

Given this premise, a sound theoretical background was developed for this investigation by reviewing, analysing, and synthesising the aspects of major urban transportation and its related vehicular accident dimensions at the urban and suburban area level that have been intensively investigated by various scholars. In this context, the various aspects considered were the relationship between urban development and traffic accidents, the influence of residential choice and other urban factors on travel decisions, the factors that influence commuter’s choice of modes, urban development for road capacity management, the influence of the geometric design of roads on traffic accidents, traffic management and vehicular accidents, and modelling approaches to traffic and traffic accident studies. The detailed literature review, synthesis, and findings from the literature are presented below.

2.2 URBAN DEVELOPMENT AND TRAFFIC ACCIDENTS

The design of streets, the overall organisation of road traffic control and management systems in an urban area, the availability of operational social and economic urban functions, the neighbourhood design, etc., constitute some of major factors influencing the frequency and severity of vehicular traffic accidents in urban areas (Retting Weinstein, Williams & Preusser, 2001). Studies have revealed that vehicular accidental risks are significantly higher on roads outside the city centre and suburban areas than in the urban centres. Similarly, significantly higher accident risks were observed on urban road links and urban road junctions (Vorko-Jovic et al., 2006). It should also be emphasised that the planning and design of buildings, housing, and neighbourhoods involves many variables that could influence the occurrence of vehicular accidents. A study by Dunphy and Fisher (1996) on the relationships between urban densities, the socio-economic characteristics of residents, and their travel characteristics revealed that there is a general tendency for less driving in higher-density regions. The analysis of trips by transit led to the conclusion that a positive relationship between density, transit usage, and household travel exist (Dunphy and Fisher, 1996). It may also be hypothesised that urban form is an external factor that could encourage or discourage the use of vehicles and walking trips to destinations, depending on the motivations and limitations of people to carry out their urban functions, thereby influencing the occurrence of vehicular traffic accidents. It is pertinent to note that the more an individual travels, the higher the chance of being involved in an accident (Handy 1996).

According to Chakrabarty, (2007), in evolving solutions to vehicular accident problems, large variations in resource-efficiency indicators need to be viewed as a problem-solving process. It should involve searching through numerous potential solutions to select one that meets the specified criteria or goals for the efficient and equitable solution to mounting urban development and urban traffic problems. In this context, the focus is to reduce individual motor vehicle travel behaviours. On the micro-level, the question of the role that local neighbourhood design plays in determining travel behaviour, the neo-traditional neighbourhood and town planners argue that neighbourhoods should encourage more walks, transit trips, and shorter trips that would reduce vehicular traffic accidents, in addition to reducing auto emissions (Daniel et al., 2000).

Similarly, a reduced road network connectivity within suburban neighbourhoods results in a reduction of physical and vehicle-related activity; approximately three times as much as overall physical activity occurs in urban neighbourhood settings (Badland, Schofield, & Garrett, 2008). However, it was observed that the daily trip-rate and driver trip-rate for households in the standard suburban areas are significantly much higher than the corresponding rates for households in the traditional neighbourhoods. It was also noted that the proportion of auto-based modes was also significantly higher in the suburban areas than in the traditional communities (Daniel et al., 2000). In this regard, studies have revealed that there is a positive relation between high street connectivity with increased levels of walking for commuting purposes on the major arterial roads of school routes (Badland et al., 2008). Route directness could alleviate accident problems in arterial roads or roads passing through suburbs or neighbourhoods of a city.

In summary, it is evident that relationships exist between traffic accidents and urban development. These relationships include, but are not limited to, urban densities, the travel behaviour of commuters, network connectivity, trip-rates, etc. The above mentioned relationships may reduce vehicular traffic accidents, which needs to be addressed while planning for the reduction of accidents and to enhance road safety in urban or suburban areas of cities (Badoe and Miller, 2000; Chakrabarty, 2007; Daniel, et al., 2000; Dunphy and Fisher, 1996; Handy 1996; Badland, et al., 2008; Hyden & Varhelyi, 2000; Retting et al., 2001; Rosman, 2001; Vorko-Jovic, et al., 2006).

2.2.1 The influence of residential choice and other urban factors on travel decisions

This section discusses the influence of residential choices, such as the commuter's residential location and choice, the occupation location, socio-economic factors, family status, etc., on travel decisions of people and their implication for vehicular traffic accidents as observed from various studies conducted earlier.

In his paper regarding the relationship between residential locations on travel behaviour, Næss (2010) indicated that the closer an individual lives to the city centre, the less time he spends on travel, and this influences the mode of travel. His study showed the effects of residential location on travel distances, trip distribution, modal split, energy use, and different travel behaviour. He concluded that residents' selection of neighbourhoods cannot be linked to their travel pattern. However, many scholars have investigated the strong relationship between residential locations and commuter's travel behaviour (Bagley and Mokhtarian, 2002; DeSalvo & Huq 2005; Kitamura, Mokhtarian & Daidet, 1997; Nechyba & Walsh, 2004; Sermons and Koppelman, 1998; Srinivasan and Ferreira, 2002). Residential choice behaviour and its associated daily or periodic urban functions have strong and long-term influence on travel decisions, including travel mode choices (Choocharukul, K., Van, H.T., & Fujii, S, 2008; Fujii and Gärling, 2005, Srinivasan and Ferreira, 2002).

According to the study by Srinivasan and Ferreira (2002), the mode choice is related to residential location types. Kitamura et al. (1997) investigated the effects of land use and attitudinal characteristics on travel, and found that several factors were related to travel behaviours and that attitude was associated with travel rather than with land use characteristics. The travel behaviour factors included the measures of residential density, public transit accessibility, mixed land use, and the presence of sidewalks (Kitamura et al., 1997).

Further, in other studies, it was revealed that the economic conditions of families and family type have influence on choice of modes; for example, individuals in a higher income group use faster modes, and are most likely to travel shorter distances to work. Individuals commuting long-distances will also use faster modes, and are most likely to experience lower marginal commuting costs (Sermons and Koppelman 1998; DeSalvo and Huq, 2005). The model which DeSalvo and Huq (2005) used in their study also suggested that households with higher non-wage incomes are more likely to live in a good normal residential area further away from the central business district or city centre.

In addition, the various rationales identified for travel mode choice consist of the person's mobility resources, time consumption, monetary costs, bodily constraints, avoidance of physical efforts, flexibility and freedom, physical exercise, environmental considerations, lifestyle signalling, habits and customs, and social norms (Næss 2005). Similarly, built environment, transportation network attributes, and demographic characteristics, moral obligation for use reduction, behavioural intentions for frequent car use, and preference for a residential place with convenient public transport also influence residential choice, car ownership, and modal choices (Bhat and Guo 2006; Choocharukul et al. 2008). In this context, Choocharukul et al.'s (2008) study found that car usage is affected by the preference of the residential location; for example, an individual who prefers to use his or her vehicle often is probably not likely to stay near an environment with a high availability of public transportation. Alternatively, individuals used to low vehicle use would refrain from an increase in vehicle use.

Another factor which may be taken into consideration for residential choice as a factor which influences commuters' choice of modes is that of an individual's occupational location (Abraham and Hunt, 1997; Freedman and Kern, 1997; Romaní, Suriñach, & Artiís, 2003; White, 1988). It has been noted that location of an individual's home and workplace determines his or her commuting behaviour. Similarly, Deitz (1998) found that job location has an effect not only on residential location choice but also on neighbourhood characteristics. The results from Vega and Reynolds-Feighan's (2009) study suggests that transportation policies aimed at reducing traffic congestion by increasing car travel costs may have larger effects on home relocation than expected, if individuals affected by these policies are working at suburban employment locations.

In summary, residential factors have an influence on a commuter's travel decisions. The mode choice of individuals is influenced by the location of the residential area where they live, their socio-economic conditions, occupation, family status, people's attitude, their moral obligation, the availability of public transportation system, etc. The selection of travel time, travel pattern, and trip generation is related to the area where the occupant lives, and, consequently, influences the vehicular accident occurrences in those locations.

2.2.2 Factors influencing commuter's choice of modes of travel

The following section discusses the literature findings on the various factors that may influence commuters' choice of mode for travel. These findings include traveller behaviour theories, psychological factors, economic factors, situational factors, and other variables that play important roles, and, consequently, influence the occurrence of vehicular traffic accidents.

In the mid-1970s, Domencich and McFadden (1975) introduced a theory which provided a framework of random utility for the choice of traveller's mode. They observe that economic variables have the maximum influence on the formulation of predictive abilities in the choice of travels modes, although this was found to be inconsistent where the decision-making of an individual is concerned (Kahneman, Tversky & Thaler, 1979). In his book on urban travel demand modelling for individuals as well as for the general equilibrium, Oppenheim (1995) observes that a commuter's decision-processes are structured in four stages, namely, the commuter's geographic location, a given time period, a specific activity, and the decisions about whether to travel or not. The commuter selects a location to conduct a specific activity based on the previous decisions, selects a transportation mode which is available, and then considers an appropriate route to travel to his/her new location (Oppenheim, 1995).

Psychological factor effects, attitudes, motives, and preferences can influence the choice of mode of travel of individuals, which is linked to the perception, beliefs, and available information (Ben-Akiva et al., 1999). Ben-Akiva et al. (1999) found that mode choice is a combination of the traveller's economic concerns, psychological preference, and habitual behaviour. The choice of commuter transport can be predicted by measuring the important relationship between the psychological and the situational factors (Collins and Chambers, 2005). Collins and Chambers (2005) observed that both these factors play equally important roles when compared with each other. However, Gilbert and Forester (1977) have indicated that decisions about the mode of choice can be argued. They found that additional variables are important with the decision of mode choice.

It needs to be understood, therefore, that, in predicting the commuter's choice of modes for their movement, it is essential to consider the commuter's travel behaviour, the various stages in commuter's decision process, and the factors which influence this process which include psychological, economic, situational, and other variables. In fact, these factors are related to the occurrence of vehicular traffic accidents in urban areas (Domencich and McFadden 1975).

2.2.3 Urban development for road capacity management and road traffic accident

A number of scholars have observed definite relationships between urban development and road capacity management which, in turn, influence road traffic accidents in urban areas. Kostof (1991) studied the relationship between urban form and road safety and observed that limited access thoroughfares separate through traffic crossing at lower speeds, and also offer more recreational spaces. A study on traffic safety by Marks (1957) examined the relationship between the traffic safety of disconnected residential subdivisions called "limited-access" communities versus street networks, particularly gridiron street networks and found that gridiron neighbourhoods had seven times more accidents when compared to the limited access communities; and three-legged (T) intersection experienced fewer accidents than four-legged intersections, irrespective of type of road networks. Therefore, Marks (1957) concluded, new subdivisions of urban areas should be built on road safety. The same author also highlighted the importance of aspects such as the differences in traffic volumes; safety effects and the rearranging of neighbourhood land uses; and the examination of neighbourhood streets, and the consideration of the safety effects of relocating road traffic, and the non-residential uses of arterial thoroughfares. One of the priorities of community design is to adhere to road safety, which relates to traffic accidents within these communities and how the design can be altered to avoid traffic accidents.

According to Dumbaugh and Rae (2009), conventional community design is based on three foundations, one of which is arterial thoroughfares, which are designed to address the specific safety needs of motorists. These thoroughfares should be wide and straight to increase sight distance for motorists. Street networks should prevent vehicle traffic from entering residential areas and reduce the number of conflicts between opposing streams of traffic. This can be achieved by replacing four-legged intersections with three-legged (T) intersections and cul-de-sacs as well as limiting the number of access points to the surrounding arterial streets. The ideal solution is only one connection to the external road network, and land use must be redesigned to reinforce the functional separation of traffic. The relationship between community design and the vehicular traffic accident incidence levels associated with urban arterials, arterial-orientated commercial development, and big box stores increase incidences of traffic-related accidents and injuries (Dumbaugh and Rae, 2009). Further, the community design strategies which essentially improve traffic safety within the urban form should include the management of mobility and access functions of urban arterials, as well as the orientation of retail and commercial uses towards lower-speed thoroughfares, the planning of land use, speed management, and access control.

Similarly, in a study by Vaconceloos (1999) on the patterns of traffic accidents in urban areas in Brazil, it was observed that urban development and uncontrolled growth play an important role in vehicular traffic accidents, while the introduction of motor vehicles in developing countries and corresponding space adaptation measures add to this; the environment as well as human factors are also natural producers of traffic accidents. A safe environment is one of the major concerns for people when they choose a residential area (Hillman, Adams and Whitelegg, 1990; Karsten, 2002).

To summarise: the following important aspects have been highlighted. The “limited-access” communities experience far fewer vehicular traffic accidents compared to the higher accessible road patterns. The chance of vehicular traffic accidents occurring at three-legged (T) intersections is lower than at four-leg intersections, irrespective of the road networks or limited access communities (Marks 1957). Dumbaugh and Rae (2009) identified that arterial thoroughfares increase the sight distance for motorists and may prevent vehicle traffic from entering residential areas, and reduce the number of conflicts between opposing streams of traffic, thus reducing the chance of occurrence of accidents. These authors also highlighted that increased traffic-related accidents are associated with the community design and urban arterials roads, arterial road-orientated commercial development, and big box stores (Dumbaugh and Rae, 2009).

2.3 GEOMETRIC ROAD DESIGN ON TRAFFIC ACCIDENTS

This section highlights various aspects of geometric design elements of roads, such as curvature, slope, gradient, lane width, and shoulder width; human factors in combination with geometric elements, and the importance of geometric design to transport planners and engineers; and their relationship with vehicular traffic accident reduction techniques to be adhered to for enhancement of road safety in urban areas.

A road with good geometric design is important to reduce traffic accidents. Li, Abdelwahab, and Brown (1994) studied the influence of road geometrics on vehicular traffic accident rates, noting that the horizontal curvature's average degree has a major impact on the relationship between accident occurrence, private access, and roadside pullout densities. Additionally, gradient and the frequency of change in a curve direction contribute positively to accident occurrence, whereas traverse slope is negatively correlated with accidents (Li et al, 1994). Steep gradient was also identified as an element that results in higher vehicular traffic accident rates than rolling or gentle gradients (Rui et al., 2009). Another element highlighted in literature was that an increase in lane and shoulder width and decrease in traffic volume leads to a decrease in the accident rate (Bester and Makunje, 1998). A recent interesting finding is that very long straight roads with a low value in flexibility of parameters may be more dangerous than gently winding roads with a flexibility of about 40 degrees/km. An increase in traffic lanes and intersections increase the number of vehicular traffic accidents in an area (Papayannoulis et al., 2000). Research has also revealed that accident rates in urban and suburban areas for two-way left-turn lanes are typically 20 per cent lower than for an undivided facility. Accident rates are 40 percent lower for a divided facility compared to an undivided facility. Further, an existing road geometric design recommendation suggested that steep descending gradients may cause braking problems for heavy goods vehicles (HGVs) and impair road safety (Rui et al., 2009; Sétra, 2007). Avoiding the location of a moderate descending gradient between two steep descending sections, gentle curved road sections instead of long stretch of road sections and increasing lane width and shoulder widths are recommended (Li et al, 1994; Rui et al., 2009; Sétra, 2007).

2.4 INFLUENCE OF HUMAN FACTORS IN ROAD TRAFFIC ACCIDENTS

The literature highlighted the fact that the majority of all road traffic accidents involve human factors either alone or in combination with other factors (Abdel-Aty and Radwan 2000; Sabey and Taylor 1980). It was observed that younger and older drivers are more likely to be involved in accidents than middle-aged drivers when experiencing heavy traffic volume. Decrease in lane width and an increase in number of lanes create more problems for older and younger drivers than for middle-aged drivers. Further, it has also been observed that older drivers experience fewer accidents if the shoulder of the road is paved, and that the involvement of younger drivers in accidents increases with speeding. It is advocated that if motorists were notified of every geometric deficiency encountered and warned to be careful of these deficiencies, the potential for occurrence of vehicular traffic accident would be reduced (Abdel-Aty and Radwan 2000; Sabey and Taylor 1980). However, this is an impossible task, so correcting geometric deficiencies is an important step toward reducing accidents (Abdel-Aty and Radwan 2000).

2.5 ROAD TRAFFIC MANAGEMENT AND VEHICULAR TRAFFIC ACCIDENTS

Many scholars have established that there is a definite link between traffic management and traffic accidents. As Choocharukul et al. (2008) and Saleh and Farrell (2007) have established, vehicular traffic levels are increasing all over the world. Several factors contribute to this phenomenon, including increasing car ownership, greater numbers of drivers, reductions in car occupancy levels, and varying levels of spending on roads (Department for Transport of Britain, 2004). Further, the increase in traffic levels is not consistent within a road network, and the peak in traffic levels differ according to (1) the time of day, (2) certain routes, and (3) certain destinations (Department for Transport of Britain, 2004). Several investigators found that departure time, however, does not have a significant influence on peak traffic travelling, and the peak period traffic is not composed of the same drivers day after day, on the same traffic routes, and at the same time (Bonsall, Montgomery and Jones, 1984). However, various ways to distribute peak traffic travelling of commuters suggested by scholars are to encourage people to (1) work flexible hours, (2) work from home for part of a week, and (3) obtain further incentives (Saleh and Farrell 2007).

Retting et al. (2001) investigated urban arterials in metropolitan areas and indicated that an important step in reducing accident risk is to identify segments and intersections with specific collision patterns. Motor vehicle accidents rarely result from a single cause and have many contributing factors, including human and environmental factors, the design and operation of urban roads, and their traffic control devices (Retting et al., 2001). Accident prevention efforts in complex urban environments require an understanding of the design and operation of the urban roads, their traffic control devices, traffic control measures, and motor vehicle collision patterns. For this purpose, it was essential to understand vehicular traffic accident types and procedures to classify these accidents (Preusser, Solomon, Leaf & Nissen, 1996; Retting, Williams, Preusser, and Weinstein, 1995). There are various methods for identifying accident areas, or black spots, i.e., accident-prone locations (Brown, 1972; Duarte and Corben, 1998; Persaud, Retting, Garder & Lord 2000; Tarko, Weiss and Sinha, 1996). The traditional black spot analysis technique identifies locations with high numbers of accidents and are generally scattered. These locations often turn out to be intersections with a very high traffic volume (Retting et al., 2001).

It may be observed that most accidents at intersections occur as a result of a vehicle that is required to stop, which is in the process of stopping or just starting up while a vehicle which has stopped, which is in the process of stopping or just starting being hit from the rear. However, several possible countermeasures available to avoid such accidents have been investigated. In this regard, the possible countermeasures for left-turn accidents consist of (1) the installation of left-turn lanes, (2) the installation of left-turn signal phasing, (3) the changing of permissive to protected left-turn phasing, (4) increasing left turn capacity, (5) avoiding the use of left-turn trap signal phasing, (6) the installation of raised medians, and (7) prohibiting left turns where they cannot be made safely (Retting et al., 2001). Similarly, counter measures for rear-end accidents consist of (1) the improvement of signal visibility, (2) evaluating the adequacy of yellow and all-red signal timing, (3) increasing the duration signal timing, if needed, (4) improving the coordination of signal timing, (5) the installation of skid-resistant pavements, (6) the installation of turn lanes, and (7) eliminating sources of driver confusion (Retting et al., 2001). Further, the counter measures for right-angled accidents are (1) evaluating the adequacy of yellow and all-red signal timing, (2) increasing the duration, if needed, (3) increasing the enforcement against red light running, (4) increasing the intersection sight distance, and (5) ensuring the adequate visibility of traffic signals and stop signs. Furthermore, right-angled accidents at high speeds can be avoided by using the green extension system and installing active advance warning signals (Retting et al., 2001). On the other hand, the counter measures for pedestrian accidents could be (1) ensuring optimal pedestrian signal phasing, (2) ensuring adequate crossing time, (3) installing median refuge islands, (4) constructing pedestrian overpasses/underpasses at locations with high pedestrian volumes and/or with wide high-speed crossings, and (5) installing and intensifying roadway illumination (Retting et al., 2001).

However, a simple method for identifying and correcting accident problems on urban arterial roads is by identifying pre-accident events and driver actions rather than using the traditional black spot analysis (Retting et al. 2001). This examines the numbers and patterns of accidents, which occur along entire segments of urban arterial roads with the emphasis on identifying those locations with excessive numbers of accidents of a particular type, and focuses on roads and intersections which are of importance within urban communities, and also provides safety-related operational and design changes for these urban arterial roads.

Another approach to identify accident problems is to understand the circumstances under which drivers and passengers are more likely to be killed or severely injured (Delen, Sharda, and Bessonov, 2006). The factors which contribute to an increased risk of being killed or severely injured in traffic accidents, namely, the demographic or behavioural characteristics of the person, environmental factors, roadway conditions at the time of the accident, and technical characteristics of the vehicle itself, need to be understood before looking for solutions. It should be observed that an obligation to traffic control measures such as restraint systems in the form of use of seat belt, the prevention of alcohol or drug use, the person's age and gender, and the vehicle's role in an accident have an important influence in the severity of the traffic accidents. However, weather conditions and the time of accident occurrence did not seem to affect the severity of the traffic accidents (Delen et al., 2006).

Hayakawa, Fischbeck, and Fischhoff (2000) investigated the actual risk environments in the domain of traffic safety (car drivers, motorcyclists, bicyclists and pedestrians) and risk statistics (death rates, relative fatality risks, and accident lethality). The findings indicated that the youngest and oldest vehicular drivers all experience extremely high accident rates while the risk for non-car users is more or less similar across age groups. This is related to higher dependence on automobiles, speed and density of vehicles on the roads, and the behaviour of car users (Hayakawa et al., 2000).

Another study, conducted on geographical variations on road traffic accidents (Jones et al., 2008), was based on a large number of potentially explanatory variables relating to population numbers and characteristics, traffic exposure, road length, curvature, and junction density, land use, elevation and hilliness, and, lastly, climate. The study demonstrated that a geographical approach to road traffic accident analysis can identify contextual associations leading to road traffic accidents. Thus, a large number of variables relating to population numbers and characteristics, traffic exposure, road length, curvature and junction density, land use, elevation and hilliness, and climate influence accidents.

In summary, the following important conclusions are drawn. The traffic load during the peak hours will be reduced if certain measures such as staggering of work hours, work locations and similar incentives are provided to the road users. The identification of accident or collision patterns requires a clear understanding of the design and operation of the specific roads and their traffic control devices (Retting et al., 2001). There are several counter-measures available for reducing or avoiding accidents, but they are location and context specific. However, there is a need for identifying and correcting accident problems, particularly in urban arterial roads by considering geographical, demographic, and traffic management measures.

2.6 VEHICULAR TRAFFIC ACCIDENT REDUCTION PROGRAMMES

Vehicular traffic accident reduction programmes in urban areas can take various forms, including site, route, and area plans (Turner and Nicholson, 1998). These programmes involve treating particular sites (or routes) on (or along) which accidents appear to have been concentrated. The other majors includes area plans, which involve seeking to reduce the number of accidents dispersed over a substantial area, and change in the pattern of traffic flow on the network in the area (Turner and Nicholson, 1998). This can be achieved by encouraging traffic moving through an area to use roads designed primarily for the movement function, and discouraging the use of the other roads, which are designed primarily for access. A traffic management scheme, which is traditionally employed to improve the efficiency of movement of traffic, can be used, often by altering the pattern of traffic flow in a network, thereby reducing the accidents (Turner and Nicholson, 1998).

In summary, road geometric design has a significant relationship with the occurrence of vehicular accidents. The most important geometric design elements are the horizontal curvature's average degree, the gradient, the frequency of change in a curve direction, lane and shoulder width, and divided facility versus undivided facility (Abdel-Aty and Radwan, 2000; Bester and Makunje, 1998; Li et al., 1994; Lord, Bhagwant, and Persaud, 2004; Matthew et al,. 2002; Papayannoulis et al, 2000; Retting et al.,1995; Rui, et al., 2009; Sabey and Taylor, 1980; Sétra, 2007; TRB, 2002; Turner and Nicholson, 1998). At the same time, road geometric design parameters influence human behaviour as it has been noted that older and younger motorists are susceptible to higher risk for traffic accidents in certain geometric design conditions. Therefore, the geometric design elements need to be tested and corrected to decrease the number of traffic accidents.

2.7 VEHICULAR TRAFFIC ACCIDENT PREDICTION

The ability to predict vehicular traffic accident rates is very important for transportation planners and engineers, as it can help to identify hazardous locations, sites which require treatment, and spots where deviations (either higher or lower rates) from expected (predicted) levels warrants further examination (Karlaftis & Golias, 2002). Ideally, the anticipated number of accidents should be estimated before a facility is built or upgraded so that potentially hazardous elements can be identified and corrected accordingly, before the new facility is used. Although a thorough planning analysis is always conducted when a transportation agency is planning to build, modify, or upgrade its facilities, traffic safety is rarely, if ever, explicitly accounted for during this process, which typically is concerned with impacts such as travel time, air pollution and fuel consumption (Lord et al., 2004). However, despite the planning and care being undertaken, efforts to reduce the number and severity of urban vehicular traffic accidents have been hampered by a lack of information about the types of accidents that predominate in urban environments (Retting et al., 1995). According to Retting et al. (1995), the lack of available tools is a deterrent while quantifying the safety of a transportation facility during the planning process. Although there are several tools to identify the potentially hazardous locations for roads in service that are well developed, they are difficult to use with current urban transportation planning models, and therefore the prediction of accidents becomes difficult; it is an issue which has been raised by various transportation organisations (Lord et al., 2004; Roberts, 2001; Traffic Research Bureau (TRC), 2002).

2.7.1 Modelling approaches for traffic accident studies

Various scholars have attempted several modelling approaches in order to analyse different aspects of traffic and traffic accidents in urban areas. This section will review in brief some important models so as to understand their suitability as well as their implications and limitations before choosing or establishing models for the current investigation. The various models discussed here include regression, binomial, generalized estimate equation, vehicle and pedestrian, decision-making system models as well as combinations of these with the maximum likelihood estimation, and Bayesian methods.

Lord and Mannering's (2010) study analysed the different modelling methods for analysing accident-frequency data and highlighted their strengths and weaknesses. Their study concluded that the most common methods used for accident-frequency models are the maximum likelihood estimation and Bayesian methods. The main advantage of the maximum likelihood estimation is that closed-form functions often exist for the most common distributions that are used. This estimation cannot be used when the likelihood function is difficult to characterise (Lord and Mannering, 2010). Bayesian estimating methods is an advance in computer modelling (Gilks, Richardsonn and Spiegelhalter, 1996). This model has the advantage of being able to handle very complex data. Using Markov Chain Monte Carlo (MCMC) methods, a sampling-based approach to estimation that is well-suited for Bayesian models; complex functional model forms can be handled (Lord and Mannering, 2010). The MCMC simulation can still be a barrier to complex model forms. The simulation time, which is a function of the size of the sample and the complexity of the model structure, can take several days, so this time-issue can still be a limiting factor in the complexity of the model (Lord and Mannering, 2010). Another accident prediction model using the Bayesian method was developed by Kim, Chung, Song, and Chon (2005). They developed an accident prediction generalised log-linear model with a negative binomial distribution with an ordinal structure and random characteristics based on the empirical Bayesian method. This model gives more limitations to the solutions for an accident model with the incorporation of the empirical Bayesian method, and includes discrete and continuous factors that cause accidents with discrete variables. MacNab (2003) researched a Bayesian hierarchical spatio-temporal model for accident and injury surveillance. The hierarchical Bayesian methodology of MacNab's research does not replace standard and existing techniques used to analyse the surveillance data collected, but rather complements these techniques. The strength of this hierarchical model is that it necessitates assumptions about the formal structure of the underlying process and imposes very few assumptions, and provides a flexible approach for handling complicated spatio-temporal trends.

Kiattikomol, Chatterjee, Hummer, and Younger (2008) investigated the use of a negative-binomial regression model approach for the prediction of accidents on interchange and non-interchange segments of urban freeways. This model assists metropolitan organization planners to forecast the future values of the variables for alternative highway networks by the use of independent variables. This model also can assist planners to evaluate the costs and benefits of safety impacting on alternative freeway networks. Abdel-Aty and Radwan (2000) investigated the use of a negative-binomial model for traffic accident occurrence and involvement. This model works on the basis of data that includes roadway characteristics, geometric characteristics and accident data as well as their locations. The model highlighted that the annual average daily traffic as the most critical factor. The model showed that, as the annual average daily traffic increased per lane, accident frequency increases significantly. Abdel-Aty and Radwan (2000) concluded that the negative binomial formulation in their research is superior.

Lord et al.'s (2004) research aim was to estimate the accident occurrence by year, using an accident prediction model based on the generalised estimate equation. A limitation of this study was that temporal correlation was not taken into consideration in the annual accident counts and therefore these authors highlighted the importance of a complete dataset with proper temporal correlation. The importance of this correlation is that an incorrect generalised estimate equation enables the procedure to be an exact solution. Furthermore, the authors concluded that the quality of this accident prediction model is reduced when the sample size is reduced. It is also highlighted the difficulties in obtaining the data related to the model (Dominique and Bhagwant, 2000).

Davis's (2004) accident prediction model for vehicle/pedestrian encounters uses statistical methods on aggregated data which may lead to a Simpson's paradox. The classical Simpson's paradox is known by its interpretation of contingency tables with an association between the variables in sub-populations (Simpson, 1951). Davis (2004) noted that this association may be reversed when the sub-populations are aggregated. By predicting the aggregate fundamental effect of a countermeasure, it is necessary to adopt the "bottom-up" approach (Davis, 2004). This approach requires firstly: the identification of the relevant accident mechanism; secondly, the determination of the fundamental effect of the countermeasure on each mechanism; and finally, the prediction of the frequency of these mechanism at the location of interest (Davis, 2004). This model can be used to produce hypothetical data from three levels of aggregation, namely, the individual vehicle/pedestrian encounter, the population of encounters at a given site, and the population sites. It has been established that the individual vehicle/pedestrian encounter level may be the most useful level for constructing an accident prediction model with deterministic mechanisms. These mechanisms consist of structural equations, variable values, such as vehicle speed, vehicle headway, vehicle initial distance, driver reaction time, braking deceleration, pedestrian speed, and pedestrian initial distance (Davis, 2004). This finding implies that statistical regularities have no independent status, but are rather the results of aggregating particular types and frequencies of mechanisms.

Durduran (2010) investigated a decision-making system based on a correlation feature selection and classifier algorithms which includes a support vector machine and artificial neural network to predict traffic accidents. Such a network can be achieved by identifying risk factors connected to environmental conditions and geographic information systems connected to vehicle accidents (Durduran, 2010). This decision-making system reduces the dimensions of traffic accidents to only one feature, and uses a correlation feature selection and classifier algorithms of traffic accident cases with that specific feature. Durduran study's results indicated that their proposed system can be used for the prediction of real traffic accidents (Durduran, 2010).

Some models make use of a combination of models. Milton, Shankar, and Mannering (2008) investigated highway accident severities and the mixed logit model by means of an exploratory empirical analysis. Milton et al's (2008) model offers methodological flexibility and a combination of frequency models – a mixed logit model to gain a better understanding of safety enhancements for overall roadway safety. This flexibility enables the capturing of factors relating to a roadway's characteristics, environmental factors, driver behaviour, vehicles types, and the interactions between them. Further, the ability of this model to consider factors relating to the accident injury-severity proportions, such as geometric, pavement, traffic, and weather conditions, provides a more comprehensive understanding of the interaction between the variables which determines transportation safety by providing new insights into accident-severity analysis (Milton, Shankar, and Mannering, 2008). Wang, Quddus, and Ison (2011) used a two-staged mixed multivariate model which combined accident frequency and severity models to predict accidents. This model has several advantages if compared to accident frequency models, and includes detailed data of individual accidents (e.g aggregated traffic, road characteristics, lighting, weather conditions, time of accidents, number of vehicles involved, and hourly traffic flow when the accident occurred). It has the ability to predict the expected number of accidents at different severity levels, even when there are many zero or low accident counts at an aggregated road segment level; it also has flexibility in terms of the model's specification and estimation. Wang et al (2011) stressed that their model is a promising alternative to accident frequency models in predicting accident counts in different categories and site ranking.

To summarise, this section focused on important literature findings pertaining to the various models established and employed in various accident analyses. Two methods and their respective advantages were highlighted by Lord and Mannering (2010), namely, the Maximum Likelihood estimation and Bayesian methods with examples of how they can be used in accident prediction models. The studies by Kiattikomol et al. (2008), and Abdel-Aty and Radwan (2000) used negative-binomial accident prediction models, but Kiattikomol et al. (2008) used this in conjunction with a regression model. This regression model may assist metropolitan organisation planners to forecast the future values of the variables through the use of independent variables. Lord et al., (2004) study emphasised the importance of a complete dataset with proper temporal correlation for use in a model whereas Davis's (2004) study concluded that the individual vehicle/pedestrian encounter level may be the most useful level for constructing an accident prediction model with deterministic mechanisms (e.g. vehicle speed, vehicle headway, vehicle initial distance, driver reaction time, braking deceleration, pedestrian speed and pedestrian initial distance). Durduran (2010) used a correlation feature selection and classifier algorithms of traffic accident cases. It was also observed that multiple model combinations address more complex traffic accident predictions.

2.8 CONCLUSION

For this investigation, the literature on vehicular traffic accident studies, urban development for road capacity management, traffic management and accidents, influence of residential choice and other urban factors on travel decisions, factors that influence commuter's choice of modes, influence of geometric design of roads on vehicular traffic accidents, the relationship between urban development and vehicular traffic accidents, and modelling approaches for vehicular traffic accident studies was reviewed. The following has been observed:

- The level of urban development should be the first main factor within an area as it has a direct influence of the traffic conditions and consequent related accidents. There exists a definitive relationship between traffic accidents and urban devilment.

- The second factor - traffic elements - which are of importance are a road's geometric design parameters, which largely influence vehicular traffic accidents. The most noted elements which influence accidents are the horizontal curvature's average degree, the gradient, the frequency of change in curve direction, lane and shoulder width, and divided facility versus undivided facility. The geometric design of a section of road is very important for accident prediction and must therefore be included in the methodology of any accident analysis and predictions.
- Thirdly, the commuter's decision process, and factors which influence this process, such as psychological, economic, situational, and other variables also influence accidents. Residential factors, economic factors, and family status, etc. influence mode choice, which has an effect on the occurrence of vehicular traffic accidents.
- Traffic calming schemes (e.g. street closures, streets with one-way movement, speed reducing devices, street improvements in suburban areas of cities) that help reduce speed considerably at junctions and at links between roundabouts were employed with some degree of success, resulting in a reduction of accidents, particularly pedestrian and bicycle accident risks.
- The various traffic accident prediction models established and used in accident analysis are Bayesian, Negative binomial, Simpson paradox, Correlation and Mixed logit models. These models are mostly location, context, or parameter-specific, and have been used with varying degrees of success.

The literature reviewed above forms the basic framework for this investigation into traffic accident analysis and the devising of road safety measures in the study area.

3. CHAPTER 3 PROFILE OF STUDY AREA

3.1 INTRODUCTION

An investigation of the study area is essential for an understanding of the characteristics, prospects, and problems of the area for successful urban planning in general and for developing planning guidelines for an efficient transportation system and the improvement of road safety in particular. In this chapter, an attempt is made to investigate and understand the various parameters of the study area, which influence the transportation system in general and the accident occurrences in the study area. These include the demographic and socio-economic parameters of the study area, such as industrial, mining, tourism resources, etc., the social and physical infrastructure, and various infrastructural-related problems faced by the study area in the existing scenario, which influence occurrence of vehicular traffic accidents.

3.2 BACKGROUND OF STUDY AREA

The study area chosen for this investigation is the city of Bloemfontein in South Africa. It is the capital city of the Free State province and has been the judicial capital of South Africa since the year 1910. The city is also known as the ‘City of Roses’ and Mangaung, ‘the place of cheetahs’. The landscape surrounding the city is predominantly dry grassland with flat plateau bordering the semi-arid region of the Karoo at 29°06′S 26°13′E at an altitude of 1395 m above sea level. The climate of the city is cold to warm, the temperature in winter months varying between -3°C and 14°C, and in summer months, between 19°C and 32°C, with frequent afternoon thunderstorms (SA History 2012). The summer season is generally confined to three months at the end and beginning of each year (December to February) while the winter season occurs for three months in mid-year (June to August). The other periods of the year are mostly moderate. The annual rainfall ranges from 600 mm to 750 mm per annum, although it tends to snow in the eastern Free State (Mangaung Municipality, 2012). This city is located within the Mangaung metropolitan municipal area that constitutes Bloemfontein city (Statistics SA, 2011). Figure 3-1 is a map of South Africa indicating the location of the Free State and Bloemfontein.

Figure 3-1: Map of South Africa and the Free State

Bloemfontein consists of several suburban areas surrounding the central business district. These urban areas consist of mixed land use with residential, commercial and civic functions. Figure 1.3 indicates all the residential and commercial areas.

3.3 DEMOGRAPHIC PROFILE

3.3.1 Population and Density of the study area

According to the latest census conducted in the year 2011 (Statistics SA, 2011), the Free State has a population of 2 759 644 people which is approximately 5,46% of the population of South Africa. Mangaung metropolitan municipality has an estimated population of 850 000.

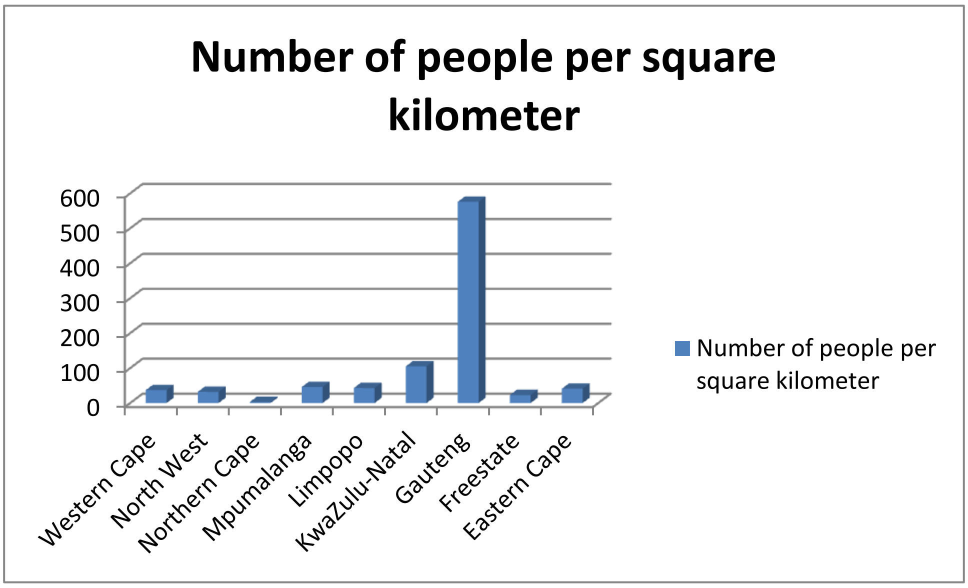

Figure 3-2: Number of people per square kilometer

Figure 3-2 presents the population densities of South Africa's various provinces. Of the nine provinces of South Africa, the province (Free State) in which the study area is located has the second lowest population density with 23 people per square kilometer (Statistics SA, 2006), which is moderate to low when compared to other provinces. The study area - Bloemfontein city - is the largest city in the province, having the highest population: about 24% of the total population of the region lives in the city with a density of 104 people per square kilometer (Statistics SA, 2011).

3.3.2 Gender and Age Structure of Bloemfontein city, Free State.

The gender and age structure of the study area is presented in Figure 3-3. It is worth noting that the largest number of people in the Free State region ranges between the ages of ten to fourteen years. They represent 11% of the province's total population of 2759644.

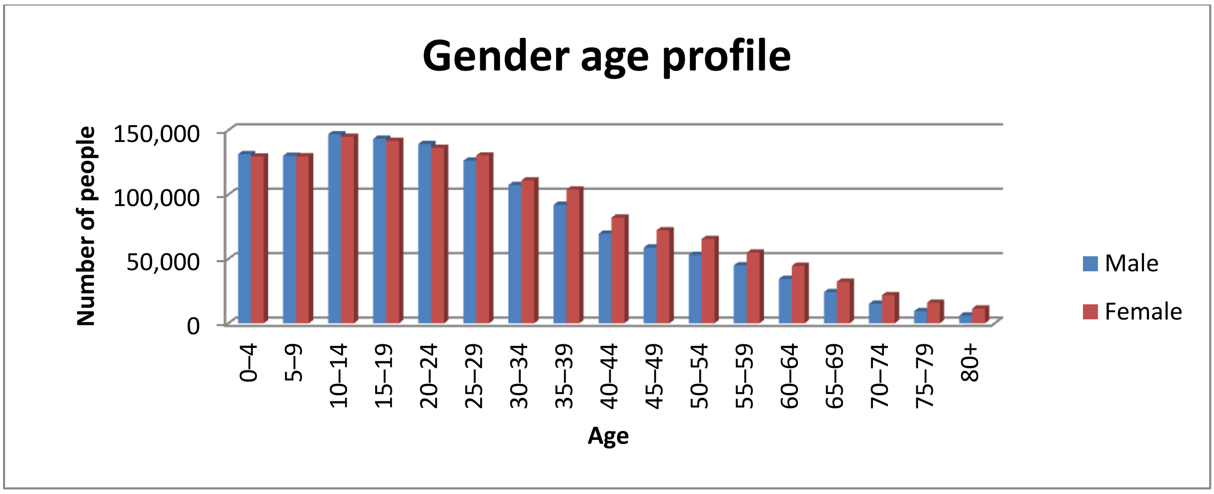

Figure 3-3: Gender profile of residents in the Free State by age group

However, a decline can be observed in the number of people in the age groups from fourteen years to eighty years. There is a decrease of 2% per age group. It should also be noted the male population in the age group up to 24 years is dominant with a cumulative total of 690913 males and 681890 females in this region, whereas the female population dominates in the age groups between 24 years to 80 years with a cumulative figure of 641089 males and 745752 females (Statistics SA, 2011). Bloemfontein population consists of 31% of the Free State's total population. The detailed age and gender structure of the population of the province is presented in Table 3.1. Bloemfontein has an estimated 850000 people in and around the city which contributes to the population of the province.

Table 3-1: Gender age profile

Free State				
Age (years)	Male (No. of people)	Female (No. of people)	Total (No. of people)	%
0–4	131362	129506	260868	9
5–9	130140	129706	259846	9
10–14	146835	144848	291683	11
15–19	143303	141614	284917	10
20–24	139273	136216	275489	10
25–29	126232	130328	256560	9
30–34	107348	110925	218273	8
35–39	91954	103903	195857	7
40–44	69528	82074	151602	5
45–49	58804	72232	131036	5
50–54	52983	65417	118400	4
55–59	45004	54844	99848	4
60–64	34455	44637	79092	3
65–69	24216	32259	56475	2
70–74	15183	21785	36968	1
75–79	9417	15970	25387	1
80+	5965	11378	17343	1
Total	1332002	1427642	2759644	100

About 31% of the population are between 10 and 24 years old with another 18% between 0 and 9 years old. Thus, 49% of the population is younger than 24 years. A total of 24% of the population are between the ages 25 and 39, which indicates that about 73% of the current population is younger than 40 years. This implies that a large portion of the population either needs outdoor activities such as going to schools, colleges, universities, various occupational activities, and other youth-related activities, etc., and so needs vehicular movement to carry out their day-to-day functions.

3.4 SOCIAL FUNCTIONS: EDUCATION AND HEALTH SCENARIOS

In the following section, the social functions, such as education and health of the population of the study area, will be discussed. South Africa's literacy rate for adults is estimated at between 80% to 89%. For youth, the rate varies between 90% and 100%, which is on par with the global literacy rates of 83,7% and 89,3% respectively for these groups (UNESCO Institute for Statistics, 2011). In the context of the study area, the literacy trend is similar to the trend of the country. Bloemfontein city is well known for its educational facilities, and even better known as an educational city. A number of national level higher institutions of learning, including the University of the Free State and the Central University of Technology

Free State are located in the city, which contribute a large number of students to this city. In addition, Bloemfontein has a number of well-known schools (Grey College, Oranje Meisies School, Eunice High, St Andrews, and others). The majority of suburbs have either a primary or a secondary school. The normal literacy rate and the number of people having some form of secondary or tertiary education are highly significant.

The study area also follows the general trends of the national health scenario in its health scenario. The general life expectancy of a male from birth is 54,9 years and for a female 59,1 years (Statistics SA, 2011). There are a number of high-level, sophisticated health service facilities in the city, including three large private hospitals, several public hospitals (3) and clinics (13) providing health care in the city.

3.5 ECONOMY

The economic distribution of South Africa has a direct correlation relation to the population density of each province. At the national level, Gauteng is the province with the highest economical influence in the country with a contribution to GDP of 33%. The province with the lowest economical influence is the Northern Cape which contributes only about 2% to GDP. Free State province recorded the second-lowest contribution (about 6%) to the GDP of the country, just above the Northern Cape (Figure 3-4). Further, it is observed that Bloemfontein is the major economic hub of the Free State Province and contributes significantly to the economy of the province in the form of GDP and employment.

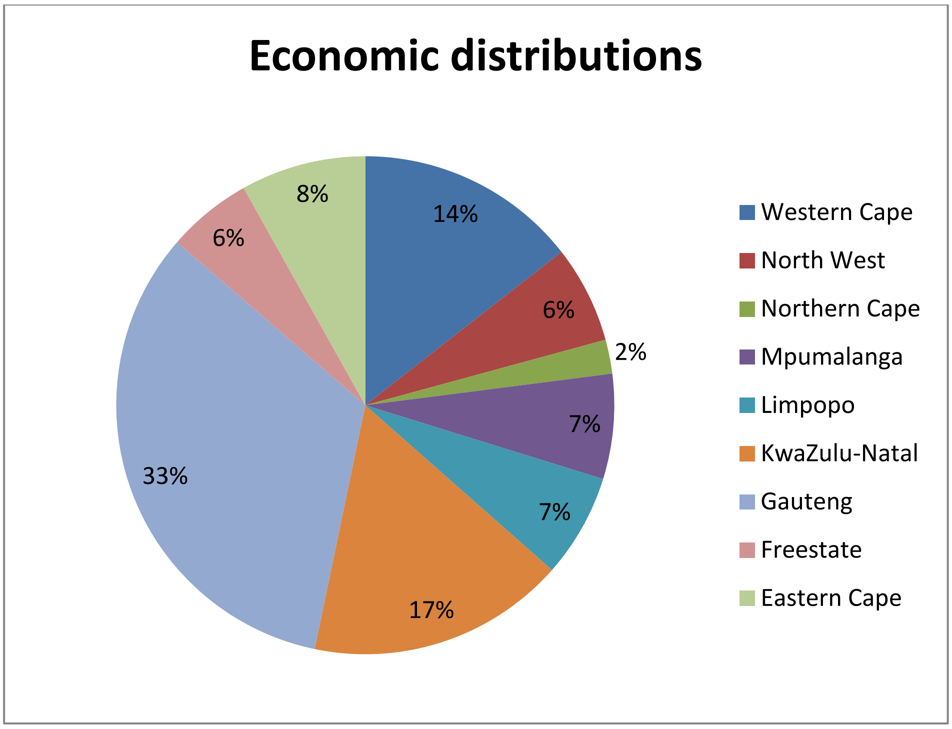

Figure 3-4: Economic situation in South Africa (Statistics SA, 2011)

3.5.1 Employment and Occupation

Free State province has three major sources of income generation, namely, mining, agriculture, and industrial activities. The majority of mining occurs in the northern parts of the province with the gold mines located around Welkom and the coal mines located near Sasolburg. Free State contributes up to 20% of the world's gold stack, with 12 gold mines providing 30% of the country's reserves. Agriculture is located in all the Free State regions, and covers all the farming disciplines. The industrial sector is centered more on the import and export of materials. From an industrial point of view, 14% of the exports are high tech, including petroleum and different waxes, but this occurs more in the region of Sasolburg. Bloemfontein is a predominantly commercially-based service oriented city although several industries are located in and around the city.

The increase in population and consequent addition to the labour force results in the supply of labour surpassing demand, and illustrates the problems of unemployment and under-employment. Thus, employment is an important factor in the economy of the study area.

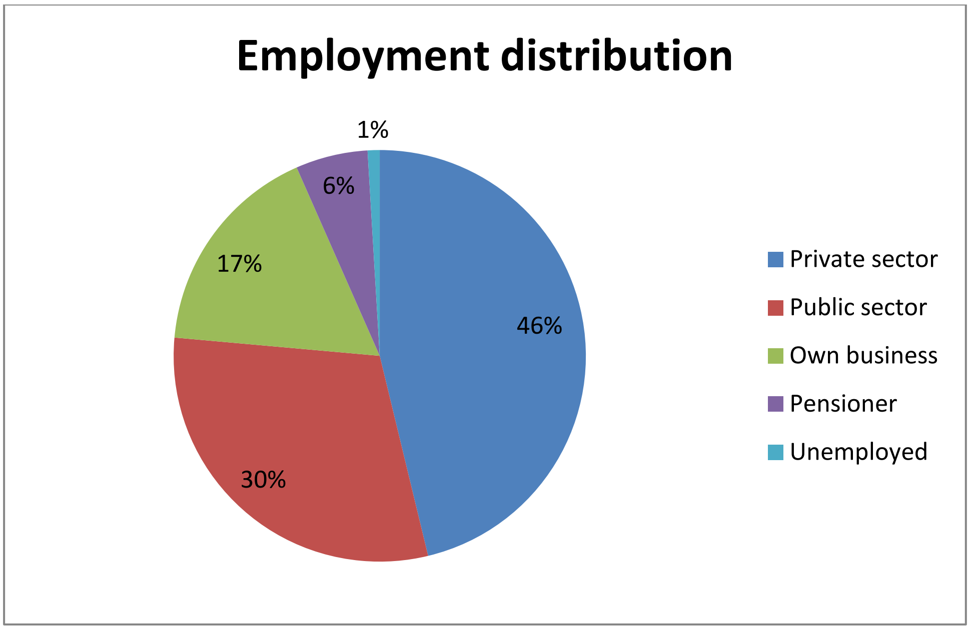

Figure 3-5: Employment distribution in Bloemfontein, Free State
(Household Surveys 2011)

According to the household surveys, the employment distribution scenario in different sectors in Bloemfontein is presented in Figure 3-5. Of the various occupational activities in terms of trade, commerce, industry, government services, and the private sector, Bloemfontein is dominated by private sector employment with about 46% of people working in this sector, followed by the public sector (30%). It is also worth noting that more than one-sixth of the working population are entrepreneurs or own their own business. Six percent of people are pensioners and only 1% was found to be unemployed. With the high number of schools, universities, and medical facilities, the study area provides larger opportunities for employment.

3.6 BASIC INFRASTRUCTURE AND HOUSING

The various basic infrastructure facilities and services in the study area include housing, services and utilities, such as water supply, sanitation, electricity, telecommunication, solid waste management system, etc. It was noted during the survey on the different types of housing within the sample areas that Bloemfontein city consists mainly of single houses including bungalow's for single-family occupation which comprises some 58% of the dwellings. The remaining 42% consists of apartment flats, group houses, townhouses and duplex units.

3.7 URBAN FORM

Urban form is the relationship between the urban patterns and the land use for a selected area. This may change from one area to another because each area differs in its characteristics and functions. Each of the suburbs of the Bloemfontein city has a unique urban pattern and land use, which is essential for an understanding of planning for road safety. Therefore, in this section, an attempt has been made to understand the general urban pattern and land use of the city in general. However, the focus will be on the selected suburban residential areas used as survey areas within the study area, namely, Universitas, Pellissier, Fichardtpark and Langenhovenpark. These areas will be treated as indicative areas for the evaluation of various parameters and elements, such as urban patterns, land use, etc.

3.7.1 Urban Patterns

Urban patterns are the result of the road layout for any suburban area whereby it has different road levels. These levels range from collector roads or local streets, to the minor and major arterial roadways in a hierarchical manner forming a road network. The function of local streets and collector roads is to serve traffic to the minor arterial roads, which then connect to the major arterial roads. At the aggregate level, this network of different hierarchical roads in an area creates a pattern, which essentially leads to the urban pattern of the area. Figure 3-6 shows the layout of Bloemfontein city and presents all the different road sections.

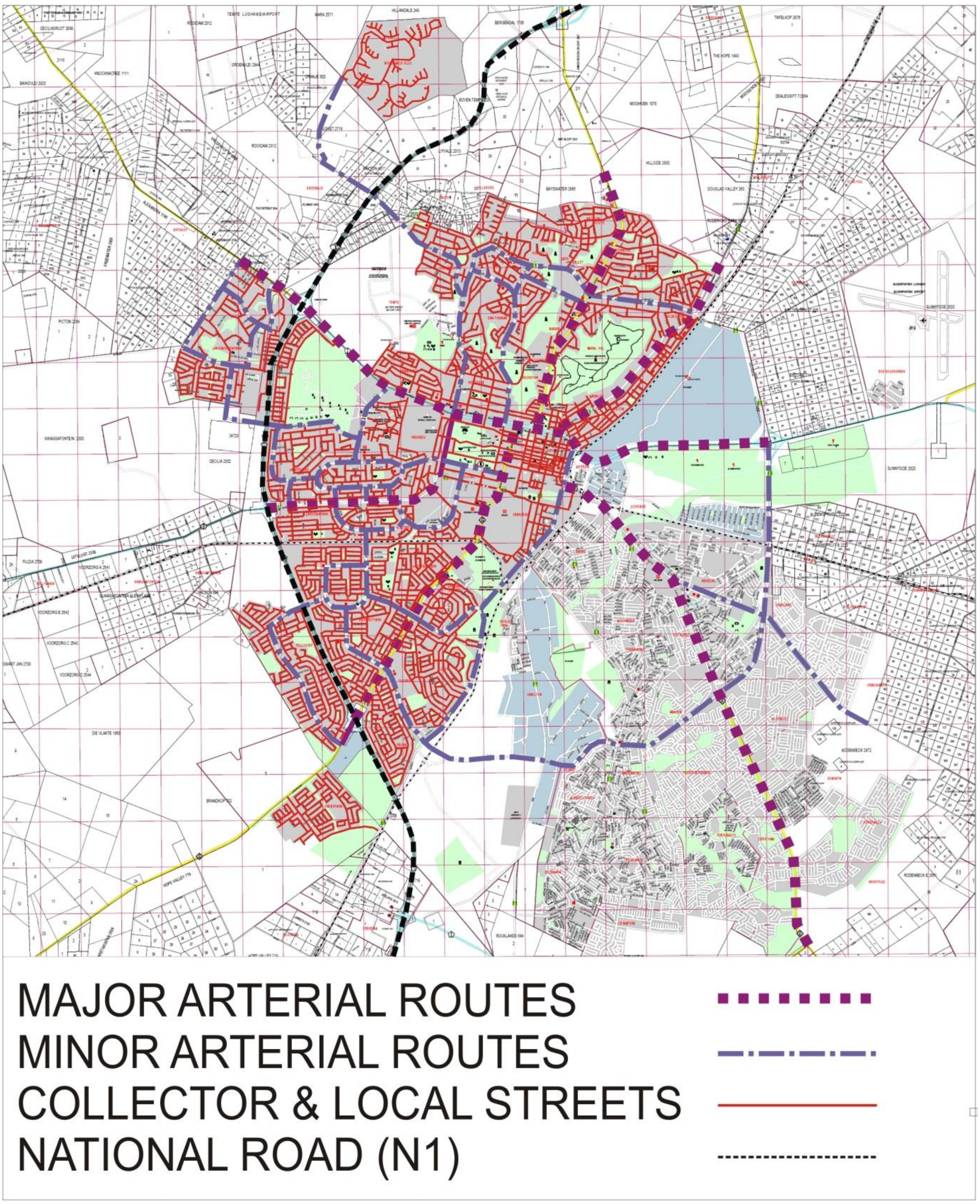

Figure 3-6: Urban patterns of Bloemfontein City

As can be seen in Figure 3-6 above, the major arterial routes originate in the centre of the city and move to the outer parts. They divide the different urban areas into portions which are easily accessible from the different areas. These areas are connected through major arterial roads. These major arterial roads are linked with the minor arterial roads, which act as linkages between the collector and local streets and the major arterial roads, thus creating an organised network. The following observation has been made:

- That the major arterial roads have a linear pattern and the minor arterial roads consist of either a linear or a loop pattern.
- That the collector and local streets manifest different types of road patterns such as gridiron, loop, combination of grid iron and loop and cul-de sacs with an occasional loop patterns.
- That the central part of the city is primarily of the gridiron pattern, although the pattern changes to a radial pattern in combination with the gridiron pattern towards the outer part of the city.

3.7.2 Land use

Land use is the representation of the functional use of an area. The various land uses in a city are residential, commercial, industrial, civic, open space, or mixed land uses, etc. Various areas of a city may belong to single land use with single functions or may have a combination of land uses or mixed land use with multiple functions. In general, Bloemfontein city is no different from any other cities. Figure 3-7 presents the broad land use map of Bloemfontein.

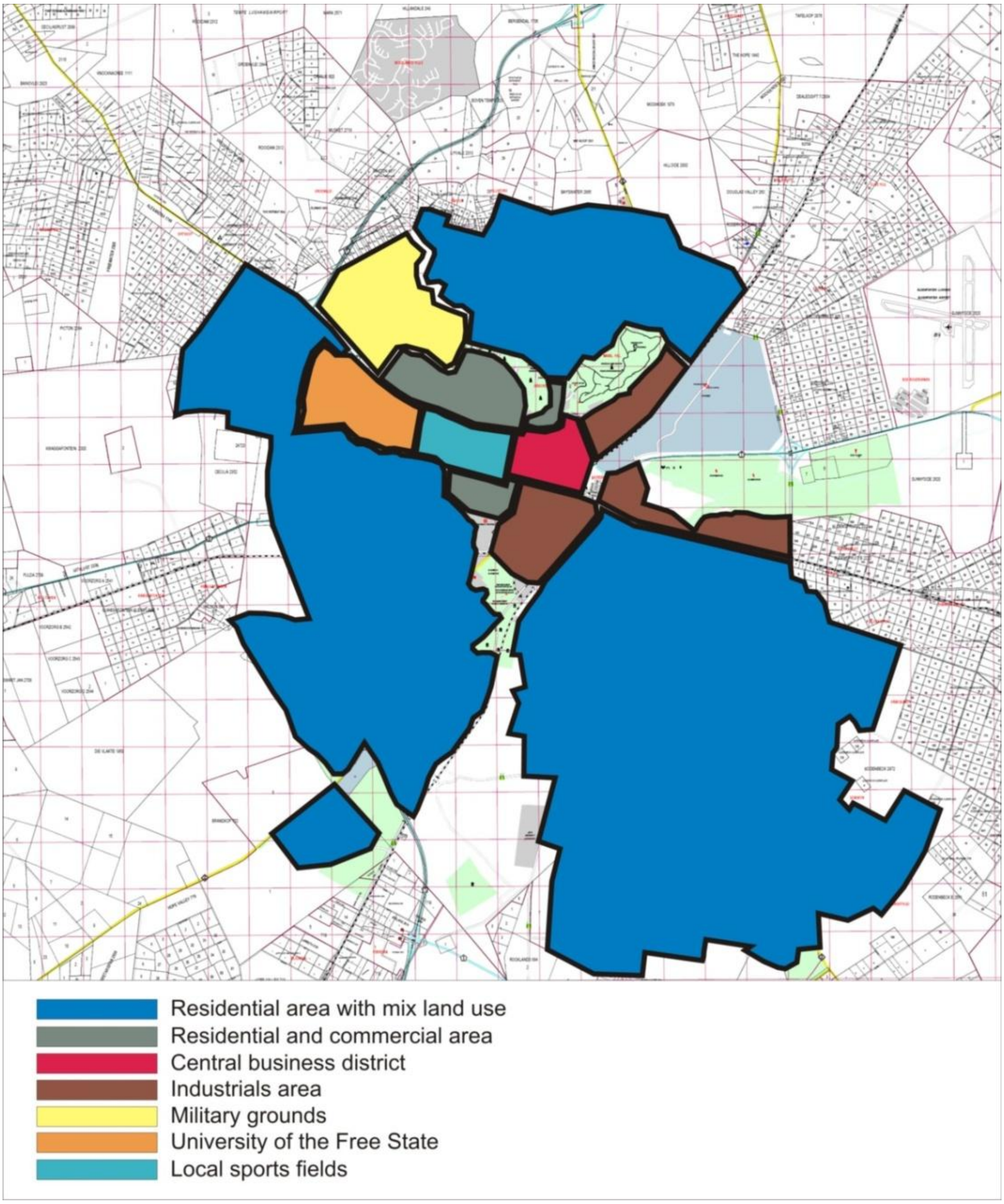

Figure 3-7: Land use of Bloemfontein City

Figure 3-7 shows that the city has a designated CBD, which is dominated by commercial and administrative functions. The area on the periphery of the CBD is mostly of mixed land use, having mixed functions, which include commercial, civic, recreational and residential activities. Towards the outer parts of the city, the areas are predominantly occupied by residential areas with mixed land use in certain locations. This is followed by the military grounds and the University of the Free State which also borders the city limit. Figure 3-8 provides the general land use pattern of the city.

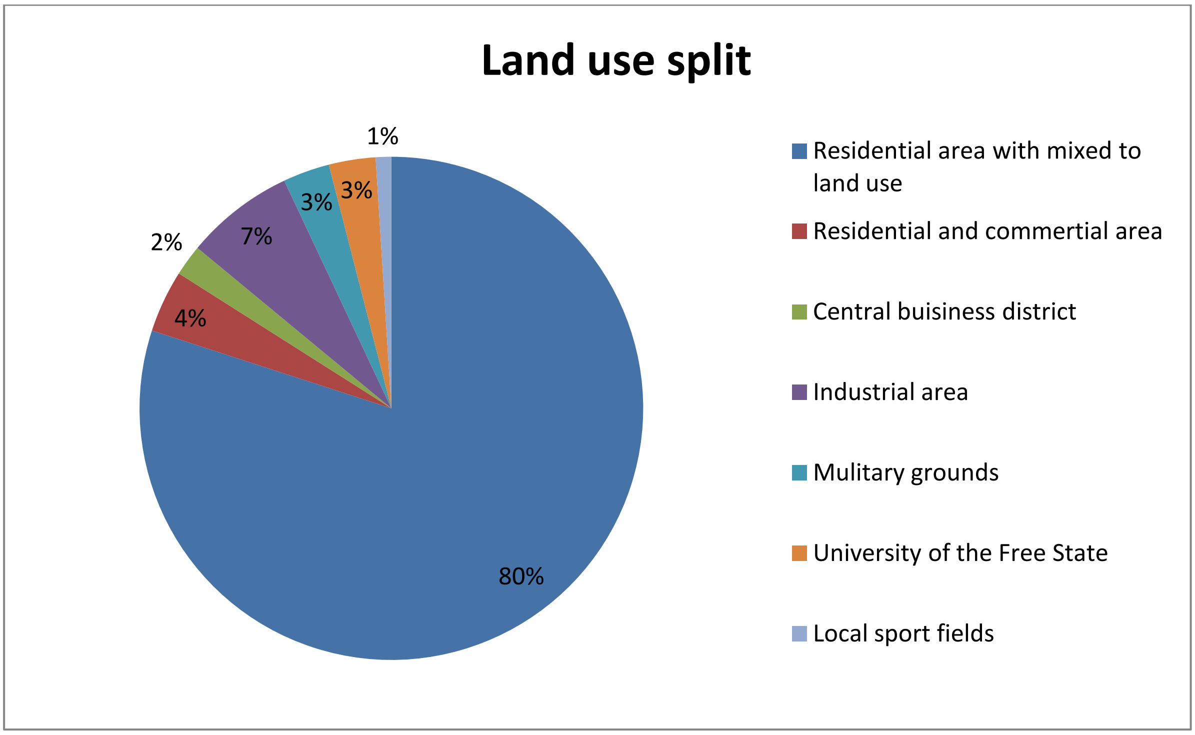

Figure 3-8: Land use split

It is worth observing that the majority of the areas (80%) of the city is given over to residential areas with mixed land uses. Industrial areas occupy only 7% of the total land use, yet they make up the second largest area. Commercial areas and mixed land use outside the CBD occupy only 4% of the total land area. The land area of the CBD is about 2% of the total land area of the city. Two other prominent features of the city such as Military grounds and University of the Free State occupy about 1% and 3% of land area respectively. The civic and entertainment land uses are confined to either commercial or mixed land uses.

3.8 TRANSPORTATION

3.8.1 Road Networks

Bloemfontein city has a hierarchical road system, with major arterial, minor arterial, collector roads as well as local streets and culs-de sac, which is presented in Figure 3-9. The majority of roads are paved, although some residential areas have unpaved roads or poorly maintained paved roads. All parts of the city are accessible via the road network. The major arterial roads act as the network distributor for the roads linking the outer suburbs to the city centre. The minor arterial roads act as arterial thoroughfares in the suburban residential areas linking the collector roads and the local streets to the major arterial roads. The collector and local streets act as the connection between the residents and the minor arterial roads.

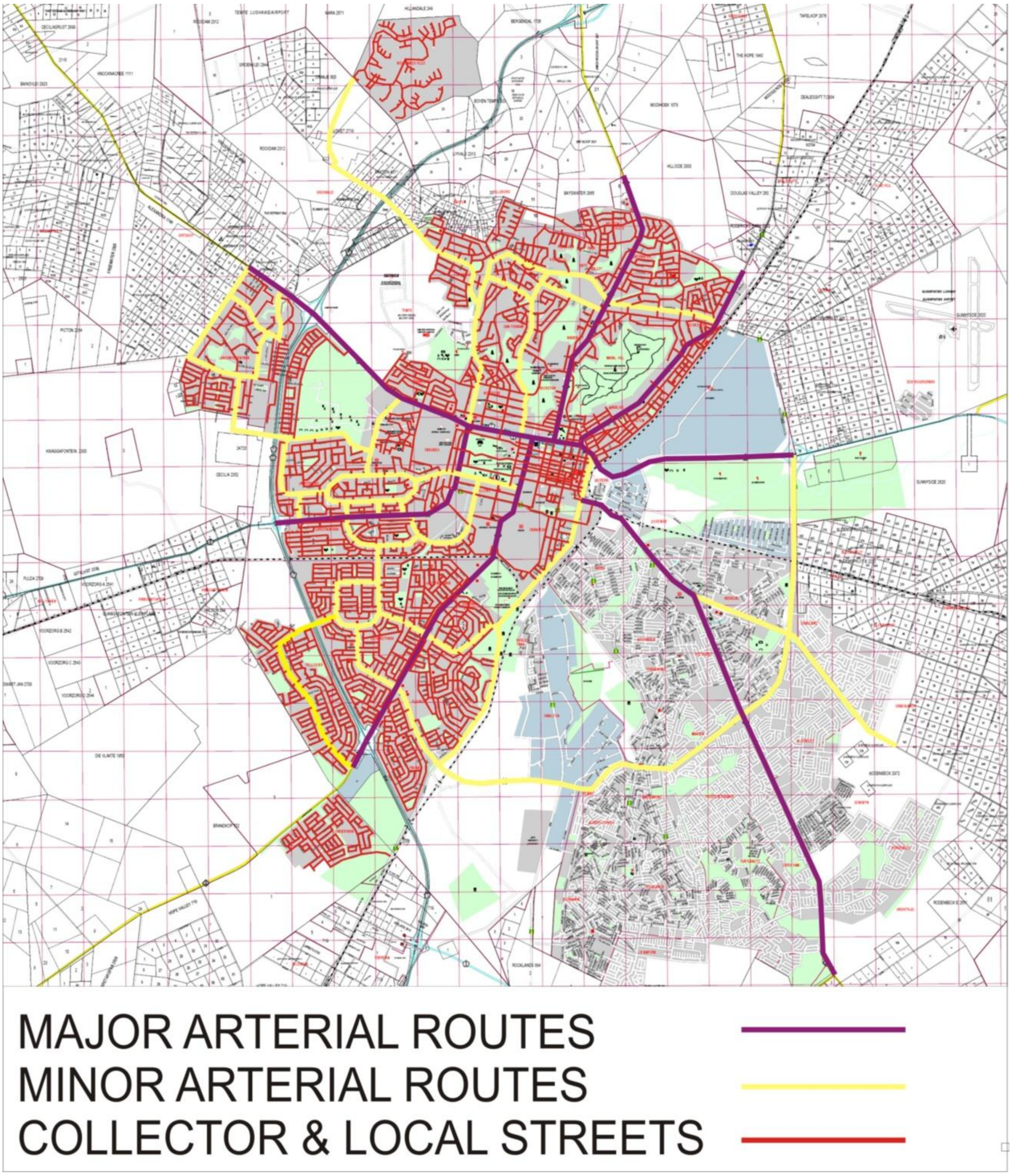

Figure 3-9: Road networks in Bloemfontein City

It should be noted that all the major arterial roads have multiple lanes with a median splitting the traffic from opposite directions. The minor arterial roads have either multiple lanes or single lanes. Almost all the collector roads and local streets are single-lane roads. In addition, most of the roads have a gentle gradient, which provides driving comfort. Except major arterial roads, most of the roads have a speed limit of 60 km/h confirming the inter-urban speed limit.

3.8.2 Nodal transfer points

The various nodal points in the road network are bus stations, bus stops, taxi ranks, etc.; their locations are presented in Figure 3-10. The smaller circular dots indicate the two main bus stops that serve as the origin points for the other bus stops. The larger circular dots are the remote bus stops which act as destination points. All the major roads, except on a few isolated routes, are used regularly by all modes of vehicles throughout the day.

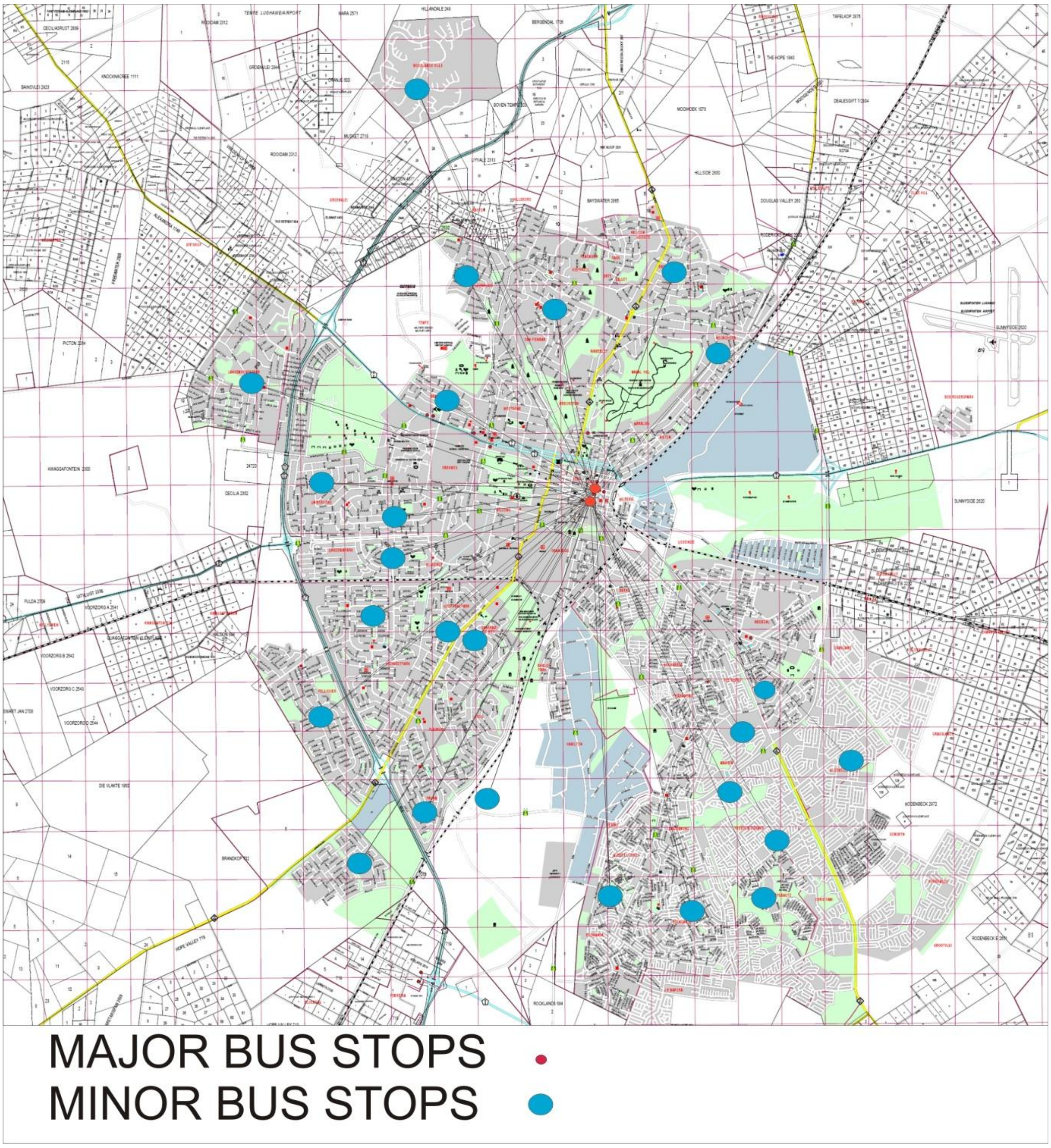

Figure 3-10: Bus stops in Bloemfontein City

The locations of the bus stops are indicative of the public transport system, which provides accessibility to individuals. The major bus stops are connected to all the suburban residential areas of the city and provide suitable transportation options during the duration of the day.

3.8.3 Types and number of vehicles

Commuters use different types of vehicles in South Africa. Table 3-2 presents the number and type of vehicles being used for each of the different provinces in South Africa (National Traffic Information System South Africa, 2010) and the Free State. In the absence of structured and organized statistical data, this information provides an indication of the scenario regarding vehicles in the study area. The major modes of travel in South Africa and in the Free State (56%) are personal/individual-driven motor cars. A large number of people (62%) use their own vehicles for their daily travel while the remaining commuters use public transportation systems, such as local taxi or bus services. The scenario is no different in the Bloemfontein city study area as an estimated 60% of people travel using their own vehicles.

Table 3-2: Number of type of vehicles (in thousands) (RTMC, 2009).

	PROVINCE								
Vehicle type	**GP**	**KZ**	**WC**	**EC**	**FS**	**MP**	**NW**	**L**	**NC**
Motorcars	2355,6	770,9	989,6	358,9	259,8	296,5	241,1	212,8	95,1
Minibuses	112	449,3	35	21,1	12,2	20,2	16,8	19	3,8
Buses, trains or midi buses	16	6,8	5	3,8	2	4	3,1	4	1,2
Motorcycle, Quadra-cycle or tricycle	129	31	72,3	22,8	19,9	18,5	14,6	9,2	7,6
Light delivery vehicle	650,9	287,4	273,3	166,1	112,5	158,3	123,7	160,5	62,2
Trucks	123,5	50,2	34,3	24,1	19,6	26,3	17,1	20,1	8,8
Other self-propelled vehicles	35,5	30,1	31,1	12,9	37,3	24	23,5	13,7	7,4
TOTAL	**3422,5**	**1425,7**	**1440,6**	**609,7**	**463,3**	**547,8**	**439,9**	**439,3**	**186,1**

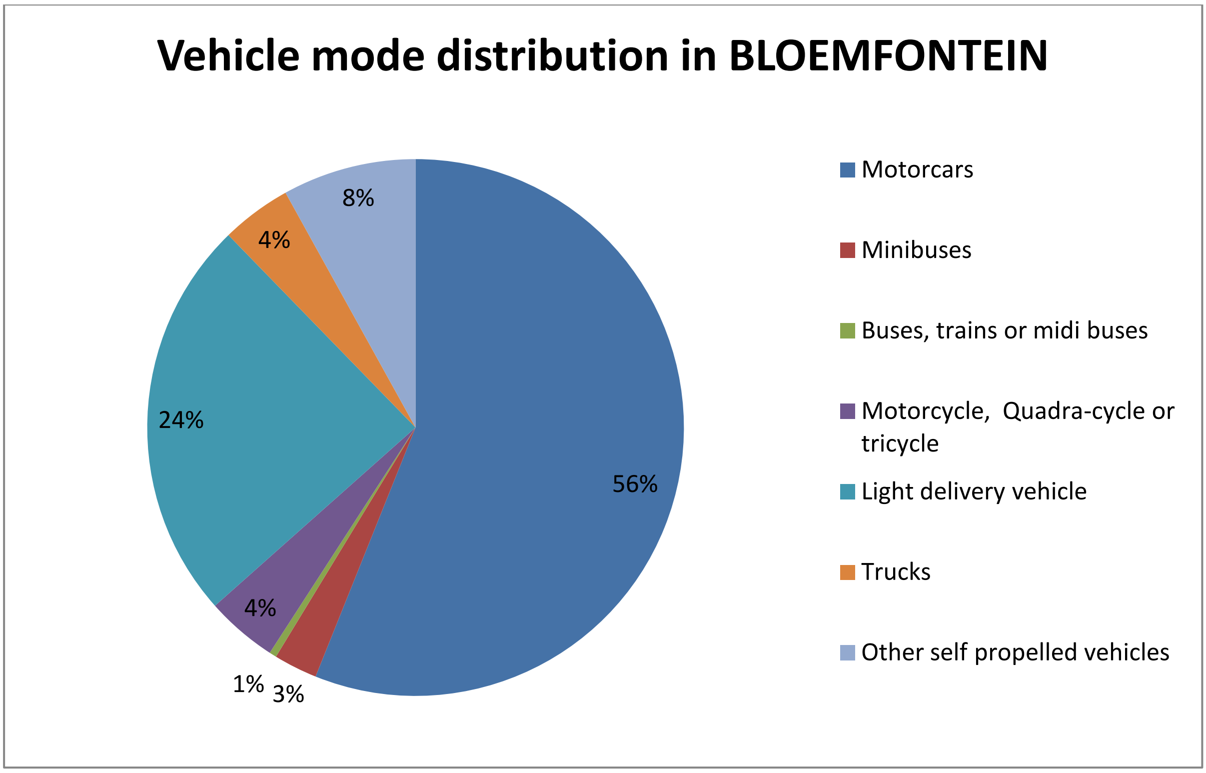

Figure 3-11: Vehicle mode distribution in Bloemfontein

Although the Free State province has the fourth-lowest number of vehicles in South Africa, in the city of Bloemfontein, motorcars are the leading mode (56%) used by people followed by light delivery vehicles (24%). The other self-propelled vehicles constitute 8% with the quantum of remaining vehicle modes varying between 1% and 4% (Figure 3-11).

3.8.4 Public transportation system (Mini-buses and Buses)

The public transportation scene in Bloemfontein city is dominated by mini-buses and buses. The mini-bus routes are similar to the passenger bus routes but the times may be more inconsistent for travelling purposes. The mini-buses work on an informal basis with an individual paying cash to travel while the passenger buses work on a weekly or monthly pass which must be purchased before entering the bus. Figure 3-12 is an example of the mini-buses operating in and around the Bloemfontein. Each of these vehicles carries approximately eight to twelve passengers. Although they carry fewer passengers per vehicle than the standard buses, they are major carriers in the public transportation system of the study area.

Figure 3-12: Mini-bus in Bloemfontein, Free State (West Cape News, 2012)

Buses are the more dominant public transportation facility in South Africa. However, the level of service varies from city to city. Interstate Bus Lines provide major public transportation facilities by using two types of buses: bus trains and rigid buses. The bus trains carry 114 passengers while the rigid buses can carry up to 65 seated passengers (Interstate Bus Lines, 2012). The frequency of bus usage will determine on the route and location. Figure 3-13 is an illustration of a standard bus of the service provider in Bloemfontein. The origin and destinations are indicated in Figure 3-10. Standard buses can take a larger number of passengers and are route-specific. Bus trains and rigid buses are used for this transportation frequency. These buses are more cost effective than the normal minibus taxis for a commuter, and have more flexible ticketing arrangements. In the study area, these buses are labeled with different routes from and to the central business district.

Figure 3-13: Bus trains in Bloemfontein, Free State (Interstate Bus lines, 2012)

3.9 TRAFFIC MANAGEMENT SYSTEMS

The traffic management systems of South Africa cities vary, depending on the category of the road, the volume of vehicles, and several other factors. The following types of traffic management systems have been observed in the study area:

- Intersections with no control - there are some junctions in the city that have no traffic control or management system, such as signalling of any sort. However, this system is limited to only minor junctions and is scarcely used inside the city.
- Intersections with a stop control on the minor road crossing a major road – this system is used to access a major road from a minor road. The vehicle must stop before entering or crossing the major road.
- Intersections with a yield control on the minor roads – this system is used to access a major road from a minor road. The vehicle must yield (give way) to traffic on the major road before entering or crossing the major road.
- Intersections with traffic signal controls – the signal will control the traffic in a way that the one direction will stop while the other direction is allowed to drive. Different phases can be implemented to control directional flow for the traffic. The majority of the junctions, particularly in the inner parts of the city, are signalised either by isolated or synchronous signalling systems. Major junctions are also provided with right-turn signals and pedestrian facilities.
- Intersections with all-way stop – this controls the traffic by means of requiring all vehicles to stop at the intersection. The driver that stops first departs first. Some of the junctions of the study area are provided with this system.
- Roundabouts – this is a circular intersection with a median situated in the middle. It works on a yield function and is not used for high traffic volumes. In Bloemfontein city, there are several such junctions, particularly at the entrance to suburban areas.
- Road pavement marking - all the pavements of roads in the city are properly marked, according to rules and regulations provided by the South African National Road Agency Limited (SANRAL) G2 manual.
- Signage - The roads of the city are provided with proper signage systems, according to the requirements; this refers to speed control, directional flow, yielding, stopping, etc.
- Speed traps – these are situated at random points within the city; they may be fixed cameras or stationed radars.

- Parking systems: Both on-street and off-street parking systems are found in the city. Such parking may be paid or free parking in the different parking areas. On- street parking is a problem when the road width is insufficient.

Some examples highlighting the traffic management system in the study area follow.

3.9.1 Example 1 - De Bruyn Street & Wynand Mouton Drive

Example 1 is the three-legged intersection joining Wynand Mouton Drive (with high traffic volume) and De Bruyn Street (with moderate traffic flow) which is controlled by an automated traffic signaling control system (Traffic Volume Survey, 2011). This system works on a system whereby one direction will have right of way to drive while the other direction must stop. Figure 3-14 is an aerial view of the intersection, and Figure 3-15 is an example of how the system works with respect to relevant traffic signals. De Bruyn Street comprises two parallel roads intersecting Wynand Mouton Drive, with a median splitting the directional flow. Wynand Mouton Drive has no median with traffic in both directions.

Figure 3-14: De Bruyn Street & Wynand Mouton Drive (Aerial view) (Google Maps, 2012)

Figure 3-15: De Bruyn Street & Wynand Mouton Drive (Street view) (Google Maps, 2012)

3.9.2 Example 2 - Van Schalkwyk Street and Haldon Road

The intersection of Van Schalkwyk Street and Haldon Road is controlled without any traffic control system (without an automated control sistem). Haldon Road has high traffic volume and has multiple lanes with a median whereas Van Schalkwyk Street is a one-way, two-lane system having moderate traffic volume, mainly for people commuting to Jim Fouché Primary and High Schools. The traffic control system at the intersection works on a combined mechanism, together with the Haldon Road traffic system to the right while Van Schalkwyk Street is controlled by a stop sign, as indicated in Figure 3-16 and Figure 3-17. Both road sections have a median which splits the directional traffic.

Figure 3-16: Van Schalkwyk Street & Haldon Road (Aerial view) (Google Maps, 2012)

Figure 3-17: Van Schalkwyk Street & Haldon Road (Street view) (Google Maps, 2012)

3.9.3 Example 3 - Paul Kruger Avenue Roundabout

Example 3 is a roundabout located at the entrance to the residential area of Universitas and, in the main, carries commuters to and from the University of the Free State. During the morning peak hours, the traffic volume is high. During the afternoon peak time, one can observe a higher number of vehicles, as most of vehicles from the local suburbs/ neighborhoods ply this intersection. The general traffic rule according to the national traffic rules, that the driver must give right of way to the vehicle approaching from the right-hand side, is observed in this intersection. This traffic control system of the intersection can be observed in Figure 3-18 and Figure 3-19. Vehicles enter from all directions with a median to split the directional traffic.

Figure 3-18: Paul Kruger Avenue Roundabout (Aerial view) (Google Maps, 2012)

Figure 3-19: Paul Kruger Avenue Roundabout (Street view) (Google Maps, 2012)

3.10 ACCIDENT SCENARIO IN THE STUDY AREA

The number of vehicular traffic accidents reported in the study area in the year 2005 and 2010 are 524 and 841 accidents respectively. It is observed that the number of occurrence of accidents has increased by 11% per year between the year 2005 and the year 2010. Most of these accidents occur on the different roads and intersections of the suburban residential areas of the city. It was also reported that the incidences of the accidents spread over the whole duration of day irrespective of the week days or weekends.

3.11 SUMMARY

The analysis of the Bloemfontein City study area revealed that:

- The Free State province has the second lowest population density, with the Mangaung (Bloemfontein and surrounding areas) district consisting of 850 000 residents.
- The majority (74%) of the population in the study area are below the age of 40 years, of which about 31% are between the ages of 10 and 24 years. Only 26% of the population is older than 40 years. This also indicates that a large portion of the population belong to the economically active group and need movement. In turn, as most people use their own vehicles, it could be construed that the majority of the drivers are confined to the 18 to 40 year age group however, it is also observed that a significant portion of people belonging to age group 40 to 64 years also drive their own vehicles.
- Bloemfontein City has schools and hospitals spread over the entire region with the larger hospitals (Universitas Hospital and Rosepark Hospital) stationed within the residential areas.

- The general unemployment rate of the country is at 25% (Statistics SA, 2011). However, the unemployment rate in the study area is low, with most people working in the private sector.
- The road patterns for Bloemfontein City comprise a linear system of main arterials which is linked to different urban areas which include loop systems, linear systems, or gridiron systems.
- Bloemfontein has a public transportation system ranging from a bus system to a taxi system which travels from and to several locations over the entire road network. However, the public transportation system seems to be inadequate as most people - an estimated 60% of the commuters use their own vehicles for their daily travel.
- The road sections and intersections make use of different traffic control systems which vary from section to section. These systems include road markings, signalised intersections, and road signage.
- Majority of the traffic accidents occur on the roads of the residential suburban areas of the city and they are spread over the whole duration of the day and seven days a week.

4. CHAPTER 4 DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 INTRODUCTION

An attempt was made to investigate the socio-economic, physical, transportation, and traffic-related conditions of the study area and their influence on the occurrence of the vehicular traffic accidents. Survey research methods (see Section 1.6.2) have been employed to collect data which was then statistically analysed to understand the various major control parameters influencing vehicular accidents in the study area. Once the data were collected, the researcher vetted all the schedules, cross checking, and correcting the discrepancies, before subsequently transferred the data into code sheets to avoid errors. Thereafter, the data were transferred to Microsoft Excel sheets, and suitable statistical analyses were done. The various analyses done include:

- A socio-economic scenario in the study area
- An analysis based on a physical survey of the road system/road network
- The relationship between traffic accidents and urban form
- The relationship between urban functions and land use
- Traffic scenarios
- Accident predictions in the study area
- Parameterisation (delineating major control parameters influencing vehicular accidents in the study area)
- Modelling for vehicular accident prediction in the study area
- Multiple regression analysis
- Simulated scenarios for policy analysis

4.2 SOCIO-ECONOMIC SCENARIO IN THE STUDY AREA

The socio-economic conditions of the study area were analysed to understand the socio-economic status of the people, their travel behaviour, and the use of various transportation modes for their daily movement, which have direct or indirect linkages to occurrence of accidents in the study area. The analysis was conducted based on different variables including: (1) Household income; (2) Age; (3) Age vs Employment; (4) Academic qualification; (5) Occupation; (6); Dwelling house type; (7) Property ownership; (8) Number and type of vehicles; (9) Travel distance; (10) Commuting trips; (11) Expenditure on transportation, and (12) Accident occurrences.

4.2.1 Income of households

Income is the most important parameter because it dictates the various functions in an urban area. The living condition and family's status varies with income. Incomes decide the purchasing and spending power of families, and have multiple effects, such as increases in standard of living, increases in the use of infrastructure services, the enhancement of socio-economic and recreational functions, and the encouragement of spending higher amounts on travel and vehicular use for movement.

The collected data has been classified into income groups for analysis purposes. The grouping has been done after a preliminary examination of the incomes of individual households and the income range variation of all the households. They have been grouped together in the nearest income groups. Care has been taken to keep the income class intervals uniform for easy and error-free unambiguous analysis. Accordingly, all the households surveyed have been classified into six annual income groups, and presented in ascending order of income: from R0-R80000, R80001-R160000, R160001-R240000, R240001-R320000, and R320001 and above. The number of families in the various income groups is presented in Table 4-1. The table makes it clear that the majority of the households surveyed (38%) have a general income of below R80000 per year. About 24% of the households are within the income range between R80001 to R160000, followed by 14% of households in the income range from R160001 to R240000. Only 12% of households fall into each of the last two income groups: between R240001-R320000 and R320000 and above. Thus it can be seen that a little more than half of the households surveyed (52%) belong to lower income groups (< R160000); about 36% of households belong to the middle-income groups (R160001-R320000); while only a little more than one-eighth of the households belong to the high-income category.

4.2.1.1 Socio-economic and demographic conditions of the study area

In this section, the general socio-economic background of the areas surveyed, and various demographic and socio-economic parameters of the households surveyed in the study area were analyzed and discussed with respect to income groups in order to have an in-depth understanding of the study area. The various parameters analyzed and discussed are employment age, level of academic qualifications, occupations, different types of living arrangements, whether residents are owners or tenants, transport modes, distance travelled by each vehicle per household, number of trips per vehicle, expenditure on transportation if and number of traffic accidents witnesses or involved by the households.

4.2.1.2 General socio-economic background of the households surveyed in the study area

Table 4-1 explains the socio-economic background of the four residential areas surveyed in relation to the household incomes. The aim of this analysis is to observe the variations in the socio-economic parameters, such as the number of households, the number of property owners, the average number of vehicles per household, the average number of people per household, the average commuting trips per household, and the average number of kilometres travelled for households in each suburb under each income category.

Table 4-1: Socio-economic background of the residential areas

Income	No. of house-holds	Ave. No. of Vehicles	Ave. No. of people per dwelling	No. of property owners	Ave. No. of commuting rounds	Ave. km/month
Fichardtpark						
< R80 000	9(30%)	2	2	1	1	500km - 1000km
R80 001 - R160 000	9(30%)	2	3	6	1	< 500km
R160 001 - R240 000	3(10%)	2	3	4	3	< 500km
R240 001 - R300 000	3(10%)	2	3	4	2	< 500km
> R300 000	6(20%)	3	3	5	3	< 500km
Subtotal	30	2.3	2.7	20	1.5	
Langenhovenpark						
< R80 000	11(36%)	2	2	4	2	500km - 1000km
R80 001 - R160 000	5(17%)	1	1	3	2	500km - 1000km
R160 001 - R240 000	7(23%)	2	2	7	2	500km - 1000km
R240 001 - R300 000	5(17%)	2	2	5	2	< 500km
> R300 000	2(7%)	2	3	3	2	< 500km
Subtotal	30	1.8	2	22	2	

Universitas						
< R80000	14(47%)	2	1	5	2	500km - 1000km
R80001 - R160000	6(20%)	1	1	4	1	500km - 1000km
R160001 - R240000	2(7%)	2	2	3	3	1001km - 1500km
R240001 - R300000	4(13%)	2	3	3	2	500km - 1000km
> R300000	4(13%)	2	2	3	2	500km - 1000km
Subtotal	30	1.8	1.8	18	2	
Pellissier						
< R80000	9(30%)	2	2	5	2	< 500km
R80001 - R160000	6(20%)	2	2	3	2	< 500km
R160001 - R240000	12(40%)	2	2	8	2	1001km - 1500km
R240001 - R300000	1(3%)	2	3	4	3	500km - 1000km
> R300000	2(7%)	3	3	4	4	1001km - 1500km
Subtotal	30	2.2	2.4	24	2.6	

The table reveals that no significant differences in the socio-economic background exist among the people in the suburbs surveyed. The following should be noted:

- The number of vehicles for the four different areas has an average number of two except for Fichardtpark and Pellissier when the income cap exceeded the R300000 barrier.
- The number of people per household may be referred back to Table 4-1 and its relevant discussion. It has been noted that, in all cases, there is an increase in the number of members within a household with an increase in income.
- The number of property owners has no relationship to their income. The frequency is inconsistent and may be more random than structured.

- The average number of commuting rounds is different for every residential area. Fichardtpark has an increase from one to three commuting rounds from the lowest to the highest income range.
- Langenhovenpark has similar commuting rounds of two for every income level. Universitas has an average commuting round of two except for the income ranges of R80001-R160 000 and R160 001-R240 000, which are one and three respectively.
- Pellissier has an average commuting round of two for the incomes of < R80000 - R240000, with an increase of one for the next two income ranges of R240001-R300000, and > R300 000.

4.2.2 Age

The age of the population in any society determines the activeness and availability of employable people. It also exerts a direct effect on the occupational structure, income, education, marital status, and responsibility of the members to the family and towards the society, which needs transportation and in turn seeks the use of motor vehicles. Bearing this information in mind, the investigation sought to understand the age group of the various family members in the households. The outcomes are presented in Table 4-2.

Table 4-2: General age of households vs Income level

Income	General Age (Years)							
	0 – 6	**7 - 13**	**14 - 18**	**19 - 24**	**25 - 40**	**41 - 60**	**> 60**	**Total**
< R80 000	**0**(0%)	**1**(1%)	**9**(12%)	25(32%)	**16**(21%)	**24**(31%)	**3**(4%)	78(100%)
	(0%)	(11%)	(31%)	(52%)	(29%)	(23%)	(20%)	(29%)
R80001 - R160000	**0**(0%)	2(4%)	**9**(16%)	**10**(18%)	11(19%)	**21**(37%)	**4**(7%)	57(100%)
	(0%)	(22%)	(31%)	(21%)	(20%)	(20%)	(27%)	(21%)
R160001 - R240000	**5**(9%)	**0**(0%)	**3**(5%)	**7**(12%)	**16**(28%)	**22**(39%)	**4**(7%)	57(100%)
	(100%)	(0%)	(10%)	(15%)	(29%)	(21%)	(27%)	(21%)
R240001 - R300000	**0**(0%)	**3**(8%)	**6**(15%)	**3**(8%)	**3**(8%)	**23**(58%)	**2**(5%)	40(100%)
	(0%)	(33%)	(21%)	(6%)	(5%)	(22%)	(13%)	(15%)
> R300000	**0**(0%)	**3**(9%)	**2**(6%)	**3**(9%)	**9**(26%)	**16**(46%)	**2**(6%)	35(100%)
	(0%)	(33%)	(7%)	(6%)	(16%)	(15%)	(13%)	(13%)
TOTAL	**5(2%)**	**9(3%)**	**29(11%)**	**48(18%)**	**55(21%)**	**106(40%)**	**15(6%)**	**267(100%)**
	(100%)	**(100%)**	**(100%)**	**(100%)**	**(100%)**	**(100%)**	**(100%)**	**(100%)**

From the table, it can be seen that more than 84% of the people belong to the 19-60 years age group, 14% are in the of 6-18 years age group, and only 6% are above 60 years of age, and 2% are infants (i.e. below 6 years). In all, about 95% of the population needs movement for their various functions, such as travelling for education, employment, recreation, etc.

4.2.3 Age vs Employment

In general, age and employment are closely related and in turn, to the income of the people and vehicular transportation. In this regard, Table 4-3 provides the annual income of people in the different age categories for employable people in the study area who need vehicular transportation to travel to their work areas.

Table 4-3: Employment age vs Income level

Income	**Employment age**					
	14 - 18	**19 - 24**	**25 - 40**	**41 - 60**	**> 60**	**Total**
< R80000	0(0%)	25(39%)	16(25%)	21(33%)	2(3%)	64(100%)
	(0%)	(57%)	(24%)	(21%)	(18%)	(29%)
R80001 - R160000	0(0%)	11(22%)	13(27%)	23(47%)	2(4%)	49(100%)
	(0%)	(25%)	(20%)	(23%)	(18%)	(22%)
R160001 - R240000	0(0%)	4(8%)	22(44%)	20(41%)	3(6%)	49(100%)
	(0%)	(9%)	(33%)	(20%)	(27%)	(22%)
R240001 - R300000	2(6%)	2(6%)	6(19%)	19(61%)	2(6%)	31(100%)
	(100%)	(5%)	(9%)	(19%)	(18%)	(14%)
> R300000	0(0%)	2(7%)	9(32%)	15(54%)	2(7%)	28(100%)
	(0%)	(5%)	(14%)	(15%)	(18%)	(13%)
Total	2(1%)	44(20%)	66(30%)	98(44%)	11(5%)	221(100%)
	(100%)	(100%)	(100%)	(100%)	(100%)	100%

The majority of employed people between the ages of 19 and 24 (57%) earn below R80000, 44% of people between ages of 25 to 40 belong to income category of R160001 and R240000, and 61% of people with ages between 41 to 60 belong to income category of R240001 to R300000. This indicates the majority in each salary bracket for each age group, and shows a growth in income with the increase in age.

4.2.4 Academic qualifications

Education is an indispensable requirement for development of human resources. It is a major factor, which decides the functions of a city. It is used as a tool to measure the social and economic development of an area. In the study area in particular, education plays a major role in its development. This investigation has tried to explore the academic development of the people in the study area. The academic qualifications and education levels of people of the study area are presented in Table 4-4.

Table 4-4: Academic qualifications vs Income level

Income	**Academic Qualification**				
	High School	**Undergraduate**	**Post-graduate**	**Technical**	**Total**
< R80000	30(49%)	21(34%)	8(13%)	2(3%)	37(100%)
	(31%)	(27%)	(20%)	(50%)	(28%)
R80001 - R160000	21(46%)	18(39%)	5(11%)	2(4%)	28(100%)
	(22%)	(23%)	(13%)	(50%)	(21%)
R160001 - R240000	22(43%)	21(41%)	8(16%)	0(0%)	30(100%)
	(23%)	(27%)	(20%)	(0%)	(23%)
R240001 - R300000	16(52%)	8(26%)	7(23%)	0(0%)	19(100%)
	(17%)	(10%)	(18%)	(0%)	(14%)
> R300000	7(23%)	11(37%)	12(40%)	0(0%)	18(100%)
	(7%)	(14%)	(30%)	(0%)	(14%)
Total	96(44%)	79(36%)	40(18%)	4(2%)	219(100%)
	(100%)	(100%)	(100%)	(100%)	(100%)

The table reveals that about 44% of the people surveyed in the study area have an education level of high school. Thirty-six percent of the population in this area have an undergraduate degree; 18% of people, a post-graduate degree; while only 2% are artisans or technicians. It can also be seen that 77% of individuals having a higher income, that is, more than R300 000, have either an undergraduate or postgraduate degree. 52% of the people earning less than R80 000 per annum have only a high school or a technical qualification.

Thus, in the income range between R0 and R300000, most people have an educational background of high school and an undergraduate degree while the other categories have low percentages. In the income range above R300 000, the majority of the people have an undergraduate or a post-graduate degree.

4.2.5 Occupation

The occupational structure of an area is an important indicator when it comes to understanding the status of the development in an urban area and, more or less, influences the households, income, standard of living, etc. This indicator also provides a background to the type of travel pattern in relation to the type of employment of people.

Table 4-5 - Occupational vs Income level

Income	Occupation					
	Private sector	**Public sector**	**Own business**	**Pensioner**	**Unemployed**	**Total**
< R80000	40(57%)	15(21%)	11(16%)	4(6%)	0(0%)	70(100%)
	45%	19%	27%	67%	0%	32%
R80001 - R160000	25(52%)	14(29%)	9(19%)	0(0%)	0(0%)	48(100%)
	28%	18%	22%	0%	0%	22%
R160001 - R240000	9(20%)	19(41%)	14(30%)	2(4%)	2(4%)	46(100%)
	10%	24%	34%	33%	50%	21%
R240001 - R300000	9(29%)	18(58%)	4(13%)	0(0%)	0(0%)	31(100%)
	10%	23%	10%	0%	0%	14%
> R300000	5(21%)	14(58%)	3(13%)	0(0%)	2(8%)	24(100%)
	6%	18%	7%	0%	50%	11%
Total	88(40%)	80(37%)	41(19%)	6(3%)	4(2%)	219(100%)
	100%	100%	100%	100%	100%	100%

The private sector contains the majority (40%) of those surveyed, with the public sector at 37%. and the remaining categories with fewer than 20% each (Own business 19%, Pensioner 3%, and Unemployed 2%). Table 4-5 indicates that the majority of people in the private sector (45%) earn below R80000 where as a higher proportion of people employed in public sector (65%) earns above R160001 per annum. People having their own business are mostly confined to the three lowest income ranges i.e. < R80 000, R80001-R160000, and R160001-R240000. The pensioners are mostly below R80000 while only 2% are unemployed with varied incomes.

4.2.6 Dwelling type

The type of dwelling is an indication of the background to the living conditions in the study area. This also reflects on the number of vehicles and the availability of parking space per dwelling house.

Table 4-6: Dwelling type vs Income level

Income	Dwelling type						
	House	Duplex	Townhouse	Flat	Student House	Other	Total
< R80 000	18(50%)	0(0%)	9(25%)	6(17%)	0(0%)	3(8%)	36(100%)
	(25%)	(0%)	(30%)	(55%)	(0%)	(38%)	(30%)
R80 001 - R160 000	14(48%)	0(0%)	12(41%)	3(10%)	0(0%)	0(0%)	29(100%)
	(20%)	(0%)	(40%)	(27%)	(0%)	(0%)	(24%)
R160 001 - R240 000	13(54%)	0(0%)	6(25%)	2(8%)	0(0%)	3(13%)	24(100%)
	(18%)	(0%)	(20%)	(18%)	(0%)	(38%)	(20%)
R240 001 - R300 000	14(82%)	0(0%)	3(18%)	0(0%)	0(0%)	0(0%)	17(100%)
	(20%)	(0%)	(10%)	(0%)	(0%)	(0%)	(14%)
> R300 000	12(86%)	0(0%)	0(0%)	0(0%)	0(0%)	2(14%)	14(100%)
	(17%)	(0%)	(0%)	(0%)	(0%)	(25%)	(12%)
TOTAL	71 (59%)	0 (0%)	30 (25%)	11 (9%)	0 (0%)	8 (7%)	120 (100%)
	(100%)	(0%)	(100%)	(100%)	(0%)	(100%)	(100%)

From Table 4-6, it may be observed that the majority of dwellings in the study area (59%) are houses, followed by townhouses (25%) while the remainder of the dwellings (16%) is flats or other types of dwelling. The table also indicates that people having higher incomes favor houses as their most preferred living arrangement whereas townhouses are used as the second-most preferred form of living arrangement in the study area. The number of individuals living in townhouses increases with a decreasing income.

4.2.7 Property ownership

Ownership of houses is an indicator of the stability and relative movement of people of an urban area. People having their own houses move less, and are generally more stable than the people having no houses located in the city. Table 4-7 shows the relationship between the numbers of property owners and the number of individuals that rent their property.

Table 4-7: House owners and Tenants vs Income level

Income	Owners	Tenants	Total
< R80000	15(44%)	19(56%)	34(100%)
	(18%)	(53%)	(30%)
R80001 - R160000	16(55%)	13(45%)	29(100%)
	(19%)	(36%)	(24%)
R160001 - R240000	22(92%)	2(8%)	24(100%)
	(26%)	(6%)	(20%)
R240001 - R300000	16(89%)	2(11%)	18(100%)
	(19%)	(6%)	(15%)
> R300000	15(100%)	0(0%)	15(100%)
	(18%)	(0%)	(13%)
Total	84(70%)	36(30%)	120(100%)
	(100%)	(100%)	(100%)

Only 30% of the residents within the residential areas are tenants while the majority of the residents (70%) are owners. The largest proportion of tenants (89%) ranges between an income of less than R80 000 to an income of between R80001-R160000. The number of owners ranges equally over the various income ranges; the income range between R160001 and R240000 accounting for 26%.

4.2.8 Number and type of vehicles

The number and type of vehicles available in households are indicators of various modes of transportation being used by people in the study area. Further, modes of transportation indicate the availability of different vehicular movement for travel in the city. This also illustrates the living standards and advancement in terms of the time/distance relationships, comfort, etc., of the city and the requirements of the physical and transport infrastructure. Bearing this mind, the investigator has conducted a detailed analysis of various modes of transportation available in the system. The results are presented in Table 4-8. The table illustrates the various types of vehicles (modes) being used by the people in the study area for their movement purposes. It was observed that (self driven) cars dominate (84%) the households in the study area, whereas just 12% of the households surveyed possess motorcycles, and only 4% of the households have other types of vehicles, such as delivery vehicles. It can also be seen that motor cars are the predominant mode across the income groups. Thus, it may be assumed that motor cars are the dominant mode within the study area, and that people use cars as their primary mode of travel for their daily travel. On the other hand, motorcycles are the second-most commonly-used vehicles in the study, although people use them for both daily travel and recreational (sport) purposes.

Table 4-8: Number and type of vehicles vs Income level

Income	**Number and type of vehicles**				
	Motorcycles	**Self-driven Cars / Light Vehicles**	**Delivery Vehicles**	**Other**	**Total**
< R80000	10(15%)	58 (85%)	0(0%)	0(0%)	68(100%)
	(33%)	(29%)	(0%)	(0%)	(28%)
R80001 - R160000	8(16%)	43(84%)	0(0%)	0(0%)	51(100%)
	(27%)	(21%)	(0%)	(0%)	(21%)
R160001 - R240000	9(16%)	44(79%)	3(5%)	0(0%)	56(100%)
	(30%)	(22%)	(100%)	(0%)	(23%)
R240001 - R300000	3(11%)	24(89%)	0(0%)	0(0%)	27(100%)
	(10%)	(12%)	(0%)	(0%)	(11%)
> R300 000	0(0%)	34(83%)	0(0%)	7(17%)	41(100%)
	(0%)	(16%)	(0%)	(100%)	(17%)
Total	30 (12%)	203 (84%)	3 (1%)	4 (3%)	243 (100%)
	(100%)	(100%)	(100%)	(100%)	(100%)

The Table 4-8 also revealed that the dominant form of vehicles owned by households, i.e., self driven vehicles are almost equally spread across the various income groups, i.e., about 50% of cars are owned by lower and lower middle income groups and 50% are owned by middle and higher income group people. The number of motorcycles occur mostly in the income bracket of below R240 000, with 90% of the residents belonging to this class. The number of delivery vehicles contributes to only 1% on the total number of vehicles owned by households.

4.2.9 Travel distance

The distance travelled by an individual is linked to the amount of usage of their mode of transportation and the amount of time spent commuting from and to their destination. Table 4-9 expresses the relationship between the distance travelled and the income, and outlines the amount of money spent on transportation by the households.

Table 4-9: The distance driven per vehicle vs Income level

Income	**Distance driven per vehicle per month**					
	< 500km	**500km - 1000km**	**1001km - 1500km**	**1501km - 2000km**	**>2000km**	**Total**
< R80000	27(47%)	18(31%)	13(22%)	0(0%)	0(0%)	58(100%)
	(38%)	(30%)	(50%)	(0%)	(0%)	(24%)
R80001 - R160000	20(56%)	10(28%)	3(8%)	3(8%)	0(0%)	36(100%)
	(28%)	(17%)	(12%)	(8%)	(0%)	(15%)
R160001 - R240000	16(26%)	14(23%)	6(10%)	14(23%)	11(18%)	61(100%)
	(22%)	(23%)	(23%)	(35%)	(25%)	(25%)
R240001 - R300000	3(7%)	14(34%)	0(0%)	7(17%)	17(41%)	41(100%)
	(4%)	(23%)	(0%)	(18%)	(39%)	(17%)
> R300000	6(13%)	4(9%)	4(9%)	16(35%)	16(35%)	46(100%)
	(8%)	(7%)	(15%)	(40%)	(36%)	(19%)
Total	72(30%)	60(25%)	26(11%)	40(16%)	44(18%)	243(100%)
	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

Table 4-9 indicates that 55% of the households travel less than 1000 kms per month, with 34% of the residents travelling more than 1501 kms per month. Most of the distance travelled has been by residents with an income of more than R240 001 per annum with total of more than 44% of the total people and 100% of the people in that income range are travelling more than 2000 kms per month. The travel distance of less than 500 kms per month is dominated by the income group earning less than R80000 per year. Thus, it indicates people with higher income travel higher distances and lower income people travel less.

4.2.10 Commuting trips

The number of commuting trips indicates the travel pattern of people, and provides an insight into the various functions and activities people carry out during the day, using vehicles for this purpose. The numbers of trips generated by households are presented in Table 4-10.

Table 4-10: Number of commuting trips per vehicle

Income	**Number of commuting rounds per vehicle**				
	1	**2**	**3**	**4**	**Total**
< R80000	23(33%)	22(31%)	2(3%)	23(33%)	70(100%)
	(29%)	(29%)	(10%)	(34%)	(29%)
R80001 - R160000	26(53%)	16(33%)	7(14%)	0(0%)	49(100%)
	(33%)	(21%)	(33%)	(0%)	(20%)
R160001 - R240000	20(33%)	17(28%)	7(11%)	17(28%)	61(100%)
	(225%)	(22%)	(33%)	(25%)	(25%)
R240001 - R300000	4(14%)	17(59%)	0(0%)	8(28%)	29(100%)
	(5%)	(22%)	(0%)	(12%)	(12%)
> R300000	6(17%)	5(14%)	5(14%)	19(54%)	35(100%)
	(8%)	(6%)	(24%)	(28%)	(14%)
Total	79(32%)	77(32%)	21(9%)	67(28%)	243(100%)
	(100%)	(100%)	(100%)	(100%)	(100%)

The majority of households (about 64%) generate one to two round trips per day. The higher number of trips is generated by households (59%) belonging to the middle and higher income groups i.e., in the income ranges between R 80001-160000, R 160001-240000, R 240001-300000, and R 300001 and above It was also found that the number of trips increases with increases in income.

4.2.11 Accident occurrences

Given the number of accidents occurring within the residential areas, it was pertinent to obtain an indication from the residents themselves about their involvement in any accidents or if they had witnessed any accident in recent years. This would indicate whether the residents within the area are the cause of most of these accidents.

Table 4-11: Traffic accidents (involved and witness) vs Income level

Income	Traffic accidents		
	Involved	Witness	Total
< R80000	11(48%)	12(52%)	23(100%)
	26%	32%	29%
R80001 - R160000	13(57%)	10(43%)	23(100%)
	31%	26%	29%
R160001 - R240000	6(55%)	5(45%)	11(100%)
	14%	13%	14%
R240001 - R300000	6(55%)	5(45%)	11(100%)
	14%	13%	14%
> R300000	6(50%)	6(50%)	12(100%)
	14%	16%	15%
Total	42 (53%)	38 (47%)	80 (100%)
	100%	100%	100%

Table 4-11 indicates that about 53% of the households surveyed were involved in an accident whereas about 47% had witnessed a traffic accident according to their income group. This reveals the high involvement of people of the study area in vehicular accidents.

With the conclusion of the different tables regarding income and the different variables, the following observations are made:

- About 85% of the people in the study area are between 19 and 60 years old, with 95% of them in the employable group, and thus needing vehicular transportation to travel to their work areas as well as numerous other locations. Therefore, it can be concluded that the study area is characterised by higher requirements for movement, particularly by vehicular transportation.
- The progression of age is linked to the type of income received. The income increases, the older the subject is. This is then linked to experience and age. It has also been shown that people with an undergraduate and post-graduate degree earn more (77% earning more than R300 000 per year) than people with only high schooling or technical qualifications.
- The private and public sector are dominant with 78% of the residents working there. This relates travel patterns to the type of work (teaching, consulting, hospitals, etc.). If there is a high demand in the frequency in movement e.g. a pensioner, someone

who owns his own business, or a person who is unemployed will move around more freely than someone in the private or public sectors.

- For the survey area, the number of owners of property (70%) is higher than the number of tenants (30%), thus indicating that more people are settled in this area. It can be thought that people who buy property will settle down with more comfort than people who are renting. If an individual stays for a longer duration at one place, the different routes will become known to him/her. The majority of these units (59%) are single-unit houses with townhouses making up 25%. Houses have a tendency to take up more space whereas cluster units (townhouses) take up less space but increase the density of the population. (Table 4-7)
- Light passenger vehicles are used most (84%) in suburban areas, with a split of 55% for less than 1000 kms per month distance travelled and 45% for a distance of more than 1000 kms. The number of commutes is either one or two per day (combined 64% of the people). This indicates that an individual is either driving to work and back or attends to other responsibilities during the day as well.
- The split between the number of people who witnessed (47%) or are involved in (53%) traffic accidents is almost equal. This indicates that the residents are all aware of accidents within their region and this may have an influence on their ability to make an appropriate route choice.

4.3 ANALYSIS BASED ON PHYSICAL SURVEYS OF ROAD SYSTEM/ROAD NETWORK

Multiple physical road surveys were done at different road sections in the study area to determine high vehicular traffic accident areas within the road network, and to establish whether any relationship exists between the physical aspects of the road sections and vehicular traffic accidents. The cumulative number of accidents was noted for the different road sections, which provided an indication of the various roads that were more prone to accidents. The physical parameters and road geometrical parameters were assessed according to South African Standards as was their relationship to vehicular traffic accidents and accident-prone conditions. This information led to the identification of high accident areas on suburban arterial roads. It was essential to identify high accident areas on suburban arterial roads to adapt future planning and designs to the reduction of accidents. In this respect, an investigation was done to find out the occurrence of vehicular traffic accidents on the different suburban arterial roads in the selected areas of the study area.

The number of traffic accident occurrences per year on the suburban road sections was grouped into two categories, namely, the number of traffic accident occurrences on road links, and the number of traffic accidents at intersections (Figure 4-1). It was observed that the number of traffic accidents at intersections vary from 0 to more than 80. The various intersections were categorised into five hierarchical groups, indicated by the letters A to E, with group A indicating the lowest number of accidents (0-19) and group E indicating the highest number of accidents (>80). However, it was also shown that most of the major intersections belong to either group A or B, for which the maximum number of accident occurrences is less than 40 per year. Similarly, the average number of accidents on road sections in the suburban arterial roads varies from a minimum of 22 to a maximum of 134 accidents per year (e.g., Paul Kruger Drive experiences 134, Benade Drive experiences 75, and DF Malherbe Street intersecting with Wynand Mouton Drive experiences 22 accidents per year on average).

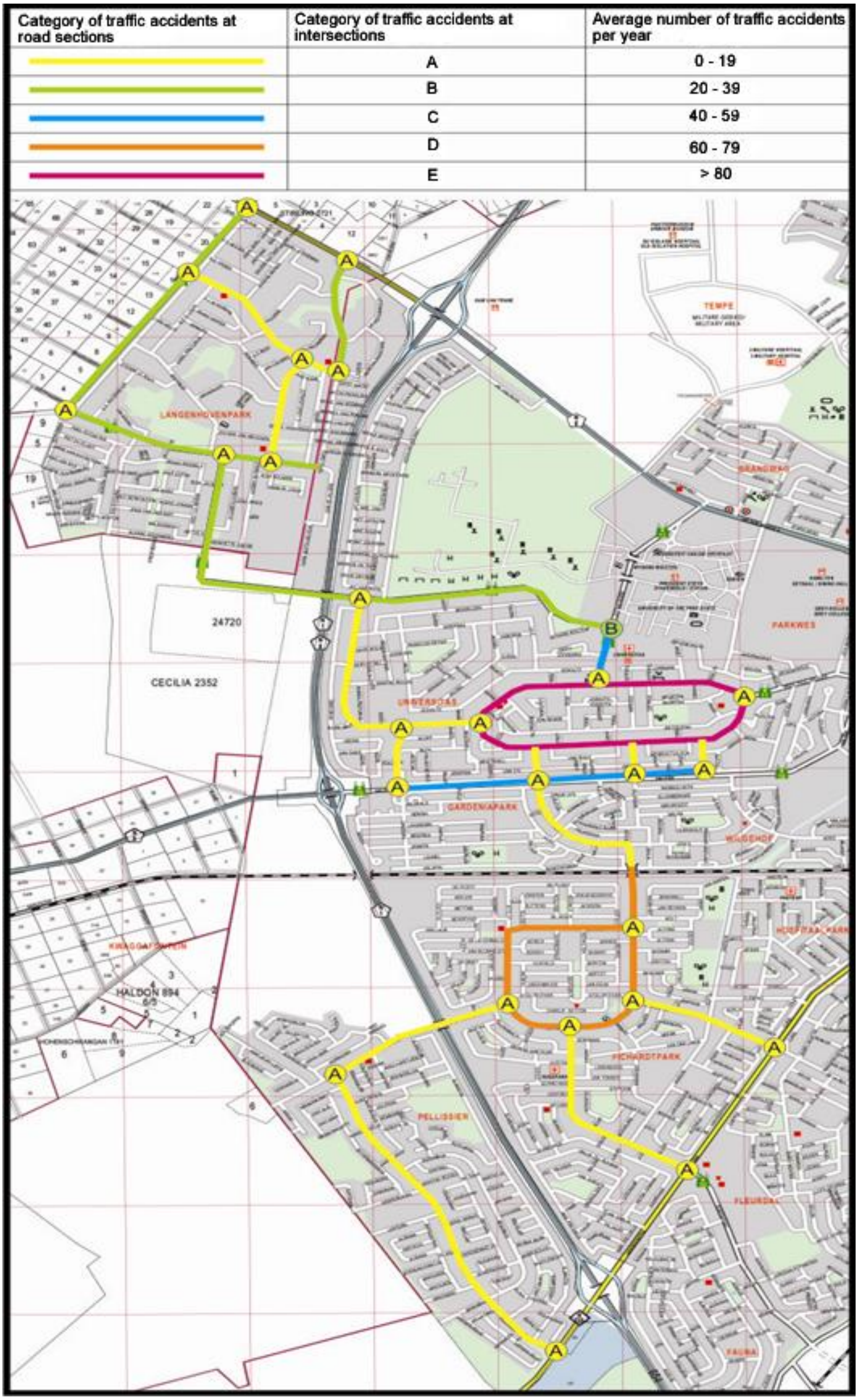

Figure 4-1: Vehicular traffic accidents at the intersections in the selected suburban areas of the study area

Further, an analysis was made to find the accident occurrences in different suburban areas, particularly on the arterial roads passing though the residential areas. It was observed that the maximum number of vehicle accidents in the arterial roads of Langenhovenpark ranged between 20 and 39 accidents per year (Figure 4-1). This is a substantial number of accidents for an urban area which is regarded as a limited access area. The numbers of accidents on other various important roads (Dirk Opperman Street, NP Van Wyk Louw Street, De Bruyn Street, Van Schalkwyk Street, Stals Road, Pellissier Drive, Volkspele Drive, Castelyn Drive, Edeling Street, Bell Street, Gerhard Beukes Street, and Olive Grinter Drive) vary between 0 and 19 traffic accidents (Figure 4-1).

The number of traffic accidents on the roads passing through Universitas varies from a minimum of zero accidents to a maximum number of 39 traffic accidents. Different roads such as De Bruyn, Van Schalkwyk, Edeling, and Gerhard Beukus Streets have a low number of accidents, varying between 0 and 19 traffic accidents per year. The occurrence of traffic accidents in Wynand Mouton Drive varies between 20 and 39 accidents, while in DF Malherbe Street, the occurrence varies between 40 and 59. Fichardtpark has a low number of traffic accidents on the majority of the roads, ranging from 0-19 accidents per year, except in Benade drive where it is very high, ranging from 60-79 accidents per year. The accidents in Pellissier are also low, varying from 0-19 accidents per year on all its roads.

In addition to it, an analysis was conducted to observe the relative vulnerability of the selected suburban areas to traffic accidents. The results are presented in the Table 4-12. The table illustrates the variation in the number of accident occurrences over six years from 2005 to 2010 in the selected residential areas in the study area for which data was available.

Table 4-12: Total number of traffic accidents in the selected four residential areas

Residential areas	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**TOTAL**
Universitas	247	269	331	309	429	383	1968
Fichardtpark	141	203	114	196	190	245	1089
Langenhovenpark	105	144	262	171	181	209	1072
Pellissier	31	53	25	48	39	34	230

(Primary survey 2011, accident survey)

The table shows that, of all the suburbs surveyed, Universitas is the residential area where the largest number of traffic accidents has occurred, with an average number of 328 accidents per year over the last six years from 2005 to 2010. The second-most vulnerable residential area for vehicular traffic accidents is Fichardtpark during the same period, except for the year 2007, in which Langenhovenpark experienced more traffic accidents than Fichardtpark. Fichardtpark had 1089 traffic accident occurrences during the period with an average of 181,5 traffic accidents per year on its arterial roads. On the other hand, the analysis of the two limited access residential areas of Langenhovenpark and Pellissier revealed that Langenhovenpark had a total of 1072 accidents with an average of 178.6 accidents per year and Pellissier had a total number of 230 traffic accidents with an average of 38,3 accidents per year on their arterial roads respectively. Thus, Universitas experienced 1.84 times more traffic accidents than Langenhovenpark and Fichardtpark, and 4.73 times more than Pellissier. Also, it was found out that Universitas area experienced 8.6 times more accidents than Pellissier, 1.8 times more than Langenhovenpark and 1.8 times more than Fichardtpark. Thus it may be concluded that limited access residential areas are relatively less vulnerable, having fewer traffic accidents than more accessible residential areas.

4.3.1 Analysis of physical and geometrical design parameters of roads

The investigation of the physical and geometrical design parameters was conducted on selected roads in the suburbs surveyed in the study area to observe the deficiencies, if any, which could lead to vehicular traffic accidents. The researcher himself conducted the investigation, and compared these parameters to the road geometry standards recommended by the G2 manual (SANDRAL, n.d) for urban roads in South Africa. The G2 manual, recommended by SANRAL, provides all the geometrical design parameter guidelines for urban roads in South Africa. For this investigation, different road sections in the study area were selected based on their importance, the choice of routes by the majority of vehicle users, their linkage with residential areas, and the number of accident occurrences.

Table 4-13 provides the criteria for each parameter of the selected road sections which were considered and their current status compared with the requisite design standards recommended by SANRAL. The table is divided into two main parts. The first part indicates the existing conditions, including lane width, number of lanes, kerb condition, shoulder width, median width, surface condition, gradient, curvature, and speed which were observed on the selected road sections. The second part specifies the design standards according to the recommended geometric design guidelines. The existing physical measurements are placed on the left-hand side of the table and the geometric design standards of South Africa are presented in the right-hand side of the table.

Table 4-13: The physical road geometric characteristics

Sections	Existing conditions at road sections														Standard design specifications			
	Kerbing accessible left	Lane Widths					Total width (metre)	Median width (metre)	Kerbing accessible right	Paved Road surfacing	Gradient %	Curvature	Average speed km/h	Average number of accidents per year	Minimum lane width (metre)	Maximum gradient %	Existing speed limit km/h	Turning radius required for road segment (metre)
		Shoulder width	Lane 1 (metre)	Lane 2 (metre)	Lane 3 (metre)	Number of lanes												
Jan Spies Street	No	N/A	3.2	3.4	N/A	2	6.6	N/A	N/A	Good	3	Gentle	76	36	3.7	6	60	210
	No	N/A	3.3	3.5	N/A	2	6.8		N/A	Good			65		3.7	6	60	210
Totius Street	Yes	N/A	3.45	3.35	N/A	2	6.8	4	No	Good	1	Gentle	77	22	3.7	6	60	210
	Yes	N/A	3.2	3.5	N/A	2	6.7		No	Good			74		3.7	6	60	210
Wynand Mouton Drive	No	N/A	4.65	N/A	N/A	1	4.7	N/A	N/A	Good	1	Gentle	75	28	3.7	6	60	210
	No	N/A	4.65	N/A	N/A	1	4.7		N/A	Good			82		3.7	6	60	210
De Bruyn Street	Yes	N/A	3.35	3.35	N/A	2	6.7	9.3	No	Good	1	Gentle	79	19	3.7	6	60	210
	Yes	N/A	3.35	3.4	N/A	2	6.8		No	Good			74		3.7	6	60	210
Paul Kruger Drive North	Yes	N/A	3.4	3.45	N/A	2	6.9	8	No	Good	1	Gentle	70	134	3.7	6	60	210
	No	N/A	3.55	3.4	N/A	2	7		No	Good			72		3.7	6	60	210
Paul Kruger Drive South	No	N/A	3.35	3.35	N/A	2	6.7	8.2	No	Good	1	Gentle	77		3.7	6	60	210
	No	N/A	3.35	3.4	N/A	2	6.8		No	Good			79		3.7	6	60	210

Sections	Existing conditions at road sections														Standard design specifications			
		Lane Widths																
	Kerbing accessible left	Shoulder width	Lane 1 (metre)	Lane 2 (metre)	Lane 3 (metre)	Number of lanes	Total width (metre)	Median width (metre)	Kerbing accessible right	Paved Road surfacing	Gradient %	Curvature	Average speed km/h	Average number of accidents per year	Minimum lane width (metre)	Maximum gradient %	Existing speed limit km/h	Turning radius required for road segment (metre)
Benade Drive North	Yes	N/A	3.4	3.85	3.3	3	11	9	No	Good	1	Gentle	78	75	3.7	6	60	210
	No	N/A	3.4	3.75	3.4	3	11		No	Good			79		3.7	6	60	210
Benade Drive South	Yes	N/A	3.65	3.8	3.4	3	11	9.6	No	Good	1	Gentle	67		3.7	6	60	210
	Yes	N/A	3.3	3.6	3.8	3	11		No	Good			72		3.7	6	60	210
Volkspele Drive	Yes	N/A	3.3	3.4	N/A	2	6.7	3	No	Good	1	Gentle	63	7	3.7	6	60	210
	Yes	N/A	3.3	3.4	N/A	2	6.7		No	Good			54		3.7	6	60	210
Pellesier Drive	Yes	N/A	6.4	3.5	N/A	2	9.9	13	No	Good	1	Gentle	72	17	3.7	6	60	210
	Yes	N/A	6.45	3.5	N/A	2	10		No	Good			68		3.7	6	60	210

(Primary survey, 2011 - physical and road geometrical characteristic)

The survey of the various physical and geometrical parameters and their comparison with the recommended geometric standards revealed that:

- Semi-mountable kerbs were designed to control drainage and protection of lower pavement materials. The kerbs in all the roads sections surveyed were found to be according to the geometric design standards recommended in the geometric design manuals. It should be noted that the entire measured road sections have mountable kerbs that either can be accessed under emergency conditions or can be restricted under normal situations. However, the deficiencies observed were a lack of adequate shoulder width in all the measured road sections, which restricts drivers' movements.
- In accordance with the design standards, the minimum lane width is 3.7 metres and, in special circumstances, this can be reduced to 3.65 metres. However, on the surveyed road sections, the majority of the roads have lane widths below the standard lane widths of 3.7m, except a few sections, where the lane widths exceed the minimum requirement. The lane widths on the road sections on Wynand Mouton Drive and Pellissier Drive were found to be exceptionally broader than the design standards, while the lane widths on Benade Drive marginally exceed the recommended width of 3.7 metres.
- The median dividers with kerbed raised medians were found to be of width ranging from 4.7 metres to 13 metres in most of the roads, which are adequate enough and help in avoiding head-on collisions, and assist vehicles back onto the road when drivers lose control. The minimum recommended width of medians is 1.6 metres for the use of pedestrians and it was observed that the median width in almost all the sections exceeds the minimum standards.
- The specified vehicular speed limit for all the selected sections is 60 km/h. However, it was observed that the average speed of the vehicles exceeds the specified speed limit on the majority of the roads. The actual speed of vehicles ranges from 58 km/h to 79 km/h. Only on very few roads (10%) does the average vehicular speed not exceed the specified speed limit.
- All of the roads surveyed have asphalt pavement with proper road seals. The conditions of the road surface are also good and free from cracks, pot holes and any other kind of obstacles, which indicate that road surface condition does not really have any influence on the traffic-related behaviour of the road users in this study.
- Further, the most common road defects causing vehicular traffic accidents are either influenced by the manoeuvring constraints for the road user or by the lack of adequate sight distance to the road user. However, it was observed that, in the road sections

surveyed, neither of these problems existed with the provision of adequate number of lanes, pavement marking, and signage, as well as sight distances (at 60 km/h, it is 90 metres; at 73Km/h, it is 110 metres as per the average speed on all roads) are provided according to design standards.

- According to the SANRAL G2 manual, the radius of curvature of a road section for a speed of 60 km/h is 210 metres. The curvatures of the road sections surveyed are found to be gentle, and the radius of curvatures is within acceptable limits. This ranged from 220 metres (Paul Kruger Drive) to 500 metres (Pellissier Drive) for some of the road sections at certain points.
- According to the geometric design standards, the gradient of roads should not exceed the maximum gradient limit of 6%. This parameter influences the sight distance of the roads and the control for high-occupancy vehicles. The minimum sight distance at a speed of 60 km/h is 180 metres. The investigation established that the gradients of all roads are mostly gentle (with a gradient of 1-2% on most roads). This also helps in the availability of appropriate sight distances under the recommended speed limit.
- Thus, this investigation reveals that the kerbing, median widths, curvature, and gradients of the roads comply with the design standards of South African urban roads. Lane widths on most of the roads are below the acceptable limits. The average speed of vehicles on the majority of the roads is much higher than the recommended speed limit. The radius of curvatures on curves conforms to design standards, and all the road sections have adequate sight distances.

4.3.2 Relationship between traffic accident and urban form

Urban form refers to the physical layout and design of the city. It is influenced by urban design elements, such as land use, density, street layout, transportation, employment areas, etc., as well as urban growth management issues, such as urban sprawl, growth patterns, and the phasing of developments. In this particular section, the most important aspects which exert a large influence on road transportation and accidents, such as land use (particularly residential and work areas), urban pattern, including road layout and road network density, growth patterns, and future developments, will be analysed.

4.3.3 Land use

The analysis of the land use of the areas surveyed revealed that each area is different, with different characteristics. The detailed land uses of each area are presented in Annexures C, D, E and F. The land use characteristics of each area are discussed below:

- **Universitas** – Universitas is basically a residential area, having some city-level major functions. The University of Free State and Universitas Hospital are located (in the northern part) in this suburban area. Some schools (at the central and south-eastern points) and commercial centres are also located in this area to cater for the needs of the people residing in the area at the local level. However, the main function of this area is residential. Most of houses are single-storied unit houses, although several clusters of houses (townhouse complexes) are also to be found here. The area also has several organised green open spaces, together with a large open space (See annexure C).
- **Fichardtpark** – This suburban area is the largest of the areas surveyed. The major function is residential; however, several major commercial activities are located in this area. Most of the houses are single-unit houses; house clusters or townhouse complexes are limited. A city-level large commercial area is situated in the centre part of this area. There are also four large schools located in the western and central parts of this area. There are substantial green spaces, with a large sports field situated on the eastern part of this area (See annexure D).
- **Pellissier –** This is the smallest of the survey areas. The whole area is mainly dedicated mainly to residential functions. The cluster dwellings are situated predominantly in the southern part, followed by the northern part of this area. There is only one school situated in this northern part. A single commercial area is also located in the northern part of this area next to the school. There is also a large open green space, which is confined to the residential area (See annexure E).
- **Langenhovenpark** – This area has large number of housing clusters (townhouses) in addition to several single-unit houses. There are open green spaces located in the central parts of this area. There are four commercial areas situated in the central and northern parts of this suburb (See annexure F).

The areas surveyed indicate that the main function of these suburbs is residential. The housing type varies from single-unit houses to cluster houses. However, some local-level civic elements, such as schools, hospitals, and open spaces, are also located in these suburbs. The commercial units within these four areas vary in magnitude but are treated as the secondary function. Table 4-14 provides other various parameters in these four suburban areas.

Table 4-14: Residential specifications

Description	**Langenhoven-park**	**Universitas**	**Fichardt-park**	**Pellissier**
Area (Km^2)	4.79	4.594	5.211	3.094
Density (People/100 m^2)	204	157	139	156
Estimated number of people	9 770	7 209	7 236	4 818
Number of single-dwellings use	1 439	1 761	2 213	1 495
Average number of people per single use	2.1	3.16	2.95	2.5
Number of cluster dwellings	3 124	822	424	663
Average number of people per cluster dwelling	2.16	2	1.67	1.63
Number of arterial routes	6	9	6	2
Number of access links into the suburban area	3	7	5	2

The table reveals that Langenhovenpark and Universitas are similar in area: 4.79 km^2 and 4.594 km^2 respectively, but their population density differs by 47 people/100m^2, whereas Fichardtpark and Pellissier differ in area but have similar population densities. Of the four areas, Langenhovenpark is the residential area having highest density with 204 persons/100m^2. This can be attributed to the area's high number of cluster dwellings (3124), as may be seen from Table 4-14 and Figure 4-1. Further, Langenhovenpark has the highest number of people (9770) followed by Universitas (7209) and Fichardtpark (7236). Pellissier has the lowest number of people with 4818 persons. Fichardtpark has the highest number of single-unit dwellings (2213 units) and Langenhovenpark has the lowest number of single-unit dwellings (1439). On the other hand, however, Langenhovenpark has the highest number of cluster dwellings (3124) in comparison to Universitas with 822 units, Fichardtpark and Pellissier with 424 units and 663 units respectively. The average number of people per single dwelling ranges from 2.1 (Langenhovenpark) to 3.16 (Universitas). The number of people per cluster dwelling ranges from 1.63 (Pellissier) to 2.16 (Langenhovenpark). The number of arterial roads is the same for both Langenhovenpark and Fichardtpark, each having 6 roads passing thorough each area. Unversitas has 9 such roads while Pellissier has only 2 such arterial roads. The arterial roads of Universitas and Fichardtpark are used largely as arterial thoroughfares. The arterial roads in Universitas and Fichardtpark have a higher number of access points to the residential area. Thus, while Universitas and Fichardtpark are high access areas, Langenhovenpark and Pellissier are considered as limited access areas. This accessibility also explains why Universitas has 1.84 times more traffic accidents than Langenhovenpark while Fichardtpark has 4.73 times more than Pellissier, although they are contiguously located (See Table 4-12 and Table 4-14).

It should also be noted that a similar number of traffic accidents occurred in Langenhovenpark (1072) and Fichardtpark (1089) (with only a marginal difference of seventeen traffic accidents) over the period of the six years from 2005 to 2010. Both these residential areas have major urban arterials roads, as well as arterial-orientated commercial developments and big box stores, such as Pick and Pay Hypermarket, Checkers Hyper, Spar, and Pick and Pay Family Stores, etc., which draw a large quantity of traffic. The land use of Fichardtpark is predominately residential, although it comprises a number of civic and social infrastructures such as one primary school, one secondary school, one school for special education, two churches, one recreational gymnasium, one private hospital, and one small shopping centre. Langenhovenpark is also predominantly residential, having suburban-area-level civic and commercial facilities. The commercial facilities such as Checkers, Pick and Pay, the weekly farmers' market, etc, are all located along the major arterial routes. The other religious facilities, such as the churches and nurseries, are located along the minor roads or within the residential areas. Pellissier, on the other hand, has only one small shopping centre, one church, and one primary school, while Universitas has only two small shopping centres, one hospital, one church, and one primary school, as shown in Figure 4-2. The primary school, located next to the arterial route in Universitas, has a tendency to restrict the flow of traffic, but only in the peak hours when the school starts in the morning and closes in the afternoon. Other land uses also indicated on Figure 4-2 include petrol stations, clinics, libraries, post offices, recreational activities, and all the cluster dwellings (single- and double-storey townhouses, flats, and old age homes) in the selected four residential areas. As a consequence of this urban form, it was observed that majority of the traffic accidents happen on the arterial roads passing through the suburban areas. The arterial roads, which are used as arterial thoroughfares, experience higher numbers of accidents, as does Paul Kruger Drive in Universitas with more than 80 accidents a year, and Benade Drive in Fichardtpark with 60 to 79 accidents per year.

In this analysis, an attempt has been made to understand the relationship between traffic accidents rates and the type of urban form in the study area. For this purpose, the land use and transportation network in the selected suburbs of Fichardpark, Universitas, Langenhovenpark, and Pelisser, where detailed surveys were conducted, were analysed thoroughly. Figure 4-2 presents the land use and different vehicular routes in the surveyed areas. The small circular dots represent commercial locations, the highlighted multi-angled blocks are cluster dwellings, and the large grey block in the middle is the central business district (CBD). Each area is indicated with a border surrounding it. The different land uses area shown in the figure and the arrows indicate the direction of vehicular movement.

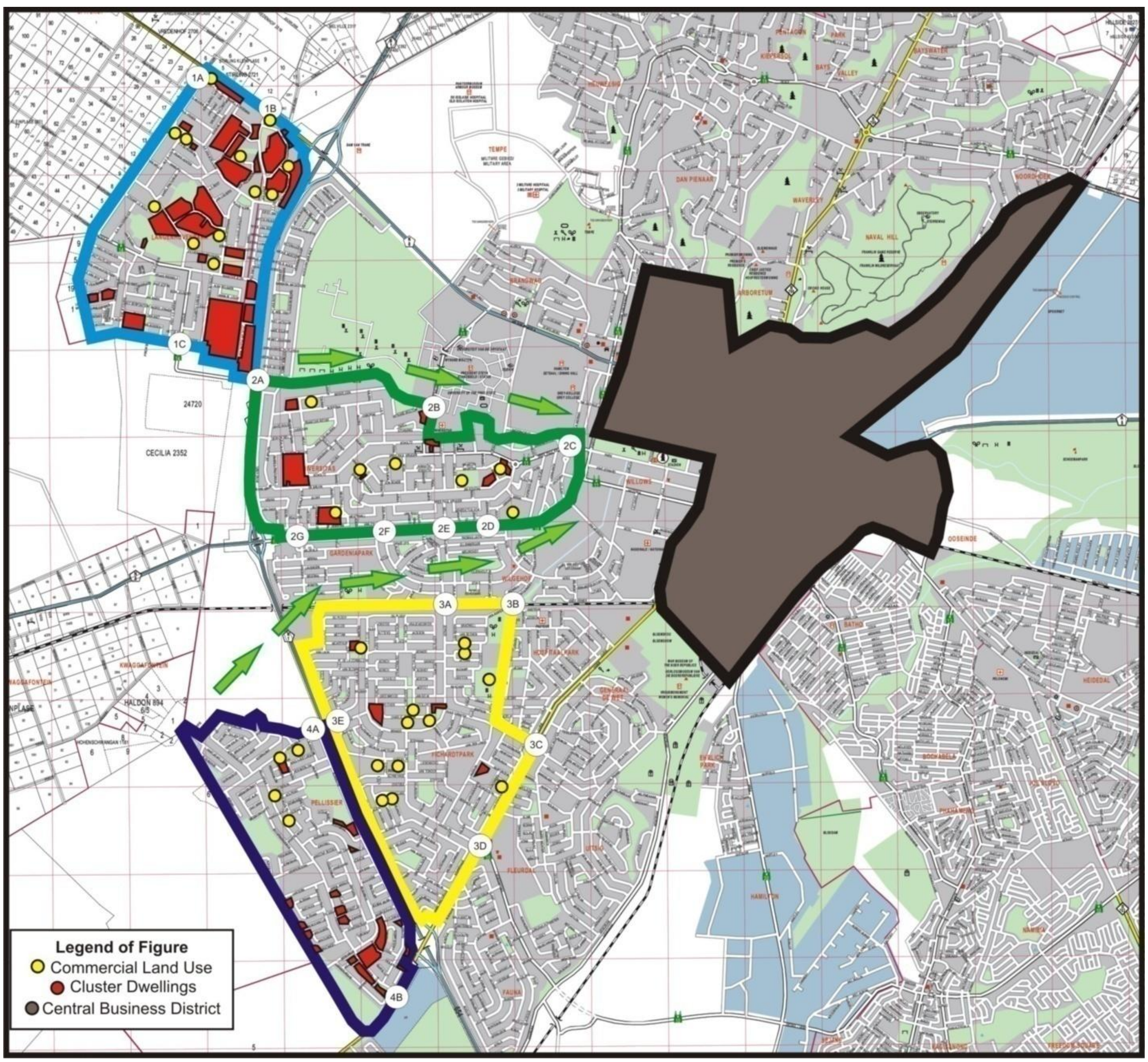

Figure 4-2: Land uses in selected areas

It has been noted that Pellissier and Fichardtpark are linked by Volkspele Drive and Eric Rosendorf Street, while Langenhovenpark and Universitas are linked by the M14 (Totius Street) and Wynand Mouton Drive. Fichardtpark and Universitas are separated by Gardenia Park, but are linked by Stals Road, as shown in Figure 4-2. Stals Road is the connection between the south-west and north-west residential areas in Bloemfontein. The reason for the use of this road is that there is a railway line splitting the two areas with only one bridge that is linked to Stals Road. This increases the number of vehicles to using this selected road.

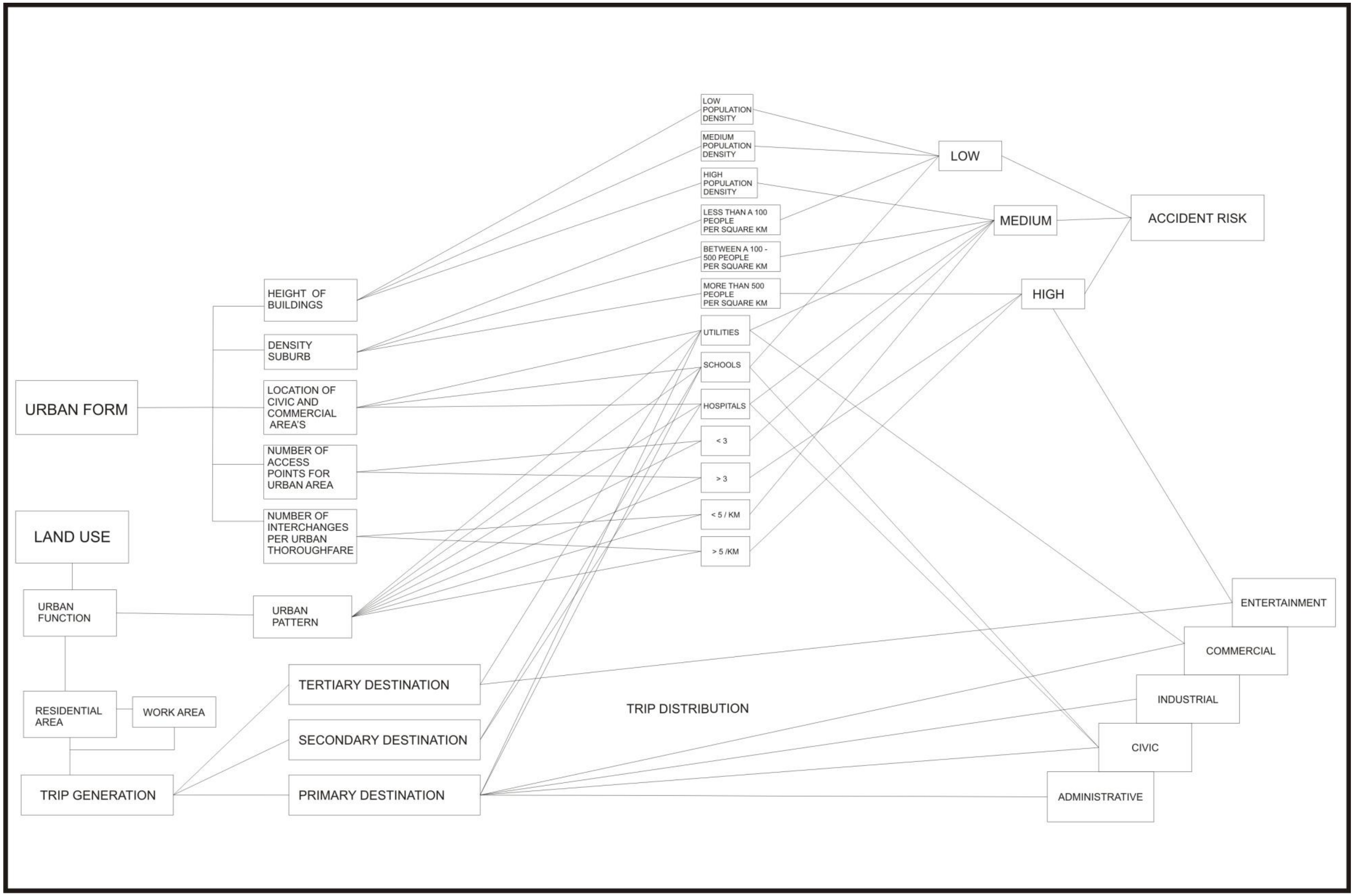

Figure 4-3: Relationship between urban form and land use

4.3.4 Urban form

Urban form is also associated with the physical characteristics of an area. In this regard, an association between the urban form and physical characteristics of the four suburban areas surveyed (Langenhovenpark, Universitas, Fichardtpark, and Pellissier) was attempted. The urban form is divided into five different categories based on the physical characteristics of the suburban areas and linked to the levels of vehicular traffic accidents risks. Figure 4.3 traces the relationship with urban form, land use, and accident risks. The analysis revealed that:

- The majority of the buildings located in these suburbs are low-rise and consist mostly of single-storey units, although a small portion of the residential buildings are double-storied; the schools and hospitals are double- or multi-storied. However, it is observed that the level of accident risk in such low-rise areas is very low. The vehicular driver is not distracted by the surrounding buildings which allow the driver with a better line of sight.
- The density of population in the suburbs, indicated in Table 4-14, illustrates that the density of population varies between 100 and 500 people per square kilometre in all the selected areas, which is higher when compared to the average density in the city. With a high number of people staying in residential areas, high-density areas provide greater opportunities for road accidents. These areas are categorised as medium accident risk areas.
- With respect to the availability of civic functions, it was observed that segregated location of civic functions provides accidents risks of low to medium levels. All the suburbs except Langenhovenpark have schools, but they are located away from other functions. Similarly, Universitas, Fichardtpark, and Langenhovenpark have hospitals but they are not mixed with other civic functions. Thus, the location of civic functions in these suburbs provides low to medium level vehicular traffic accident risks.
- Table 4-14 outlines the numbers of access points into the different suburban areas. Langenhovenpark and Pellissier have three or fewer access points, whereas Universitas and Fichardtpark have as many as seven accesses. It follows that the level of accident risk on access points is low with the risk increasing with an increase in the number of accesses points.
- The number of interchanges per km is high in the Universitas and Fichardtpark areas. In some roads, the number of interchanges exceeds 5, therefore they are classified in the high risk category for vehicular traffic accidents.

Further, an analysis was conducted to observe the number and types of trips generated in these suburban areas based on the urban functions and land use. In this regard, the various functional areas are classified as primary, secondary, and tertiary destinations based on the type of function. The land use is divided into two different components, namely, the urban function and the urban pattern. The urban function is that the selected areas are all predominantly residential areas which link with their work areas.

The primary destinations include places with personal objectives, such as work places, and learning areas, such as high schools or universities, In these cases, drivers travel from their houses to work places, drop off the children at the schools, or drive to the universities to attend classes. Table 4-10 reveals that about one-third of households use one commuting round, while another one-third of households use two commuting rounds per day. The secondary destinations consist of commercial areas, utility stores, lower grade schools, etc. The activities include travelling to buy groceries after work or picking up children at lunch time. About 64% of the household vehicles use 1 to 2 commuting rounds per day to these destinations. Tertiary destinations, which include exceptional or emergency activity places, such as hospitals, garages, religious places, etc, do not form part of commuter's day-to-day activities as a household may visit a doctor or go to a garage to fix a car only when it is required or in the case of an emergency. Thus, it was concluded that the households in these suburban areas generally generate one to two commuting round trips per day for their primary functions while the number of trips generated for other functions is insignificant.

4.3.5 Urban pattern

The urban pattern is one of the main factors which may influence the movement of vehicles in residential suburban areas and impact on the consequent occurrence of accidents. In this regard, the following observations can be made about the study area.

Figure 4-4: Urban pattern for Universitas

The urban pattern and consequent road network system in Universities area (Figure 4-4) depicts a multiple loop system, combining collector roads and local streets with the arterial roads. The function of the arterial roads here is to bring the traffic in and out of this area. There is one entrance on the northern, one on the eastern side, and one on the western side (the route to Langenhovenpark) of the area. There are four entrances located on the southern side of this area. Inside the loops, the collector and local streets create a gridiron type of pattern linking the arterial roads. The loop system, combined with the gridiron pattern, offers more choices for commuters to reach their destinations within the residential areas. However, as the vehicles have to come to the arterial roads to go in or out of the area, there is a significant pressure on the arterial roads. Thus, while the accident risks in the collector roads and local streets are low, the arterial roads are susceptible to higher accident risks.

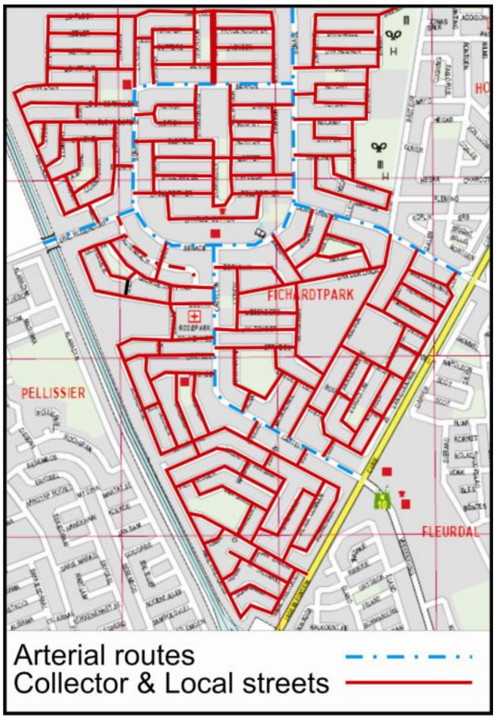

Figure 4-5: Urban pattern for Fichardtpark

The urban pattern and road network of Fichardtpark is shown in Figure 4.5. There are four entrances into its area, all of them located on the arterial routes. They are situated on the northern, south-eastern, and western sides (the route to Pellissier) of the suburb. The suburb has a linear pattern in the outer areas, leading to a loop pattern in its interior areas. The collector roads and local streets comprise a gridiron pattern which links to the arterial roads. Thus, while the linear pattern allows vehicles a through access, the interior loops offer choices of movement. Therefore, similar to the Universitas suburb, the arterial roads of Fichardtpark are susceptible to high pressure and higher risks of accidents, whereas collector roads and local streets are, relatively, under less pressure and, consequently, have lower accident risks.

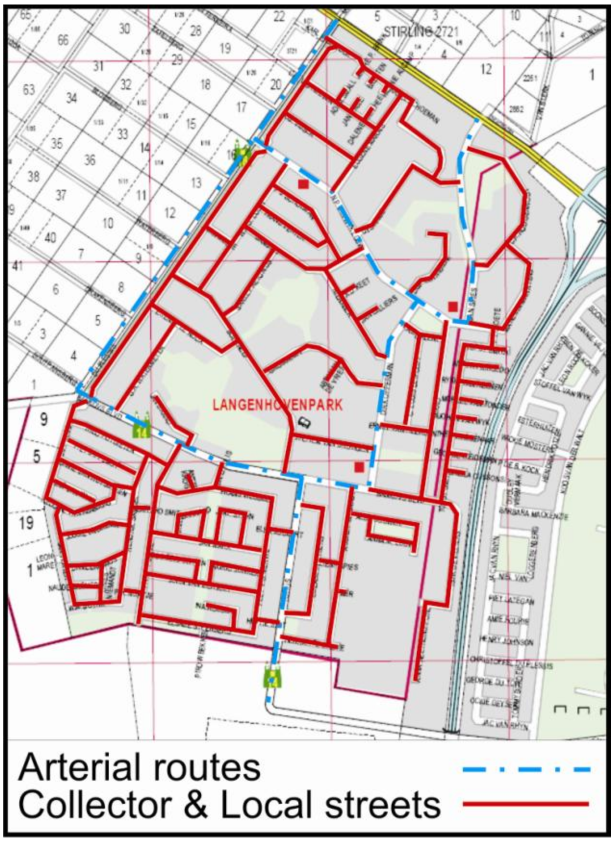

Figure 4-6: Urban patterns for Langenhovenpark

Figure 4.6 presents the urban pattern and road network system of Langenhovenpark. There are only three access points to this suburb from the outside, of which two are located on the northern side and one on the southern side. Unlike Universitas and Fichardtpark, however, the arterial roads in this suburb have a loop pattern. The collector and local streets create a gridiron pattern. Since this is a limited access area, with arterial roads having a loop pattern, and interior roads forming a gridiron pattern, all the roads offer more choices of movement for the commuter. Therefore, the vehicular pressure on all roads is low and, consequently, the risk of accidents is also relatively low.

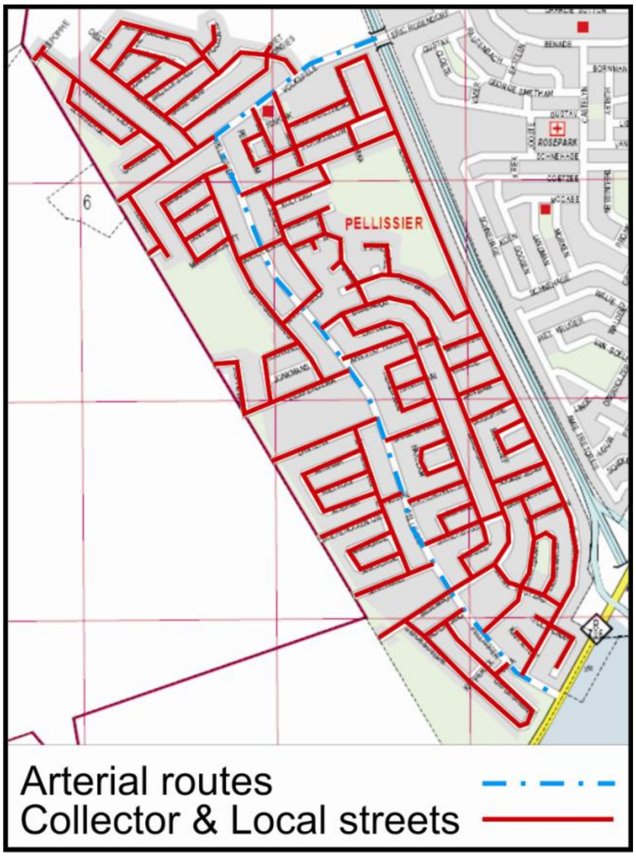

Figure 4-7: Urban patterns for Pellissier

The arterial road in the Pellissier suburb manifests a linear patten (Figure 4.7). There are two access points with one is located on the northern side and the other on the southern side. The same road connects both access points. The collector and local streets develop a gridiron pattern and link to the arterial road. Therefore, similar to Universitas and Fichardtpark, the arterial roads of this suburb are subjected to high pressure and, consequently, higher risks of accidents, whereas collector roads and local streets are under relatively less pressure and thus have lower accident risks.

It is thus concluded that:

- All the suburbs - Langenhovenpark, Fichardtpark, Universitas, and Pellissier - have similar urban patterns with marginal variations.
- The arterial roads in Fichardtpark, Universitas, and Pellissier are of linear pattern while they create a loop system in Langenhovenpark.
- The collector roads and local streets combine gridiron and loop patterns for the road networks in all the suburbs.
- Universitas and Fichardtpark suburbs have a high number of access points which are located on the arterial roads.

- The arterial roads of Fichardtpark, Universitas, and Pellissier are under high pressure and have higher risks for the occurrence of accidents, whereas the loop system of arterial roads in Langenhovenpark makes it less vulnerable to accident risks.
- All the interior roads, such as collector roads and local streets, have low vehicular pressure on them so the risk of accidents in these roads relatively low.

4.4 ANALYSIS OF TRAFFIC SCENARIOS

The analysis of traffic scenarios in the study area was conducted to understand the volume of traffic and its basic movement patterns in the study area's suburbs. In this section, traffic volume and the speed of vehicles during peak and off-peak hours of the day will be analysed and discussed.

4.4.1 Traffic volume

The traffic volume surveys were conducted to observe the traffic volume pattern on the arterial roads and to compare the number of traffic accidents with the volume of traffic at various intersections, thus providing an indication of the relationship between traffic volumes and the occurrence of traffic accidents in the study area. Figure 1-6 shows the locations of all the intersections and road sections where traffic volume surveys were conducted. The different road sections are labelled as follows:

Table 4-15: Surveyed routes

Road Name	Code	Road Name	Code
Totius Street	(Road 1)	Wynand Mouton Drive	(Road 2)
De Bruyn Street	(Road 3)	Paul Kruger Drive (S)	(Road 4)
Paul Kruger Drive (N)	(Road 5)	Paul Kruger Drive (E)	(Road 6)
Gardenia Avenue	(Road 7)	Van Schalkwyk Street	(Road 8)
Haldon Drive	(Road 9)	Edeling Street	(Road 10)
Stals Road	(Road 11)	Benade Drive (N)	(Road 12)
Benade Drive (S)	(Road 13)	Eric Rosendorf Street	(Road 14)

Table 4-16: Surveyed Intersections

Intersection	Roads joining the intersection
Intersection A	Wynand Mouton Drive, De Bruyn Street, and M14 (Totius Street)
Intersection B	Haldon Road, Van Schalkwyk Road, and Gardenia Park;
Intersection C	Haldon Road, Edeling Street, and Stals Road
Intersection D	Paul Kruger Drive Circle
Intersection E	Benade Drive and Rosendorf Street

The volume surveys were conducted from 06:00 hours to 20:00 hours every day for one week, which thus included five weekdays and two weekend days at the designated intersections and road sections. The survey times were limited to 6.00 and 20:00 hours because the period is generally considered as average business hours when normal vehicular traffic movement may be observed on Bloemfontein's suburban roads, after which it reduces to very meagre numbers. Therefore, the times outside this defined period were not considered for the survey. The survey hours and duration were arrived at on the basis of a pilot study conducted on weekdays and weekends before the main survey was carried out.

The various modes or types of vehicles recorded were buses, delivery vehicles, passenger vehicles, motorcycles, bicycles, and pedestrians. However, all the vehicles were converted to Passenger Car Units (PCUs) according to the metric system of the geometric guidelines of South Africa. Passenger Car Units (PCU) to quantify the volume of vehicles in equivalent PCUs. The metric systems used for conversion is given in Table 4.17.

Table 4-17: Total number of traffic accidents in the four selected residential areas (SANDRAL, no date: 3-28)

No.	Vehicle type	Equivalent PCU
1	Passenger cars (including taxis or pick-ups)	1
2	Buses, tractors, and trucks	1.75
3	Commercial vehicles	3
4	Motorcycles	0.75
5	Bicycles	0.33

4.4.2 Traffic Volume in different road sections

The traffic volume survey on different roads was conducted to establish the volume of traffic on the roads at different periods of the day and to identify the roads generally selected by commuters to reach their destinations. The different roads for the survey were selected on the basis of their importance and the number of accidents occurring on these roads. This is illustrated in Figure 4-8 which highlights the number of PCU's per road section. All the roads selected were major suburban arterial roads connecting different suburbs.

Table 4.18 presents the average traffic volume on different roads. It was observed that the traffic volume varies from a minimum of 54 PCUs to 1613 PCUs per hour on the roads of selected suburban arterial roads. The variations of hourly peak volume of traffic in different roads during different periods of the day are shown in Figure 4.9 and Table 4.18.

The analysis revealed that pattern of traffic volume in all the roads is similar. The traffic volume is highest during the period 07h00 to 08h00 followed by 16h00 to 17h00 and 17h00 to 18h00 on almost all the roads. During the other periods of the day, i.e., 08h00 to 16h00 and 18h00 to 19h00, the volume of traffic was found to be average after which the traffic volume declines.

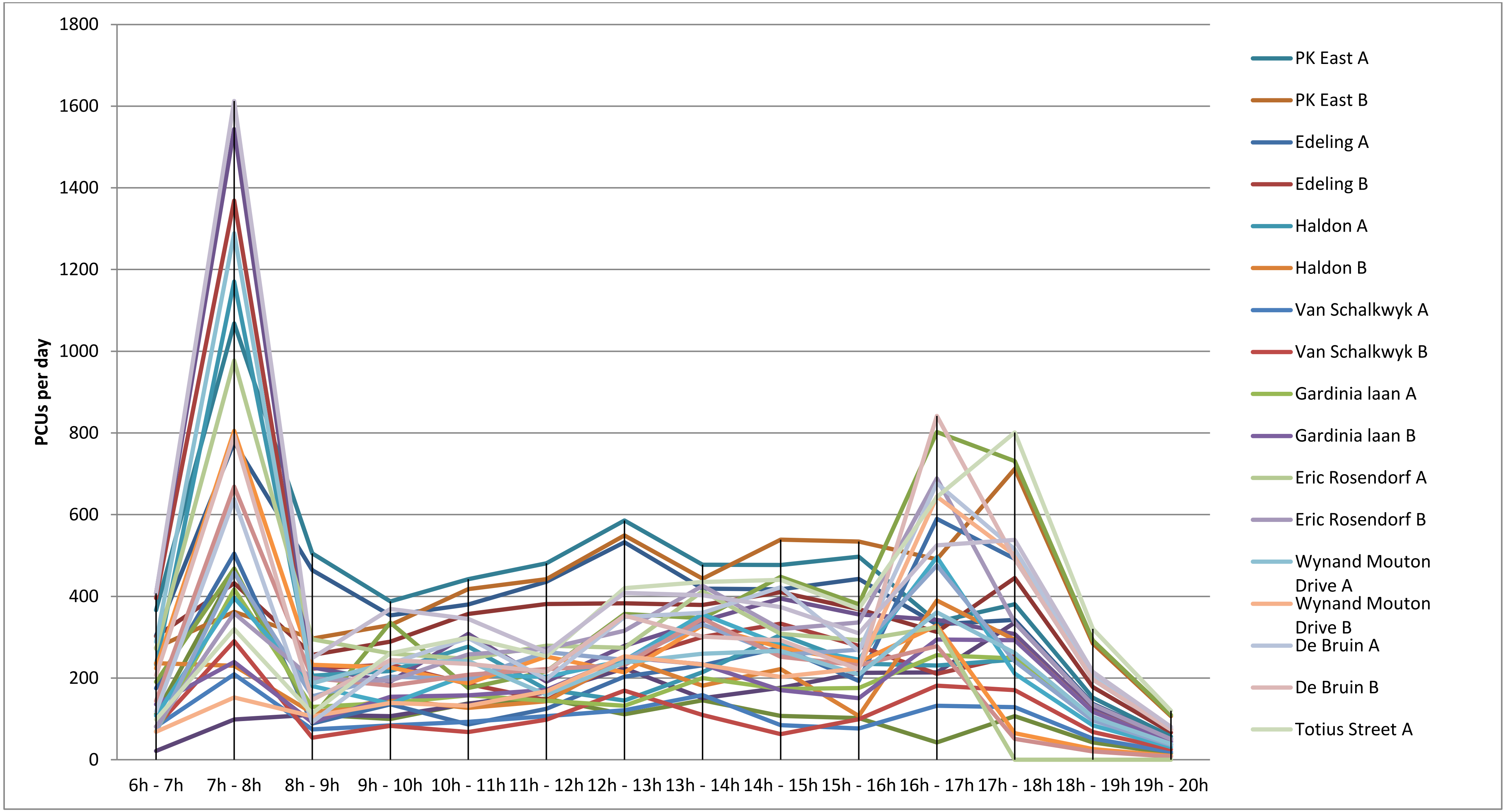

Figure 4-8: Average vehicular traffic in PCUs per hour

Table 4-18: Traffic volume surveyed on different routes (road sections) and traffic accidents

	Route number	Direction of flow	Average PCUs per hour (6h – 8h)	Average per hour (8h – 16h)	Average per hour (16h – 18h)	Average Number of accidents per year
Totius Street	1	North	210	324	722	25
		South	1010	340	532	
Wynand Mouton Drive	2	East	789	225	312	26
		West	111	182	573	
De Bruyn Street	3	North	379	278	596	20
		South	501	252	517	
Paul Kruger Drive (S)	4	East	286	121	75	127
		West	60	160	275	
Paul Kruger Drive (N)	5	East	541	431	337	
		West	368	353	379	
Paul Kruger Drive (E)	6	East	718	482	360	
		West	318	444	602	
Gardenia Avenue	7	North	188	173	294	0
		South	244	157	252	
Van Schalkwyk Street	8	North	186	93	176	3
		South	146	100	131	
Haldon Drive	9	East	234	161	342	59
		West	702	222	238	
Edeling Street	10	North	340	167	541	5
		South	883	243	233	
Stals Road	11	North	976	286	325	20
		South	330	295	767	
Benade Drive (N)	12	North	515	244	354	87
		South	253	244	197	
Benade Drive (S)	13	East	407	234	165	
		West	264	240	359	
Eric Rosendorf Street	14	East	625	296	163	9
		West	220	290	513	

Figure 4-9 provides an analysis of traffic volume on a two-hourly basis in order to observe the behaviour of traffic volume (average of all the roads) on the roads of the study area. It can be seen that the maximum traffic volume occurs between 06h00 and 08h00 which, together with the period from 16h00 to 18h00, are higher than the other periods of the day. The highest traffic volume occurs between 16h00 and 18h00, followed by 06h00 to 08h00 while the lowest traffic volume occurs between 18h00 to 20h00. These figures indicate that the two periods from 16h00 to 18h00 and from 06h00 to 08h00 are the most important periods of the day from a traffic volume point of view. These two time periods of the day are treated as peak hours with 06h00 to 08h00 as peak hour 1 and 16h00 to 18h00 as peak hour 2.

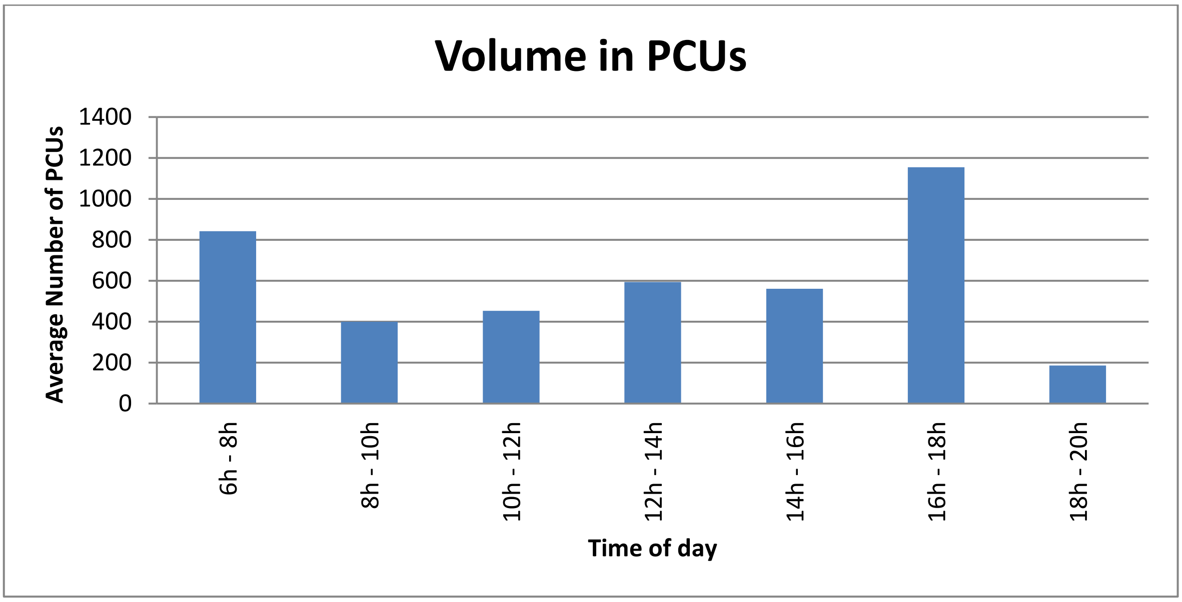

Figure 4-9: Peak-time traffic volumes

The analysis also reveals that the traffic movement in different residential areas is frequent, with the average number of vehicles during the peak hours being 395 PCUs per hour and 251 PCUs per hour during off-peak hours. The average variation between peak time and off-peak time is about 57%. With respect to individual volumes of traffic on individual arterial roads, it was found that Totius Street, a connection between Langenhovenpark and Universitas, carries 2020 PCUs leaving Langenhovenpark in the morning peak hours with 1444 PCUs entering this area in the afternoon peak hours. Similarly, Eric Rosendorf Street, a connection between Pellissier and Fichardtpark, carries 1250 PCUs leaving the area in the morning peak hours and 1025 PCUs entering the area during the afternoon peak hours.

It can also be observed that arterial roads passing inside the residential areas carry a high number of traffic volume (PCUs) as evident from roads such as Paul Kruger Drive, which passes through the Universitas residential area, carrying a total traffic volume of 4582 PCUs per morning peak hours (06h00–08h00), and Benade Drive, situated in Fichardtpark, which carries 2878 PCUs per day (both in only one direction). Thus, it is clear that there are high influxes of traffic volume in the arterial roads of the different suburban areas of the study area. Some of the road sections carry a large number of traffic (PCUs) with an observed maximum traffic volume of over 10 000 PCUs per day in both directions. The high traffic volume in these roads indicates the importance of the suburban arterial roads in the study area as well as their vulnerability to vehicular accidents.

The importance of this section has been to confirm that the traffic volume of each residential area accords with the other factors such as size, density, land use, and the socio-economic background of the areas. This has been established above, thereby eliminating Dumbaugh and Rae's (2009) variable of traffic volume in this study, while supporting the findings of Marks' 1957 study that a relationship exists between safety and land form.

4.4.3 Traffic Volume at Intersections

The volume of the traffic at intersections gives an indication of the utilisation of different roads in a road network and identifies the directional split for the traffic at different times of the day. It also provides an indication of the capacity of the intersections for traffic movement.

4.4.3.1 Intersection A

Intersection A is a three-legged intersection (T-junction) comprising Totius Street on the west, Wynand Mouton Drive on the east, and De Bruyn Street on the south. It is an intersection with a traffic signal control which has a two-phase system (controlling traffic in two directions with right-turn facilities. The western leg of this intersection is connected to the M14 (Totius Street). This road is connected to Langenhovenpark which is situated next to (i.e. west of) Universitas. Wynand Mouton Drive constitutes the eastern leg. This road is situated on the border of Universitas (a residential area) and the University of the Free State. This roadway leads to one of the entrances of the university as well as to several other locations. The southern leg of this intersection leads into the centre of Universitas, and is used for driving through Universitas to other residential areas. Figure 4-11 indicates the layout and volume of traffic in PCUs at this intersection in the first peak time, off-peak time, and the second peak time as well as the flow of traffic during other periods of the day.

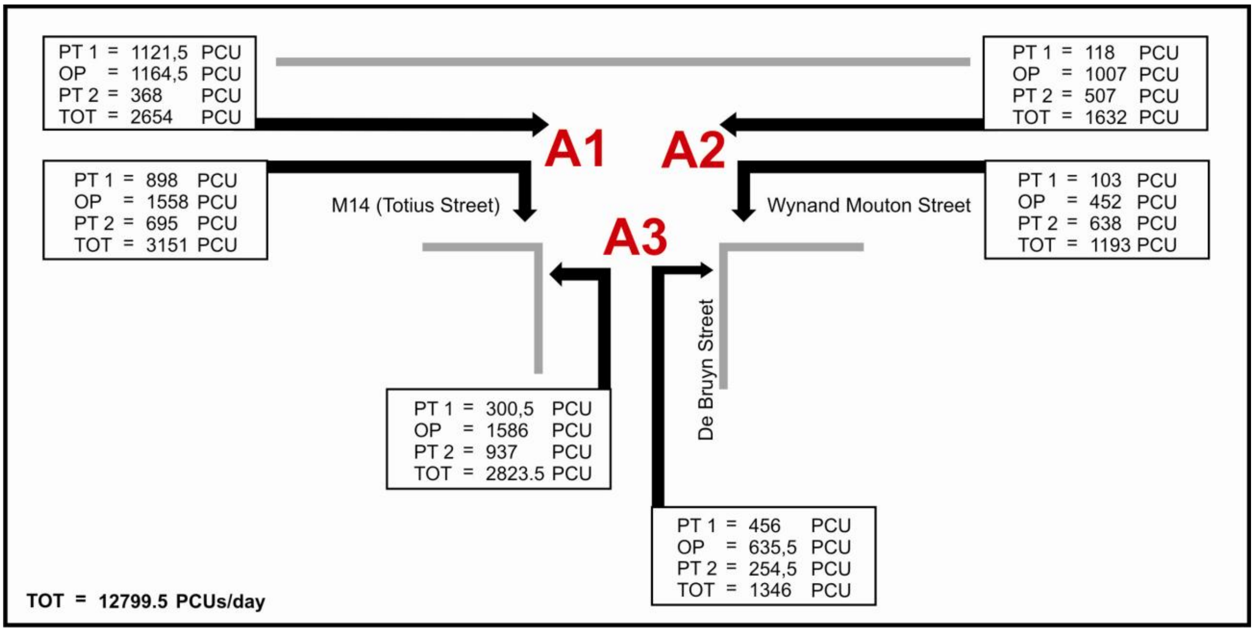

Figure 4-11: The number of PCUs at Intersection A and the traffic flow

This figure shows that there are 2654 PCUs of traffic travelling from point M14 (Totius Street) (A1) to Wynand Mouton Drive (A2), and 3151 PCUs travelling from point A1 to De Bruyn Street (A3) during the surveyed period. Secondly, the total traffic flow between 06:00 hours and 18:00 hours from Wynand Mouton Drive indicates that there are 1632 PCUs travelling from point A2 to point A1, and 1193 PCUs travelling from point A2 to point A3. Further, it indicates that 2823,5 PCUs are travelling from point A3 to point A1, and 1346 PCUs travelling from point A3 to point A2. This traffic flows from the combined residential areas to one of the University of the Free State's entrances, which is located in the northern part of Universitas. Thus, there are very large numbers of vehicles travelling from Langenhovenpark to Universitas, from Langenhovenpark to Wynand Mouton Drive, and from De Bruyn Street in Universitas to the residential area of Langenhovenpark. A slipway is provided for A1 and A3 when turning left, thus avoiding conflict outside the intersection. The total of 3151 PCUs turning right into the contact area from A1 may increase the opportunity for an accident. Although this is only a three-legged intersection, a large number of vehicles use this intersection. A total of 12799,5 PCUs make use this intersection per day from any direction, the majority of these vehicles (45%) come from A1 (M14 / Totius Street).

4.4.3.2 Intersection B

Intersection B is used by commuters from the residential areas of Langenhovenpark and Universitas travelling to Jim Fouché Primary and Secondary Schools, and from Gardenia Avenue (B2) to Van Schalkwyk Street (B4), as well as by commuters travelling to the M19, which provides access to the N1 national road connecting to Kimberley. Road section B2 enters Gardenia Park, while road section B4 connects to Universitas. Haldon Drive (B1 and B3) heads into the city in the east or leaves Bloemfontein in the west. Haldon Drive is the major road while Gardenia Avenue and Van Schalkwyk Street are minor roads. This is an intersection with stop control on the minor road crossing with the major road, with no traffic control system. Figure 4-12 indicates the number of PCUs at this intersection in the first peak time, off-peak time, and the second peak time.

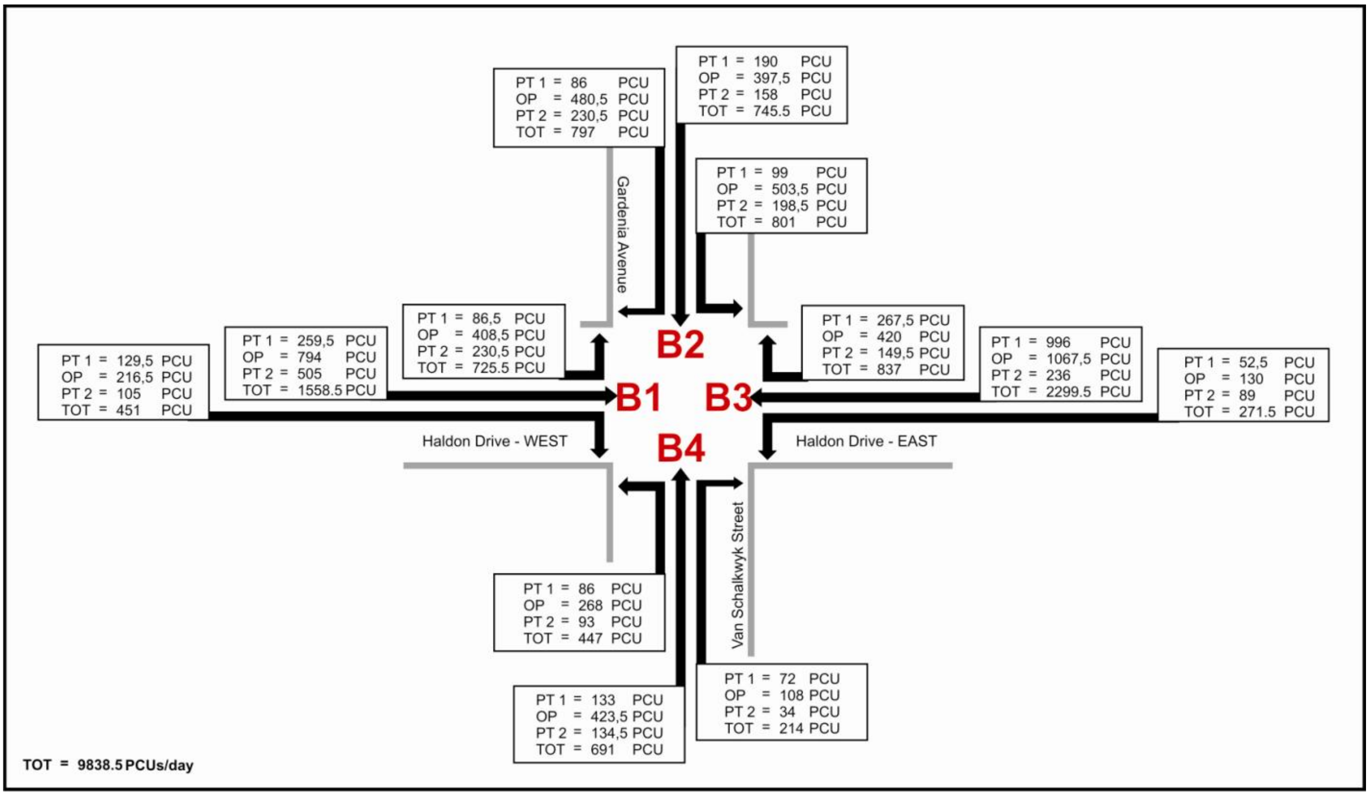

Figure 4-10: The number of PCUs at Intersection B and the traffic flow.

An average of 9838,5 PCUs pass through this intersection per day. This is fewer than the volume of traffic (12182 PCUs) passing through intersection A, a figure 30% higher than the traffic volume at Intersection B. It can also be seen that Haldon Drive East (B3) generates the highest traffic volume at this intersection (3408 PCUs per day) which occurs because of the vehicles travelling from Intersection C to intersection B. Secondly, about 2735 PCUs per day travel from the M19 into the city of Bloemfontein through B1. Thirdly, B2, which joins the residential areas of Langenhovenpark and Universitas, has a total of

2343.5 PCUs per day. However, it should also be noted that B3 has also very large numbers of PCUs travelling from point B3 to point B1, i.e., from Haldon Road east to Haldon Road west (M19), with 2299.5 PCUs travelling in the first peak period, and 1067.5 PCUs during the off-peak period. Except for the morning peak traffic, Van Schalkwyk Street generates about of the PCUs passing through point B2.

4.4.3.3 Intersection C

Intersection C is situated in Haldon Drive, and connects Universitas with Wilgehof. It is a traffic-signal-controlled intersection with a two-phase system. Haldon Drive East (C3) and Haldon Drive West (C1) are a part of a major arterial road while Stals Road (C2) and Edeling Street (C4) are part of the minor arterials. This intersection is used by commuters travelling from the residential areas of Langenhovenpark and Universitas to the residential areas south of the city such as Fichardtpark and Pellissier (point C2 to point C4); as well as by commuters who are travelling to the M19 from the centre of the city (point C3 to point C1). Figure 4-13 indicates the number of PCUs at this intersection in the first peak time, off-peak time, and in the second peak time.

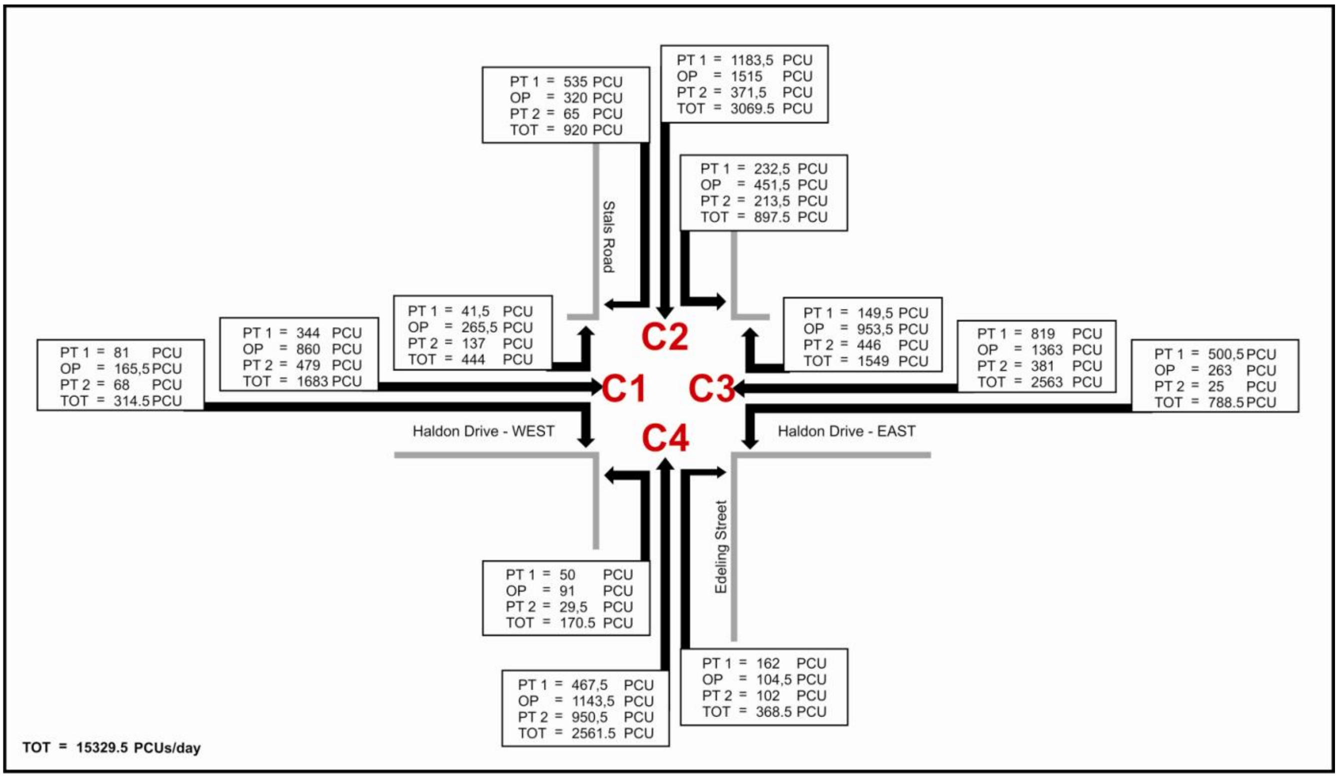

Figure 4-11: The number of PCUs at Intersection C and the traffic flow.

From the Figure 4.13, it may be observed that about 15329.5 PCUs commute between points C2 and C4, which is the largest of all the intersections surveyed in the study area.

The highest first peak time volume from point C2 to point C4, is 1183,5 PCUs, followed by 950,5 PCUs travelling from point C4 to point C2. The off-peak time period also has a high number of PCUs travelling in straight lines across the intersection: from point C1 to point C3, point C2 to point C4, point C3 to point C1, and point C4 to point C2. The volume of traffic is relatively low during the second peak time, with the highest total being 950,5 PCUs from point C2 to point C4, thus demonstrating that there is a significant number of commuters travelling from Universitas to the southern residential areas of Bloemfontein, whereas the second-highest total is only 479 PCUs, travelling from C1 to C3.

4.4.3.4 Intersection D

Intersection D is a traffic roundabout at Paul Kruger Drive. This is a large roundabout at which the rule of giving way to traffic from the right applies before entering the roundabout. This roundabout can be seen as an interlinkage for most of the traffic from the west and east as well as to services inside the residential area of Universitas. Most of the commuters using this roundabout are either on their way to the central areas of Bloemfontein city after exiting at Paul Kruger exit (D2), or on their way to one of the University of Free State's entrances or to the Universitas Hospital by exiting at Paul Kruger North (D1), or on their way to Langenhovenpark and surrounding areas by exiting at point D1 or Paul Kruger South (D3). Figure 4-14 indicates the number of PCUs at this intersection in the first peak time, off-peak time, and the second peak time.

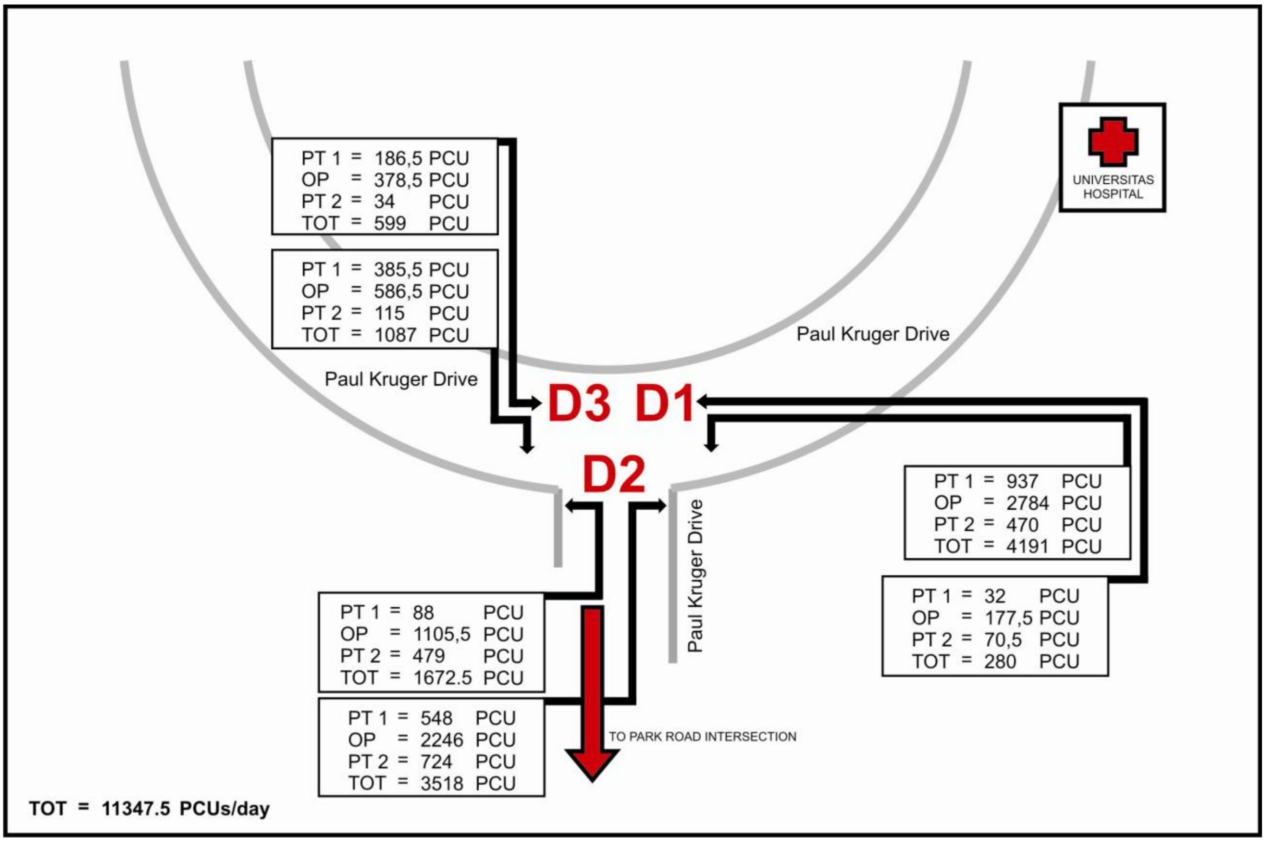

Figure 4-12: The number of PCUs at Intersection D and the traffic flow.

The above figures reveal that the majority of commuters use the northern route (D1) and eastern route of Paul Kruger Drive (D2) with a total volume of traffic of 4435 PCUs and 5190,5 PCUs respectively. The southern route (D3) of Paul Kruger Drive has less traffic (1686 PCUs) than the other two legs. It is also observed that there is a very large number of commuters (2784 PCUs) (from the university, the hospital, or one of the residential areas into the central area of Bloemfontein) travelling in the off-peak time from point D1 to point D2. There are also large numbers of commuters (2246 PCUs) travelling from point D2 to point D, indicating that commuters who are travelling between point D2 and point D1 may be commuting more than once a day to the exiting areas of these two points.

4.4.3.5 Intersection E

Intersection E is a three-legged intersection with stop-control on the minor road crossing the major road. The major road is Benade Drive and the minor road is Eric Rosendorf Street. This intersection is used mainly by commuters travelling from and to the residential area of Pellissier or its surrounding areas. Figure 4-15 indicates the number of PCUs at this intersection in the first peak time, off-peak time, and the second peak time. The Eric Rosendorf Street entrance is one of only two entrances into Pellissier, which have limited access to the residential area.

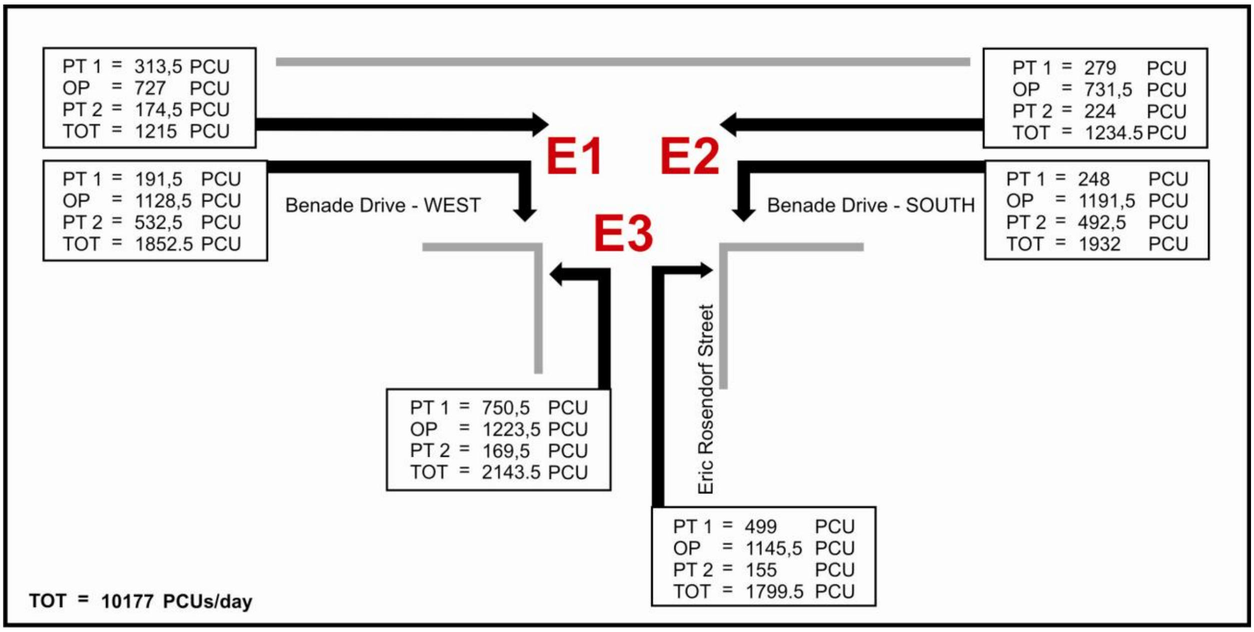

Figure 4-13: The number of PCUs at Intersection E and the traffic flow.

From the above figures, it may be noted that this intersection has a total traffic volume of 10177 PCUs per day, which is higher than Intersection B and lower than the other intersections surveyed. The largest number of PCUs at this intersection are travelling from Gardenia Park (E3) to Benade Drive West (E1): 750,5 PCUs in the first peak period, followed by 532,5 PCUs for the afternoon peak period, travelling from point E1 to point E3. However, during the off-peak period, the traffic volume from point E3 to point E1 is 1123,5 PCUs. The high traffic volume during this period may be attributed to the presence of the primary school located in Pellissier. The directional split from Eric Rosendorf Street towards Benadé Drive is 60% towards the western side and 40% to the southern side of Benadé Drive. This is an indication that there is a two-directional flow with multiple travel destinations.

In summary, it may be concluded that:

- The intersection that links the selected residential areas with one another, (intersection C joining Stals Road, Edeling Street, and Haldon Road) has by far the highest number of traffic volume of PCUs passing through it. This indicates that commuters prefer travelling between the residential areas of Universitas, Gardenia Park, Wilgehof, and Fichardtpark, in which the road passing through Fichardtpark and Universitas acts as a thoroughfare for Langenhovenpark and Pellissier.

- The second-highest number of traffic volume (PCUs/day) was observed at intersection A, which is one of the access and exit points for the residential areas of Langehovenpark.
- The third-highest traffic volume of PCUs/day was found at Intersection D (the Paul Kruger Drive roundabout) in Universitas. The road passing through this residential area was established as a thoroughfare, which commuters use to access the residential areas of Langenhovenpark.
- From this analysis, it may be seen that traffic movement varies with the time of day, with a very low traffic volume in the off-peak hours leading to under-utilisation of the roads to a very high traffic volume in the peak hours, creating huge pressure not only on the arterial roads but also on the intersections of the suburbs of the study area.

4.5 SPEED SURVEY ANALYSIS

The speed surveys were conducted at various road sections on the arterial suburban roads of the suburbs selected for survey (See Chapter 1, Figure 1-6). The speed surveys were done at different times of the day; the average speed of vehicles during the different time periods is presented in Table 4.19.

Table 4-19: Speed survey results

Name of the roads	**Average Speed of vehicles at different hours of the day**			**Average speed of vehicles**
	06h00 - 8h00	8h00 - 16h00	16h00 - 20h00	
Jan Spies Drive	66 km/h	70 km/h	76 km/h	71 km/h
Totius Street	65 km/h	82 km/h	80 km/h	76 km/h
Wynand Mouton Drive	75 km/h	81 km/h	80 km/h	79 km/h
De Bruyn Street	74 km/h	78 km/h	79 km/h	77 km/h
Paul Kruger Drive North	73 km/h	69 km/h	72 km/h	71 km/h
Paul Kruger Drive South	78 km/h	81 km/h	76 km/h	78 km/h
Benade Drive North	77 km/h	81 km/h	78 km/h	78 km/h
Benade Drive South	67 km/h	73 km/h	69 km/h	69 km/h
Volkspele Drive	56 km/h	59 km/h	61 km/h	58 km/h
Pellissier Drive	70 km/h	72 km/h	68 km/h	70 km/h
Average	70 km/h	74 km/h	74 km/h	72,7 km/h

It is evident that the average speeds of vehicles exceed the maximum general speed limit of 60 km/h on almost all the roads, irrespective of the time of the day. It is also evident that the average speeds of vehicles are lower during morning hours than the afternoon and evening hours. However, Volkspele Drive is the only road where the average speed of vehicles was found to be below the city's general speed limit. Further, it was found that, during the same period of the day, the average speed of vehicles is higher when the volume of traffic is smaller when compared to the volume of traffic with a higher average speed for vehicles on these roads,

4.6 ACCIDENT PREDICTIONS IN THE STUDY AREA

Accident prediction is crucial in the search for plausible actions for their prevention and/or reduction as well as for enhancing road safety. Traffic accidents occur under different circumstances and are influenced by several parameters, including the physical and spatial, the road network and traffic related, road geometry and road condition, urban form, land use and urban function, as well as vehicle-related, human behaviour-related parameters, etc. An accident may occur because of the influence of any single variable of the parameters or because of a combination of several variables under one parameter or across the parameters. Therefore, it is absolutely essential to delineate the most influential control parameters and variables, which cause vehicular traffic accidents in an area, and develop an accident prediction model by considering all the major control parameters and variables in order to predict accidents. The following sections deal with the delineation of the major control parameters and variables which influence vehicular accidents in the study area and the development of an appropriate model based on the major control parameters to predict accidents in the study area. For this purpose, various statistical techniques, such as correlation coefficients and the chi-square test, were used to observe the major control parameters influencing vehicular accidents in Bloemfontein. These were followed by the development of a multiple regression model for the prediction of accidents in the study area.

4.7 CORRELATION COEFFICIENTS

The correlation coefficient method was used to analyse the parameters which have a significant influence on vehicular accidents in the study area. The data collected from the surveys for this investigation were utilised for this purpose, and correlation coefficients between the dependent variable and various independent variables were established. The number of accidents in the study area was considered as the dependent variable and all other variables under different parameters, such as socio-economic, traffic, road geometry, vehicular, urban form, and land use, human behavioural, etc., were considered as independent variables for analysis. The correlations between the dependent variable i.e., occurrence of number accidents and various other independent variables were established and presented below. Further, in order to check the mutual exclusiveness of the independent variables and their significance, the chi-square test was conducted. The variables with a significant correlation coefficient were chosen as the control variables, which influence vehicular accidents in the study area and employed for further analysis and model development.

Table 4.20 presents the variables with the significant correlation coefficients of all the variables. The number of accidents occurring in the study area correlates highly with the number of access points from residential areas to the arterial routes (0.943), Average Daily Traffic (0.887), median width of the roads (0.547), road width (0.464) and speed of vehicles (0.260) in that order. The variables having lower or insignificant correlation coefficients were ignored for further analysis.

Table 4-20: Correlation coefficients of major independent variables with vehicular accident occurrences

Independent variables	**Road width**	**Speed (Km/h)**	**ADT**	**No. of Access roads**	**Median width**
Vehicular Accidents	0.464	0.260	0.887	0.943	0.547

The high correlation coefficient between the number of access points to the arterial routes and the occurrence of vehicular accidents supports the premise that the greater the number of intersections or access points on a road section in the arterial roads, the higher the probability of traffic accidents occurring. The high correlation between the occurrence of vehicular accidents and average daily traffic means that the denser the roads or the traffic, the higher the occurrence of accidents. Variables, such as speed and median width, have relatively lower correlation coefficients with the occurrence of accidents, yet they are also significant, and thus influence the occurrence accidents in the study area. Variables, which have very insignificant correlation coefficients, such as the physical condition of the road, its gradient, the transitional curves, the addition of a paved shoulder, and the type of traffic, human behaviour, and vehicular parameters, were not considered as major control variables for the occurrence of vehicular accidents. Thus, the major control variables, which largely influence the vehicular accidents in the study, are the number of accesses from residential areas to arterial roads, Average Daily Traffic, road width, median width, and the speed of vehicles.

Further, in order to test the interdependency of the independent variables, the chi-square test was conducted; the results are presented in Table 4-21. In this test, two variables are considered independent if the Chi-square value is ideally zero (null hypothesis) or insignificant (close to zero). If the Chi-square value is high (close to one), it signifies interdependency between variables.

Table 4-21: Chi-square results

Variables	Vehicular Accidents	Road width	Speed (Km/h)	ADT	No. of Access roads	Median width
Vehicular Accidents	1	1.19E-59	0	2.049E-08	0	4.164E-33
Road width		1	0	0	0	0
Speed (Km/h)			1	0	0	0
ADT				1	0	9.445E-49
No. of Access roads					1	0.008
Median width						1

The results of the chi-square test shown in Table 4-21 reveal that the chi-square coefficients between the variables are highly insignificant, thus confirming the null hypothesis. Therefore, the major variable variables, which influence vehicular accidents in the study area, are independent and mutually exclusive.

4.8 MODELLING FOR ACCIDENT PREDICTION IN THE STUDY AREA

By considering the major control parameters influencing traffic accidents in the study area, an attempt was made to develop a model, which would be able to predict the number of accidents per year in the study area under varied conditions. Accordingly, a close examination of the various modelling approaches available (literature review section 2.7.1) was done. After examining the available data, the various major control parameters influencing accidents, and the consequent applicability of the various models for the prediction of accidents in the study area, it was observed that the multiple linear regression model would be the most relevant for the study area. Accordingly, a model was developed to predict the number of accidents per year. The model was employed to develop various scenarios under different simulated conditions based on the plausible policy guidelines were evolved for reduction of accidents and improving road safety in the study area.

4.9 MULTIPLE REGRESSION ANALYSIS

A multiple regression model was established by considering the number of vehicular traffic accident occurrences in a year as the dependent variable and the most influential independent variables such as, ADT, road width, speed, median width and number of accesses to arterial roads per kilometre. The values of ADT were taken in equivalent PCUs, speed was considered in km/h, and road width and median width both were taken in metres. The number of accesses to arterial routes are numbers without units. All the data points having accident occurrences and the related parameters observed from physical survey were utilised for the development of the model. The model was built by using the SPSS software. The functional equation for the multiple regression model, and the model established are presented as below:

$$y = f(x_1, x_2, x_3, \ldots x_n)$$

or $$y = \alpha x_1+\beta x_2+\gamma x_3+\delta x_4+\ldots\ldots+\zeta x_n+\varepsilon$$

where

y = dependent variable

$x_1, x_2, x_3, \ldots x_n$ are independent variables.

$\alpha, \beta, \gamma, \delta, \ldots\ldots \zeta$ are regression coefficients

ε = the standard error

The multiple regression model established was

$$y = -1.394x_1 + 0.323x_2 + 0.005974x_3 + 4.367\,x_4 - 4.802x_5 - 44.627$$

where

y = Number of accidents per year on the road sections

x_1= Road width

x_2= Speed (Km/h)

x_3= ADT in PCUs

x_4= Number of accesses

x_5= Median width

$r^2 = 0.93$

4.9.1 Validation of the model

The model established was validated to observe its suitability and correctness before employing it for future predictions and scenario analysis. For this purpose, the model was used to compute outputs from the set of inputs of the same variables available in other streets of the study area, which were not considered in the survey and subsequent analysis. The model results were closely examined and compared to the actual data available in the study area. The comparison between model results and the real data available are presented in Table 4-22 and Figure 4-16.

Table 4-22: Validation of model

	Road width (m)	**Speed (Km/h)**	**ADT**	**Nr. of access routes**	**Median width**	**Current Accidents**	**Simulated accidents**
Pellissier Drive	19.9	70	8250	18	13	17	15.663
Dirk Opperman Road	14.4	68	5953	4	0	11	10.250
Castelyn Drive	17.5	77	8084	15	12	13	11.979

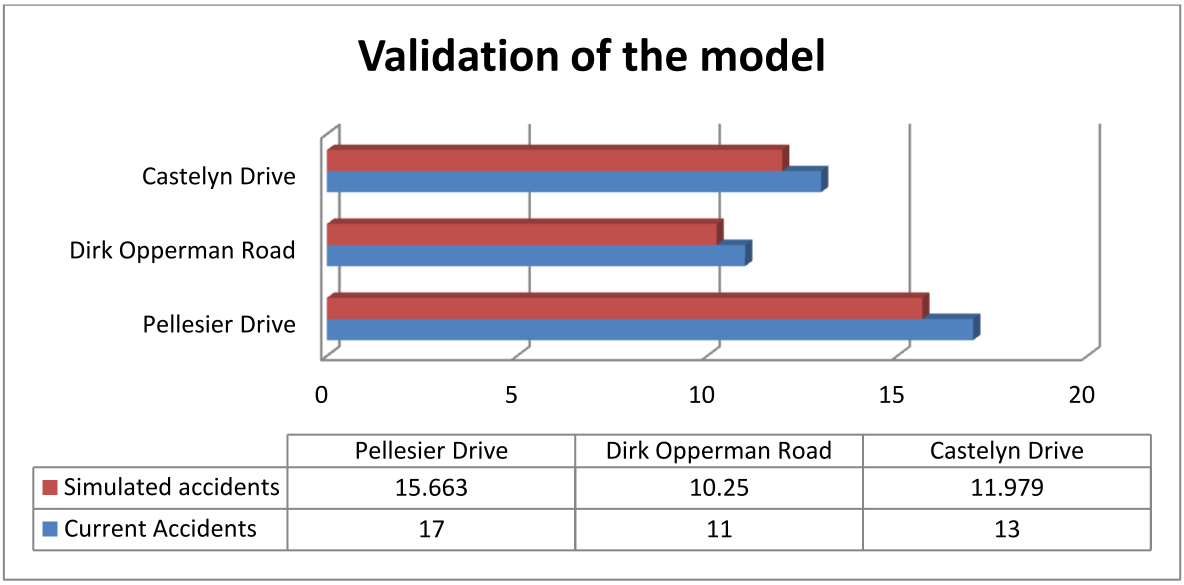

Figure 4-14: Validation of model

It was observed that the model results closely matched the actual data available with a variation of only 6.81% to 7.86% in the study area, thereby validating the model for its applicability for the prediction of vehicular accidents in the study area.

4.9.2 Forecasting of accidents

The validated multiple regression model was applied to predict the number of vehicular accidents in the area under various simulated scenarios by varying the independent variables. The various scenarios and predicted results are presented below.

4.10 SCENARIOS

For developing scenarios, a set of plausible policy runs were made and accordingly different scenarios were generated accordingly, based on the prevailing trend in the study area as observed from the survey. Further, expert opinion and the opinion of officials involved in traffic management were also considered in order to arrive at plausible decisions regarding developing scenarios. The important control variables which are considered for developing the simulated scenarios are:

- Change in road width
- Change in ADT
- Change in speed
- Change in number of accesses to arterial roads
- Change in median width

The simulation of conditions and the variation of the various independent variables forming the prediction of accidents are presented in the Table 4-23.

Table 4-23: Simulation conditions for prediction accidents in the study area

No.	Simulation conditions of variables	Variation in conditions
1	**Road width**	Varied from 7.5m minimum to 14.5m maximum at every 0.5 m increment
2	**Speed**	Varied from 40 km/hour minimum to 110 km/hour maximum at every 5 km/h increment
3	**ADT**	Varied from 6500 ADT minimum to 14000 ADT maximum at every 500 increment
4	**Number of accesses**	Varied from a minimum of 2 accesses to a maximum of 23 accesses per km with an increment of 1 access per simulation
5	**Median width**	Varied from 0 m minimum to 10 m maximum at 1 m increments

A number of simulation runs were conducted by considering the variables individually and in combination (presented in appendix A). From a total number of 486 simulated scenario's developed, 11 most important and feasible scenarios (Table 4-24) and 3 scenario's (Table 4-25, Table 4-26 and Table 4-27) based on special conditions were considered and discussed for the development of strategies for the reduction of traffic accidents and improvement of road safety.

The first stage of simulation is whereby every variable is considered and analysed separately. This gives the idea of the impact of each variable separately. The next stage consists of combining of variables (simultaneous changes to multiple variables in a planned sequence). This sequence starts by considering two variables, then three, then four, five, and, finally, all six variables respectively in that order. When single or multiple parameters is changed for the purpose of the simulation, the remainder of the parameters is left as its original specification. Appendix A illustrates the different simulations that were conducted. All the different simulations have been evaluated, and the most feasible scenarios (Table 4.24) have been considered for policy analysis.

Table 4-24: Most feasible scenarios

Policies	Simulation	Road width	Speed (Km/h)	ADT	Number of access roads	Median width	Number of accidents					
							Totius Road	Wynand Mouton Drive	De Bruyn Street	Paul Kruger Drive	Benade Drive	Volkspele Drive
1	**46**				8		38	43	3	35	13	22
2	**103**		65		9		39	43	3	36	14	29
3	**138**			8500	12		45	71	20	25	6	44
4	**198**		80	8500	12		46	71	21	27	8	51
5	**295**	7.5	60		8		41	40	5	39	28	31
6	**439**	8.0		7000	9		31	51	6	11	3	30
7	**326**			6500	8	0	35	42	35	34	22	29
8	**400**	12.0	110	11500		10	17	12	47	121	104	17
9	**422**		60	6500	8	0	30	35	30	29	18	30
10	**455**	8.0	65	7000	9		27	46	2	8	0	32
11	**486**	7.5	60	8000	8		28	47	2	9	1	33

4.10.1.1 Scenario1 (Simulation 46)

Scenario 1: The number of access streets has been changed from their existing number (Table 4-24) to eight per kilometre with the remainder of the variables remaining unchanged.

It has been observed that access points from residential areas to thoroughfares are one of the most important parameters, because it has a greater influence on the occurrence of accidents. Therefore, an attempt has been made to understand influence of the number of access points on occurrence of the vehicular accidents in the thoroughfares of suburban areas of the study area by changing it from its current number (Table 4-24) to 8 per kilometre of route length. The results of the model are presented in the Figure 4-15.

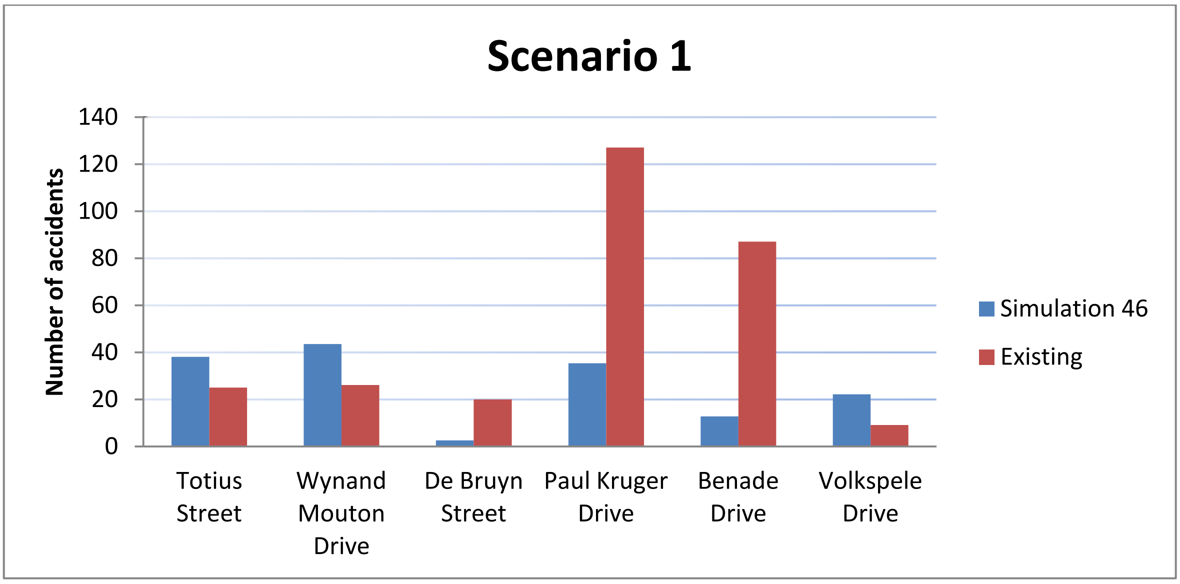

Figure 4-15: Number of occurrence of vehicular accidents under simulated scenario 1 and existing scenario

The figures revealed that the number of accidents in Totius street, Wynand Mouton Drive, and Volkspele Drive would increase to 38, 43, and 22 respectively which are higher by 52%, 65%, and 144% over the normal scenarios. On the other hand, De Bruyn Street, Paul Kruger Drive, and Benade Drive would register 3, 35, and 13 accidents which would reduce the present scenarios by 85%, 73%, and 85%. However, the lower number of accidents under the simulated conditions than actually occur in existing scenarios result because Paul Kruger Drive and Benade Drive have more access points than the perceived number (8) of access points. Thus, it was observed that, while three roads would register higher accident numbers with an increase of access points to the

thoroughfares alone, three other roads would register a lower number of accidents with the lowering of the number of access points on those roads.
However, if the number of access streets is below eight in existing conditions, the number of accidents will increase with an increase in access points.This shows that number of access points has a definite influence on the occurrence of accidents, with the number of accidents increasing with an increase in accesses to arterial routes.

4.10.1.2 Scenario 2 (Simulation 103)

Scenario 2: The speed has been changed to 65 km/h and the number of accesses to arterial routes to 9 per kilometre with the remainder of the variables remaining unchanged (Combination of speed and number of accesses).

Although the general speed limit within the city is 60 km/h, Table 4-24 illustrates that all the traffic on these roadways exceed this limit except Volkspele Drive. The average speed of these roadways combined is 73 km/h. Thus, the speed limit has been reduced by 8km/h. The number of accesses to arterial routes has been changed to nine per kilometre to restrict the number of collision points and to relate their influence to the number of accidents that occur.

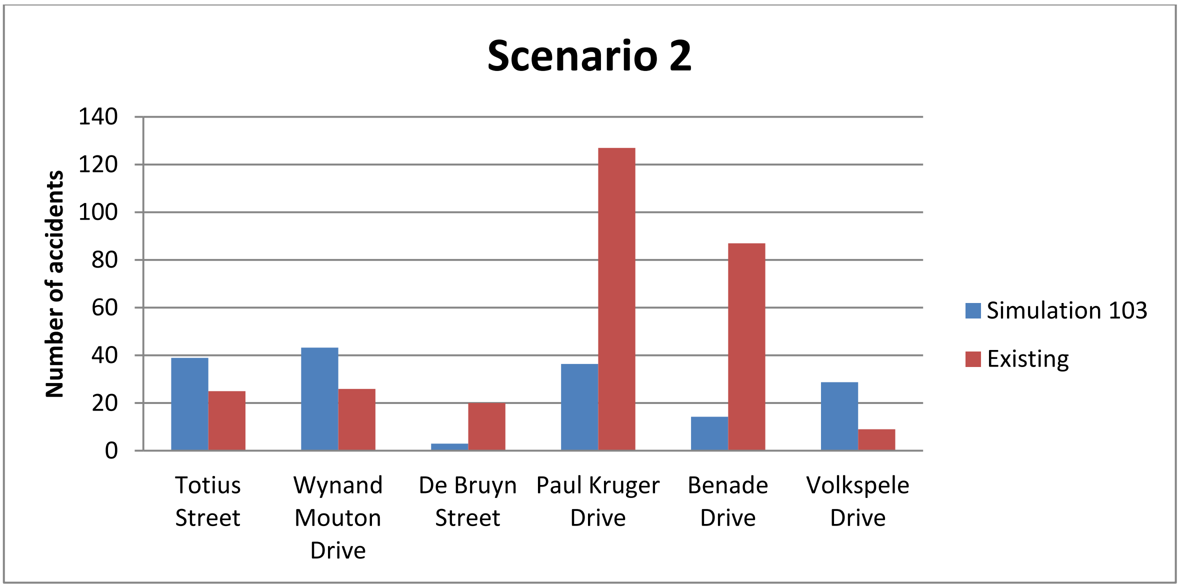

Figure 4-16: Occurrence of vehicular accidents under simulated scenario 2 and in the existing scenario

It can be seen that Totius street, Wynand Mouton Drive, and Volkspele Drive will experience an increase in the number of accidents from the existing occurrences of 25, 26, and 9 to 39, 43, and 29, thus raising the occurrence of accidents by 56%, 65%, and

222% respectively. On the other hand, the number of accidents in De Bruyn Street, Paul Kruger Drive, and Benade Drive will be decreased from 20, 127, and 87 to 3, 36, and 14, thus leading to a reduction of accidents by 85%, 72%, and 84% respectively. This indicates that increases in speed above the average speed and in the number of access points from current numbers would increase the number of accidents whereas lowering speed from the current average speed and decreasing the number of access points would together produce a reduced number of accidents in the study area.

4.10.1.3 Scenario 3 (Simulation 138)

Scenario 3: The ADT has been changed to 8500 PCUs and the number of accesses to arterial roads increased to 12 with the remainder of the variables (Table 4-24) remaining unchanged (Combination of ADT and number of accesses).

The average daily traffic is an indication of the frequent use for a road section. The frequent use of the road is linked to the number of accidents. In the current scenario, Totius street, Paul Kruger Drive, and Benade Drive have more than 10000 PCUs while the number of access points varies between 4 and 29. Thus, in this simulated scenario, a combination of an ADT of 8500 PCUs and 12 access points to arterial roads have been considered. The scenario is presented in Figure 4.18.

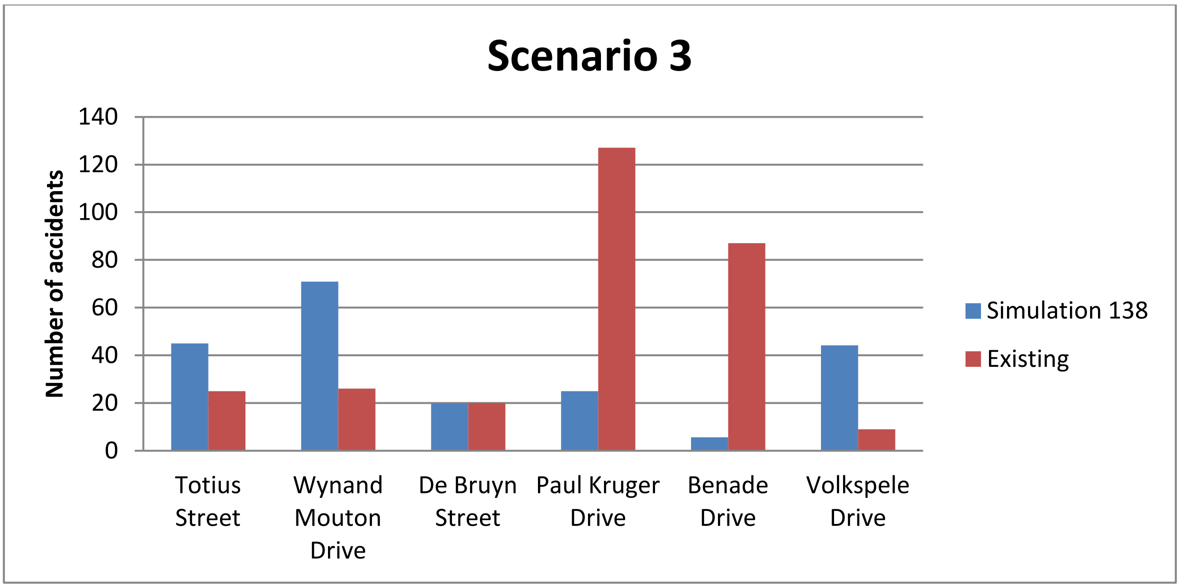

Figure 4-17: Number of vehicular accidents under simulated scenario 3 and in the existing scenario

It should be noted that De Bruyn Street is not influenced by the change in parameters as the numbers of accidents remain unchanged at its current level of 20 accidents per year. Totius street, Wynand Mouton Drive, and Volkspele Drive would experience increase in accidents from 25, 26, and 9 to 45, 71, and 44 respectively, registering increases of 80%, 170%, and 388% respectively. Paul Kruger Drive and Benade Drive would experience a decrease in the number of accidents from 127 and 87 to 25 and 6 respectively, registering decreases of 79% and 93% respectively in the occurrence of accidents. It can also be seen that the roads having a higher number of accesses as well as an increase in ADT experience a large increase in the occurrence of accidents, whereas a decrease in ADT from current levels combined with a marginal increase of access points would lead to a significant decrease in the occurrence of accidents.

4.10.1.4 Scenario 4 (Simulation 198)

Scenario: The ADT has been changed to 8500 with the number of access streets to 12. The speed has been changed to 80 km/h with the remainder of the variables (Table 4.24) unchanged (Combination of speed, number of accesses to arterial roads, and ADT).

The speed has been changed to 80 km/h, which is 7 km/h higher than the average speed of the selected roads, and combined with an ADT of 8500 PCUs and 12 accesses to arterial roads.

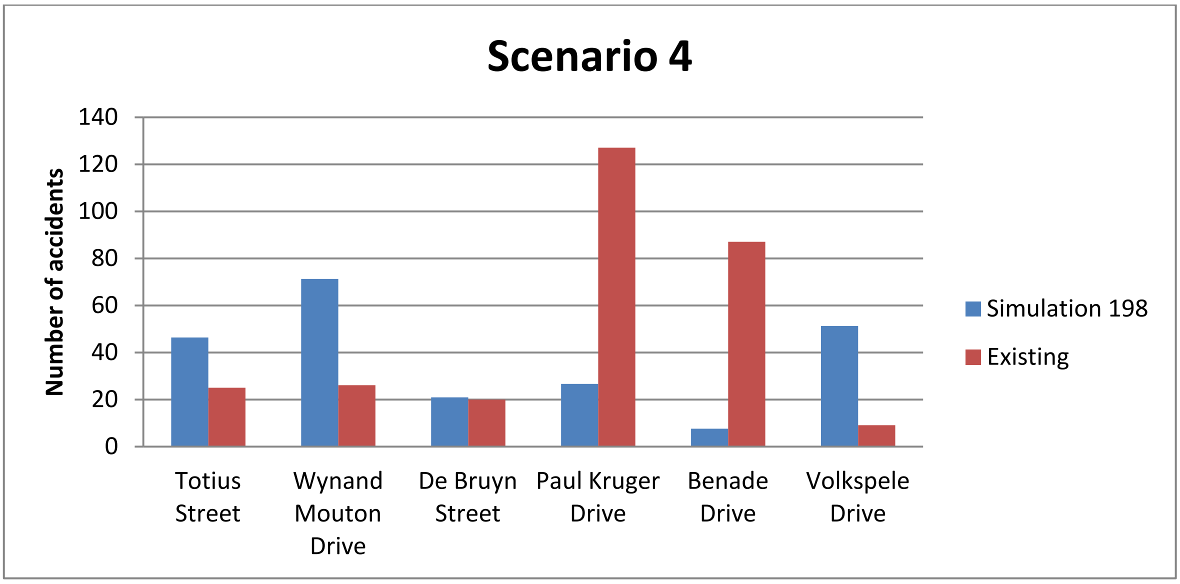

Figure 4-18: Number of vehicular accidents under simulated scenario 4 and in the existing scenario

The number of accidents for De Bruyn Street is increased by one accident per year, which is very marginal. However, Totius street and Wynand Mouton Drive have steep increases in accident numbers from 25 and 26 to 46 and 71 respectively. This is an increase of 84% and 173% respectively over the current occurrence of accidents. Paul Kruger Drive and

Benade Drive experience a decrease in the number of accidents from 127 and 87 to 27 and 8 respectively. The decrease of accidents is not significant in comparison to scenario 3 because the speed in the two road sections is below 80 km/h, which is not much higher than the average speed in the existing scenario.

4.10.1.5 Scenario 5 (Simulation 295)

Scenario: The road width has been changed to 7.5 metres with the number of access streets to 8 and the speed has been changed to 60 km/h with the remainder of the variables (Table 4.24) unchanged (Combination of road width, number of access streets, and speed).

The speed is changed to the general speed limit for this city, namely, 60 km/h. The road width has been changed to 7.5 metres for all road sections and the number of access roads has been changed to 8.

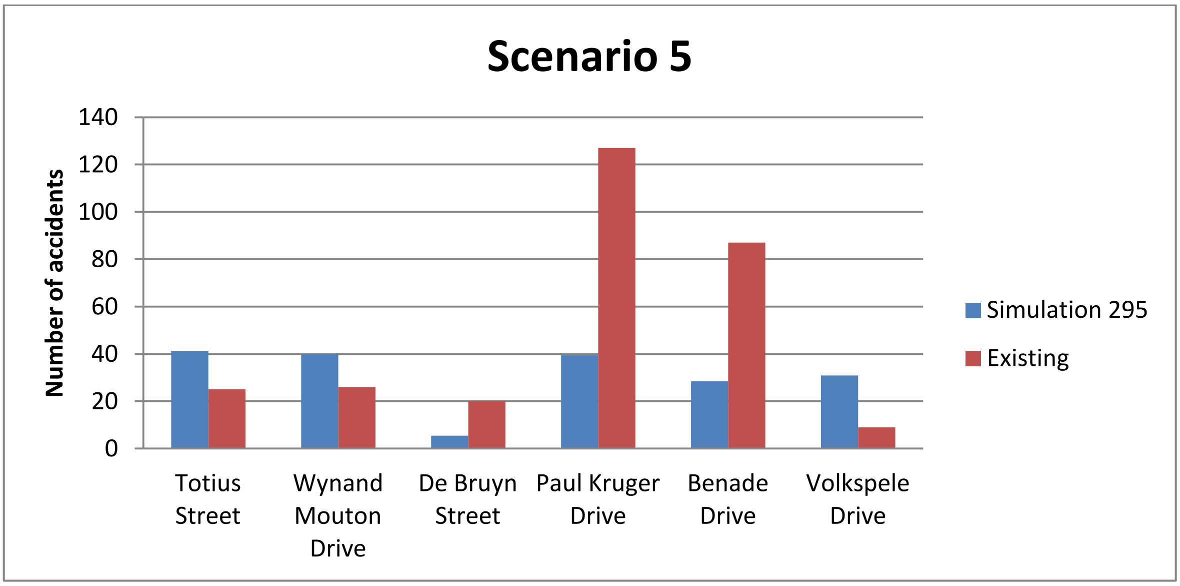

Figure 4-19: Number of occurrence of vehicular accidents under simulated scenario 5 and existing scenario

This scenario shows an increase in the occurrence of accidents in Totius street, Wynand Mouton Drive and Volkspele Drive from 25, 26, and 9 to 41, 40, and 31 respectively, i.e., an increase of 64%, 54%, and 244% respectively. This is due to the fact that these road sections have a lower number of accesses (i.e., 5, 4, and 5 accesses in the three roads respectively) than the 8 accesses envisaged in the simulation. On the other hand, De Bruyn Street, Paul Kruger Drive, and Benade Drive would experience a decline in the number of accidents from 20, 127, and 87 to 5, 39, and 28 respectively. It should be noted that the road width of all these roads is 7.5m; however, the actual number of accesses extreamly high and speed (70 km/h to 80 km/h) are much higher than the envisaged simulated variables. Thus, a decrease in number of accesses and speed with no significant change in road width will lead to a decline in occurrence of accidents.

4.10.1.6 Scenario 6 (Simulation 439)

Scenario: The road width has been changed to 8 metres, the number of access streets to 9, and the ADT to 7000 with the remainder of the variables (Table 4-24) unchanged (Combination of road width, ADT, and number of accesses to arterial roads).

The road width and the number of access streets have been changed to 8 metres and to 9 accesses to arterial roads respectively. This is a small alteration to the policy 5, although the speed has been unaltered, and the number of ADTs has been set at 7000.

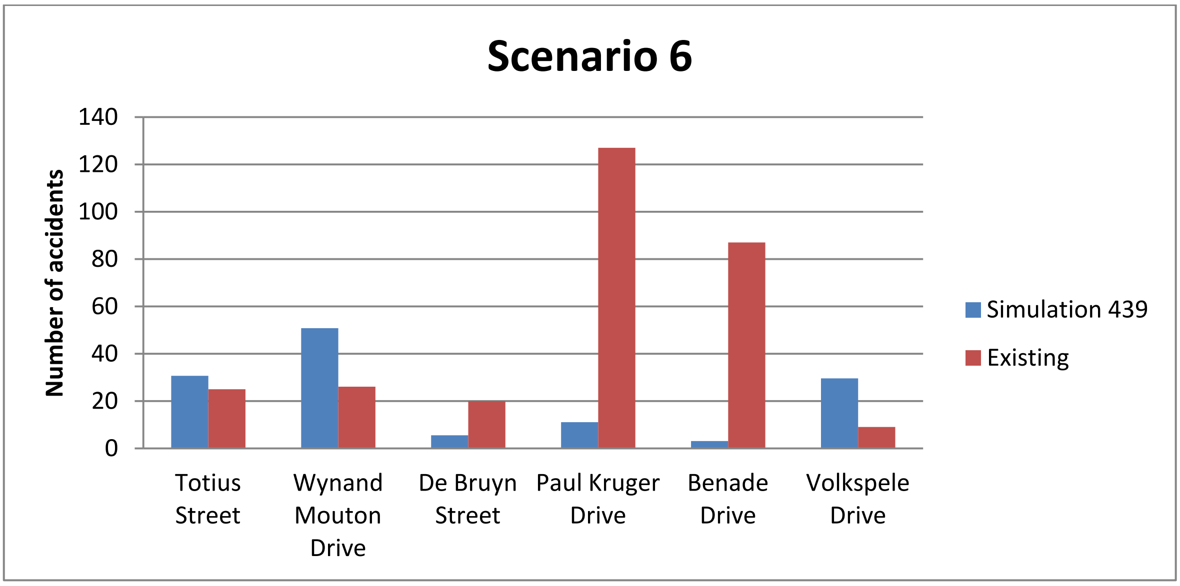

Figure 4-20: Number of vehicular accidents under simulated scenario 6 and in the existing scenario

This simulated scenario reveals that there would be a large reduction of traffic accidents in Paul Kruger Drive and Benede Drive from 127 and 87 to 11 and 3, a reduction of 91% and 97% respectively. Similarly, De Bruyn Street would also have a reduction from 20 to 6 accidents (70%). However, a significant increase in accidents would be experienced in Totius street, Wynand Mouton Drive, and Volkspele Drive (i.e., from 25, 26 and 9 to 31,9 (24%), 51 (96%), and 30 (233%) respectively). Totius street would have a smaller increase because it would have a greater advantage with the ADT drop from 10261 to 7000.

Thus, it may be observed that a significant reduction in accidents would occur in Paul Kruger Drive and Benade Drive, whereas a smaller decrease of accidents would occur in De Bruyn Street. The results for the remaining roads indicate that there would be an increase in accidents in Volkspele Drive and Wynand Mouton Drive. Therefore, it can be inferred that an increase in the values of the variables from their existing levels will lead to an increase in the occurrence of accidents while a decrease in their values would lead to a reduction in the occurrence of accidents.

4.10.1.7 Scenario 7 (Simulation 326)

Scenario: The median width has been changed to 0 metres, the number of access streets to 8, and the ADT to 6500, with the remainder of the variables (Table 4-24) unchanged (Combination of ADT and number of accesses to arterial roads with no median).

The reduction of median width will influence all the roadways with large medians. Reducing the median width to zero basically indicates that there is no median. A median provides a safe split between the directional traffic. The greater the median width, the fewer the accidents that are likely to occur. The ADT has been changed to 6500 to restrict the number of vehicles, while the number of access streets has been changed to 8.

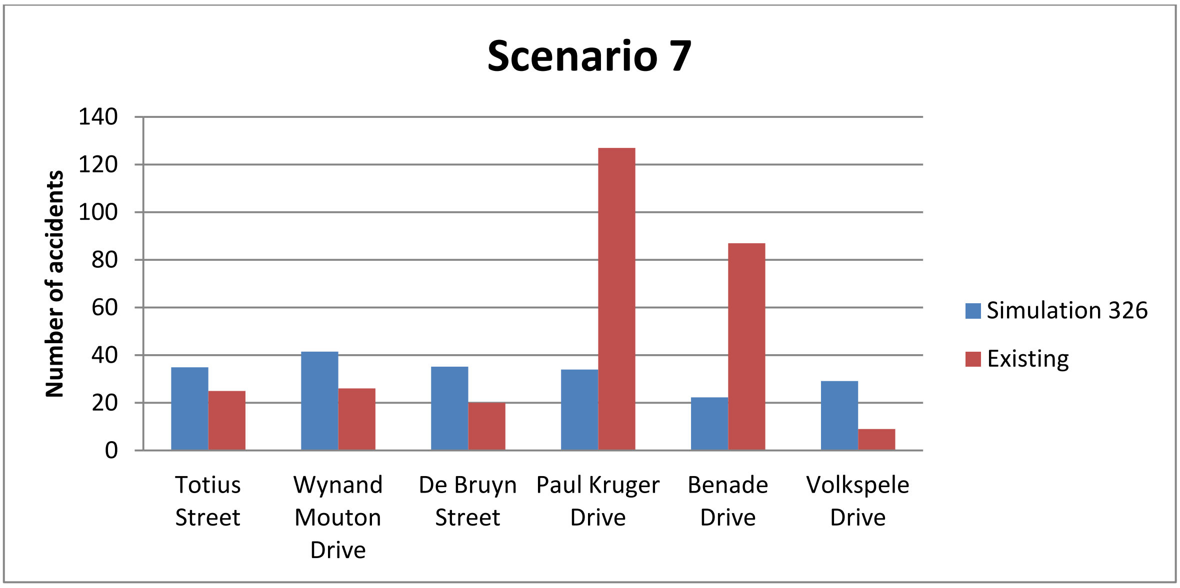

Figure 4-21: Number of vehicular accidents under simulated scenario 7 and in the existing scenario

These simulated results reveal that Benede Drive and Paul Kruger Drive are the only roads which would be positively influenced in this scenario. The number of accidents would be reduced by 73% (from 127 to 34) and 75% (from 87 to 22) in Paul Kruger Drive and Benede Drive respectively. Both roads are busy with a higher volume of daily traffic and a higher number of accesses, so a restriction of both the ADT and the number of accesses without any median would result in the reduction of accidents. However, on the other roads, such as Totius street, Wynand Mouton Drive, Volkspele Drive, and De Bruyn Street, there would be a moderate to significant increase in accidents (i.e, a 40% increase in Totius street, a 62% increase in Wynand Mouton Drive, a 222% increase in Volkspele Drive, and a 75% increase in De Bruyn Street. This increase is due to the fact that all of these roads have significant median widths, even though the ADT and the number of accesses are lower than envisaged in the simulation. This suggests that, in less busy roads, if the ADT and the number of accesses to them are increased without providing proper median width, the occurrence of accidents would increase significantly.

4.10.1.8 Scenario 8 (Simulation 400)

Scenario: The median and road width has been changed to 10 and 12 metres respectively, together with increase in speed to 110 km/h and the ADT to 11500 PCUs, keeping other variables (Table 4-24) unchanged (Combination ADT, speed, road width, and median width)

A combined scenario was simulated where the speed was increased to 110 km/h which is about 37 km/h above the average speed (73 km/h) and 50 km/h above the city speed limit for the selected roads. Together with this increase, the median widths have been increased to 10 metres from their normal widths while road widths have been increased to 12 metres. Also in these roads, the ADT was increased to 11500.

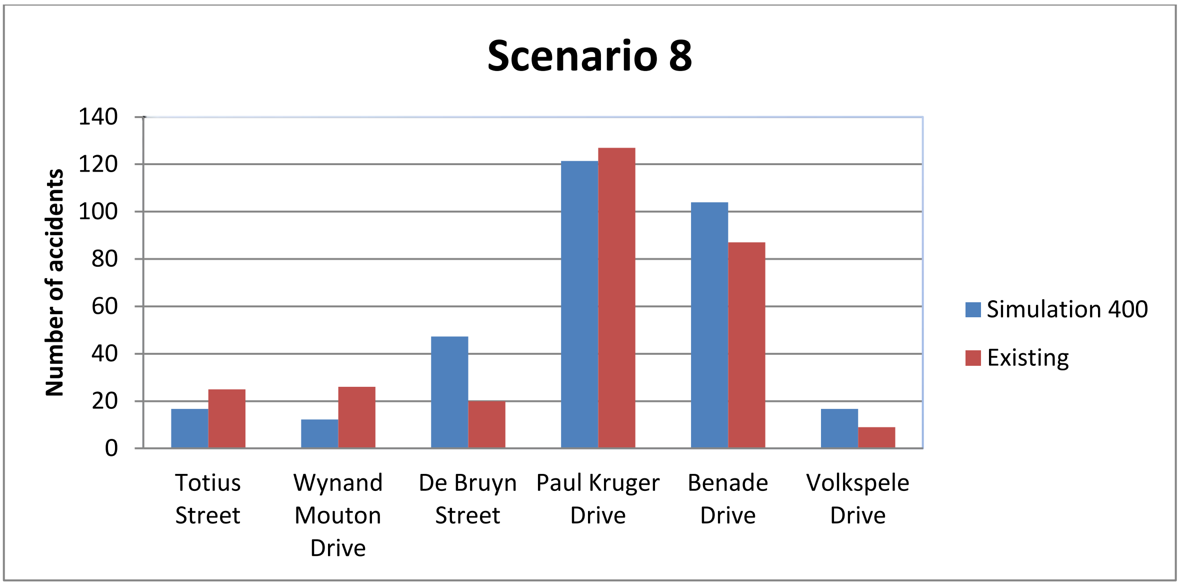

Figure 4-22: Number of occurrence of vehicular accidents under simulated scenario 8 and in the existing scenario

This results in this scenario reveal that De Bruyn Street and Volkspele Drive would experience significant increases (135% and 89% respectively) in the occurrence of accidents whereas Benade Drive would experience a marginal increase (24%). This means that higher occurrences of accidents would be experienced with significant increases in speed and in ADT, irrespective of any increase in road width and in median width. On the other hand, busy roads, such as Totius street, Wynand Mouton Drive, and Paul Kruger Drive, would experience a reduction in the occurrence of accidents (32%, 54% and 5% respectively). Thus, the increase in road width and median width would assist in either controlling or reducing the occurrence of accidents on busy roads with lower widths, despite high speed and high ADT.

4.10.1.9 Scenario 9 (Simulation 422)

Scenario: The speed has been kept to the city speed limit of 60 km/h, the number of access roads has been changed to 8, the ADT has been changed to 6500, with no provision of medians (table 4-24), while the remainder of the variables remain unchanged (Combination ADT, speed, number of accesses to arterial roads, with no medians).

This scenario has been envisaged for roads where the space availability for roads is highly restricted.

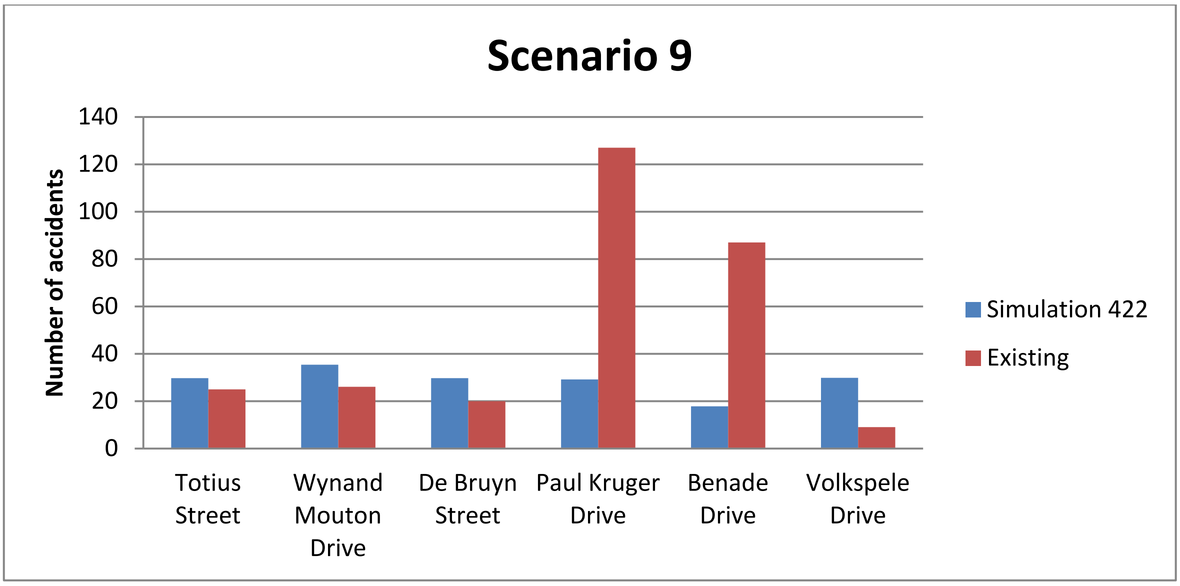

Figure 4-23: Number of occurrence of vehicular accidents under simulated scenario 9 and in the existing scenario

The scenario results show that there would be insignificant to moderate increases in the occurrence of accidents in roads such as Totius street, Wynand Mouton Drive, and De Bruyn Street (11%, 35%, and 50% respectively), while Volkspele Drive would experience a huge increase (233%) in the incidence of accidents. However, there would be a significant reduction in accidents in Paul Kruger Drive and Benade Drive. This is due to the presence of a large number of access streets to these roads and a high ADT in the existing conditions hence a reduction in them would reduce the number of accidents. This means that, if the speed and ADTs are limited, together with limited accesses, even without a median, there would be either a marginal increase or a reduction in the occurrence of accidents.

4.10.1.10 Scenario 10 (Simulation 455)

Scenario: The road width has been changed to 9 metres, the speed has been changed to 65 km/h. the number of access roads has been changed to 8 and the ADT has been changed to 7000 with the remainder of the variables remaining unchanged (combination road width, ADT, speed, number of accesses to arterial roads with).

The width of the road has been increased to 9 metres in order to standardise the road width in the city and the speed has been taken as 65 km/h in order to observe the consequences of increasing the speed limit of the city by 8%, together with an average ADT of 7000 PCUs.

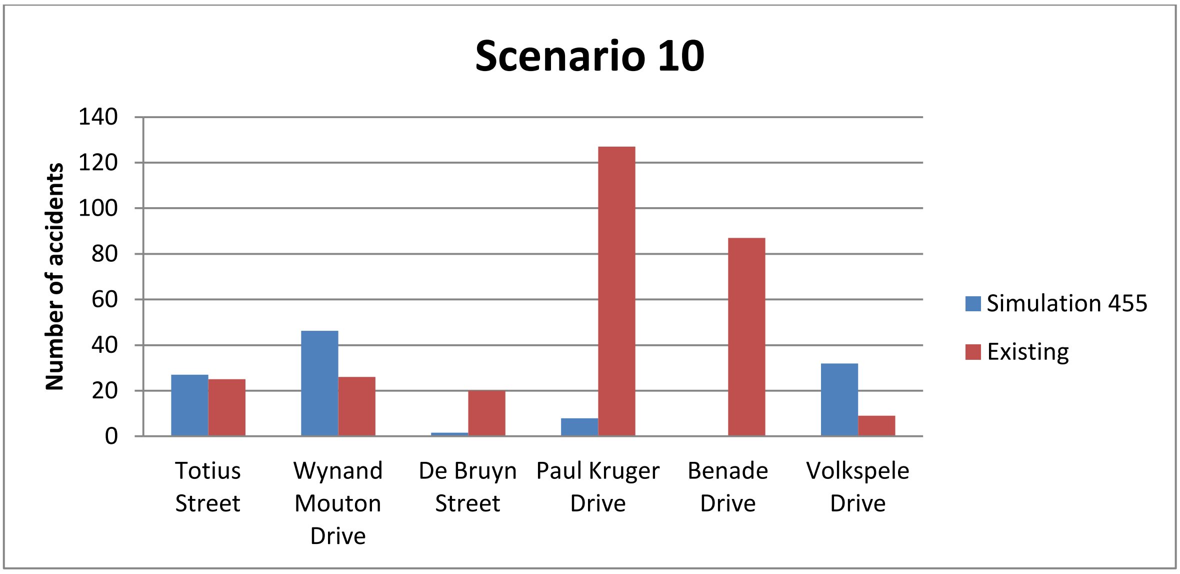

Figure 4-24: Number of occurrence of vehicular accidents under simulated scenario 10 and in the existing scenario

From these results, it can be seen that there would be a reduction of, or control over, the occurrence of accidents in almost all roads except Wynand Mouton Drive and Volkspele Drive. The maximum reduction of accidents would occur on road sections such as De Bruyn Street, Paul Kruger Drive, and Benade Drive, which have a high number of access roads, high ADT, and average vehicular speeds that are higher than the city speed limit in the existing scenario. These roads would experience significant reductions (90%, 96% and 100% respectively) in the occurrence of accidents. Totius street would experience a very marginal increase (8%) of accidents. However, Wynand Mouton and Volkspele Drives would experience large increases in the occurrence of accidents. These two cases are exceptional as the simulated scenario is very similar to existing scenarios, and it may be that there are other possible variables which influence the reduction of accidents in these two roads.

4.10.1.11 Scenario 11 (Simulation 486)

Scenario: The road width has been changed to 7.5 metres, the speed to 60 km/h, the number of access roads to 8, and the ADT to 8000 with the remaining variables unchanged (Combination road width, ADT, speed, number of accesses to arterial roads).

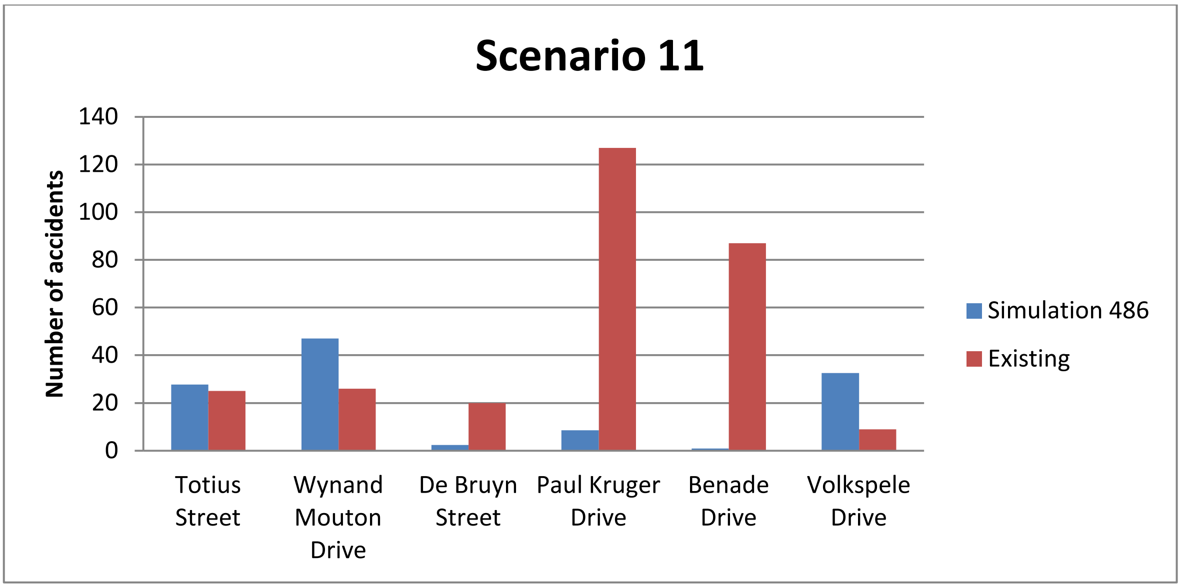

Figure 4-25: Number of vehicular accidents under simulated scenario 11 and in the existing scenario

In this scenario, it should be noted that three of the roads - De Bruyn Street, Paul Kruger Drive, and Benade Drive – would experience a drastic reduction in the occurrence of accidents 90%, 92,% and 99% respectively. Simultaneously, although it can be seen that the occurrence of accidents would increase in the other three roads, namely, Totius street, Wynand Mouton Drive, and Volkspele Drive, the increase would not be very high.

4.10.1.12 Special conditions

The previous simulated scenarios have shown that not all road sections show similar trends if variables are changed to all the road sections simultaneously. Therefore, in addition to the above scenarios, certain special scenarios were considered in these limiting or extreme conditions in order to observe the trends of accident occurrence in the study area under such circumstances. In these scenarios, every road is analysed individually under limiting scenarios.

4.10.1.12.1 Special condition 1

Table 4.25 presents the special condition 1 in which the speed has been reduced to 50 km/h from the city speed limit of 60 km/h for all roads, and the ADT has been reduced by 20% from the existing ADT on all roads except Volkspele Drive, and the number of accesses to Paul Kruger and Benede Drive has been reduced by 48% for both, while all other variables remain same as in the existing scenario.

Table 4-25: Special condition 1

	Road width (m)	Speed (Km/h)	ADT	Number of access streets	Median width	New number for accidents	Existing number of accidents
Totius Street	13.5	50	8,209	5	4	4	25
Wynand Mouton Drive	9.4	50	5,460	4	0	8	26
De Bruyn Street	13.5	50	8,514	12	9.3	11	20
Paul Kruger Drive	13.9	50	10,524	15	8	42	127
Benade Drive	22	50	10,091	13	9.6	12	87
Volkspele Drive	13.4	50	7,728	5	3	6	9

This scenario was considered as Volkspele Drive, Paul Kruger Drive, and Benade Drive provide exceptional results that are contrary to the normal trends under normal simulated scenarios.

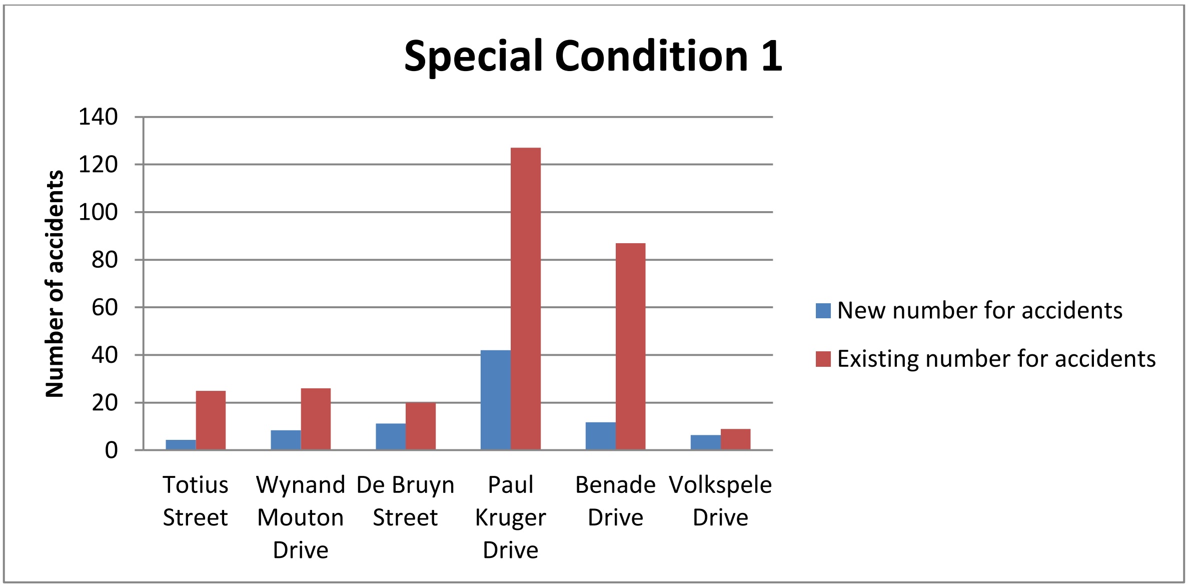

Figure 4-26: Special condition 1

From this scenario, it can be seen (Figure 4-26) that there is a significant reduction of accidents on all roads. Although the number of accidents in Paul Kruger Drive would still be significantly higher than other roads, yet a 67% reduction of accidents in the road without changing the size of the road or the median width would still be significant.

Overall, there would be a reduction in the occurrence of accidents averaging 71% on all roads.

4.10.1.12.2 Special condition 2

The previous condition focused on the reduction of speed, the ADT, and the number of access streets on selected roads. This is a follow-up from the previous condition whereby the conditions were kept except that the speed was reduced further to 40 km/h. All other parameters were kept as in the case of special condition 1. This scenario was considered in order to observe what the impact of drastically reducing the city speed limit would be on the occurrence of road accidents.

Table 4-26: Special condition 2

	Road width (m)	Speed (Km/h)	ADT	Number of access streets	Median width	New number for accidents	Existing number of accidents
Totius Street	13.5	40	8 209	5	4	1	25
Wynand Mouton Drive	9.4	40	5 460	4	0	5	26
De Bruyn Street	13.5	40	8 514	12	9.3	8	20
Paul Kruger Drive	13.9	40	10 524	15	8	39	127
Benade Drive	22	40	10 091	13	9.6	9	87
Volkspele Drive	13.4	40	7 728	5	3	3	9

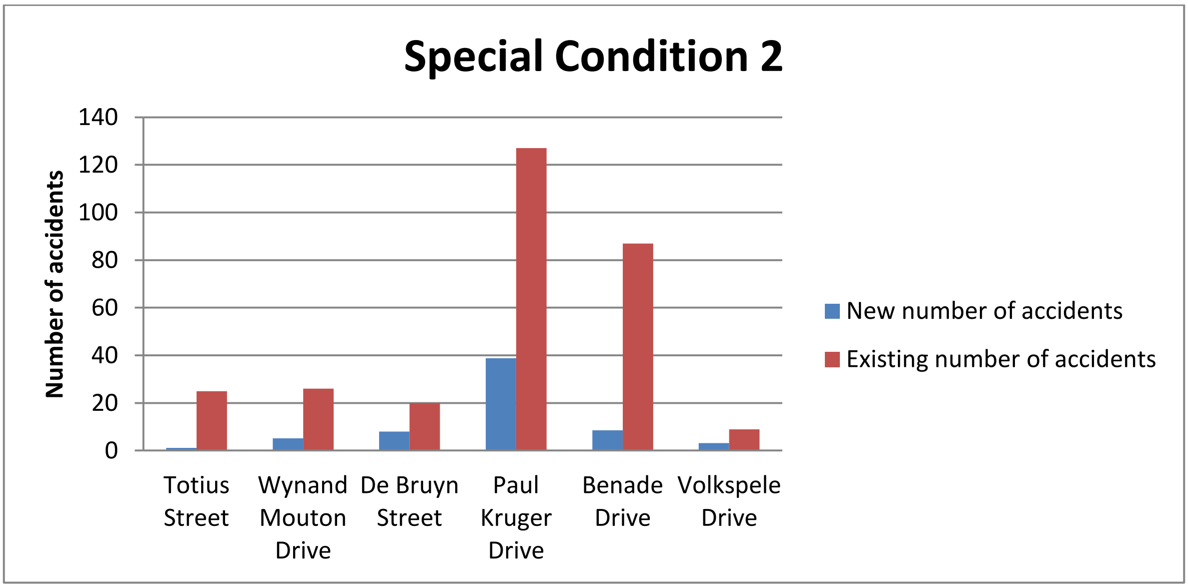

Figure 4-27: Special condition 2

The simulated result (Figure 4.27) revealed that, with a significant decrease in speed limit, the number of accidents would be reduced drastically. There would be a minimum of 60% and a maximum of 96% decrease in road traffic accidents if the speed were drastically reduced, together with a reduction of traffic volume on busy roads and a reduction of the number of accesses in highly accessible roads. However, it can be seen that the lower the speed, the lower the occurrence of accidents. This scenario could act as a boundary condition in the accident prediction analysis.

4.10.1.12.3 Special condition 3

In addition to the above limiting scenarios, one worst case scenario was considered as another boundary condition. In this scenario, the focus was on the growth of the ADT and the speed within the residential area. The other existing conditions remained unchanged.

Table 4-27: Special condition 3

	Road width (m)	Speed (Km/h)	ADT	Number of access streets	Median width	New number for accidents	Existing number for accidents
Totius Street	13.5	120	12,313	5	4	51	25
Wynand Mouton Drive	9.4	120	8,190	4	0	47	26
De Bruyn Street	13.5	120	10,217	12	9.3	44	20
Paul Kruger Drive	13.9	120	15,786	29	8	157	127
Benade Drive	22	120	15,137	25	9.6	117	87
Volkspele Drive	13.4	120	9,274	5	3	38	9

The speed is increased to a 120 km/h and the ADT is increased by 20%. These have been changed to forecast the effect if the traffic increases with the speed accumulating.

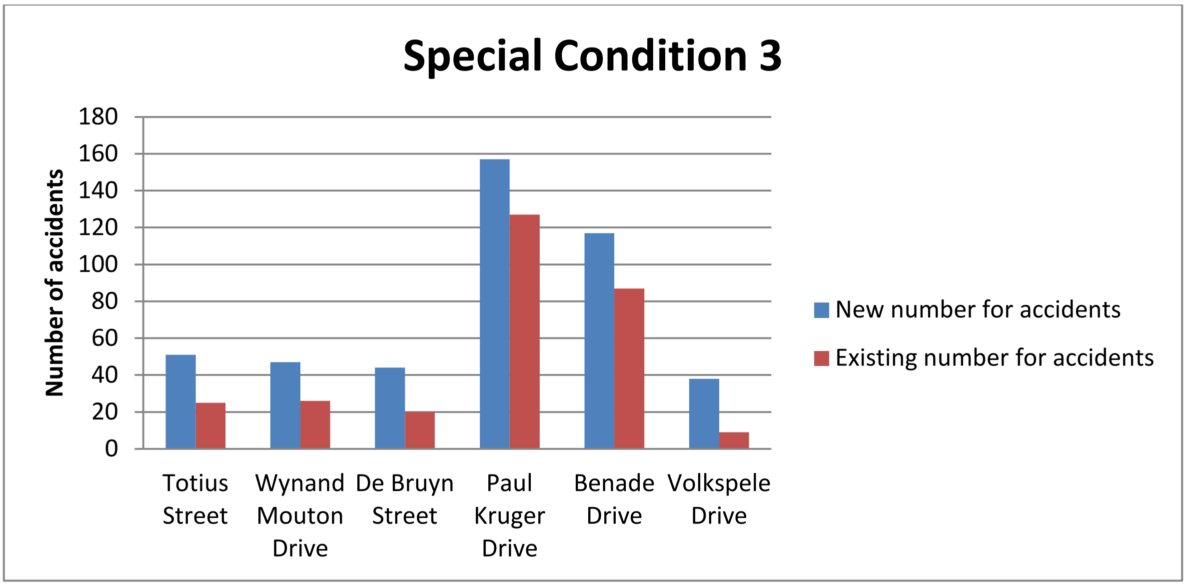

Figure 4-28: Special condition 3

Figure 4.29 presents the simulated results of this scenario. In this scenario, it can be seen that there will be a significant increase in occurrence of accidents on all the roads. Volkspele Drive will experience the highest increase (325%) of traffic accidents. Totius Street, Wynand Mouton Drive, and De Bruyn Street would experience increases in accidents occurrence ranging from 82% to 120%. Paul Kruger Drive and Benade Drive would have the lowest increase (23% and 34% respectively) in the number of accidents. respectively This is due to the fact that these roadways are already carrying a high number of ADTs and have a very high average speed in the current situation. Thus it may be observed that, in the extreme scenarios of very high speeds and a high ADT, roads carrying less ADT and having an average speed on a par with the current situation, would experience significant increases in occurrence of accidents while roads carrying exceptionally high ADT and having a high average speed in the current scenario would experience a moderate increase in the occurrence of accidents.

4.10.1.13 Hypothesis testing

From the validated regression model obtained, a test was done to prove if the hypothesis is either true or false. Table 4-28 illustrates the results of the hypothesis testing which was done by varying one variable i.e., the number of accesses to the suburban arterial roads and keeping all other variables unchanged (average values of the surveyed results of various variables). In this regard, the values of the variable considered are: average speed, 73 km/h; road width, 14 metres, the ADT, 9850 and the median width, 5.65 metres.

Table 4-28: Hypothesis testing

Number of access streets	4	6	8	10	12	14
Number of accidents	9	17	26	35	44	52

Table 4-28 shows that, with an increase in the number of accesses to suburban arterial roads from the residential areas or vice versa, the number of occurrences of accidents increases in a parallel context. This proves the hypothesis considered in this investigation: that if the numbers of accesses to suburban arterial roads are reduced, the occurrence of accidents will decrease.

4.10.1.14 Comparison of policy

Figure 4-29 presents a comparative analysis of the various scenarios obtained and discussed. The comparative analysis was conducted to observe the most suitable scenario(s), which could be considered for general policy formulation for the reduction of accidents, and the improve road safety in the study area.

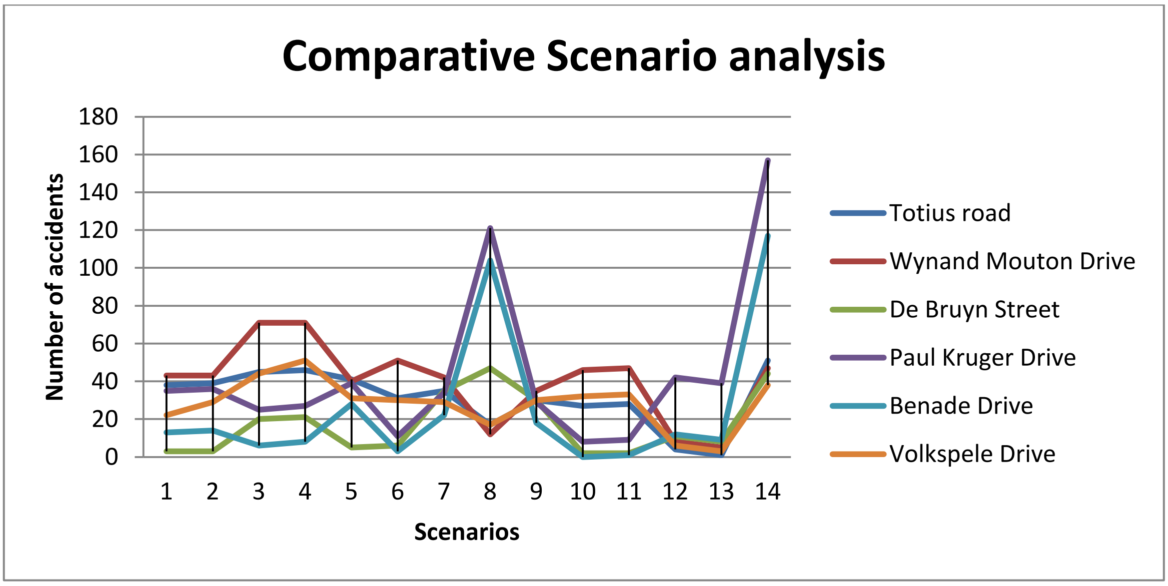

Figure 4-29: Comparative analysis of various scenarios

This comparative analysis reveals that, in scenario 8, the study area would experience a very high number of accidents on at least two road sections. This would automatically dispense with scenario 8 for consideration in future policy development. Similarly, under scenarios 3 and 4, some of the roads (Wynand Mouton Drive and Volkspele Drive) would have higher occurrences of accidents. Except for isolated occurrences, all other scenarios (scenarios 1, 2, 5, 6, 7, 9) provide similar trends of lower accident occurrences on almost all the roads. However, in scenarios 10, 11 and 12, there would be the lowest occurrence of accidents, therefore they provide the most suitable conditions for the reduction of accidents in the study area. Since scenarios 11 and 12 are special scenarios with limiting conditions and can be used only in exceptional situations, scenario 11, which is a combined scenario, based on an average road width of 8 metres, a speed of 60 km/h, a maximum number of 8 access roads to arterial roads, and an average ADT of 8000 PCUs, is considered most appropriate for evolving policy guidelines for the reduction of accidents and the improvement of road safety on the arterial roads of the suburban areas of the study area.

5. CHAPTER 5 FINDINGS, POLICY GUIDELINES, AND CONCLUSION

5.1 INTRODUCTION

The development of a set of planning and design guidelines to improve the road safety and reduce vehicular traffic accidents on the arterial roads of the suburban areas of the Bloemfontein city, South Africa required an investigation that evaluated the existing socio-economic, road and traffic-related scenarios in the city and explored the causes of vehicular traffic accidents, as well as predicted the occurrence of accidents on the suburban arterial roads in different scenarios. Therefore, for this purposes of this present investigation, different kinds of analysis were made at various stages, including a literature review, the analyses of data both from survey and secondary sources, and the development of a regression model for the prediction of vehicular accidents under various simulated scenarios.

In this chapter, inferences are drawn from the results of the analyses conducted, followed by the development of a planning concept for the reduction of accidents. The inferences drawn and development concept were used to evolve policy guidelines and plausible recommendations for the reduction of vehicular accidents on the arterial roads of the suburban areas of the study area. These inferences are presented in the following section.

5.2 INFERENCES FROM LITERATURE REVIEW

The following inferences can be made:

- Higher number of accidents occur on the arterial roads (thoroughfares) passing through the suburban residential areas with more commercial land use.
- The occurrence of accidents varies on the arterial routes. The roads having a higher number of accesses to residential areas and passing through mixed land use or multiple functional areas experience a higher number of accidents because of a high volume of traffic (ADT). On the contrary, limited access residential suburban areas experience fewer accidents in their arterial roads.
- The majority of the vehicular accidents occur near intersections or in specific areas near the intersections, better known as black spots.

- The road’s geometric design parameters, such as the horizontal curvature’s average degree, the gradient, the frequency of change in a curve’s direction, road width, lane and shoulder width, and medians influence vehicular accidents on the roads.
- Speed and the lack of appropriate lane width influence the occurrence of higher numbers of accidents on the arterial routes carrying higher traffic.
- There exists a relationship between traffic accidents and urban development. Urban densities, the travel behaviour of commuters, network connectivity, trip-rate, etc., influence vehicular traffic accidents.
- Residential factors have an influence on a commuter’s travel decisions. The mode choice of individuals is also influenced by the location of the residential area, socio-economic conditions, occupation, family status, people’s attitude, moral obligation, and the availability of public transportation system. In addition to these, travel time, travel patterns, and trip generation also influence vehicular accident occurrences in suburban areas.
- The factors which influence commuters’ decision-making processes, such as psychological, economic, and situational factors, are related to the occurrence of vehicular traffic accidents in suburban areas.
- The departure time of commuters during peak hours does not have a major impact on the increase of traffic levels.
- The identification of accident or collision patterns requires a clear understanding of the design and operation of specific roads and their traffic control devices.
- The countermeasures available for reducing or avoiding accidents are location- and context-specific.
- There is a need for identifying and correcting accident problems, particularly in urban arterial roads by considering geographical, demographic, and traffic management measures.
- Several models are available for accident predictions. These models are mostly location-, context-, or parameter-specific, and have been used with varying degrees of success. Therefore, the development of an appropriate accident prediction model based on the context and location is essential for reliable prediction which can then be used for development of policy guidelines for the reduction of vehicular accidents.

5.3 INFERENCES FROM SURVEYS, SPATIAL ANALYSES, AND THE REGRESSION MODEL IN THE STUDY AREA

The inferences drawn from the various surveys conducted in the study area, spatial analyses, and statistical modelling are presented below:

- The average household size in the study area is 2.02
- The average number of vehicles per household in the study area is 2.
- About 95% of people in the study area are employed.
- About 95% of people need vehicular transportation for their daily functions.
- About 60% of people use private or individual vehicles for their transportation needs with 40% using public transportation.
- The average number of trips (commuting rounds) generated by households is 2.
- The number of accidents in the different suburban areas of the study area ranges from 31 to 429 per year.
- The number of accidents at the intersections of surveyed areas varies from 0 to 38 per annum.
- The number of accidents on surveyed road sections varies from 0 to 160 in the study area per annum.
- The rate of accidents has been increasing by 11% over the last five years in the study area.
- The lane width should be more than 3.7 metres per lane according to the design standards. However, in the study area, the majority of the roads have lane widths narrower than the required design width; and the narrower lanes occur mainly on the roads that have multiple lanes.
- The road width of the different sections varies from narrow road sections with single lanes (3.35m) to wider road sections with multiple lanes (9.95m).
- The ADT is more than 6800 PCUs per day on most of the arterial roads in the suburban areas of the study area. However, on some roads, it is as high as 13155 PCUs. The high volume of traffic indicates the importance of the suburban arterial roads in the study area for the vehicular movement of people conducting their daily activities.
- There are two peak hours of traffic flow in the study area: from 06h00 to 08h00 and from 16h00 to 18h00 daily. However, on certain roads, the peak hours vary, particularly on roads that pass civic facility areas with schools or universities.
- The speed of the vehicles in some cases exceeds the permissible limit of 60 km/h on the arterials routes in the suburbs of the study area.

- The higher speed (exceeding the general speed limit), together with the high volume of traffic during peak hours, makes the suburban arterial roads vulnerable to vehicular traffic accidents.
- The number of access roads from the residential areas to arterial roads is the most important cause of accidents.
- The number of accesses from residential areas to suburban arterial thoroughfares ranges from a minimum of 8 to 15 per kilometre in certain roads.
- Not all road sections have medians. However, certain roads have a median width varying from 3m to 13m.
- Most of the major intersections in the study area, with very few exceptions, are controlled by automatic signal systems.
- The un-signalised intersections are controlled by stop signs. The roundabouts are controlled by systems similar to stop signs.
- The pavement condition of most roads is good. Adequate pavement markings and traffic signs are provided in the roads of the study area.
- Most of the curves in roads have a gentle radius of curvature.
- The sight distances provided in the surveyed roads are according to the design standards.
- Most of the roads surveyed have a gentle gradient.
- Although kerbs are provided in almost all roads, they are not accessible.
- There are no shoulders provided on the sides of the roads surveyed.
- The major parameters which were found to be most influential are road width, speed (km/h), ADT, the number of access roads, median width, and the number of lanes of the specific road sections. It was found that these parameters are the major contributors to traffic accidents in the suburban areas of Bloemfontein.
- Of the different parameters, the number of access roads has the largest bearing on the occurrence of accidents in the study area.
- All the suburbs surveyed have similar urban forms and urban patterns with marginal variations in land use and urban functions.
- Urban form, land use, and urban functions influence the generation of traffic in the study area, except that the number of accesses to residential areas from the arterial roads do not influence the occurrence of accidents directly in the study area.
- Civic functions, such as schools, colleges, universities, hospitals, entertainment centres as well as commercial centres, also attract more traffic at certain hours of

day, but their influence on the occurrence of vehicular traffic accidents is not significant.

- The arterial roads in the majority of the suburban areas are of a linear pattern, although in some of the suburban area, they create a loop system.
- The collector roads and local streets develop a combination of gridiron and loop patterns of road network in all the suburbs.
- The arterial roads with higher accesses have higher risks for the occurrence of accidents, whereas the loop system arterial roads are less vulnerable to accident risks.
- The interior roads, such as collector roads and local streets, have low vehicular pressure on them and the risk of accidents in such roads is relatively low.
- The various scenarios developed from the regression model analysis revealed that the occurrence of accidents on various roads varies according to the combination of five major control parameters: road width, ADT, speed, the number of accesses to arterial roads, and median width.
- Individual parameters do not influence the occurrence of accidents significantly.
- A composite scenario with a minimum road width of 7.5 m., a speed limit of 60 km/h, an ADT of 8000 maximum and maximum 8 accesses provides the most suitable scenario for the reduction of accidents on the majority of the roads.
- However, there are roads which need special scenarios with limitations in certain parameters, such as limiting the ADT, the average speed and/or the number of accesses to arterial roads, whatever the case might be to, in order to reduce the occurrence of accidents.

However, from this investigation, it can be observed that only a few of the geometrical design aspects are troublesome in the study area. The main two concerns are:

- First, the road width according to the design standards should be more than 3.7 metres per lane. It was found that majority of the roads have lanes that are less than the design width, and this occurs mainly on the roads having multiple lanes.
- Secondly, the average speed of the vehicles exceeds the legal limit of 60 km/h on most of the roads.

Speed and the lack of appropriate lane width can influence the occurrence of a higher number of accidents on the arterial routes carrying higher traffic. Retting *et al*. (2001) identified possible countermeasures for left-turn and rear-end crashes that could be included in the future recommendations of this study, and which will be submitted to the South African Police Station in Park Road, Willows, Bloemfontein, South Africa. These findings, combined with the impact of the relative high speed occurrences and the lack of space, are linked to the increase in accidents within the residential areas.

5.4 PLANNING CONCEPT FOR VEHICULAR TRAFFIC ACCIDENT REDUCTION

A traffic accident reduction and road safety enhancement concept has been devised for the study area based on the major control parameters influencing the occurrence of accidents on the arterial roads of the study area. This investigation reveals that managing the speed and the ADT, increasing the road width, reducing the number of accesses from residential areas to arterial roads and increasing lane width and median width would help in reducing the occurrence of accidents and in improving road safety in the study area. In order to develop a set of broad policy guidelines and plausible recommendations, the following broad planning concept strategies have been adopted. They are:

1. Speed is one of major control parameters which influence the occurrence of accidents in the study area. It was observed that, in most of major suburban arterial roads, the actual average speed exceeds the general speed limit of 60 km/h significantly. So managing the speed of vehicles on the arterial roads within the specified permissible limit of 60 km/h is one of the foremost requirements.
2. Most of roads are over-occupied during peak hours (more than 7000 PCUs); during other periods, the ADT was found to be very scanty. Therefore, managing the flow of the ADT according to the capacity of the roads, particularly during peak hours, to control overcrowding, needs to be considered. The management of the ADT or diverting the volume of traffic to other roads would also reduce under the under-utilisation of other roads.
3. Road widths are functions of the land area available for roads. Road width is also related to number of lanes and lane widths. Increasing the widths of road sections to an appropriate level according to design standards (3.7 metres per lane which provides a minimum road width of 7.4 metres) is essential for smooth traffic movement in the study area.
4. Residential areas are connected to arterial roads by access roads. A higher number of access road provides higher access to residential areas, and also make the arterial roads more accessible, thus increasing the risk of accidents. Therefore, there is a need for limiting the accesses from residential areas to arterial roads to a minimum, i.e., less than 8 access roads per kilometre.

5. Medians help in separating the direction of flow of traffic which, in turn, reduces the conflict in the traffic. Therefore medians of a width required by design standards are necessary to avoid the risk of accidents in the study area.

5.5 ALTERNATIVE POLICIES

Based on this planning concept, a number of alternative policy scenarios have been devised, based on the various simulated scenarios developed from the accident prediction model and taking into account the various parameters. These are presented below.

- Policy 1 - A policy has been developed based on limiting the number of access streets to 8. This would result in a decrease in the number of accidents on the arterial routes of suburban areas of the study area by an average of 48%.
- Policy 2 - A policy has been developed based on increasing the speed limit to 65 km/h and the number of access streets to 9. This would result in a 44% decrease in the number of accidents on the arterial routes of suburban areas of the study area.
- Policy 3 - A policy has been developed based on an ADT of 8500 and an increase in number of access streets to 12. This would result in a 28% decrease in the number of accidents on the arterial roads of suburban areas of the study area.
- Policy 4 - A policy has been developed based on raising the speed limit to 80 km/h, while maintaining the ADT at 8500 and the number of access streets at 12. This would result in a 24% decrease in the number of accidents on the arterial roads of suburban areas of the study area.
- Policy 5 - A policy has been developed that takes into account a road width of 7.5 metres, a speed limit of 60 km/h, and 8 access streets. This would result in a 37% decrease in the number of accidents on the arterial routes of suburban areas of the study area.
- Policy 6 - A policy has been developed that considers a road width of 8 metres, an ADT of 7000, and 9 access roads. This would result in a 55% decrease in the number of accidents in the arterial routes of suburban areas of the study area.
- Policy 7 - A policy has been developed that considers an ADT of 6500, 8 access streets, and median widths of 0 metres. This would result in a 33% decrease in the number of accidents in the arterial routes of suburban areas of the study area.
- Policy 8 - A policy has been developed based on a road width of 12 metres, a speed of 110 km/h, an ADT of 11500, and a median width of 10 metres. This would result in an 8% decrease in the number of accidents in the arterial routes of suburban areas of the study area.

- Policy 9 - A policy has been developed based on a speed of 60 km/h, an ADT of 6500, 8 access streets, and a median width of 0 metres. This would result in a 41% decrease in the number of accidents in the arterial routes of suburban areas of the study area.
- Policy 10 - A policy has been developed based on a road width of 8 metres, a speed of 65 km/h, an ADT of 7000, and 9 access streets. This would result in a 61% decrease in the number of accidents in the arterial routes of suburban areas of the study area.
- Policy 11 - A policy has been developed based on a road width of 8 metres, a speed of 60 km/h, an ADT of 8000, and 8 access streets. This would result in a 60% decrease in the number of accidents in the arterial routes of suburban areas of the study area.

5.5.1 Recommended policies

The investigator observed that the policy number 11 would be most suitable for the reduction of accidents based on the detailed analysis of the policies and their results. The policy has been developed based on the composite scenario of limiting the speed to 60 km/h, increasing the road width to a minimum of 7.5 metres, reducing the number of accesses to a maximum of 8, limiting the ADT to a maximum of 8000, and providing a flexible median width. This would result in the reduction of traffic accidents by a minimum of 60%. However, location specific policies with variations in speed, control, or reduction in ADT, and restrictions on the number of accesses to residential areas from arterial roads may be opted for in specific roads of the study area.

5.6 PLAUSIBLE PLANNING GUIDELINES AND RECOMMENDATIONS

The focus of this study has been to reduce the number accidents on the arterial roads passing through the suburban areas of Bloemfontein city. In addition to the above policy guidelines, therefore, the following feasible recommendations are proposed, based on the analysis of various factors, the results of the surveys, expert discussions, and observations made for accident reduction in the study area.

- The number of accesses from residential areas to arterials roads needs to be reduced appropriately without compromising adequate accessibility so that the risk of accidents occurring is reduced.
- In the current scenario, general urban form and land use have relatively minor influences on traffic accidents. However, mixed land use areas, such as residential areas with significant commercial areas, are more vulnerable and their increasing influence on the occurrence of accidents cannot be ignored. Thus, in planning,

proper zoning at the local suburban level and the reduction of mixed land use is necessary.

- Individual-driven cars are the major component of the vehicular traffic in the study area. The lack of an adequate public transportation system is one of the major reasons for this problem. Therefore, the promotion of a public transportation system would be helpful in reducing the volume of traffic on the arterial roads, thus helping to reduce the occurrence of accidents.
- The provision of an adequate number of lanes with appropriate width in accordance with the geometric design guidelines will increase the capacity of the roads and help the smooth flow of traffic, and this essentially would reduce the occurrence of accidents.
- Speed reduction techniques need to be implemented in order to control the speed of vehicles on the arterial roads because speed is one of the major parameters causing accidents in the study area.
- Most importantly, even if uniform policy measures are considered for all roads, specific localised policy measures should also be considered for certain roads, based on the characteristics of the roads and their traffic as well as the characteristics of the area,.
- The under-utilised local roads may be utilised during peak hours by diverting the traffic from the arterial roads through appropriate traffic control and management.
- The gridiron and loop systems of road network system which are an integral part of the suburban area urban form need to be better utilised to alleviate the pressure of traffic on arterial road, particularly during peak hours.
- Control measures, such as restricting flow of vehicles in a particular direction as well as encouraging the use of certain under-utilised roads during specific periods (peak hours) of the day, would reduce the traffic volume on the arterial roads of the study area.
- The un-signalised major intersections or intersections with stop signs need to be converted to automated signalised intersections to avoid uncertainties in drivers.
- Although road conditions are observed to be good, the maintenance aspect of the roads should be investigated, nonetheless.

5.7 CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

The increase in traffic volume on the suburban arterial roads and the consequent increase in accidents warranted an investigation for the reduction of vehicular accidents and the improvement of road safety in the study area. In this research, an urban planning approach was considered to analyze the problem and explore plausible policy and planning guidelines in order to alleviate the problem. The investigation was conducted with the broad objective of exploring the most influential causes of vehicular traffic accidents on the suburban arterial roads, as well as the influence of various urban functions and land use, vehicular traffic, and road geometry parameters on the occurrence of accidents, in order to arrive at appropriate planning and policy guidelines to improve road safety in the study area.

For this purpose, survey research methodology was used for the collection of data and the subsequent statistical analyses. A suitable multiple linear regression model was developed to predict the occurrence of vehicular traffic accidents on the arterial roads of the suburbs in the study area, and to create various simulated scenarios under varied conditions. The analysis revealed that speed, the number of accesses to arterial roads, the ADT, road widths, and the median are the most influential parameters in the occurrence of vehicular accidents in the arterial roads passing though the suburbs of the study area. Based on the analyses and the model results, the hypothesis was tested. It was established that suburban arterial roads with limited accesses to residential areas would have fewer vehicular traffic accidents than arterial roads with unrestricted access from residential areas. Furthermore, a number of alternate policy scenarios were developed, based on the simulated model results, and plausible planning guidelines were recommended to alleviate the problem of vehicular accidents and to improve road safety. It was also observed that a policy which combines limiting the average speed to 60 km/h, restricting the ADT to 8000 PCUs, limiting the number of accesses to and from residential areas to 8 would reduce the occurrence of accidents by 60% on the majority of suburban arterial roads in the study area. However, concurrently, certain location-specific policies are needed to reduce vehicular accidents for some arterial roads that are exceptions in their physical and traffic characteristics.

The investigation also has certain limitations, one of which was the limited nature of the survey conducted in the study area. The surveys were conducted in a small number of selected suburban areas during limited hours of the day because of a shortage of manpower, limited time, and budgetary constraints. The study also suffered from the lack of availability of structured statistical data pertaining to the study area. Further, the scope of the research was confined to Bloemfontein city. In order to generalize the implications of this research, similar investigations in other cities of the country are needed, and there is a need for extensive surveys and thorough understanding of the detailed scenarios.

The research also offers several opportunities for further research. Some possibilities for further research include:

- The investigation of the influence of the vehicular and psychological aspects of the drivers in the accident analysis. These were ignored in the present investigation.
- An investigation at the micro level to complement the macro level analysis.
- The integration of an intelligent transportation system, based on technological advancement, with the urban planning approach employed in this investigation.

However, it is envisaged that, if the plausible policy and planning guidelines developed by the current investigation are implemented, vehicular traffic accidents in the suburban arterial roads of Bloemfontein city would be reduced substantially. Consequently, a significant improvement in road safety would be achieved.

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ANNEXURE A
Model results

Simulation	Road width	Speed (Km/h)	ADT	Number of access roads	Median width	Number of accidents					
						Totius street	Wynand Mouton Drive	De Bruyn Street	Paul Kruger Drive	Benade Drive	Volkspele Drive
1		60				20	20	14	122	82	10
2		65				21	21	16	124	84	11
3		70				23	23	18	125	86	13
4		75				25	25	19	127	87	14
5		80				26	26	21	129	89	16
6		85				28	28	23	130	91	18
7		90				30	30	24	132	92	19
8		95				31	31	26	133	94	21
9		100				33	33	27	135	95	23
10		105				34	34	29	137	97	24
11		110				36	36	31	138	99	26
12		115				38	38	32	140	100	27
13		120				39	39	34	142	102	29
14			6500			3	24	8	87	50	2
15			7000			6	27	11	90	53	5
16			7500			8	30	14	93	56	8
17			8000			11	33	17	96	59	11
18			8500			14	36	20	99	62	14
19			9000			17	39	23	102	65	17
20			9500			20	42	26	105	68	20
21			10000			23	45	29	108	71	23
22			10500			26	48	32	111	74	26
23			11000			29	51	35	114	77	29
24			11500			32	54	38	117	80	32
25			12000			35	57	41	120	83	34
26			12500			38	60	44	123	86	37
27			13000			41	63	47	126	89	40
28			13500			44	66	50	129	92	43
29			14000			47	69	53	132	95	46
30	7.5					33	29	28	136	107	17
31	8.0					33	28	28	135	107	17
32	8.5					32	27	27	135	106	16

33	9.0					31	27	26	134	105	15
34	9.5					31	26	26	133	104	14
35	10.0					30	25	25	132	104	14
36	10.0					30	25	25	132	104	14
37	10.5					29	24	24	132	103	13
38	11.0					28	24	23	131	102	12
39	11.5					28	23	23	130	102	12
40	12.0					27	22	22	130	101	11
41	12.5					26	22	21	129	100	10
42	13.0					26	21	21	128	100	10
43	13.5					25	20	20	128	99	9
44	14.0					24	20	19	127	98	8
45	14.5					24	19	19	126	97	7
46				8		38	43	3	35	13	22
47				9		42	48	7	40	17	26
48				10		47	52	11	44	21	31
49				11		51	57	16	48	26	35
50				12		56	61	20	53	30	40
51				13		60	65	24	57	35	44
52				14		64	70	29	61	39	48
53				15		69	74	33	66	43	53
54				16		73	78	37	70	48	57
55				17		77	83	42	75	52	61
56				18		82	87	46	79	56	66
57				19		86	91	51	83	61	70
58				20		90	96	55	88	65	74
59				21		95	100	59	92	70	79
60				22		99	105	64	96	74	83
61				23		104	109	68	101	78	88
62					0	44	26	65	165	133	23
63					1	39	21	60	161	128	19
64					2	35	16	55	156	123	14
65					3	30	12	50	151	119	9
66					4	25	7	45	146	114	4
67					5	20	2	41	141	109	0
68					6	15	0	36	137	104	0
69					7	11	0	31	132	99	0
70					8	6	0	26	127	95	0
71					9	1	0	21	122	90	0
72					10	0	0	17	117	85	0
73		60	6500			0	18	2	82	46	2
74		65	7000			2	23	7	87	51	7
75		70	7500			7	27	12	92	55	11
76		75	8000			11	32	16	96	60	16

77		80	8500			16	36	21	101	64	21
78		85	9000			20	41	25	105	69	25
79		90	9500			25	46	30	110	74	30
80		95	10000			30	50	35	115	78	35
81		100	10500			34	55	39	119	83	39
82		105	11000			39	59	44	124	87	44
83		110	11500			43	64	48	128	92	48
84		115	12000			48	69	53	133	97	53
85		120	12500			53	73	58	138	101	58
86	7.5				0	53	29	73	174	153	32
87	8.0				1	47	23	68	169	148	26
88	8.5				2	42	18	62	163	142	21
89	9.0				3	36	12	57	158	137	15
90	9.5				4	31	7	51	152	131	10
91	10.0				5	25	1	46	147	126	4
92	10.0				6	20	0	41	142	121	0
93	10.5				7	15	0	35	137	116	0
94	11.0				8	9	0	30	131	110	0
95	11.5				9	4	0	24	126	105	0
96	12.0				10	0	0	19	120	99	0
97	12.5				11	0	0	13	115	94	0
98	13.0				12	0	0	8	109	88	0
99	13.5				13	0	0	2	104	83	0
100	14.0				14	0	0	0	98	77	0
101	14.5				15	0	0	0	93	72	0
102		60		8		33	37	0	30	8	23
103		65		9		39	43	3	36	14	29
104		70		10		45	49	9	42	20	35
105		75		11		51	55	15	48	26	41
106		80		12		57	61	21	54	32	47
107		85		13		63	67	27	60	38	53
108		90		14		69	73	33	66	44	59
109		95		15		75	79	39	72	50	65
110		100		16		81	85	45	78	56	71
111		105		17		87	91	51	84	62	77
112		110		18		93	97	57	90	68	83
113		115		19		99	103	63	96	74	89
114		120		20		105	109	69	102	80	95
115		125		21		111	115	75	108	86	100
116		130		22		117	121	81	114	92	106
117		135		23		123	127	87	120	98	112
118	7.5	60				28	22	23	131	103	18
119	8.0	65				29	23	24	132	104	19
120	8.5	70				30	24	25	133	105	20

121	9.0	75				31	25	26	134	105	21
122	9.5	80				32	26	27	135	106	22
123	10.0	85				33	27	27	136	107	22
124	10.0	90				34	29	29	137	109	24
125	10.5	95				35	30	30	138	110	25
126	11.0	100				36	31	31	139	111	26
127	11.5	105				37	31	32	140	112	27
128	12.0	110				38	32	33	141	113	28
129	12.5	115				39	33	34	142	113	29
130	13.0	120				40	34	35	143	114	30
131	13.5	125				41	35	35	144	115	30
132	14.0	130				42	36	36	145	116	31
133	14.5	135				43	37	37	146	117	32
134			6500	8		16	42	0	0	0	15
135			7000	9		23	49	0	3	0	22
136			7500	10		30	56	5	10	0	29
137			8000	11		38	64	13	18	0	37
138			8500	12		45	71	20	25	6	44
139			9000	13		52	78	27	32	13	52
140			9500	14		60	86	35	40	20	59
141			10000	15		67	93	42	47	28	66
142			10500	16		74	100	49	54	35	74
143			11000	17		82	108	57	62	42	81
144			11500	18		89	115	64	69	50	88
145			12000	19		97	122	71	76	57	96
146			12500	20		104	130	79	84	64	103
147			13000	21		111	137	86	91	72	110
148			13500	22		119	144	93	98	79	118
149			14000	23		126	152	101	106	87	125
150	7.5		6500			11	27	16	96	71	10
151	8.0		7000			13	29	19	98	73	12
152	8.5		7500			15	31	21	101	75	14
153	9.0		8000			18	34	23	103	78	17
154	9.5		8500			20	36	25	105	80	19
155	10.0		9000			22	38	28	108	82	21
156	10.0		9500			25	41	31	111	85	24
157	10.5		10000			28	43	33	113	87	27
158	11.0		10500			30	46	35	115	90	29
159	11.5		11000			32	48	38	117	92	31
160	12.0		11500			34	50	40	120	94	33
161	12.5		12000			37	53	42	122	97	36
162	13.0		12500			39	55	44	124	99	38
163	13.5		13000			41	57	47	127	101	40
164	14.0		13500			44	59	49	129	103	43

165	14.5		14000			46	62	51	131	106	45
166			6500		0	22	24	53	126	97	16
167			7000		1	20	22	51	124	95	14
168			7500		2	18	20	49	122	93	12
169			8000		3	16	19	47	120	91	11
170			8500		4	14	17	45	118	89	9
171			9000		5	13	15	44	117	87	7
172			9500		6	11	13	42	115	86	5
173			10000		7	9	11	40	113	84	3
174			10500		8	7	10	38	111	82	2
175			11000		9	5	8	36	109	80	0
176			11500		10	4	6	34	108	78	0
177			12000		11	2	4	33	106	77	0
178			12500		12	0	2	31	104	75	0
179			13000		13	0	0	29	102	73	0
180			13500		14	0	0	27	100	71	0
181			14000		15	0	0	25	98	69	0
182				8.000	0	57	43	47	74	59	36
183				9.000	1	57	43	47	73	58	36
184				10.000	2	56	43	46	73	58	36
185				11.000	3	56	42	46	72	58	35
186				12.000	4	56	42	45	72	57	35
187				13.000	5	55	41	45	72	57	34
188				14.000	6	55	41	45	71	56	34
189				15.000	7	54	40	44	71	56	33
190				16.000	8	54	40	44	70	55	33
191				17.000	9	53	40	43	70	55	33
192				18.000	10	53	39	43	69	55	32
193				19.000	11	53	39	42	69	54	32
194				20.000	12	52	38	42	68	54	31
195				21.000	13	52	38	42	68	53	31
196				22.000	14	51	37	41	68	53	30
197				23.000	15	51	37	41	67	52	30
198		60		8		33	37	0	30	8	23
199		65		9		39	43	3	36	14	29
200		70		10		45	49	9	42	20	35
201		75		11		51	55	15	48	26	41
202		80		12		57	61	21	54	32	47
203		85		13		63	67	27	60	38	53
204		90		14		69	73	33	66	44	59
205		95		15		75	79	39	72	50	65
206		100		16		81	85	45	78	56	71
207		105		17		87	91	51	84	62	77
208		110		18		93	97	57	90	68	83

209		115		19		99	103	63	96	74	89
210		120		20		105	109	69	102	80	95
211		125		21		111	115	75	108	86	100
212		130		22		117	121	81	114	92	106
213		135		23		123	127	87	120	98	112
214		60			0	39	20	59	161	129	24
215		65			1	36	17	56	157	125	21
216		70			2	33	13	53	154	122	18
217		75			3	29	10	50	151	119	14
218		80			4	26	7	46	148	116	11
219		85			5	23	4	43	145	113	8
220		90			6	20	1	40	141	109	5
221		95			7	17	0	37	138	106	2
222		100			8	14	0	34	135	103	0
223		105			9	10	0	30	132	100	0
224		110			10	7	0	27	129	97	0
225		115			11	4	0	24	126	94	0
226		120			12	1	0	21	122	90	0
227		125			13	0	0	18	119	87	0
228		130			14	0	0	15	116	84	0
229		135			15	0	0	11	113	81	0
230		60	6500	8		10	35	0	0	0	15
231		65	7000	9		19	44	0	0	0	24
232		70	7500	10		28	53	3	9	0	33
233		75	8000	11		37	62	12	18	0	42
234		80	8500	12		46	71	21	27	8	51
235		85	9000	13		55	80	30	36	17	60
236		90	9500	14		64	89	39	44	26	69
237		95	10000	15		73	98	48	53	34	78
238		100	10500	16		82	107	57	62	43	87
239		105	11000	17		91	116	66	71	52	96
240		110	11500	18		100	125	75	80	61	105
241		115	12000	19		109	134	84	89	70	114
242		120	12500	20		118	143	93	98	79	123
243		125	13000	21		127	152	102	107	88	132
244		130	13500	22		136	161	111	116	97	141
245		135	14000	23		145	170	120	125	106	150
246		60		8	0	52	37	42	69	54	37
247		65		9	1	53	38	43	70	56	38
248		70		10	2	54	40	44	71	57	39
249		75		11	3	56	41	45	72	58	41
250		80		12	4	57	42	46	74	59	42
251		85		13	5	58	43	48	75	60	43
252		90		14	6	59	44	49	76	61	44

253		95		15	7	60	46	50	77	63	45
254		100		16	8	62	47	51	78	64	47
255		105		17	9	63	48	52	79	65	48
256		110		18	10	64	49	53	81	66	49
257		115		19	11	65	50	55	82	67	50
258		120		20	12	66	51	56	83	68	51
259		125		21	13	67	53	57	84	70	52
260		130		22	14	69	54	58	85	71	54
261		135		23	15	70	55	59	87	72	55
262	7.5	60		8		41	40	5	39	28	31
263	8.0	65		9		47	45	11	45	34	36
264	8.5	70		10		52	51	16	50	39	42
265	9.0	75		11		57	56	21	55	44	47
266	9.5	80		12		62	61	27	61	50	52
267	10.0	85		13		68	66	32	66	55	57
268	10.0	90		14		74	72	38	72	61	63
269	10.5	95		15		79	78	43	77	66	69
270	11.0	100		16		84	83	48	82	71	74
271	11.5	105		17		90	88	54	88	77	79
272	12.0	110		18		95	94	59	93	82	84
273	12.5	115		19		100	99	64	98	87	90
274	13.0	120		20		105	104	70	103	93	95
275	13.5	125		21		111	109	75	109	98	100
276	14.0	130		22		116	115	80	114	103	106
277	14.5	135		23		121	120	85	119	108	111
278	7.5	60			0	47	22	68	169	149	32
279	8.0	65			1	44	19	64	166	145	28
280	8.5	70			2	40	15	60	162	141	24
281	9.0	75			3	36	11	56	158	137	21
282	9.5	80			4	32	7	52	154	133	17
283	10.0	85			5	28	3	48	150	129	13
284	10.0	90			6	25	0	45	147	126	10
285	10.5	95			7	21	0	41	143	122	6
286	11.0	100			8	17	0	37	139	118	2
287	11.5	105			9	13	0	33	135	115	0
288	12.0	110			10	9	0	29	131	111	0
289	12.5	115			11	5	0	25	127	107	0
290	13.0	120			12	1	0	22	124	103	0
291	13.5	125			13	0	0	18	120	99	0
292	14.0	130			14	0	0	14	116	95	0
293	14.5	135			15	0	0	10	112	91	0
294	7.5		6500	8		24	44	0	4	0	23
295	8.0		7000	9		31	51	6	11	3	30
296	8.5		7500	10		37	57	12	18	10	36

297	9.0		8000	11		44	64	19	24	16	43
298	9.5		8500	12		51	71	25	31	23	50
299	10.0		9000	13		57	77	32	38	30	56
300	10.0		9500	14		65	85	39	45	37	64
301	10.5		10000	15		71	91	46	52	44	70
302	11.0		10500	16		78	98	53	58	50	77
303	11.5		11000	17		85	105	59	65	57	84
304	12.0		11500	18		91	111	66	72	64	90
305	12.5		12000	19		98	118	73	78	70	97
306	13.0		12500	20		105	125	79	85	77	104
307	13.5		13000	21		111	131	86	92	84	110
308	14.0		13500	22		118	138	93	98	90	117
309	14.5		14000	23		125	145	99	105	97	124
310	7.5	60	6500			6	21	11	91	66	11
311	8.0	65	7000			13	29	19	98	73	12
312	8.5	70	7500			15	31	21	101	75	14
313	9.0	75	8000			18	34	23	103	78	17
314	9.5	80	8500			20	36	25	105	80	19
315	10.0	85	9000			22	38	28	108	82	21
316	10.0	90	9500			25	41	31	111	85	24
317	10.5	95	10000			28	43	33	113	87	27
318	11.0	100	10500			30	46	35	115	90	29
319	11.5	105	11000			32	48	38	117	92	31
320	12.0	110	11500			34	50	40	120	94	33
321	12.5	115	12000			37	53	42	122	97	36
322	13.0	120	12500			39	55	44	124	99	38
323	13.5	125	13000			41	57	47	127	101	40
324	14.0	130	13500			44	59	49	129	103	43
325	14.5	135	14000			46	62	51	131	106	45
326			6500	8	0	35	42	35	34	22	29
327			7000	9	1	37	44	38	36	25	32
328			7500	10	2	40	47	40	39	27	34
329			8000	11	3	42	49	43	42	30	37
330			8500	12	4	45	52	45	44	33	39
331			9000	13	5	48	54	48	47	35	42
332			9500	14	6	50	57	50	49	38	44
333			10000	15	7	53	59	53	52	40	47
334			10500	16	8	55	62	56	54	43	50
335			11000	17	9	58	64	58	57	45	52
336			11500	18	10	60	67	61	59	48	55
337			12000	19	11	63	70	63	62	50	57
338			12500	20	12	65	72	66	65	53	60
339			13000	21	13	68	75	68	67	56	62
340			13500	22	14	71	77	71	70	58	65

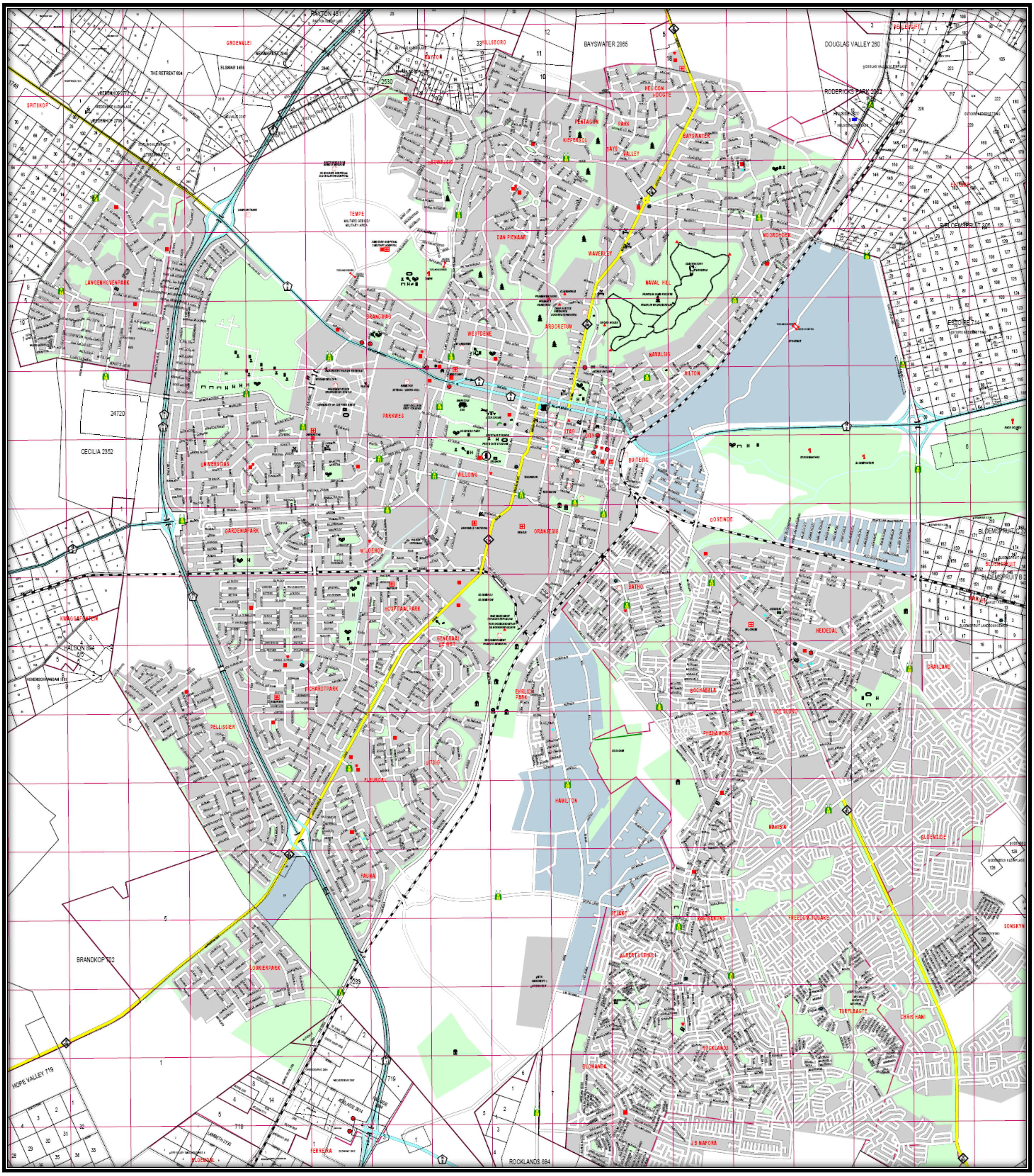
341			14000	23	15	73	80	73	72	61	67
342	7.5		6500		0	30	27	61	135	117	24
343	8.0		7000		1	28	24	58	132	114	22
344	8.5		7500		2	25	22	56	130	112	19
345	9.0		8000		3	23	19	53	127	109	17
346	9.5		8500		4	20	17	51	125	107	14
347	10.0		9000		5	18	14	48	122	104	12
348	10.0		9500		6	16	12	47	120	102	10
349	10.5		10000		7	13	10	44	118	100	7
350	11.0		10500		8	11	7	42	115	97	5
351	11.5		11000		9	8	5	39	113	95	2
352	12.0		11500		10	6	2	37	110	92	0
353	12.5		12000		11	3	0	34	108	90	0
354	13.0		12500		12	1	0	32	105	87	0
355	13.5		13000		13	0	0	29	103	85	0
356	14.0		13500		14	0	0	27	100	82	0
357	14.5		14000		15	0	0	24	98	80	0
358		60	6500		0	17	18	47	121	92	17
359		65	7000		1	16	18	47	121	92	16
360		70	7500		2	16	18	47	120	92	16
361		75	8000		3	16	17	47	120	91	16
362		80	8500		4	16	17	46	120	91	16
363		85	9000		5	16	17	46	120	91	16
364		90	9500		6	15	17	46	120	91	15
365		95	10000		7	15	17	46	119	91	15
366		100	10500		8	15	16	46	119	90	15
367		105	11000		9	15	16	45	119	90	15
368		110	11500		10	15	16	45	119	90	15
369		115	12000		11	14	16	45	119	90	14
370		120	12500		12	14	16	45	118	90	14
371		125	13000		13	14	15	45	118	89	14
372		130	13500		14	14	15	44	118	89	14
373		135	14000		15	14	15	44	118	89	14
374	7.500			8.000	0	66	46	56	83	79	45
375	8.000			9.000	1	65	45	54	81	78	44
376	8.500			10.000	2	63	44	53	80	77	42
377	9.000			11.000	3	62	43	52	79	76	41
378	9.500			12.000	4	61	42	51	78	75	40
379	10.000			13.000	5	60	40	50	77	73	39
380	10.000			14.000	6	60	40	49	77	73	39
381	10.500			15.000	7	58	39	48	75	72	37
382	11.000			16.000	8	57	38	47	74	71	36
383	11.500			17.000	9	56	37	46	73	70	35
384	12.000			18.000	10	55	35	45	72	68	34

385	12.500			19.000	11	54	34	44	71	67	33
386	13.000			20.000	12	53	33	43	70	66	32
387	13.500			21.000	13	52	32	42	69	65	31
388	14.000			22.000	14	51	31	40	67	64	30
389	14.500			23.000	15	49	30	39	66	63	28
390	7.5	60	6500		0	25	21	55	130	112	25
391	8.0	65	7000		1	24	20	55	129	111	24
392	8.5	70	7500		2	23	19	54	128	110	23
393	9.0	75	8000		3	22	18	53	127	110	22
394	9.5	80	8500		4	21	17	52	126	109	21
395	10.0	85	9000		5	20	16	51	125	108	20
396	10.0	90	9500		6	20	16	51	125	108	20
397	10.5	95	10000		7	19	15	50	124	107	19
398	11.0	100	10500		8	18	14	49	123	106	18
399	11.5	105	11000		9	18	13	48	122	105	18
400	12.0	110	11500		10	17	12	47	121	104	17
401	12.5	115	12000		11	16	11	46	121	103	16
402	13.0	120	12500		12	15	10	45	120	102	15
403	13.5	125	13000		13	14	10	45	119	101	14
404	14.0	130	13500		14	13	9	44	118	100	13
405	14.5	135	14000		15	12	8	43	117	100	12
406	7.5	60		8	0	60	40	50	78	75	45
407	8.0	65		9	1	61	40	51	78	75	46
408	8.5	70		10	2	61	41	51	79	76	46
409	9.0	75		11	3	62	41	52	79	76	47
410	9.5	80		12	4	62	42	52	80	76	47
411	10.0	85		13	5	63	42	52	80	77	48
412	10.0	90		14	6	64	44	54	81	78	49
413	10.5	95		15	7	65	44	54	82	79	49
414	11.0	100		16	8	65	45	55	82	79	50
415	11.5	105		17	9	66	45	55	83	80	50
416	12.0	110		18	10	66	45	56	83	80	51
417	12.5	115		19	11	66	46	56	84	81	51
418	13.0	120		20	12	67	46	57	84	81	52
419	13.5	125		21	13	67	47	57	85	82	52
420	14.0	130		22	14	68	47	58	85	82	53
421	14.5	135		23	15	68	48	58	86	82	53
422		60	6500	8	0	30	35	30	29	18	30
423		65	7000	9	1	34	40	34	33	22	34
424		70	7500	10	2	38	44	38	37	26	38
425		75	8000	11	3	42	48	42	42	30	42
426		80	8500	12	4	46	52	46	46	34	46
427		85	9000	13	5	50	56	50	50	39	51
428		90	9500	14	6	55	60	55	54	43	55

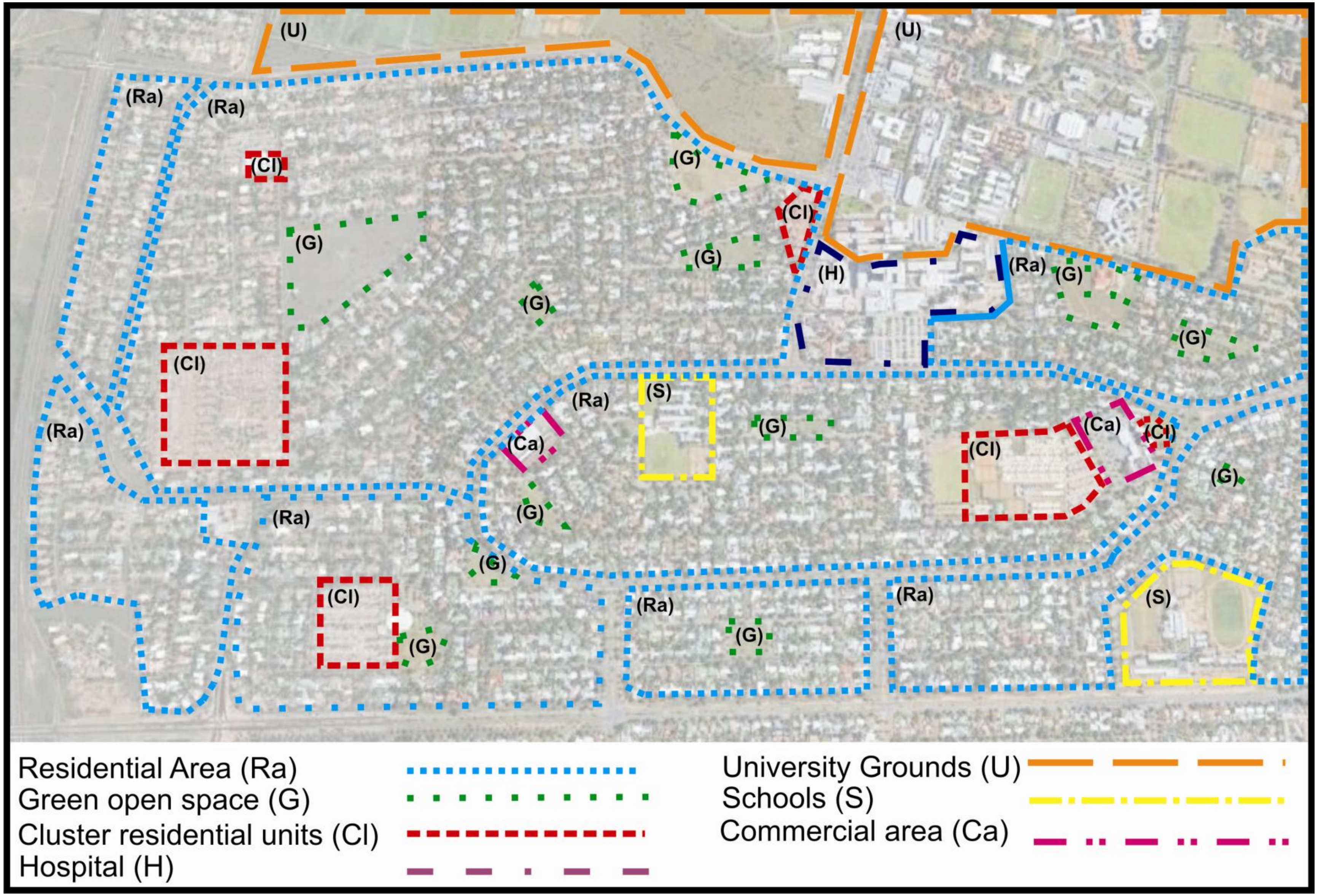
429		95	10000	15	7	59	65	59	58	47	59
430		100	10500	16	8	63	69	63	62	51	63
431		105	11000	17	9	67	73	67	67	55	67
432		110	11500	18	10	71	77	71	71	59	71
433		115	12000	19	11	75	81	75	75	64	76
434		120	12500	20	12	80	85	80	79	68	80
435		125	13000	21	13	84	90	84	83	72	84
436		130	13500	22	14	88	94	88	87	76	88
437		135	14000	23	15	92	98	92	92	80	92
438	7.5		6500	8	0	43	44	44	43	43	37
439	8.0		7000	9	1	45	46	45	45	44	39
440	8.5		7500	10	2	47	48	47	47	46	41
441	9.0		8000	11	3	49	50	49	48	48	43
442	9.5		8500	12	4	51	52	51	50	50	45
443	10.0		9000	13	5	52	53	53	52	52	47
444	10.0		9500	14	6	55	56	55	55	54	49
445	10.5		10000	15	7	57	58	57	57	56	51
446	11.0		10500	16	8	59	60	59	58	58	53
447	11.5		11000	17	9	61	62	61	60	60	55
448	12.0		11500	18	10	62	63	63	62	62	57
449	12.5		12000	19	11	64	65	65	64	64	58
450	13.0		12500	20	12	66	67	66	66	65	60
451	13.5		13000	21	13	68	69	68	68	67	62
452	14.0		13500	22	14	70	71	70	70	69	64
453	14.5		14000	23	15	72	73	72	71	71	66
454	7.5	60	6500	8		19	38	0	0	0	24
455	8.0	65	7000	9		27	46	2	8	0	32
456	8.5	70	7500	10		35	55	10	16	8	40
457	9.0	75	8000	11		44	63	18	24	17	48
458	9.5	80	8500	12		52	71	26	33	25	57
459	10.0	85	9000	13		60	79	35	41	33	65
460	10.0	90	9500	14		69	88	44	50	42	74
461	10.5	95	10000	15		77	97	52	58	51	82
462	11.0	100	10500	16		86	105	60	66	59	90
463	11.5	105	11000	17		94	113	69	75	67	99
464	12.0	110	11500	18		102	121	77	83	75	107
465	12.5	115	12000	19		111	130	85	91	84	115
466	13.0	120	12500	20		119	138	93	100	92	124
467	13.5	125	13000	21		127	146	102	108	100	132
468	14.0	130	13500	22		135	155	110	116	108	140
469	14.5	135	14000	23		144	163	118	124	117	148
470	7.5	60	6500	8	0	38	38	38	38	38	38
471	8.0	65	7000	9	1	41	41	41	41	41	41
472	8.5	70	7500	10	2	45	45	45	45	45	45

473	9.0	75	8000	11	3	48	48	48	48	48	48
474	9.5	80	8500	12	4	52	52	52	52	52	52
475	10.0	85	9000	13	5	55	55	55	55	55	55
476	10.0	90	9500	14	6	60	60	60	60	60	60
477	10.5	95	10000	15	7	63	63	63	63	63	63
478	11.0	100	10500	16	8	66	66	66	66	66	66
479	11.5	105	11000	17	9	70	70	70	70	70	70
480	12.0	110	11500	18	10	73	73	73	73	73	73
481	12.5	115	12000	19	11	77	77	77	77	77	77
482	13.0	120	12500	20	12	80	80	80	80	80	80
483	13.5	125	13000	21	13	84	84	84	84	84	84
484	14.0	130	13500	22	14	87	87	87	87	87	87
485	14.5	135	14000	23	15	91	91	91	91	91	91
486	7.5	60	8000	8		28	47	2	9	1	33

ANNEXURE B
Map – Bloemfontein

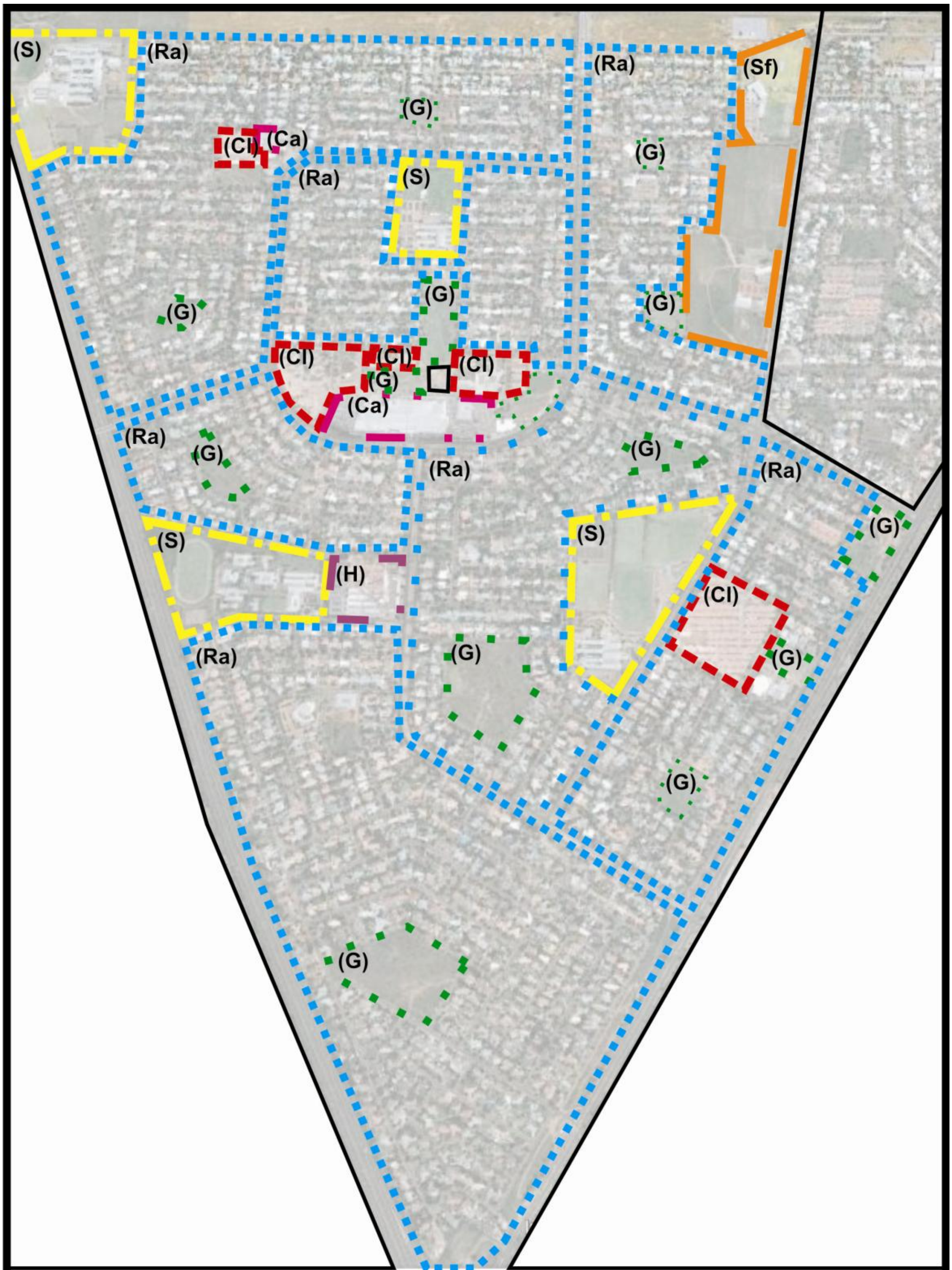

BAYSWATER 2865
DOUGLAS VALLEY 260
RODERICKS PARK 2373
HILLSBORO
GRONVLEI
THE RETREAT 604
SPITSKOP
24720
CECILIA 2352
BRANDKOP 702
HOPE VALLEY 719
ROCKLANDS 684
LANGENHOVENPARK
UNIVERSITAS
GARDENIAPARK
PELLISSIER
LOURIERPARK
FAUNA
FLEURDAL
WESTDENE
ARBORETUM
WAVERLEY
NAVAL HILL
NAVALSIG
HILTON
WILLOWS
ORANJESIG
BATHO
HEIDEDAL
HAMILTON
NAMIBIA
FREEDOM SQUARE
ROCKLANDS
BLOMANDA
JB MAFORA
TURFLAAGTE
CHRIS HANI
GRASSLAND
SONSKYN
DAN PIENAAR
NOORDHOEK
PENTAGON PARK
HEUWELSIG
BRANDWAG
PARK WEST
HUGENOTE
HILLSIDE
ESTOIRE 714
BLOEMSPRUIT

ANNEXURE C
Land use - Universitas



(U)
(U)
(Ra)
(Ra)
(Cl)
(G)
(G)
(Cl)
(G)
(H)
(Ra)
(G)
(G)
(G)
(Cl)
(Ra)
(S)
(G)
(Ca)
(Cl)
(Ra)
(Ca)
(Cl)
(G)
(G)
(Ra)
(G)
(Cl)
(Ra)
(G)
(Ra)
(S)
(G)
Residential Area (Ra)
Green open space (G)
Cluster residential units (Cl)
Hospital (H)
University Grounds (U)
Schools (S)
Commercial area (Ca)

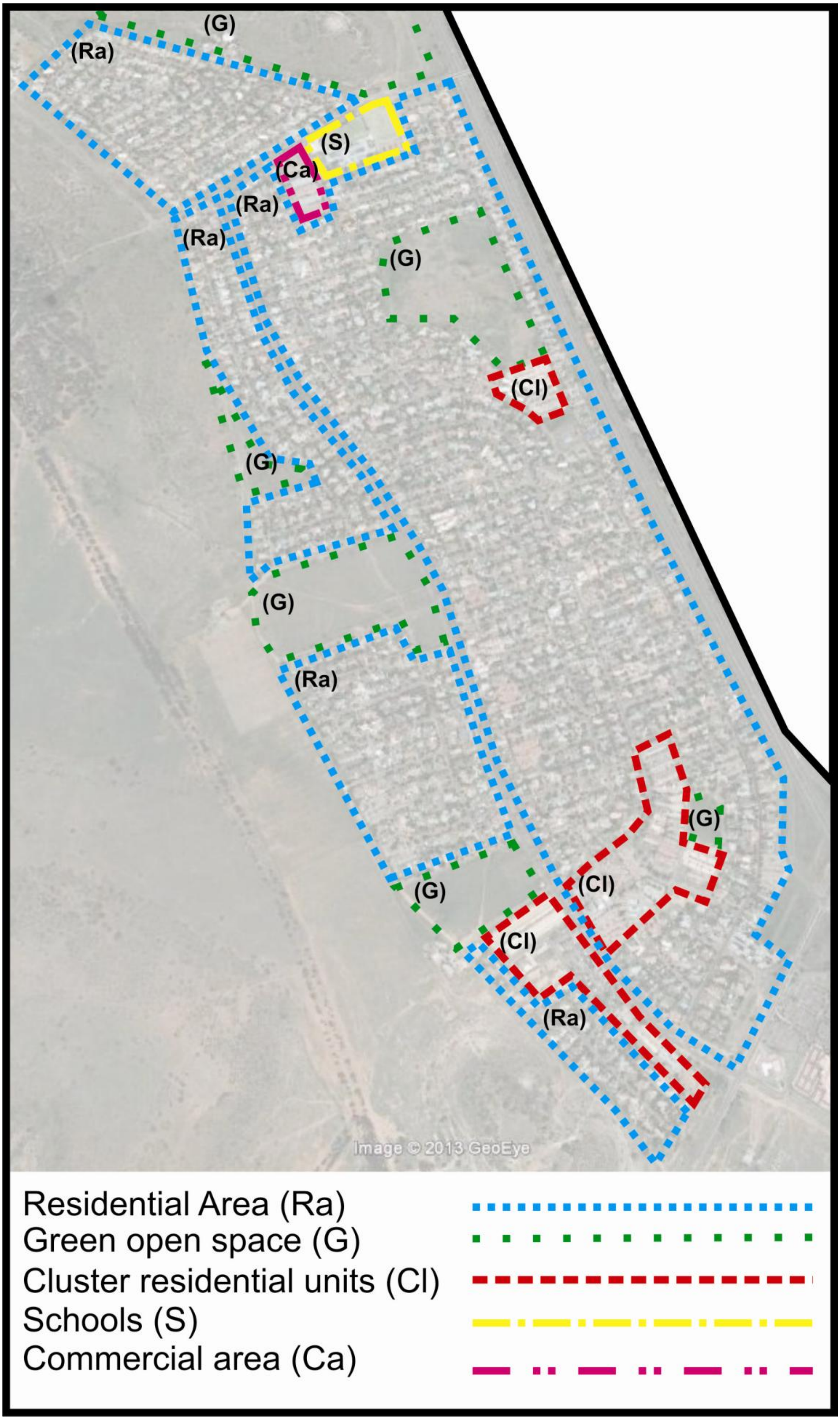
ANNEXURE D
Land use – Fichardtpark



Residential Area (Ra)	
Green open space (G)	
Cluster residential units (Cl)	
Hospital (H)	
Sport Fields (Sf)	
Schools (S)	
Commercial area (Ca)	

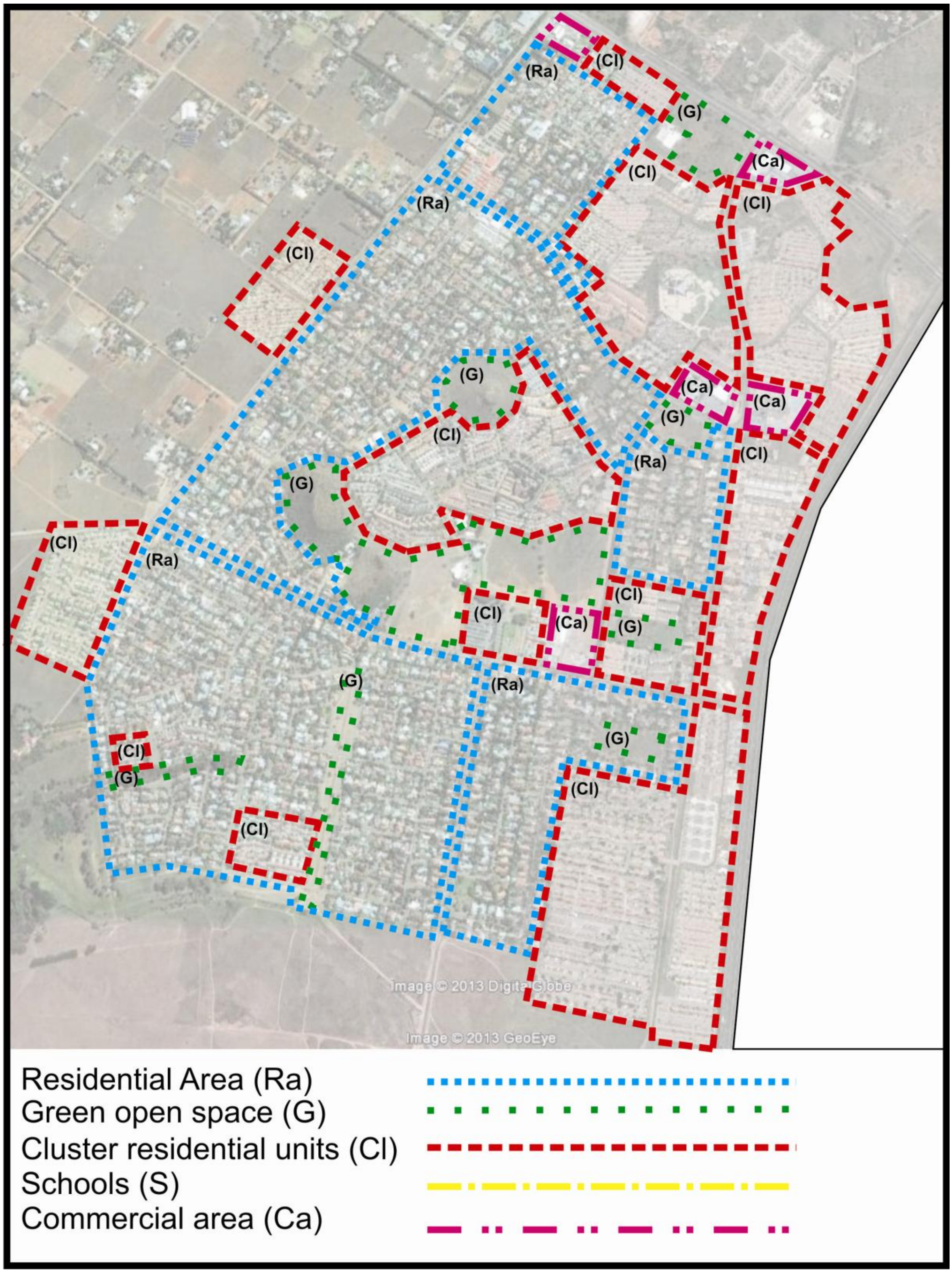
ANNEXURE E

Land use - Pellissier


(G)
(Ra)
(S)
(Ca)
(Ra)
(Ra)
(G)
(Cl)
(G)
(G)
(Ra)
(G)
(Cl)
(G)
(Cl)
(Ra)
Image © 2013 GeoEye
Residential Area (Ra)
Green open space (G)
Cluster residential units (Cl)
Schools (S)
Commercial area (Ca)

ANNEXURE F

Land use - Langenhovenpark


(Ra)
(Cl)
(G)
(Ca)
Image © 2013 DigitalGlobe
Image © 2013 GeoEye
Residential Area (Ra)
Green open space (G)
Cluster residential units (Cl)
Schools (S)
Commercial area (Ca)

ANNEXURE G
Model variables

	Road width	Speed (Km/h)	ADT	Number of access routes	Median width	Lanes	Accidents
Totius Street	13.5m	76 km/h	10 261 per day	5 per km	4m	4	25
Wynand Mouton Drive	9.4m	79 km/h	6 825 per day	4 per km	0m	2	26
De Bruyn Street	13.5m	77 km/h	8 514 per day	12 per km	9.3m	4	20
Paul Kruger Drive	13.9m	75 km/h	13 155 per day	29 per km	8m	4	127
Benade Drive	22m	74 km/h	12 614 per day	25 per km	9.6m	6	87
Volkspele Drive	13.4m	58 km/h	7 728 per day	5 per km	3m	4	9