ESTABLISHING AND APPLYING SPEED-FLOW RELATIONSHIPS FOR TRAFFIC ON SOUTH AFRICAN FREEWAYS

By

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THESIS

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Declaration

It is hereby certified that the writer has compiled all calculations, results, drawings and graphs in this thesis, unless otherwise indicated and were never submitted before, in its entirety or partially, to any other university for the purpose of obtaining a degree.

J. Roux

Abstract

Peak morning traffic-flow data were obtained from video footage of three representative freeway sections on the N1 and N2 westbound towards Cape Town. Flow, speed, and density measurements were made from the footage with the aid of a stopwatch.

Many researchers (2-12) have originated and developed models to describe the relationships between traffic flow characteristics (speed, flow, and density) on freeways. In this report, a number of these models have been investigated with data obtained from South African freeways. The ability of each model to predict flow parameters over the entire range of data was evaluated with the aid of statistical methods. The tests were performed by regressing average speed vs. average density. Flow-density and speed-flow relationships were derived through application of the steady-state equation (2.6). In each case, a final model was chosen through visual inspection that consisted of two separate curves, one for the uncongested flow regime and one for the congested flow regime. Furthermore, speed-flow relationships were examined for individual lanes and compared to relationships established for average lanes. The models were also compared to models obtained from overseas studies (1,16,19) as well as from studies done locally (17).

A secondary objective of this study is to investigate the performance of existing freeway facilities through application of the relevant models to the traffic-flow data of a particular facility. The current peak-morning performance of the N2 freeway section is investigated in terms of travel-time and travel cost. The particular study section consists of three lanes, the right hand lane being an HOV lane dedicated to taxis and buses. Different hypothetical cases are investigated. The first hypothetical case is an investigation into the traffic situation on the freeway section without the influence of the HOV lane. The second hypothetical case investigates the traffic situation on the section with perfect operation of the HOV lane. The current performance of the N2 section is compared to the performance of each of the hypothetical cases.

Opsomming

Oggend-spits verkeersvloei data is verkry vanaf drie verteenwoordigende seksies op die N1 en N2 deurpaaie naby Kaapstad met die gebruik van ‘n video kamera. Vloei, spoed, end digtheid opnames is gemaak met behulp van ‘n stophorlosie.

Verskeie navorsers (2-12) het modelle gepostuleer en ontwikkel om die verhoudings tussen verkeersvloei eienskappe (spoed, volume, en digtheid) op deurpaaie te beskryf. In hierdie verslag word ‘n aantal van hierdie modelle ondersoek met data wat verkry is van Suid-Afrikaanse deurpaaie. Die vermoë van elke model om vloei eienskappe oor die hele bestek van die data te voorspel is geëvalueer met behulp van statistiese metodes. Statistiese toetse behels ‘n regressie analise van gemiddelde spoed teenoor gemiddelde digtheid. Volume-digtheid en spoed-volume verwantskappe is direk afgelei vanaf Vergelyking 2.6. Vir elke geval is ‘n finale model m.b.v. visuele inspeksie gekies wat bestaan het uit twee afsonderlike kurwes, een kurwe vir die vry-vloei regime en ‘n ander kurwe vir hoë-digtheid toestande. Verder word spoed-volume verwantskappe vir afsonderlike deurpad-lane ondersoek en vergelyk met verwantskappe wat verkry is vir gemiddelde lane. Die modelle word ook vergelyk met modelle wat verkry is vanaf oorsese studies (1,16,19), sowel as met modelle wat plaaslik verkry is (17).

‘n Sekondêre doel van hierdie studie is om die prestasie van bestaande deurpad-fasiliteite te ondersoek deur die verskillende modelle aan te wend tot die verkeers-vloei data van ‘n betrokke fasiliteit. Die prestasie van die N2 deurpad seksie gedurende oggend-spits verkeer is ondersoek in terme van reistyd en ryskoste. Die betrokke seksie bestaan uit drie lane, waarvan die regter laan gereserveer is vir busse en taxis. Verskeie hipoteses is ook ondersoek. Die eerste hipotese is ‘n ondersoek na die verkeers-vloei kondisie op die seksie sonder die invloed van die bus- en taxi-laan. Die tweede hipotese ondersoek die seksie met perfekte werking van die bus- en taxi-laan. Die huidige prestasie van die N2 seksie is vergelyk met die prestasie van elk van die hipoteses.

Dedicated to our Heavenly Father

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LIST OF ABBREVIATIONS

NDoT	National Department of Transport
HOV	High Occupancy Vehicle
PHF	Peak-hour Factor
HCM	Highway Capacity Manual
Pcu	Equivalent Passenger car unit
OMT	Ontario Ministry of Transportation
RMSE	Root-Mean-Square error
FFS	Free-flow speed
DOT	Department of Transport
CTO	Comprehensive Traffic Observation
CBD	Central Business District
CSIR	Council for Scientific and Industrial Research

CHAPTER 1

ORIGIN AND OBJECTIVE OF THE STUDY

1.1 Traffic Flow on Freeways

Since the advent of the modern motorcar, emphasis in transportation began to shift from the static aspects of road design to the dynamic aspects of traffic flow. The ever-changing movement of traffic on transport facilities like freeways is probably one of the most familiar occurrences in everyday life. Understanding the manner in which vehicles behave under varying conditions becomes paramount in order to maintain the safe and efficient movement of persons and goods on transport facilities.

The freeway is a facility that was specifically created to move large volumes of traffic safely at relatively high speeds. However, when traffic demand exceeds the capacity of a particular freeway facility, a phenomenon known as a "breakdown in flow" occurs, resulting in extremely low speeds and high congestion. The theory of traffic flow enables us to describe the relationship between flow, density and speed for all conditions of traffic flow on freeways. Unknown characteristics can be estimated once a particular relationship between two flow characteristics is known.

The speed-flow relationship of traffic is of specific importance in practical application. Speed-flow relationships are applied in many areas of transportation and traffic engineering. It has been used as a tool to determine design capacities for roads, to determine level of service for traffic flow (based on the *Highway Capacity Manual (HCM 2000 (1))* "Level of Service" concept), and to calculate travel costs on a specific road section.

Many researchers (2-12) have originated and developed models to describe the relationships between traffic flow characteristics (speed, flow, and density) on freeways. There are at least two approaches to the traffic flow problem. The microscopic approach (car-following theory) is concerned with individual vehicular speed and spacing, while the macroscopic approach deals with traffic-stream flows, densities, and average speeds. It has however been shown that these two approaches are interrelated (4).

1.2 A Vision for South African Transport

With the aim of addressing future transportation needs, an eighteen-month review process led by the National Department of Transport (NDoT) was undertaken. The process involved intensive consultation with various stakeholders in the transportation sector and culminated in the White Paper on National Transport Policy. Cabinet and Parliament approved the White Paper in 1996 and the following vision for the transportation system was developed:

"Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost, in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable."

The National Department of Transport began the *Moving South Africa: A Transport Strategy for 2020 (20)* project in June 1997. The project encompassed a 14-month process to take the vision developed in the 1996 White Paper, and develop a twenty-year strategy to realise it.

Various customer groups were examined for the purpose of identifying their different transportation needs and goals. Urban passenger transport has been identified as the area requiring the most in-depth analysis, as well as being the area where the vast majority of passengers reside. The performance of the urban transport system is expected to deteriorate drastically towards 2020. Public transport journey time and cost, car dependence, as well as the number of customers who lack affordable basic access to motorised transport, are expected to increase significantly.

Between 1972 and 1996, the number of cars in South Africa increased by 72%. This phenomenon is a direct result of low car operating costs, ineffective land use patterns, inferior public transport alternatives, and a large infrastructure investment in roads. Furthermore, the fact that car costs are relatively low and likely to decline towards 2020, combined with incomes that are expected to rise, will ensure that more people will be able to afford cars in the future. Future forecasts suggest that car ownership will increase by a further 64% towards 2020, which in turn will increase congestion and pollution considerably.

One of the biggest drivers behind poor public transport performance (and increasing car dependence) are dispersed land use patterns due to ineffective spatial planning. The creation of transport corridors with the subsequent focusing of investment and resources on these corridors is regarded as being the single most important component of the urban strategy. It will ensure that overall system costs and subsidies are lowered, travel speeds are raised, and service frequencies are improved. One way of achieving optimum utilisation of these corridors is by dedicating existing road infrastructure to public transport in the form of High Occupancy Vehicle (HOV) lanes or 'busways'. In this report, an HOV lane refers to a lane giving preferential treatment to buses and taxis only.

1.3 Objective of the Study

Several researches (2-12) have developed theoretical models to describe the relationships between volume, density and speed on freeways. These models have been used to establish traffic flow relationships in various overseas studies. With the objective of testing the relevance of overseas models to South African conditions, a number of these models have been investigated with data obtained from South African freeways. Models obtained from three separate freeway sections on the N1 and N2 were compared to overseas models (1,16,19), as well as models obtained from local studies (17). The ability of each model to describe the entire data range was evaluated with the aid of statistical methods.

Also, in the belief that there are two regimes of traffic flow (9), namely uncongested flow and congested flow, separate curves were used to describe each regime. In each case, a "Composite model" consisting of two separate curves (one for each regime) was used to describe the entire data range.

In the past, many researchers have concentrated on relationships for the freeway as a whole instead of individual lanes. In this report, speed-flow relationships were examined for each of the lanes and compared to relationships established for average lanes, the objective being to determine whether the usual practice of averaging over all the lanes is in fact justified.

Another objective of this study is the application of the established curves to investigate the performance of existing freeway facilities. In this report, the current performance of the N2 freeway westbound towards Cape Town was investigated in terms of travel-time and travel costs. The particular study section consists of three lanes, the right hand lane being an HOV lane dedicated to taxis and buses only. Different hypothetical cases were investigated through application of models, developed for other freeway sections, to the traffic-flow data obtained from the N2 freeway section. The first hypothetical case (Hypothetical Case 1) is an investigation into the traffic situation on the freeway section without the influence of the HOV lane. Hypothetical Case 2 investigates the traffic situation on the section with perfect operation of the HOV lane. It was therefore possible to compare the current performance of the section to the performance of each of the hypothetical cases.

1.4 Layout of Thesis

Chapter 1: Origin and Objective of the Study

Chapter 2: A brief overview of the theory of traffic-flow relationships is given, including the definition of some terms. A summary is also given of theoretical car-following models developed by various researchers.

Chapter 3: This chapter contains traffic-flow data (speed, flow, and density) obtained from three representative sections on the N1 and N2 freeway westbound towards Cape Town.

Chapter 4: Traffic-flow data is analysed and various models are established for separate lanes as well as average freeway lanes. These models are compared to other models established locally and overseas.

Chapter 5: The performance of the N2 freeway section (with an HOV lane) is investigated through application of models developed for different freeway sections. A description of the current traffic situation and each of the hypothetical cases are given and comparisons are made with regards to travel-time and travel cost.

Chapter 6: Conclusions drawn from the results and recommendations for future studies.

CHAPTER 2

TRAFFIC FLOW THEORY

2.1 Overview of theory

Before the various theories of traffic flow can be defined, we must firstly define some of the relevant terms. Traffic flow is generally described and measured using three interrelated variables namely speed U, volume (and/or rate of flow) Q, and density K. These variables are only meaningful when expressed in terms of averages over time and distance.

The following section contains definitions of various terms as described in the *HCM 2000 (1)*.

2.2 Definition of terms

(a) Volume (Q)

(i) Volume is the total number of vehicles that pass over a given point or section of a lane or roadway during a given time interval and may be expressed in terms of annual, daily, hourly, or sub-hourly periods.

(ii) Rate of flow is the equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval of less than 1 h, usually 15 min. For example, if n vehicles were observed passing a point during a given time interval t, the rate of flow (veh/h) would be:

$$q = \frac{n}{t} \tag{2.1}$$

(iii) The maximum flow (Q_m) is the maximum number of vehicles that pass over a given point or section of a lane or roadway during a given time interval when the speed and density of the traffic is at its optimum.

(iv) Capacity is defined as the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions.

(v) The peak-hour factor (PHF) is the ratio of the total hourly volume to the peak flow rate within the hour:

$$\text{PHF} = \frac{\text{Hourly volume}}{\text{Peak flow rate (within the hour)}} \tag{2.2}$$

If 15 min. periods are used, the PHF may be computed as follows:

$$\text{PHF} = \frac{V}{4 \times V_{15}} \tag{2.3}$$

Where PHF = peak-hour factor,
V = hourly volume (veh/h)
V_{15} = volume during peak 15min of peak hour (veh/15min)

(b) Speed (U)

(i) Speed is defined as a rate of motion of a vehicle or stream of vehicles expressed as distance per unit of time, generally as kilometres per hour (km/h).

(ii) Optimum speed (U_0) is defined as the speed at maximum flow during conditions of optimum density.

(iii) Average travel speed is a traffic stream measure based on travel time observed on a known length of highway. It is the length of the segment divided by the average travel time of vehicles traversing the segment, including all stopped time delays. It is also a space mean speed.

(iv) Average running speed is a traffic stream measure based on the observation of vehicle travel times traversing a section of highway of known length. It is the length of the segment divided by the average running time of vehicles to traverse the segment. Running time includes only time that vehicles are in motion.

(v) Free-flow speed (U_f) is defined as the average speed of vehicles on a given facility, measured under low-volume conditions, when drivers tend to drive at their desired speed and are not constrained by control delay.

(vi) Time mean speed (U_t) is the arithmetic average of speeds of vehicles observed passing a point on a highway; also referred to as the average spot speed. The individual speeds of vehicles passing a point are recorded and averaged arithmetically. Thus

$$U_t = \frac{\sum\left(\frac{dx}{dt}\right)}{N} = \frac{\sum U_i}{N} \qquad (2.4)$$

Where dx = the distance travelled by the individual vehicles

U_i = the speeds of the individual vehicles

N = the number of vehicles

(vii) Space mean speed (U_s) is a statistical term denoting an average speed based on the average travel time of vehicles to traverse a segment of roadway. It is called a space mean speed because the average travel time weights the average to the time each vehicle spends in the defined roadway segment or space. Thus

$$U_S = \frac{dx}{\frac{1}{N}\sum dt} \tag{2.5}$$

Where dx = known distance travelled by vehicles

dt = individual travel times of vehicles over distance dx

N = the number of vehicles

Measurements of space mean speed will always provide a lower value for speed compared to the value of time mean speed.

The two quantities q (volume) and k (density) are related to one another, and the mean speed of vehicles is $u = \frac{q}{k}$ since unit length of road containing k vehicles is emptied in time k/q.

Wardrop (2) established that the following relationship known as the steady-state equation is only valid for space mean speed.

$$Q = U_S K \tag{2.6}$$

He consequently derived the following relationship for computing time mean speed from space mean speed:

$$U_t = U_s + \frac{\sigma_s^2}{U_s} \tag{2.7}$$

Where U_t = the time mean speed

U_s = the space mean speed

σ_s^2 = the variance about the space mean speed

The variance is calculated as follows:

$$\sigma_s^2 = \sum_{i=1}^{n} k_i (u_i - U_s)^2 / K \qquad (2.8)$$

Where k_i = the density during the specific interval i.

K = the average density for the whole period

(c) Density (K)

(i) Density is defined as the number of vehicles occupying a given length of a lane or roadway at a particular instant, averaged over time and usually expressed as vehicles per kilometre (veh/km). Density describes the proximity of vehicles to one another and reflects the freedom to manoeuvre within the traffic stream.

If a given length of road dx is occupied by n vehicles during a given instant, then:

$$K = \frac{n}{dx} \qquad (2.9)$$

(ii) Average density is the average number of vehicles per unit length of road taken over a given time period.

(iii) Optimum density (K_o) is the density of the traffic when the volume of the traffic is at its capacity over a given length of road.

(iv) Jam density (K_j) is the density of a row of stationary vehicles when the flow rate is equal to zero.

2.3 Relationships among basic parameters

The basic relationships among the three parameters speed (space mean speed U_s), flow (Q) and density (K) cited in Equation 2.6, assumes a linear relationship between density and speed. Figure 2.1 shows a generalised representation of these relationships, which are the basis for the capacity analysis of uninterrupted-flow facilities.

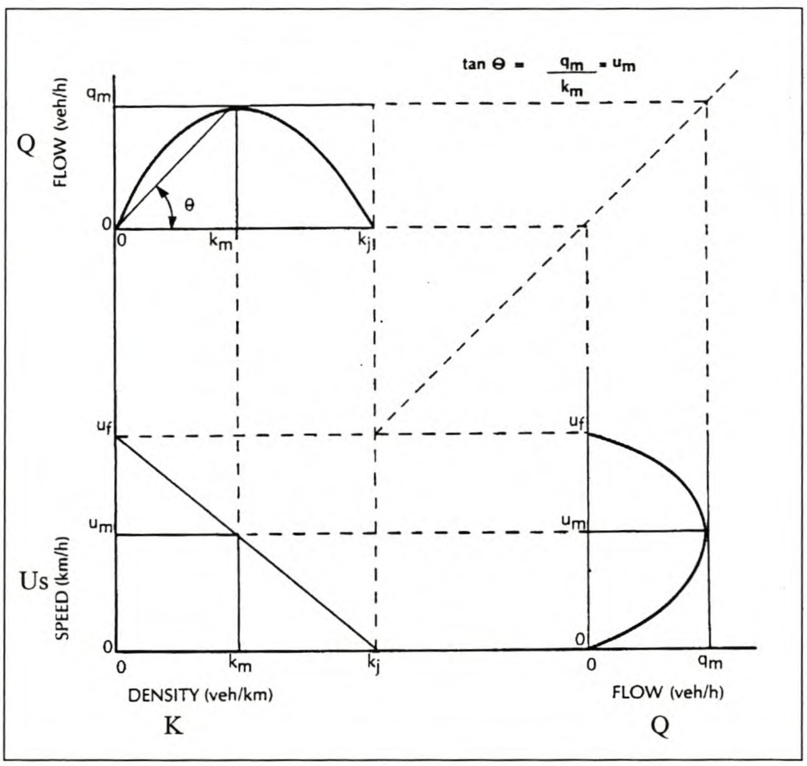

Figure 2.1: Generalised speed-, density-, and flow rate relationships on uninterrupted-flow facilities.

The shapes and values of the above curves depend on the prevailing traffic and roadway conditions on the segment of road under study and on its length in determining density. It is important to note that it is unlikely that the full range of functions would appear at any study location. Survey data usually show discontinuities, with parts of these curves not present.

Several points on the curves in Figure 2.1 are of interest. Firstly, a zero flow rate occurs under two different conditions. One is at zero density where there are no vehicles on the facility. The speed at this point is theoretical and is represented by u_f, the speed at which a vehicle would travel if there were no other vehicles or constraints on the roadway (free flow speed).

The second condition of zero flow-rate is when density becomes so high that vehicles are forced to come to a complete stop. The speed is therefore zero and vehicles cannot pass a point on the roadway. The density at which all movement stops is called the jam density, denoted by k_j.

Between these two points, as flow increases from zero, density also increases, as there are more vehicles on the roadway. Speed declines as a result, because of the interactions between the vehicles. As density increases further, speed decreases significantly before capacity is reached. Capacity is reached when the product of density and speed results in the maximum flow rate. At this point, the optimum speed (u_m or u_0), optimum density (k_m), and maximum flow (q_m) are reached. From this point, as the density increases further towards jam density, flow and speed decrease to zero.

Furthermore, the slope of any line drawn from the origin of the speed-flow curve to any point on the curve ($\tan\theta$) represents density (Equation 2.6). Similarly, the slope of any line drawn from the origin to the curve on the flow-density curve, represents speed. The low-density, high-speed sides of the curves represent under-saturated traffic flow conditions (light traffic), while the high-density, low-speed sides represent over-saturated conditions (heavy traffic).

The simplified model illustrated in Figure 2.1 assumes a single linear relationship between speed and density. This is however seldom the case and several researchers have constructed more complex models to describe this relationship. These models range from single and three regime linear to more elaborate exponential and logarithmic functions. The theory of some of the most pertinent traffic flow models will be discussed in the next section.

2.4 Empirical car-following models

Several researchers have developed theoretical models to describe the relationships between volume, density and speed on freeways. In general, there are two approaches to this problem. The first approach is the microscopic approach (car-following theory), which considers individual vehicle spacing and speeds. The second approach (macroscopic approach) is concerned with traffic-stream flows, densities, and average speeds. It has been shown that these two approaches are interrelated.

2.4.1 Microscopic traffic flow theory

In order to describe vehicular flow in a microscopic manner, it was necessary to describe the motion of pairs of vehicles following each other (Figure 2.2). *Pipes (3)* formulated the expression:

$$x_n - x_{n+1} = L + S(\dot{x}_{n+1}) \qquad (2.10)$$

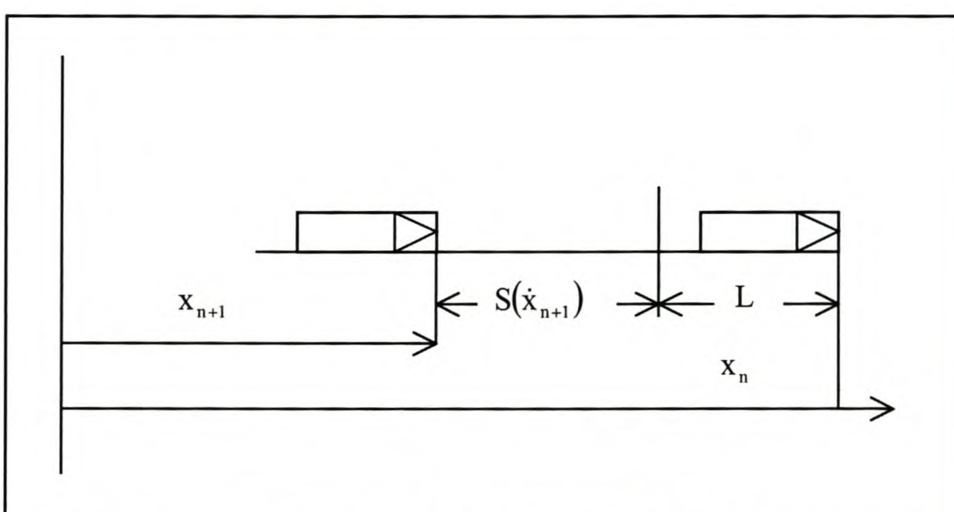

Figure 2.2: Basis for Car-Following formula

Where x_n = the position of the leading vehicle

x_{n+1} = the position of the following vehicle

L = the distance headway at standstill, including the length of the leading vehicle

S = the response time of the driver in the following vehicle

Differentiation of Equation 2.10 results in the basic equation of the car-following models:

Response = Sensitivity X Stimulus

Where *Stimulus* = Function of the difference in speed between two following vehicles.

Thus, the acceleration (response) of the following vehicle is a function of sensitivity times the relative speed.

$$\ddot{x}_{n+1}(t+T) = \lambda[\dot{x}(t) - \dot{x}_{n+1}(t)] \tag{2.11}$$

Where λ = sensitivity factor

T = the time lag of response to the stimulus

Gazis, Herman, and Rothery (4) proposed a general expression for the sensitivity factor, λ:

$$\lambda = a \frac{\dot{x}^{m}_{n+1}(t+T)}{[x_n(t) - x_{n+1}(t)]^{l}} \tag{2.12}$$

Where a, m, and *l* = constants

Thus, the general expression for microscopic theories becomes:

$$\ddot{x}_{n+1}(t+T) = a \frac{\dot{x}^{m}_{n+1}(t+T)}{[x_n(t) - x_{n+1}(t)]^{l}} [\dot{x}_n(t) - \dot{x}_{n+1}(t)] \tag{2.13}$$

It can be shown that when m = 0 and *l* = 0, the general equation reverts to Equation 2.11. Equation 2.13 together with the exponents m and *l*, will be shown to be very important in developing steady-flow equations later in this chapter.

2.4.2 Macroscopic traffic flow theory

Macroscopic theories of traffic flow date back to 1935, when *Greenshields (5)* hypothesised that a linear relationship existed between average density and average space mean speed:

$$U_s = U_f \left[1 - \frac{K}{K_j} \right] \tag{2.14}$$

Where U_f = average free-flow speed

K_j = jam density

It can be shown that this linear relationship between speed and density results in parabolic functions for both volume and density relationships and volume and speed relationships (by substituting $U_s = Q/K$ into Equation 2.14).

Instead of using a statistical approach, *Lighthill and Whitham (6)* applied fluid dynamic principles to various highway occurrences. Based on this, *Greenberg (7)* in 1958 proposed a macroscopic traffic flow model by applying the problem of one-dimensional fluid flow to the traffic-flow situation. He established the following relationship between speed and density:

$$\frac{\partial k}{\partial t} + \frac{\partial q}{\partial x} = 0 \tag{2.15}$$

Which resulted in:

$$\frac{du}{dt} = -c^2 \left(\frac{1}{k} \right) \frac{\partial k}{\partial x} \tag{2.16}$$

After integration:

$$u = c.\ln\left(\frac{k_j}{k} \right) \tag{2.17}$$

Where c = U_0 (speed at maximum flow)

In 1960, *Underwood (8)* proposed an exponential speed-density relationship in the form:

$$u = u_f e^{-k/k_0} \quad (2.18)$$

Where k_0 = density at maximum flow

Edie (9) hypothesized that there were two regimes of traffic flow: free-flow and congested flow. He proposed the use of an exponential speed-density relationship (Equation 2.18) for the free-flow regime, and the *Greenberg* equation (Equation 2.17) for the congested flow regime.

Using the fluid-flow analogy approach proposed by the *Greenberg* equation, *Drew (10)* proposed the following parabolic speed-density relationship:

$$\frac{du}{dt} = -c^2 k^n \frac{\partial k}{\partial x} \quad (2.19)$$

After integration:

$$u = u_f \left[1 - \left(\frac{k}{k_j} \right)^{\frac{n+1}{2}} \right] \quad \text{for } n > -1 \quad (2.20)$$

Drake, May, and Schofer (11) proposed a bell-shaped curve that gave satisfactory results when compared to speed-density measurements:

$$u = u_f e^{-\frac{1}{2}\left(\frac{k}{k_0}\right)^2} \quad (2.21)$$

2.4.3 Interrelationship between macroscopic and microscopic theories

A paper published by *Gazis, Herman, and Rothery (4)* in 1960 showed that several proposed macroscopic theories are mathematically equivalent to the general expression for microscopic theories (Equation 2.13), provided proper integers are selected for the exponents *m* and *l*.

For example, Equation 2.13 results in the *Greenshields (5)* equation if *m* = 0 and *l* = 2. Also, *Drew (10)* showed that equation 2.13 can be transformed into Equation 2.20 by setting *m* = 0 and varying *l* (for n = 2*l* – 3). Thus, all previously mentioned models can be described by the generalised equation (Equation 2.13) through the use of appropriate *m* and *l* values.

Gazis, Herman, and Rothery (4) have obtained the following expression by integrating Equation 2.13:

$$f_m(u) = c' + c.f_l(s) \tag{2.22}$$

Where u	=	steady-state speed of a traffic stream
s	=	constant average spacing
c and c'	=	appropriate constants consistent with physical restrictions

By using this general equation, *May and Keller (12)* developed a matrix of steady-flow equations for different *m* and *l* values. This matrix is illustrated in Table 2.1.

A close inspection of the matrix in Table 2.1 reveals that all the previously reported microscopic and macroscopic models can be located in terms of *m* and *l* combinations. For example, the *Greenberg (7)* model (eq. 2.17) is obtained when m = 0 and *l* = 1, the *Drew (10)* model (eq. 2.20) is obtained when m = 0 and *l* = 3/2, the *Greenshields (5)* model (eq. 2.14) is obtained when m = 0 and *l* = 2, the *Underwood (8)* model (eq. 2.18) is obtained when m = 1 and *l* = 2, and the bell-shaped curve proposed by *Drake, May, and Schofer (11)* (eq. 2.21) is obtained when m = 1 and *l* =3.

Table 2.1: Steady-state flow equations for different *m* and *l* values

	m < 1	m = 1	m > 1
$l < 1$	$U^{1-m} = c\left(K^{l-1} - K_j^{l-1}\right)$	No solution	$U^{1-m} = U_f^{1-m} + c.K^{l-1}$
$l = 1$	$U^{1-m} = c.Ln\left(\frac{K_j}{K}\right)$	$Ln(U) = c.Ln\left(\frac{K_j}{K}\right)$	$U^{1-m} = c.Ln\left(\frac{K_j}{K}\right)$
$l > 1$	$U^{1-m} = c\left(K^{l-1} - K_j^{l-1}\right)$	$Ln\left(\frac{U_f}{U}\right) = c.K^{l-1}$	$U^{1-m} = U_f^{1-m} + c.K^{l-1}$

A list of the models mentioned above is shown in Table 2.2 (macroscopic format) in matrix notation.

Table 2.2: Matrix of existing traffic-flow models

	$m = 0$	$m = 1$
$l = 0$	$u = \frac{1}{s}\left(\frac{1}{k} - \frac{1}{k_j}\right)$ with s = constant	-
$l = 1$	$u = u_0.\ln\left(\frac{k_j}{k}\right)$	-
$l = 1.5$	$u = u_f\left(1 - \left(\frac{k}{k_j}\right)^{1/2}\right)$	-
$l = 2$	$u = u_f\left(1 - \frac{k}{k_j}\right)$	$u = u_f e^{-k/k_0}$
$l = 3$	-	$u = u_f e^{-\frac{1}{2}\left(\frac{k}{k_0}\right)^2}$

The matrix of steady-flow equations developed by *May and Keller (12)* (Table 2.1) enables the utilization of non-integer m and *l* values, and consequently, expressions can be determined which more closely resemble actual speed-density relationships.

We are also able to recognise certain trends in the shape of the curves by keeping one of the exponents, *m* or *l*, constant. In Figure 2.3, a constant value of 1 is chosen for the exponent *m*, while the exponent *l* is changed in steps of 0.2.

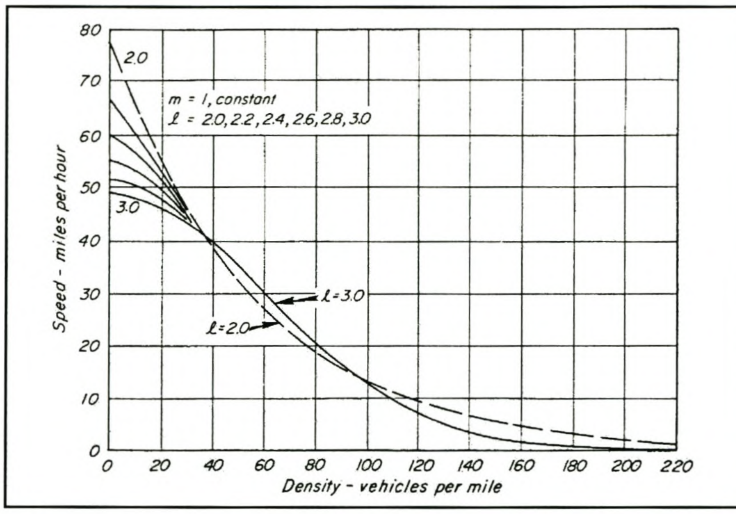

Figure 2.3: The effect of varying parameter *l* on the speed-density relation

CHAPTER 3

DATA ACQUISITION

3.1 Introduction

The *Highway Capacity Manual (1)* (HCM) is extensively used for freeway analysis and design in South Africa. It is however based on studies done under American conditions. In this chapter, the onus is on acquiring data of traffic flow on South African freeways during periods of highest demand. The objective is to analyse the data so that we can establish speed/flow/density relationships relevant to South African conditions of traffic flow. The data represented in this chapter will be analysed in Chapter 4.

Three representative sections were selected for study. The selection of each section was dependent on the prevailing traffic situation on the concerned freeway segment during morning peak-traffic conditions. In order to obtain accurate speed/flow curves, it was necessary to obtain representative data that covered the full speed/flow/density domain. Data were needed for the full range traffic-flow conditions ranging from free-flow conditions to heavily congested (bumper-to-bumper) conditions. To this end, it was needed to find appropriate sections where bumper-to-bumper conditions were reached in the morning, while it was also important to choose sufficient time-periods for study to ensure that all the degrees of congestion were covered.

Studies have also shown that various factors influence driver behaviour on a given stretch of road. These factors should be taken into account during section selection and should be reasonably consistent with other similar sections in order to ensure that the conclusions drawn from this report are applicable to other areas. These factors are:

(i) Roadway conditions

These conditions include factors like number of lanes, lane widths, shoulder widths and lateral clearance, design speed, horizontal and vertical alignments, road condition, and adjacent land use.

(ii) Traffic conditions

These conditions include factors like traffic composition (heavy vehicles, public transport vehicles, etc.), directional and lane distribution, parking, and pedestrians.

(iii) Diverse conditions

These include factors like weather conditions, season, visibility, speed restrictions, etc.

Another important aspect was the ability to collect data accurately. In this study, data were collected with a video camera from fixed vantage points near each section under study. From the footage collected in this manner, it was possible to observe average density values for each lane during fixed time-intervals. Average speeds (space mean speed) for each lane were also determined from this footage by calculating vehicle travel times for each lane over predetermined distances using a stopwatch.

Therefore, for each section, the location of the vantage point as well as the choice of section length was very important to ensure that an adequate distance of road could be filmed. The choice of a section length is of great importance and a trade-off between various requirements. These requirements are:

- Vehicles changing lanes while travelling through the section will complicate speed and density measurements for separate lanes. The shorter the section, the smaller the probability that a lane change will take place within the section.

- The speed of a vehicle travelling through the section is calculated using the time it takes to traverse the length of the section. The travel-time of separate vehicles is measured with the use of a stopwatch. The length of the section should therefore be sufficient to minimise the error in measurement caused by operator inaccuracy.

- The density of traffic on each lane of the section is calculated by dividing the number of vehicles occupying the section at a particular instant by the length of the section (expressed as veh/km). Therefore, the longer the section, the more accurate the density measurements will be.

- Finally, it is important to be able to distinguish between different vehicle types when analysing the video footage of the traffic flow on the section. The length of the section is therefore also restricted by the available camera resolution. The length of each section of road was measured using standard land surveying equipment.

During playback of the filmed footage for each section, each reference point used during the surveying (which was done during filming) was identified and marked on the television screen. These markers were used as distance beacons during speed and density measurements.

Average speed and density values for each lane were measured during 1-minute time intervals. Distinction was made between passenger cars, minibus taxis, trucks, and buses. During analysis for each section, adjustment factors were used to convert heavy vehicles (trucks and buses) to passenger car equivalents (pcu's). These adjustment factors were dependent on the type of terrain for each section and were taken from Table A-1 in Appendix A (*Papacostas and Prevedouros (13),* Table 4.3.3).

3.2 Section 1: N1 (Century City)

3.2.1 Location

The N1 freeway near Century City is a 6-lane dual carriageway primarily carrying urban commuter traffic towards Cape Town during the morning peak period. The section under study is situated on the 3 lanes inbound towards Cape Town between the Wingfield interchange and the interchange connecting Sable Road to the N1 (Refer to Figure 3.1). The speed limit is 120 km/h.

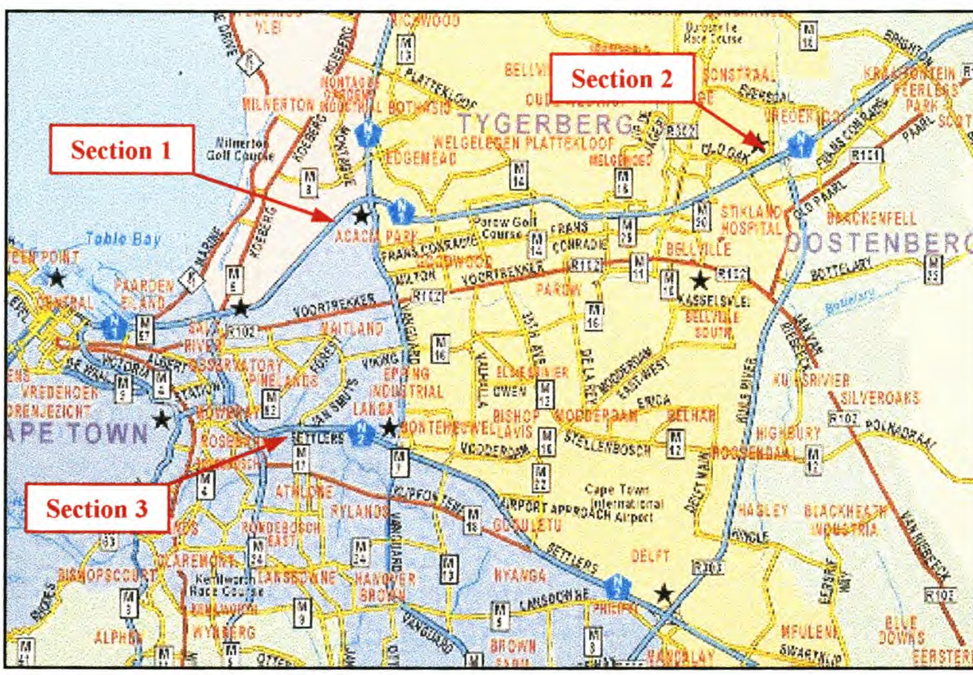

Figure 3.1: Map showing locations of study sections

3.2.2 Road Type and Geometry

The prevailing conditions on the section of road under study largely correspond to the base conditions described in the *Highway Capacity Manual (1)*. The section included lane widths of 3.6 m, a clearance of over 1.8 m between the edges of the travel lanes and the nearest obstructions at the roadside and on the median, a free-flow speed of about 100 km/h, a very small percentage of heavy vehicles (3.17%), level terrain (grade less than 5%), good weather conditions during the study, and no impediments to through traffic due to traffic control or turning vehicles.

3.2.3 Data collected

As mentioned earlier, data were collected with the aid of a video camera. Figure 3.2 is a picture-frame extracted from actual video footage. The vantage point was located 70 m from the N1 on a construction site crane. For the purpose of analysis in this report, the length of Section 1 was chosen as 77 m. This length was measured with the aid of standard land surveying equipment and is demarcated in Figure 3.2.

Figure 3.2: Footage for Section 1 (N1 near Century City)

An observation of the traffic flow on the section of road during morning peak conditions warranted a study period of about 3 hours (06:00-09:00). The battery-life of the video camera only allowed for a single session of $1^1/_2$ h to be filmed on a given day. This meant that the study period had to be divided into two $1^1/_2$ h sessions on consecutive days. In order to eliminate the effect of weekend traffic, only Tuesdays, Wednesdays and Thursdays were considered for analysis. For this particular section, the first filming session was from 06:00 to 07:30 on Wednesday the 28^{th} of March (2001) and the second session was from 07:30 to 09:00 on Thursday the 29^{th}.

Traffic counts:

Vehicles were counted from the video footage over consecutive 1 min. intervals for each of the three lanes. Distinction was made between passenger cars, taxis, trucks and buses. The heavy vehicles were converted to equivalent passenger car units (pcu's) with the use of passenger car equivalents given in Table A-1 in Appendix A. For this particular section, these equivalents were chosen as 1.7 for trucks and 1.5 for buses (Level terrain). Figure 3.3 is an illustration of the results obtained from the traffic count made for all three lanes over consecutive 1 min. intervals, with all vehicles converted to equivalent pcu's. Raw data of all the traffic counts are given in Table A-2 in Appendix A.

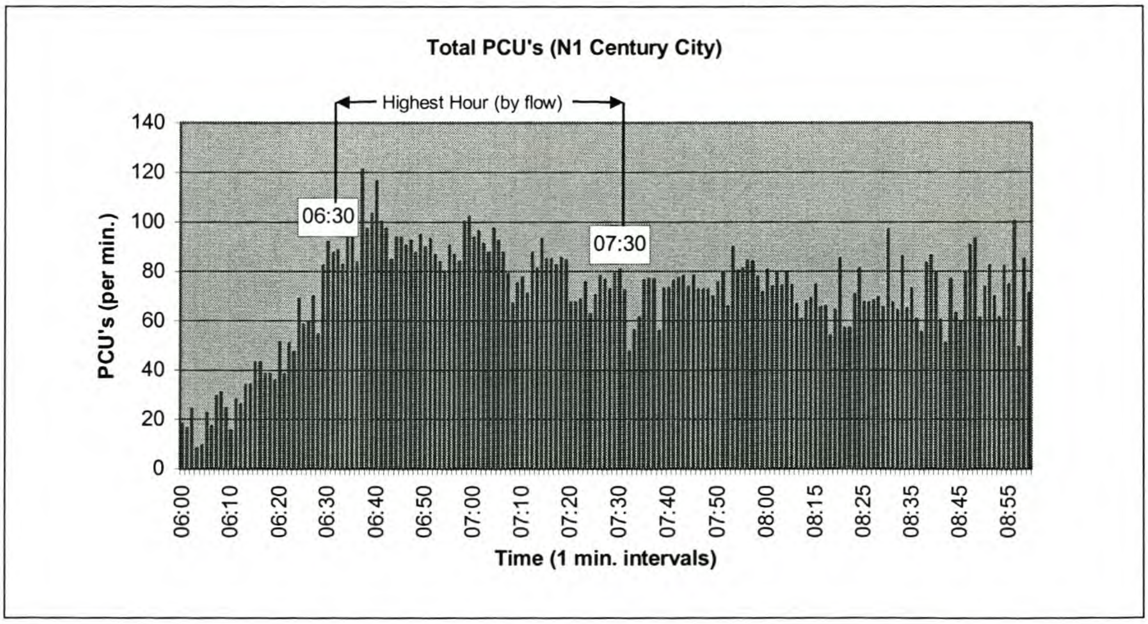

Figure 3.3: Consecutive 1 min. traffic-counts for all lanes (N1 Century City)

The section operates at free-flow conditions in the early morning with demand increasing steadily up to a point where the maximum flow is reached (about 06:30). From this point onwards, it seems as if the flow stays relatively high and it is difficult to make any predictions regarding traffic operating conditions (level of congestion, average travel speeds, etc.). It would be risky to make any observations without referring to the change in either the speed or density over the same time period.

Density observations:

The average value of five density observations (spread out through the interval) made during each 1-minute interval was taken as the density value for that particular interval (veh/km). Figure 3.4 is an illustration of the change in average density for all three lanes (veh/km/lane) during consecutive 1 min. intervals. Table A-3 in Appendix A contains all the speed, density, and flow data measured on Section 1. This data was used for analysis in the next chapter.

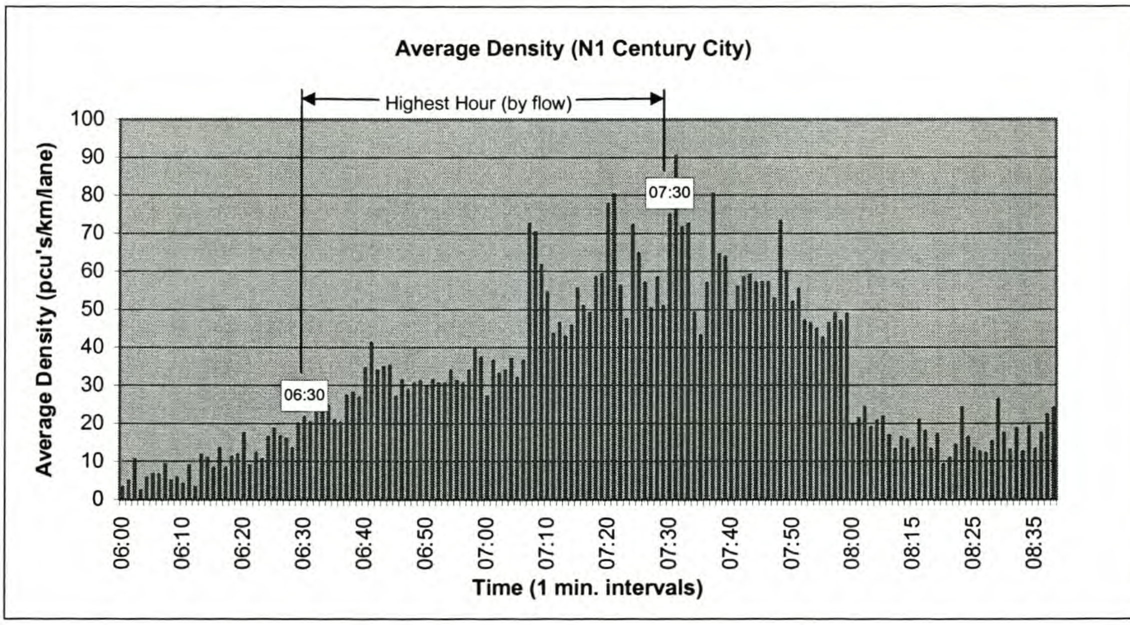

Figure 3.4: Average density measurements over consecutive 1 min. intervals (N1 Century City)

From Figure 3.4, it is clear that density increases gradually with demand up to a point of heavy congestion (about 07:10). From this point onwards, the density fluctuates around a high value, a situation otherwise known as a breakdown in flow. This is an indication that the capacity of the particular section is insufficient to cope with the required demand. The fluctuation of the density around this high value is due to unstable conditions caused by shockwaves (stop-start conditions). Due to this fluctuation, it is difficult to calculate the jam density for this particular section. It is however clear that the average jam-density is anything in excess of 90 veh/km/lane (highest density value in Figure 3.4).

The largest volume of traffic passed through Section 1 between 06:40 and about 07:06 (refer to Figure 3.3). The traffic density observed from Figure 3.4 for this period stayed relatively constant at a reasonably low value. This value is known as the optimum density of the section (Chapter 2), the density at which the volume of the traffic crossing the particular section is close to its capacity. For this section, the average density value for this period (optimum density) is about 33 veh/km/lane (calculated from Table A-3).

A sudden decrease in average density is observed at about 08:00. This reduction is due to a sudden drop in demand for the particular section. From this point onwards, density stays relatively constant at a very low value. This entails that the particular section is operating at close to free-flow conditions.

Speed measurements:

The average value of five travel-time measurements (spread out through the interval) made during each interval was calculated. This value was again used to calculate the average space mean speed (Chapter 2) for each interval on each lane, expressed in km/h. Figure 3.5 is an illustration of the change in average speed for all three lanes.

Vehicles travelling through the section in the early morning travel at average speeds of close to about 90 km/h. This average speed stays relatively constant while density increases gradually up to about 06:30. This implies that the speed at which vehicles travel on a particular section of freeway is relatively insensitive to changes in traffic density on the same section, provided that the density stays well below its optimum value.

The average speed at which vehicles travelled through the section stayed relatively constant during the time interval when the largest volume of traffic passed over the freeway-section (between 06:40 and about 07:06). The speed for this condition is known as the optimum speed (Chapter 2). For Section 1, the optimum speed was calculated by determining the average value for speed observed over this period (from Table A-3). A value of about 60.34 km/h was obtained.

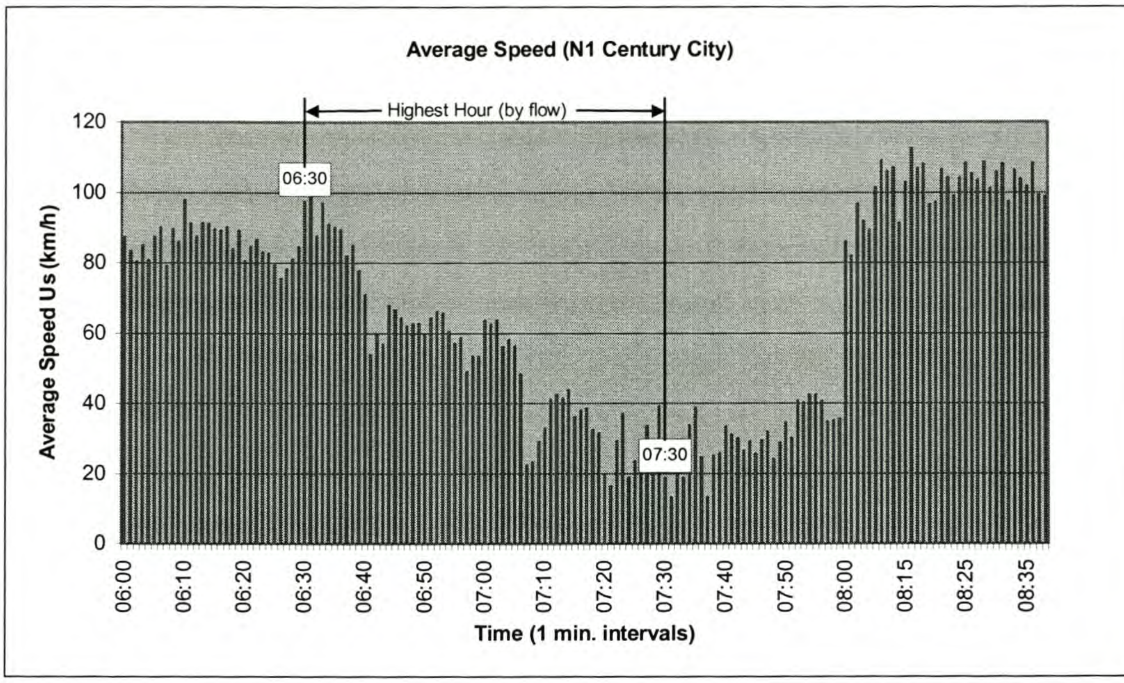

Figure 3.5: Average speed measurements for all lanes over consecutive 1 min. intervals (N1 Century City)

During the next interval (between 07:06 and 08:00) the capacity of the section is exceeded. Finally, there is a sudden increase in average speed at about 08:00, as a sudden drop in demand is experienced. A relatively high average speed is observed from this point onwards. This, together with the very low average density observed for this period, shows that the particular section is operating at close to free-flow conditions. The average speed measured during free-flow conditions is known as the free-flow speed (Chapter 2) and was calculated at about 102 km/h for this particular section.

An interesting observation is the fact that the average speed calculated during free-flow conditions after 08:00 is about 10 km/h higher than the average speed calculated before 06:30. This is a reasonably large difference, especially if we consider that the traffic density on the section was extremely low during both periods. Several factors may contribute to this occurrence. One of the factors contributing to this lower average speed may be a reduction of visibility in the early morning, which adversely affects the driver's perception of a safe travelling speed.

Peak hour:

The consecutive 60 min of the day when a freeway experiences its highest traffic-volume is known as the "Highest Hour" (or peak hour). For Section 1, the consecutive 60 min period of highest traffic-volume was calculated between 06:30 and 07:30 (Depicted in Figure 3.3 and Figure 3.4). The ratio of this volume to the maximum rate of flow computed on the basis of an interval *t* within the peak hour (e.g. 5 min.) is known as the *peak-hour factor* (PHF), defined in Chapter 2.

In other words, the PHF is a measure of demand uniformity or demand peaking and is of significant importance for freeway capacity analysis. Referring to Figures 3.3, 3.4 and 3.5, it is clear that a very high demand for this section is experienced from about 06:30 until 08:00, signified by a high level of flow and congestion and a reduction in average speed. It is therefore the concern of the author that the normal use of the PHF is inadequate in measuring uniformity of demand in this case, as a large portion of demand is not accounted for by the peak hour. For the purpose of analysis, use has been made of a peak $1^1/_2$-hour in this report (06:30 to 08:00 for Section 1).

3.3 Section 2: N1 (near R300)

3.3.1 Location

The second section was situated located on the N1 freeway between Old Oak interchange and the Stellenberg interchange (R300), illustrated in Figure 3.1. It was located on the two lanes of the 4-lane dual carriageway inbound towards Cape Town with a speed limit of 120 km/h. This particular section of road carries a large volume of urban commuter traffic from the Paarl region, as well as from Kuilsrivier on the R300 in towards Cape Town.

3.3.2 Road Type and Geometry

The prevailing conditions on Section 2 again corresponded to a great extent to the base conditions described in the *Highway Capacity Manual (1)*. The section was however located just after a relatively steep upgrade (higher than 5% grade) where the N1 passes beneath the R300. For this reason, the area around Section 2 has been classified as rolling terrain (although the grade of the section was below 2%). 5.01 % of the observed traffic consisted of heavy vehicles.

3.3.3 Data collected

Figure 3.6 is a picture-frame extracted from actual video footage of Section 2. The vantage point was located on the intersection bridge where Old Oak road passes over the N1. The length of Section 2 was chosen as 75 m and was again measured with standard land surveying equipment. This length is indicated in Figure 3.6. The first $1^1/_2$ h was filmed on Tuesday the 13^{th} of February (2001) from 06:00 to 07:30. The second $1^1/_2$ h was filmed on the following day from 07:30 to 09:00.

Figure 3.6: Footage for Section 2 (N1 near the R300)

Traffic counts:

For Section 2, the passenger car equivalents were chosen as 4.0 for trucks and 3.0 for buses (Rolling terrain) from Table A-1 in Appendix A. Figure 3.7 contains results obtained from the traffic count made for both lanes over consecutive 1 min. intervals. Raw data of all the traffic counts for Section 2 are given in Table A-4 in Appendix A.

From Figure 3.7, there is a rapid increase in demand up to a point where maximum flow is reached (about 06:20). From this point onwards, demand stays relatively high throughout the study period.

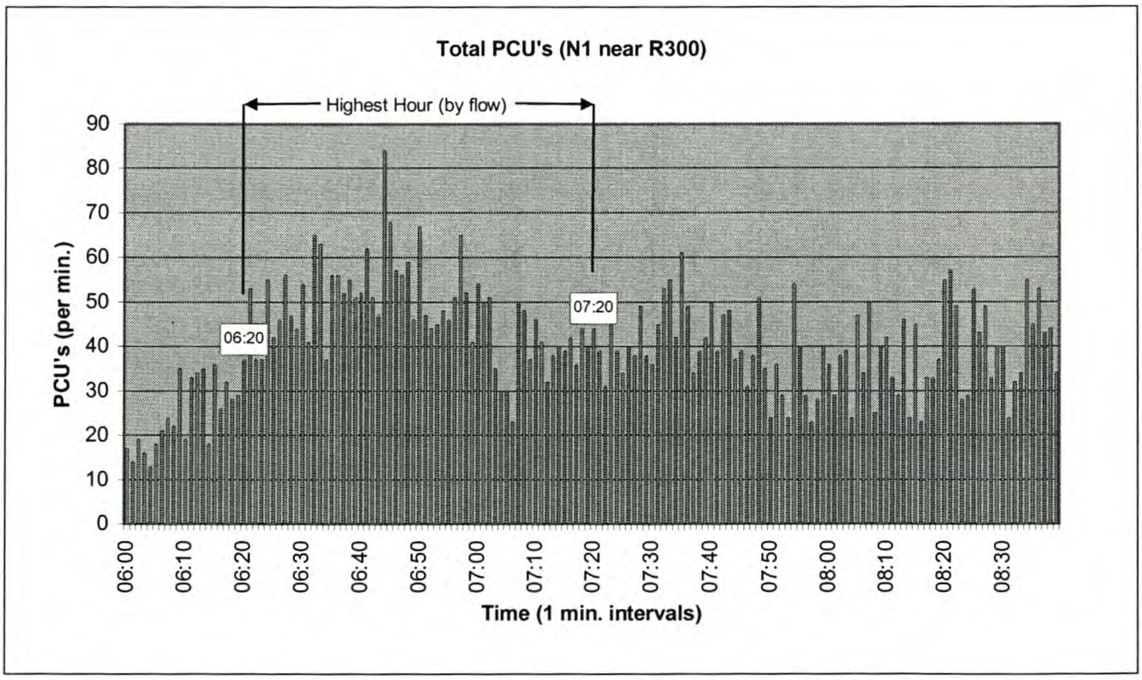

Figure 3.7: Consecutive 1 min. traffic-counts for all lanes (N1 near R300)

Density observations:

Figure 3.8 is an illustration of the average change in density for both lanes (veh/km/lane) during consecutive 1 min. intervals. Table A-5 in Appendix A contains all the speed, density, and flow data measured on Section 2.

From to Figure 3.8, there is a gradual increase in density throughout the early morning up to about 06:45. A sudden increase in density can be observed at about

06:50, which means that the capacity of the section has suddenly been exceeded. Unstable conditions follow. No accurate predictions regarding the jam density can be made from the figure. The jam density may even be much higher than the highest density value observed from the figure (120 veh/km/lane).

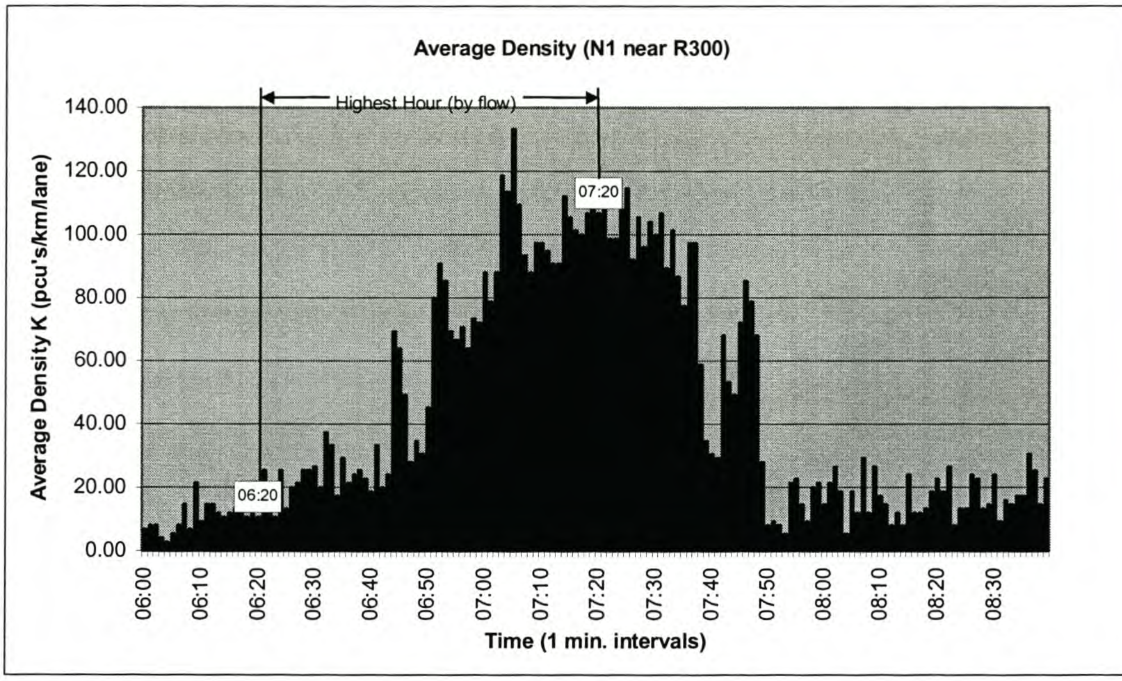

Figure 3.8: Average density measurements over consecutive 1 min. intervals (N1 near R300)

Estimating the optimum density for Section 2 from Figure 3.8 is no simple task. A closer observation of Figures 3.7 and 3.8 (between 06:20 and about 06:50) reveals that the value for optimum density lies somewhere between 20 and 30 veh/km/lane.

A sudden decrease in average density is observed at about 07:50. This reduction is due to a sudden drop in demand for the particular section. From this point onwards, the particular section seems to be operating at close to free-flow conditions.

Speed measurements:

Figure 3.9 is an illustration of the change in average speed for both lanes. Refer to Table A-5 in Appendix A for a complete table of all the speed data calculated for Section 2.

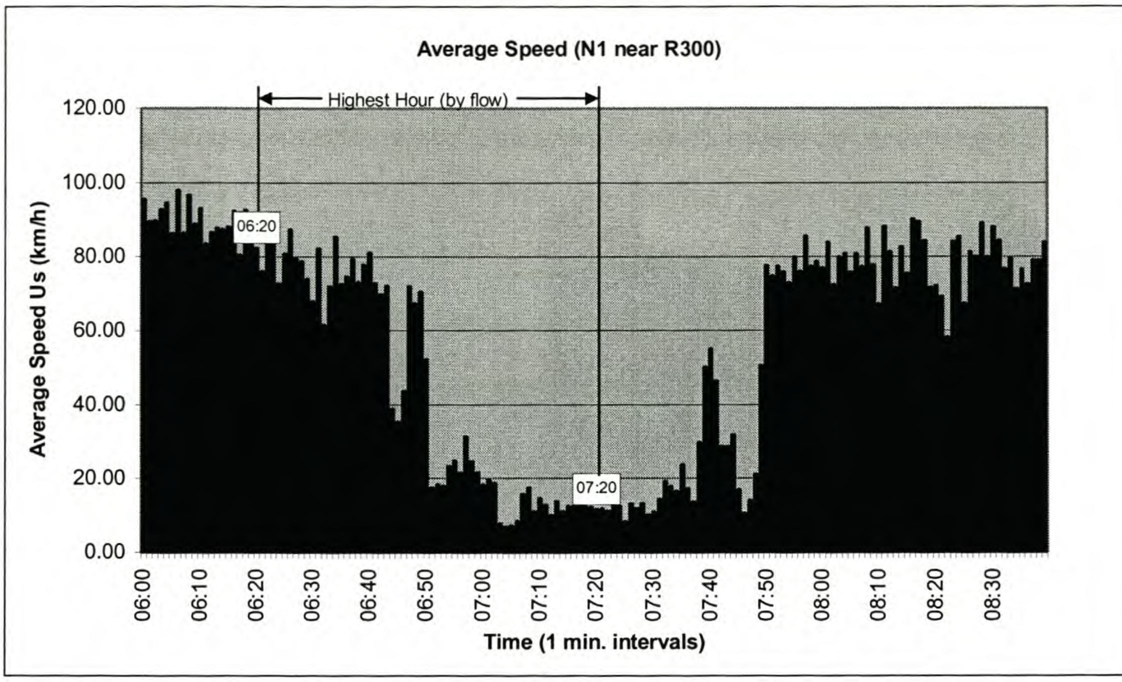

Figure 3.9: Average speed measurements for both lanes over consecutive 1 min. intervals (N1 near R300)

Vehicles travel through the section in the early morning at an average speed of about 90 km/h. The average speed decreases gradually to about 70 km/h with a gradual increase in density up to about 06:50. This gradual decrease in average speed at low-density conditions is more significant than what was experienced for Section 1. This implies that the speed at which vehicles travel through Section 2 is more sensitive to changes in traffic density than for Section 1. This can be ascribed to various factors. One factor may be the influence of the rolling terrain of Section 2 on traffic conditions. The rolling terrain may have an adverse effect on the driver's perception of a safe travelling speed with an increase in density. A safe travelling speed is dependant on factors like sight distance and braking distance. A rolling terrain has a decreasing effect on both.

The fact that Section 2 consists of only two lanes, may also contribute to this phenomenon. For Section 1, where three lanes are available, slower moving vehicles are more effectively segregated from faster moving vehicles. Very slow moving vehicles (e.g. heavy vehicles) tend to travel in the left hand lane (slow lane), while very fast moving vehicles travel in the right hand lane (fast lane). Vehicles moving at in-between speeds tend to travel in the middle lane and therefore have less influence on the fast moving traffic. For Section 2, there is a high speed deferential between the two lanes. Slow moving vehicles in the left hand lane impede vehicles that would otherwise have been travelling at in-between speeds. These faster moving vehicles (in-between speeds) are forced onto the right hand lane (fast lane), thereby forcing all vehicles on the fast lane to travel at slower speeds.

As for optimum density, it is also difficult to calculate the optimum speed for Section 2. A closer look at Figure 3.7 reveals that the largest volume of traffic passed over the section somewhere between 06:35 and 06:50. The average observed speed during this interval stayed relatively constant at about 66 km/h. We can estimate that the optimum speed for Section 2 is close to this value.

During the next interval (between 06:50 and 07:50) the capacity of the section is exceeded. Vehicles travel at speeds well below 20 km/h during this period. An interesting observation is that the average speed calculated for Section 2, during heavy congested conditions, is lower than what was experienced for Section 1. For Section 1, the calculated average speed remained higher than 20 km/h.

A sudden drop in demand is experienced at about 07:50. A relatively high average speed is observed from this point onwards. However, a relatively high flow of traffic through the section is still experienced for the same period. It is therefore unsafe to assume that the section is operating at close to free-flow conditions during this period, as the speeds of the vehicles will most probably be influenced by each other (especially for 2-lane sections). A free-flow speed of about 90 km/h is therefore estimated from the early morning data.

The "Highest Hour" (peak hour) for Section 2 (depicted in Figures 3.7 through 3.9) was calculated between 06:20 and 07:20. A very high demand for Section 2 was however experienced from about 06:20 until 07:50. Therefore, for the purpose of analysis, use of a peak $1^1/_2$-hour is again justified.

3.4 Section 3: N2 (near Athlone Power Station)

3.4.1 Location

Section 3 was situated on the N2 next to Hazendal close to the Jan Smuts interchange where the M16 crosses the N2 (see Figure 3.1). It was located on the three lanes of the 6-lane dual carriageway inbound towards Cape Town with a speed limit of 100 km/h. This particular section of road carries a large volume of urban commuter traffic in towards Cape Town. A large portion of this traffic consists of public transport modes (buses and taxis) carrying passengers from the Khayelitsha township, Mitchell's Plain, Nyanga, and surrounding areas. The right hand lane is reserved for high occupancy vehicles (buses and taxis) during morning peak conditions in the form of an exclusive HOV lane.

3.4.2 Road Type and Geometry

The prevailing conditions on Section 3 were very similar to the base conditions described for Section 1, with the observed traffic consisting of 4.77 % heavy vehicles. The grade of the particular section was below 2%.

3.4.3 The HOV lane

Preferential lanes on freeways for high occupancy vehicles (minibus taxis and buses for N2 freeway) have been implemented in a number of locations throughout the world. They can generally be classified as belonging to one of three groups (14*)*:

(i) Normal flow exclusive bus or bus/carpool lane where one of the lanes in the peak flow direction is reserved for the exclusive use of buses or buses and carpools.

(ii) Contra-flow exclusive bus or bus/carpool lane where the median lane in the non-peak direction is reserved for the exclusive use of buses or buses and carpools travelling in the peak direction.

(iii) Separate lanes for the exclusive use of buses or buses and carpools within the freeway road reserve.

For Section 3, the median lane (right hand lane) in the peak flow direction is reserved for buses and minibus taxis only during the morning peak period (06:30 to 09:00) with ramps on the left hand side of the freeway only (group i). Refer to Figure 3.10.

Figure 3.10: Exclusive HOV lane during morning peak conditions

The primary advantages of the type of HOV lane currently in operation on Section 3 are:

- A low implementation cost.
- Operational flexibility, since no permanent structures need to be constructed.
- Switching between priority and non-priority operations can be achieved without too much effort (refer to Figure 3.10).

The primary disadvantages are:

- A potential hazard of weaving into and out of the priority lane due to a high speed-differential between the reserved lane and the adjacent lane.

- A possible reduction in capacity on the priority lane as a result of vehicles exciting from the priority lane having to slow down in order to enter the adjacent non-priority lane.
- Increased congestion on the non-priority lanes, since all the HOV vehicles must use the non-priority lanes in the vicinity of the ramps.

3.4.4 Data collected

Figure 3.11 is a picture-frame of Section 3 extracted from actual video footage. The vantage point was located next to the N2, 85 m high on one of the cooling towers belonging to Athlone Power Station. The length of Section 3 was chosen as 135 m and was again measured with standard land surveying equipment. This length is indicated in Figure 3.11.

For the purpose of analysing traffic flow conditions on Section 3, a suitable study period had to be chosen. It was decided that a study period would be used that corresponded to the period when the HOV lane was in operation (06:30 to 09:00). The first $1^1/_2$ h was filmed on Wednesday the 2nd of May (2001) from 06:30 to 08:00. The second hour was filmed on the following day from 08:00 to 09:00.

Figure 3.11: Footage for Section 3 (N2 Athlone Power Station)

Traffic counts:

For Section 3, the passenger car equivalents were chosen as 1.7 for trucks and 1.5 for buses (level terrain) from Table A-1 in Appendix A. Figure 3.12 contain results obtained from the traffic count made for each of the three lanes over consecutive 1 min. intervals. Raw data of all the traffic counts for Section 3 are given Table A-6 in Appendix A.

Demand increases rapidly in the early morning up to a point where the maximum flow is reached at about 06:48. From this point onwards, demand stays relatively high up to a point where the flow suddenly drops at about 07:21 (or so it seems). From Figure 3.12 alone, it is however not possible to establish whether this sudden drop in flow is due to a drop in demand, or whether it is as a result of heavy congestion.

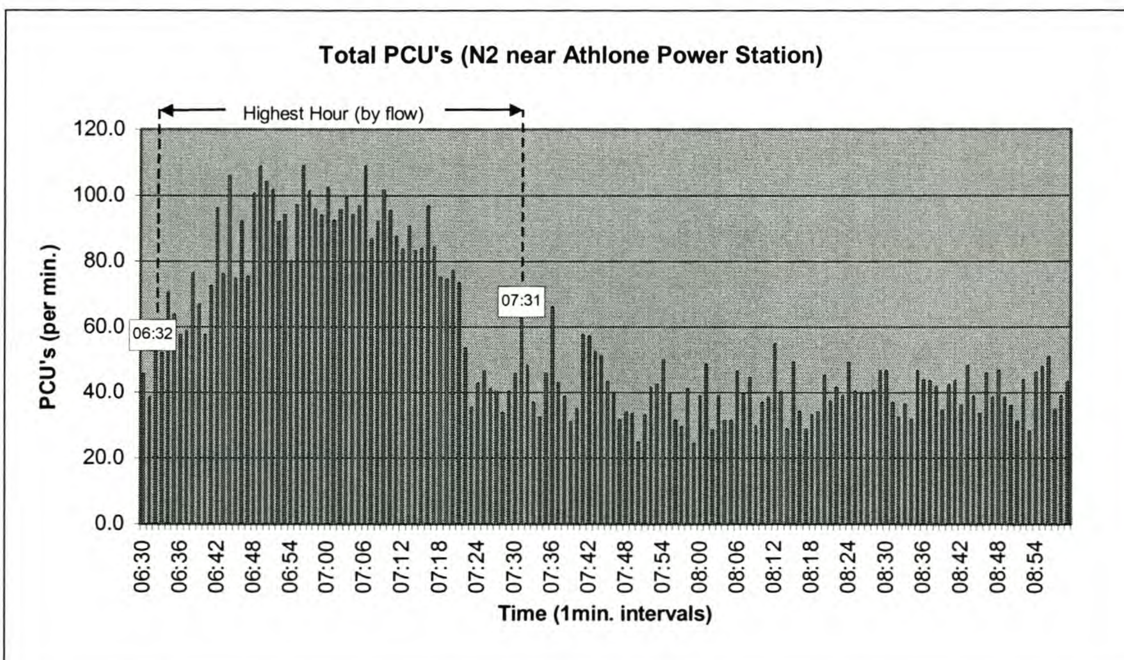

Figure 3.12: Consecutive 1 min. traffic-counts for all lanes (N1 Athlone Power Station)

An interesting observation is the modal distribution of vehicles travelling on the HOV lane during the study period. Of the total number of vehicles counted travelling on the HOV lane (while in operation), 71% are passenger cars, 25% are taxis, and 4%

are buses. This high percentage of passenger cars is a result of inadequate law enforcement over the period of operation of the HOV lane.

Density observations:

Figure 3.13 is an illustration of the average change in density for all three lanes (veh/km/lane) during consecutive 1 min. intervals. Table A-7 in Appendix A contains all the speed, density, and flow data measured on Section 3.

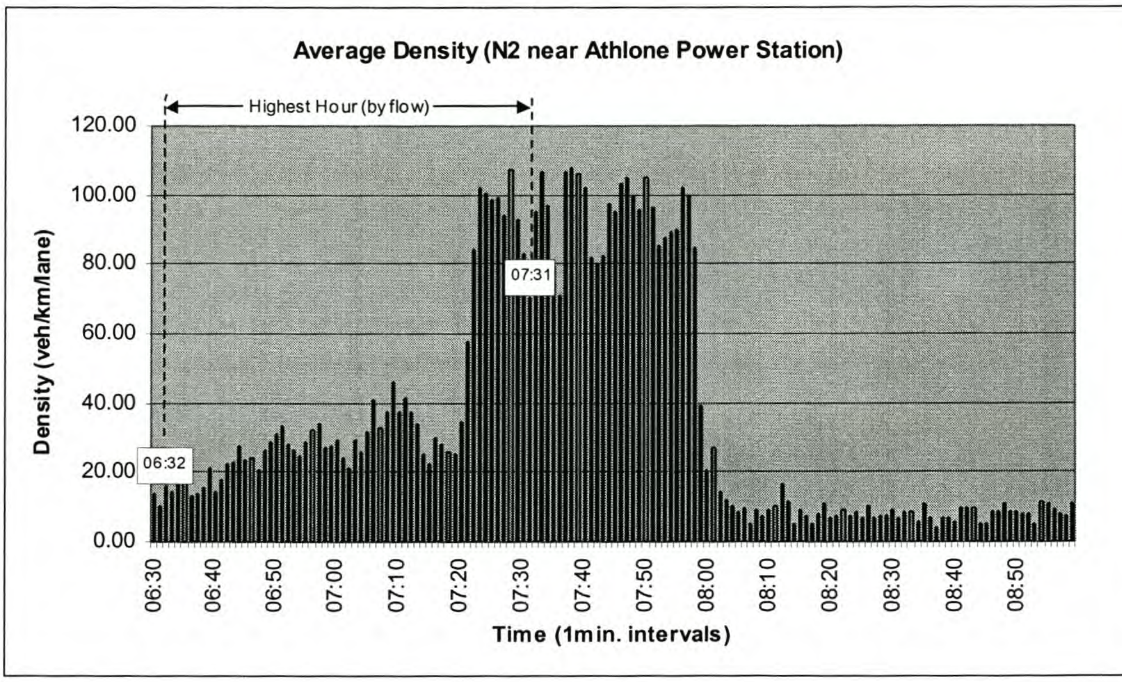

Figure 3.13: Average density measurements over consecutive 1 min. intervals (N2 near Athlone Power Station)

From Figure 3.13, there is a gradual increase in density throughout the early morning up to about 07:10. A sudden increase in density can be observed at about 07:20, which suggests that the capacity of Section 3 has suddenly been exceeded. Unstable conditions follow, characterised by fluctuating density values.

It is not possible to calculate an accurate value for the optimum density for Section 3. It is however possible to make a safe estimation through inspection of both figures 3.12 and 3.13. The largest volume of traffic passed through the freeway section between 06:48 and about 07:17. Relatively low average density values were observed during this period. We can assume that the value for the optimum density for Section 3 is close to the average density observed for this period. A value of 31 veh/km/lane was calculated by averaging the values obtained from Table A-7 in Appendix A for this period.

The sudden decrease in average density at 08:00 is due to a sudden drop in demand. Average densities lower than 10 veh/km are observed from this point onwards, indicating that the particular section is operating at close to free-flow conditions.

Speed measurements:

Figure 3.14 is an illustration of the change in average speed for all the lanes of Section 3. Refer to Table A-7 in Appendix A for a complete table of all the speed data calculated for Section 3.

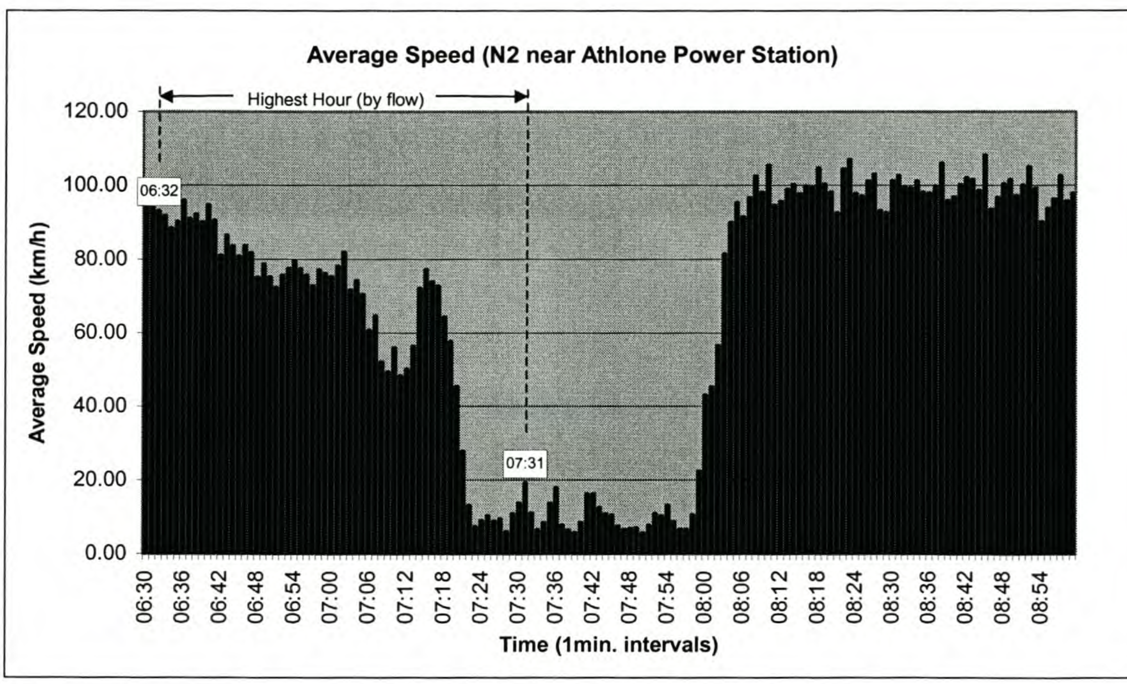

Figure 3.14: Average speed measurements for all lanes over consecutive 1 min. intervals (N2 near Athlone Power Station)

There is a gradual decrease in average speed in the early morning up to about 06:48 from about 100 km/h to just below 80 km/h. After this point, there is a short period where the average speed stays relatively constant (06:48 to 07:05). This is also the period during which the largest volume of traffic passed through the freeway section. We can estimate that the optimum speed for Section 3 is close to the average speed value for this period. A value of 76 km/h was calculated from Table A-7 in Appendix A. This value is much higher than the 60 km/h calculated for Section 1.

During the next interval (between 07:20 and 08:00) the capacity of the section is exceeded and a breakdown in flow is experienced. The average speed of the vehicles travelling through the section during this period stays well below 20 km/h. This is much lower than what was experienced for Section 1. It is therefore evident that Section 3 experienced a higher level of congestion during the morning peak period.

Finally, a sudden increase in average speed is observed just after 08:00. This is again due to a sudden drop in demand for this particular section. For the rest of the study period, the average calculated speed stays almost constant, during which the average density stays below 10 veh/km/lane. We can confidently assume that the section is operating at close to free-flow conditions during this period. The free-flow speed for this period was calculated at about 99 km/h.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

In this chapter, the onus is on establishing speed-flow relationships for traffic flows relevant to South African freeway conditions. These relationships will prove to be useful for design purposes since the figures in the *Highway Capacity Manual (1)* (HCM) are based on studies done in America under conditions different from that in South Africa.

Also, in the HCM, the relationships between speed and flow on multilane freeways are averaged over all the lanes. In this chapter, speed/flow/density relationships have been examined for individual lanes by fitting curves proposed by different authors (Chapter 2) to data obtained from three sections on the N1 and N2 close to Cape Town (Chapter 3). These curves were also compared to average-lane curves obtained from data of all the lanes and are shown to be markedly different. Further comparisons were also made with the curves obtained from studies done overseas (e.g. the HCM) as well as other relationships established during studies done in South Africa (17).

4.2 Models utilised

As mentioned earlier in Chapter 2, several researchers have developed theoretical models to describe the relationships between volume, density and speed on freeways. In this chapter, some of the most prominent models have been tested on the available traffic-flow data. The extent to which the different models were able to describe the whole range of speed-density data, was used as the criterion to decide on the best model.

The results were obtained with statistical methods of analysis of the different models. Where these methods were insufficient, personal judgement was used to select the most practical and functional models. The graphical representations of volume-density and speed-volume relationships were obtained through the application of the steady state equation Q = U.K (Equation 2.6).

The following models were used for analysis of the data acquired for each lane on each section during the given study period:

- The Greenshields Model

  Greenshields (5), who was one of the earliest investigators of traffic characteristics, proposed a linear relationship between flow and concentration (expressed by Equation 2.14):

$$u_s = u_f\left[1 - \frac{k}{k_j}\right] \tag{2.14}$$

  This model is very simple to use and several investigators have found good correlation between the model and the observed data. Due to theoretical reasons, other models have found greater acceptance.

- The Greenberg Model

  Greenberg (7), using fluid dynamic principles (described in Chapter 2), has postulated an exponential speed-density model of the form:

$$u = u_0 . \ln\left(\frac{k_j}{k}\right) \tag{2.17}$$

The constant, u_0, is the speed at maximum flow (optimum speed). Good agreement between this model and field data were found for congested flows. This model, however, breaks down at low concentrations as will be shown later in this chapter.

- <u>The Underwood Model</u>

Underwood (8) has also demonstrated an exponential model in the form:

$$u = u_f e^{-k/k_0} \qquad (2.18)$$

This model showed reasonably good agreement with field data at low concentrations. However, one shortcoming of the model is that it does not represent zero speed at high concentrations.

- <u>The Drake, May, and Schofer Model</u>

Drake et al. (11) proposed the use of a bell-shaped or normal curve as a model of speed-density in the form:

$$u = u_f e^{-\frac{1}{2}\left(\frac{k}{k_0}\right)^2} \qquad (2.21)$$

Very good agreement between this model and field data were found at low concentrations. However, this model tends to underestimate the observed speed at high concentrations (shown later in this chapter).

- <u>The Multi-regime Matrix Model</u>

May and Keller (12) developed a matrix of steady-flow equations for different *m* and *l* values (Table 2.2). By using this matrix, and by choosing particular *m* and *l* combinations, a wide variety of shaped curves for the speed-density relationship can be selected. For the purpose of analysis in this report, all the matrix equations displayed in Table 2.2 have been fitted to the data through the use of regression analysis. For each case, the model that best described the whole range of speed-density data were selected for further analysis.

- The Composite Model

Edie (9) has pointed out that traffic behaviour appears to be different at high densities and at low densities. He introduced the idea of the use of two speed-density models, one for free flow and one for congested flow. He proposed the use of the Underwood Model for the free-flow regime and the Greenberg Model for the congested-flow regime. In this report, the best model obtained (in each case) for the free-flow regime was selected for further analysis in conjunction with the best model obtained for the congested-flow regime.

4.3 Analytical procedure for evaluating traffic-flow models

For the purpose of analysis in this report, the speed-density relation rather than the flow-density or the speed-flow relation was selected as the relationship for evaluation. Once this equation is evaluated, the other relationships can be obtained by using the steady state equation Q = U.K (Equation 2.6). The reason for this preference is that the speed-density relation has the advantage of being easier to handle mathematically.

As mentioned in Chapter 2, a range of different models can be obtained by selecting different m and l values (refer to Equation 2.13). In order to define a specific equation that best describes the form of the data, the different parameters m, l, U_0, U_f, K_0, K_j, and c must be determined. In this report, these parameters were obtained with the use of regression analysis (least squares estimation). The different parameters were determined by maximizing the correlation coefficient R^2. For this purpose, the solver function in Excel (Windows based spreadsheet) was used. Problems were encountered during the solving process due to the great number of parameters. Trial and error through the estimation of initial values for parameters U_0, K_j, U_f, K_0, and c at times solved the equations.

4.3.1 Regression procedure

The first step in analysing the relationship between two characteristics is to graph the data with the independent variable or regressor (in our case the density) on the x-axis and the dependent variable or response (speed) on the y-axis. Such a graph is called a scatter plot, and it allows us to visualise the relationship between the two characteristics. By studying the nature of the relationship, we are able to suggest reasonable models.

Our equation for predicting the nature of the observed data depends on various unknown parameters. These parameters are again dependent on the type of model being fitted to the data and are estimated by the method of least squares, which minimises the errors in predicting the observed data. The least square estimates of the parameters specifically minimise the sum of the squares of the residuals (the residuals is the vertical difference between the observed values for the response and the predicted values). The residual is therefore an estimate of the error for our prediction of the actual value. Let e_i be the ith residual defined by:

$$e_i = \mathrm{y}_i + \hat{\mathrm{y}}_i \tag{4.1}$$

Where y_i = the observed value of the ith response

$\hat{\mathrm{y}}_i$ = the estimated value of the ith response

Values for e_i near zero is an indication of a good fit. Furthermore, an appropriate measure of the quality of the fit is the sum of the squares of the residuals, $\mathrm{SS}_{\mathrm{res}}$, defined by:

$$\mathrm{SS}_{\mathrm{res}} = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (\mathrm{y}_i - \hat{\mathrm{y}}_i)^2 \tag{4.2}$$

$\mathrm{SS}_{\mathrm{res}}$ also provides a basis for estimating σ^2, which is the variance of the random errors.

4.3.2 Analysis of the model

The overall variability in the data, SS_{total}, can be partitioned into two components. The first component, SS_{reg}, represents the variability explained by the model, while the second component, SS_{res}, measures the variability left unexplained and therefore usually attributed to error. The sum of squares due to regression, SS_{reg}, is defined by:

$$SS_{reg} = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{4.3}$$

Where $\bar{y}$ = the overall mean

SS_{reg} measures the variability among the predicted values. The overall variability in the data, SS_{total}, can then be given by:

$$SS_{total} = SS_{reg} + SS_{res} \tag{4.4}$$

A model that does not fit the data well indicates that virtually all of the variability remains unexplained. As a result, SS_{reg} is relatively small and SS_{res} is relatively large. On the other hand, a model that fits the data well indicates that the predicted values are quite different from the overall mean. In this case, SS_{reg} is relatively large. This means that the model accounts for much of the total variability, and SS_{res} is relatively small.

The coefficient of determination, R^2, uses both the relative sizes of the variability explained by the regression model and the total variability to measure the overall adequacy of the model. It is defined by

$$R^2 = \frac{SS_{reg}}{SS_{total}} = \frac{SS_{total} - SS_{res}}{SS_{total}} = 1 - \frac{SS_{res}}{SS_{total}} \tag{4.5}$$

It is therefore guaranteed that $0 \leq R^2 \leq 1$. R^2 may also be interpreted as the proportion of the total variability explained by the model. For models that fit the data well, R^2 is near 1. Models that poorly fit the data have R^2 values close to 0. One problem is to decide what value for R^2 constitutes a good one. For the purpose of analysis in this report, a value for R^2 close to 0.9 is considered adequate. This means that the given model explains 90% of the total variability. The best models in each case were chosen on the basis of their overall ability to describe the speed-density data. In some cases, models were used in conjunction because of their ability to describe certain areas of the data well (while failing at other areas). In most cases, these models on their own failed to describe the whole range of the data well, resulting in relatively low R^2 values. As a result, specific models were selected to represent certain areas of data through visual inspection.

4.4 Fitting of Curves: Speed-Density relationship

The different curves discussed in Section 4.2 were fitted to the data obtained for each lane of each section with the use of regression analysis (discussed in Section 4.3). In each case a final model (Composite model), describing the whole range of speed-density data, was represented by two separate curves. The curve that best described the data at low concentrations was used to represent the free-flow regime, while the curve that best described the data at high concentrations was used to represent the congested-flow regime.

4.4.1 Separate Lanes

Regression analysis results for each model are summarised in Tables B-1 through B-3 of Appendix B-1.

- **The Greenshields Model**

The Greenshields Model is represented by Equation 2.14: $u_s = u_f\left[1 - \frac{k}{k_j}\right]$

For the Greenshields model, the known parameters are the exponents *m* and *l* (*m* = 0, *l* = 2). The free-flow speed, u_f, and jam density, k_j, were defined as unknown variables. Figures B-1 through B-8 in Appendix B-1 are illustrations of the

Greenshields curve fitted to lane data of each section. Regression analysis yielded the following values:

Section 1: N1 near Century City

Left lane: $u_f = 100.55$ km/h, $k_j = 81.50$ veh/km, $R^2 = 0.824$.

Middle lane: $u_f = 119.30$ km/h, $k_j = 72.23$ veh/km, $R^2 = 0.836$.

Right lane: $u_f = 138.04$ km/h, $k_j = 72.06$ veh/km, $R^2 = 0.833$.

Section 2: N1 near R300

Left lane: $u_f = 88.65$ km/h, $k_j = 105.87$ veh/km, $R^2 = 0.897$.

Right lane: $u_f = 101.51$ km/h, $k_j = 111.79$ veh/km, $R^2 = 0.930$.

Section 3: N2 near Athlone Power Station

Left lane: $u_f = 90.29$ km/h, $k_j = 99.54$ veh/km, $R^2 = 0.921$.

Middle lane: $u_f = 110.41$ km/h, $k_j = 101.78$ veh/km, $R^2 = 0.928$.

Right lane: $u_f = 119.90$ km/h, $k_j = 94.44$ veh/km, $R^2 = 0.926$.

Figure 4.1 is an example of the Greenshields model fitted to the right hand (fast) lane data of Section 1.

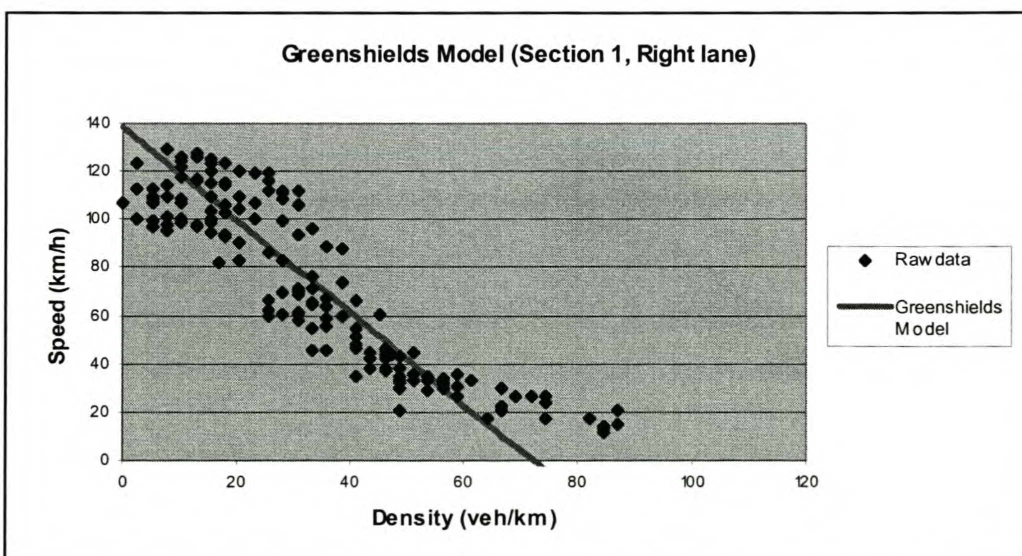

Figure 4.1: Greenshields model fitted to right hand lane data (Section 1)

From the figures, it is clear that although relatively good R^2 values are obtained in some cases, certain areas of the data are not sufficiently represented by the Greenshields curve. A relatively good fit is obtained for the free-flow data, while the speeds at higher densities are underestimated. It is therefore apparent that the Greenshields model is not adequate for describing the whole speed-density domain for traffic on freeways.

- **The Greenberg Model**

The Greenberg Model is represented by Equation 2.17: $u = u_0 . \ln\left(\frac{k_j}{k}\right)$

For the Greenberg model, the known parameters are the exponents *m* and *l* ($m = 0$, $l = 1$). The optimum speed, u_0, and jam density, k_j, were defined as unknown variables. Figures B-9 through B-16 in Appendix B-1 are illustrations of the Greenberg curve fitted to lane data for each section. Regression analysis yielded the following values:

Section 1: N1 near Century City

Left lane:	u_0 = 39.16 km/h, k_j = 125.19 veh/km, R^2 = 0.602.
Middle lane:	u_0 = 41.87 km/h, k_j = 116.38 veh/km, R^2 = 0.712.
Right lane:	u_0 = 48.95 km/h, k_j = 107.18 veh/km, R^2 = 0.560.

Section 2: N1 near R300

Left lane:	u_0 = 32.99 km/h, k_j = 144.67 veh/km, R^2 = 0.842.
Right lane:	u_0 = 35.86 km/h, k_j = 149.45 veh/km, R^2 = 0.759.

Section 3: N2 near Athlone Power Station

Left lane:	u_0 = 30.59 km/h, k_j = 128.06 veh/km, R^2 = 0.839.
Middle lane:	u_0 = 44.00 km/h, k_j = 123.54 veh/km, R^2 = 0.883.
Right lane:	u_0 = 36.17 km/h, k_j = 125.88 veh/km, R^2 = 0.822.

Figure 4.2 is an example of the Greenberg model fitted to the right hand lane data of Section 1. Relatively low R^2 values were obtained in most cases, indicating that the Greenberg model fails to explain a significant amount of the total

variability, in particular the data at low densities. The congested data (high-density side) are however well represented.

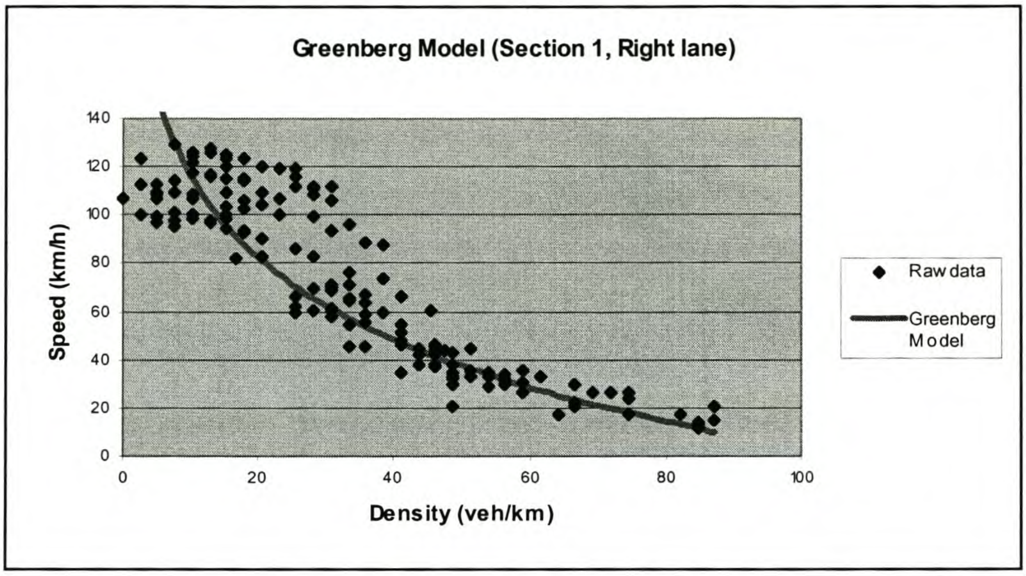

Figure 4.2: Greenberg model fitted to right hand lane data (Section 1)

- **The Underwood Model**

The Underwood Model is represented by Equation 2.18: $u = u_f e^{-k/k_0}$

For the Underwood model, the known parameters are the exponents *m* and *l* (*m* = 1, *l* = 2). The free-flow speed, u_f, and optimum density, k_0, were defined as unknown variables. Figures B-17 through B-24 in Appendix B-1 are illustrations of the Underwood curve fitted to lane data for each section. Regression analysis yielded the following values:

<u>Section 1: N1 near Century City</u>

Left lane: u_f = 114.72 km/h, k_0 = 43.85 veh/km, R^2 = 0.773.

Middle lane: u_f = 144.06 km/h, k_0 = 36.68 veh/km, R^2 = 0.792.

Right lane: u_f = 237.65 km/h, k_0 = 26.87 veh/km, R^2 = 0.729.

<u>Section 2: N1 near R300</u>

Left lane: u_f = 104.40 km/h, k_0 = 49.14 veh/km, R^2 = 0.896.

Right lane: u_f = 119.68 km/h, k_0 = 49.18 veh/km, R^2 = 0.929.

Section 3: N2 near Athlone Power Station

Left lane: $u_f = 103.73$ km/h, $k_0 = 42.73$ veh/km, $R^2 = 0.908$.

Middle lane: $u_f = 134.77$ km/h, $k_0 = 43.44$ veh/km, $R^2 = 0.915$.

Right lane: $u_f = 137.70$ km/h, $k_0 = 42.83$ veh/km, $R^2 = 0.929$.

Figure 4.3 is an example of the Underwood model fitted to the right hand lane data of Section 1.

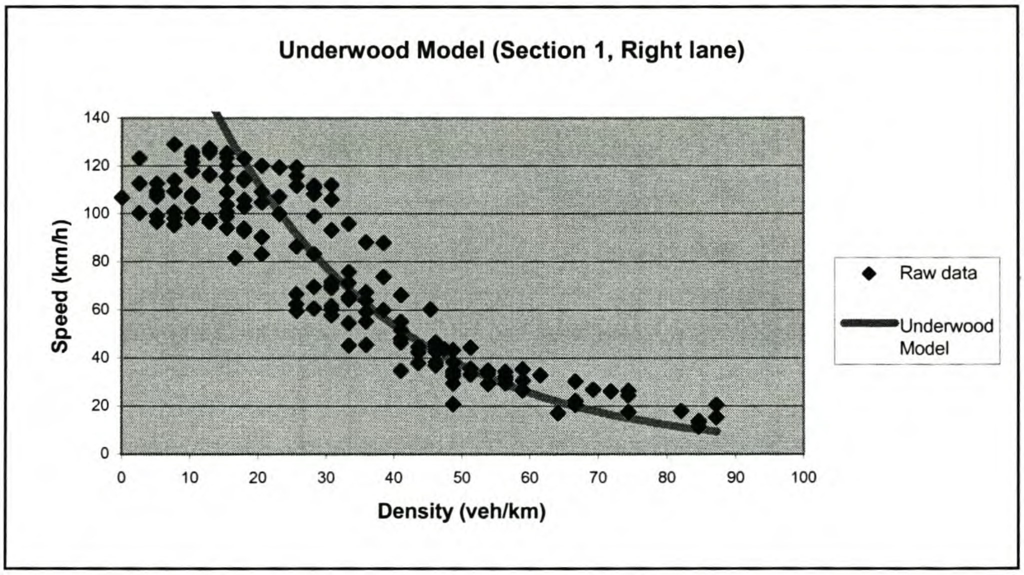

Figure 4.3: Underwood model fitted to right hand lane data (Section 1)

High R^2 values are obtained for Section 2 and Section 3. However, through visual inspection of the curves, it seems as if the model slightly overestimates the free-flow speed. The congested data (high-density side) are well represented by the Underwood model for Section 1 and Section 2. For Section 3, the model overestimates the speed during high-density conditions.

Another shortcoming of the Underwood model is that it does not represent zero speed at high concentrations. This has resulted in the Greenberg model being favoured above the Underwood model for describing congested speed-density data.

- **The Drake, May and Schofer Model**

The Drake et al. Model is represented by Equation 2.21: $u = u_f e^{-\frac{1}{2}\left(\frac{k}{k_0}\right)^2}$

For the Drake et al. model, the known parameters are the exponents *m* and *l* (*m* = 1, *l* = 3). The free-flow speed, u_f, and optimum density, k_0, were defined as unknown variables. Figures B-25 through B-32 in Appendix B-1 are illustrations of the Drake et al. curve fitted to lane data of each section. Regression analysis yielded the following values:

<u>Section 1: N1 near Century City</u>

Left lane:	u_f = 91.52 km/h, k_0 = 36.32 veh/km, R^2 = 0.859.
Middle lane:	u_f = 106.32 km/h, k_0 = 32.84 veh/km, R^2 = 0.863.
Right lane:	u_f = 127.05 km/h, k_0 = 31.17 veh/km, R^2 = 0.869.

<u>Section 2: N1 near R300</u>

Left lane:	u_f = 82.09 km/h, k_0 = 43.39 veh/km, R^2 = 0.922.
Right lane:	u_f = 95.51 km/h, k_0 = 42.77 veh/km, R^2 = 0.959.

<u>Section 3: N2 near Athlone Power Station</u>

Left lane:	u_f = 86.47 km/h, k_0 = 34.36 veh/km, R^2 = 0.932.
Middle lane:	u_f = 104.99 km/h, k_0 = 37.42 veh/km, R^2 = 0.948.
Right lane:	u_f = 127.05 km/h, k_0 = 31.17 veh/km, R^2 = 0.930.

Figure 4.4 is an example of the Drake et al. model fitted to the right hand lane data of Section 1. Relatively high R^2 values were obtained for the Drake et al. model. The uncongested data (low-density side) are well represented by the Drake et al. curve, while the congested speeds are underestimated.

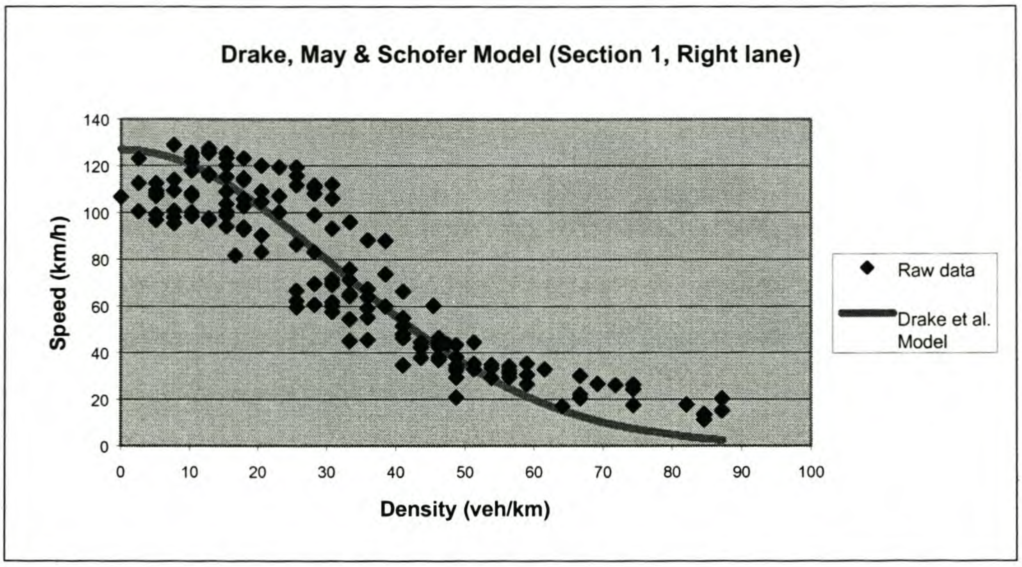

Figure 4.4: Drake et al. model fitted to right hand lane data (Section 1)

- **The Multi-regime Matrix Model**

The various steady-flow equations for different *m* and *l* values in the matrix developed by *May and Keller (12)* (Table 2.2) were tested on the available data of each section with the use of regression analysis. In each case, the particular equation that best described the whole range of speed-density data was selected for further analysis. For the Multi-regime model, the exponents *m* and *l* together with other variables like U_f, K_0, K_j, and c (depending on the particular equation) were defined as unknown parameters. This meant that some of the equations in Table 2.2 consisted of as many as four unknown parameters. Trial and error through the estimation of initial values for parameters U_f, K_j, K_0, and c solved some of the equations during regression analysis.

Figures B-33 through B-40 in Appendix B-1 are illustrations of the Multi-regime curves that best described the data for each lane of each section. Regression analysis yielded the following values:

<u>Section 1: N1 near Century City</u>

Left lane equation: $\mathrm{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 3.812$, $u_f = 87.42$ km/h, $c = 1.60\text{E-}05$, $R^2 = 0.865$.

Middle lane equation: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1, l > 1$

Variables: $m = 1.009$, $l = 3.169$, $u_f = 101.00$ km/h, c = 1.95E-06, $R^2 = 0.861$.

Right lane equation: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1, l > 1$

Variables: $m = 1.076$, $l = 3.440$, $u_f = 118.48$ km/h, c = 5.17E-06, $R^2 = 0.872$.

Section 2: N1 near R300

Left lane equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.792$, $u_f = 84.08$ km/h, c = 6.41E-04, $R^2 = 0.923$.

Right lane equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.760$, $u_f = 97.93$ km/h, c = 7.44E-04, $R^2 = 0.960$.

Section 3: N2 near Athlone Power Station

Left lane equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.720$, $u_f = 88.42$ km/h, c = 1.23E-03, $R^2 = 0.934$.

Middle lane equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.893$, $u_f = 106.10$ km/h, c = 5.44E-04, $R^2 = 0.948$.

Right lane equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.634$, $u_f = 118.77$ km/h, c = 1.74E-03, $R^2 = 0.953$.

Figure 4.5 is an example of the Multi-regime Matrix model fitted to the right hand lane data of Section 1.

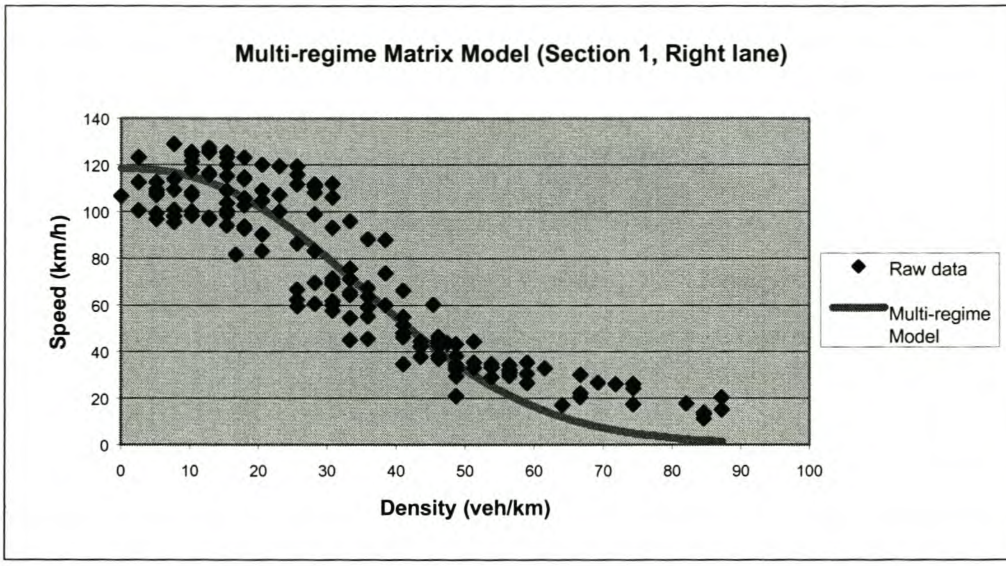

Figure 4.5: Multi-regime Matrix model fitted to right hand lane data (Section 1)

A bell-shaped curve similar to the Drake et al. curve yielded the best fit for uncongested conditions in each case. In fact, the values of the exponents *m* and *l* obtained for the Multi-regime curves were in some cases very close to the values used in the Drake et al. curve ($m = 1$, $l = 3$). In most cases however, slightly higher R^2 values were obtained for the Multi-regime curves. This can be attributed to the use of non-integer values for exponents *m* and *l*.

Furthermore, the bell-shaped curves used for the Multi-regime model again fail to describe the data at low densities (like the Drake et al. model).

- **The Composite Model**

The Composite model consists of two separate curves for each lane of each section. One curve describes the data at low concentrations (free-flow regime), while another curve describes the data at high concentrations (congested-flow regime).

In this report, it was decided that the Greenberg model best described the congested-flow regime, while the Multi-regime model was used to represent the free-flow regime. Figures B-41 through B-48 in Appendix B-1 are illustrations of the Composite model consisting of separate curves fitted to lane data of each section. The following values were obtained from regression analysis results of previous models:

Section 1: N1 near Century City

Left lane:

Free-flow curve: $\mathrm{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1$, $l > 1$

Variables: $l = 3.812$, $u_f = 87.42$ km/h, $c = 1.60E\text{-}05$.

Congested-flow curve: Greenberg ($m = 0$, $l = 1$)

Variables: $u_0 = 39.16$ km/h, $k_j = 125.19$ veh/km

Overall Variability: $R^2 = 0.867$

Middle lane:

Free-flow curve: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1$, $l > 1$

Variables: $m = 1.009$, $l = 3.169$, $u_f = 101.00$ km/h, $c = 1.95E\text{-}06$

Congested-flow curve: Greenberg ($m = 0$, $l = 1$)

Variables: $u_0 = 41.87$ km/h, $k_j = 116.38$ veh/km

Overall Variability: $R^2 = 0.863$

Right lane:

Free-flow curve: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1$, $l > 1$

Variables: $m = 1.076$, $l = 3.440$, $u_f = 118.48$ km/h, $c = 5.17E\text{-}06$

Congested-flow curve: Greenberg ($m = 0$, $l = 1$)

Variables: $u_0 = 48.95$ km/h, $k_j = 107.18$ veh/km

Overall Variability: $R^2 = 0.865$

Figure 4.6 is an example of the Composite model fitted to the right hand lane data of Section 1.

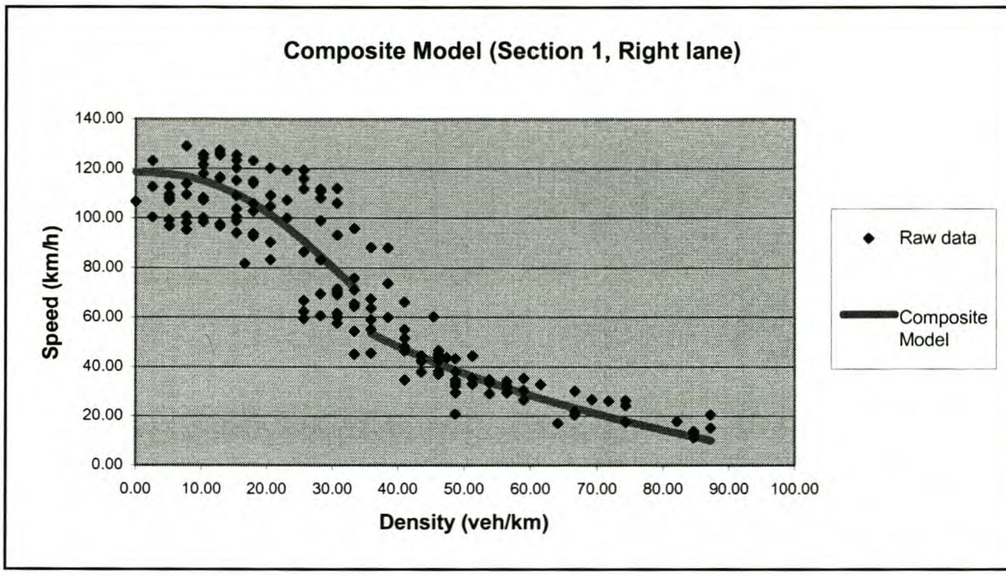

Figure 4.6: Composite model fitted to right hand lane data (Section 1)

Overall R^2 values close to 0.9 were obtained for each of the lanes of Section 1. This, together with the fact that a good representation of both the uncongested and congested data is achieved, leads the author to believe that the Composite model is very effective in describing traffic flow on Section 1.

Figure 4.7 is an illustration of the Composite model describing the speed-density relationship for each of the three lanes of Section 1.

From Figure 4.7, we can clearly distinguish between the different lanes when looking at uncongested side of the graph. It is evident that the fastest vehicles travel in the right hand lane, while the slowest vehicles travel in the left hand lane. We can estimate a free-flow speed of about 120 km/h for vehicles travelling in the right hand lane, 100 km/h for vehicles in the middle lane, and about 88 km/h for vehicles in the left hand lane. The difference in average speed between the three lanes decreases as the density increases.

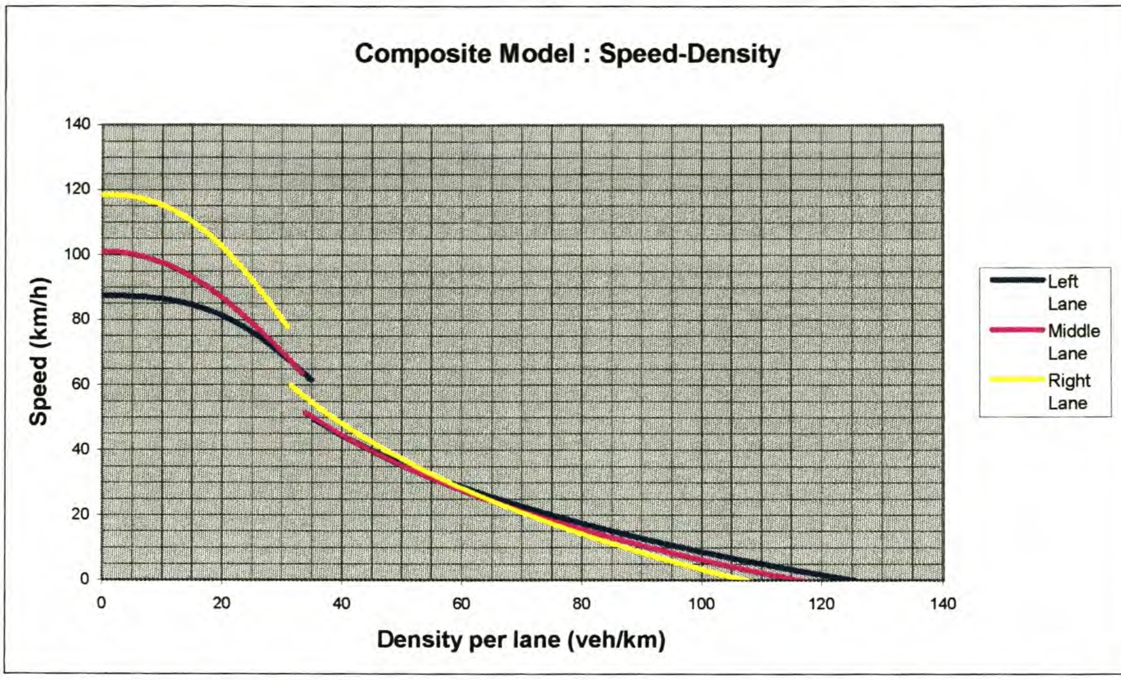

Figure 4.7: Speed-Density relationship for separate lanes (Section 1, N1 near Century City)

There is a very small difference between the three congested curves in Figure 4.7. This is due to the fact that when the capacity of the section is exceeded, all vehicles are forced to travel at speeds well below their desired speeds. The jam-density for the right hand lane is about 108 veh/km, 117 veh/km for the middle lane, and about 126 veh/km for the left hand lane.

Bearing in mind that the Composite model consists of two separate curves for each lane, each with its own point where capacity is reached, a specific density value had to be chosen for separation between the uncongested and congested regimes. When *Edie (9)* combined two theoretical models (*Underwood (8)* model for low densities, *Greenberg (7)* model for high densities), he chose a separation point where the two models became tangent when plotted against each other.

In this report, the separation point was chosen as the point where capacity is reached for the uncongested curves (Multi-regime curves). The corresponding density value was used as the separation point.

Once the Composite model for the speed-density relationships were established, the corresponding flow-density curves and speed-flow curves could be determined by applying the steady state equation (Equation 2.6). Figure 4.8 is an illustration of the flow-density relationship derived from the Composite model for Section 1.

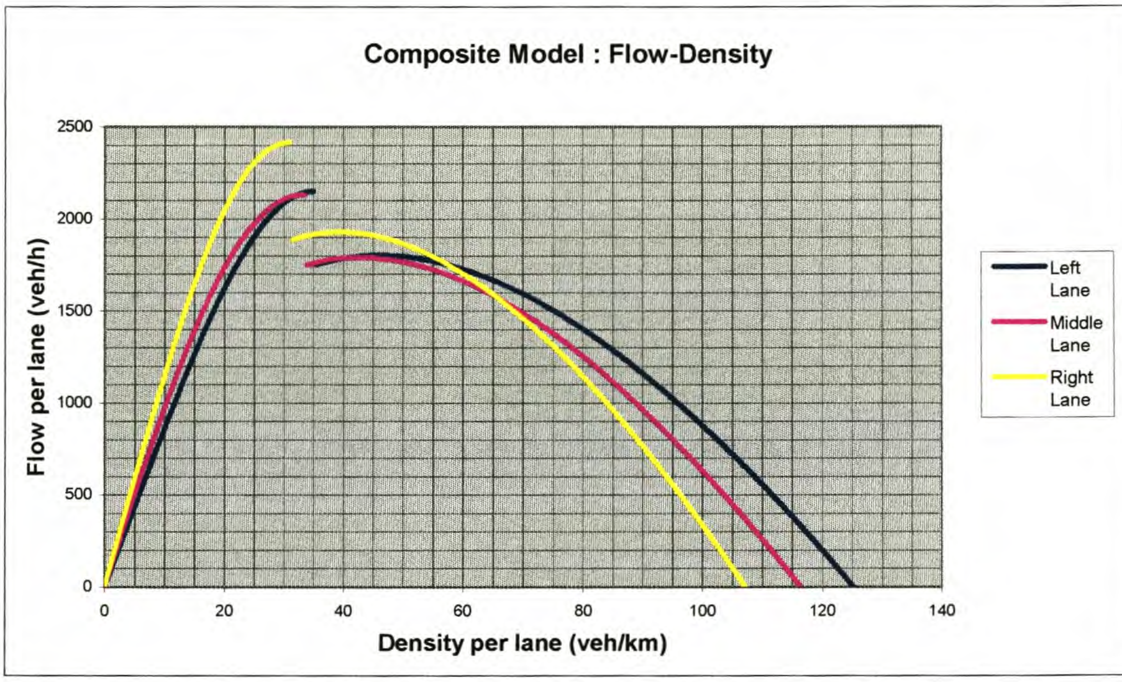

Figure 4.8: Flow-Density relationship for separate lanes (Section 1, N1 near Century City)

The flow of traffic on a given section of road increases together with the density up to a point where the capacity of the section is reached. From this point onwards, the flow decreases to zero as the density increases up to its maximum (jam-density). Also, in the absence of density, there can be no flow, thus the curve must pass through the origin.

The uncongested curves have higher capacities than the congested curves. The right hand lane has the highest uncongested capacity of about 2400 veh/h, while the middle and left hand lanes have capacities of about 2150 veh/h. It is possible that a sudden shift from the uncongested to the congested curves occur at flows lower than capacity during a particular peak-period.

The optimum density for the right hand lane is about 30 veh/km, while the optimum density for both the middle and left hand lane is about 35 veh/km.

Figure 4.9 is an illustration of the speed-flow relationship derived for Section 1.

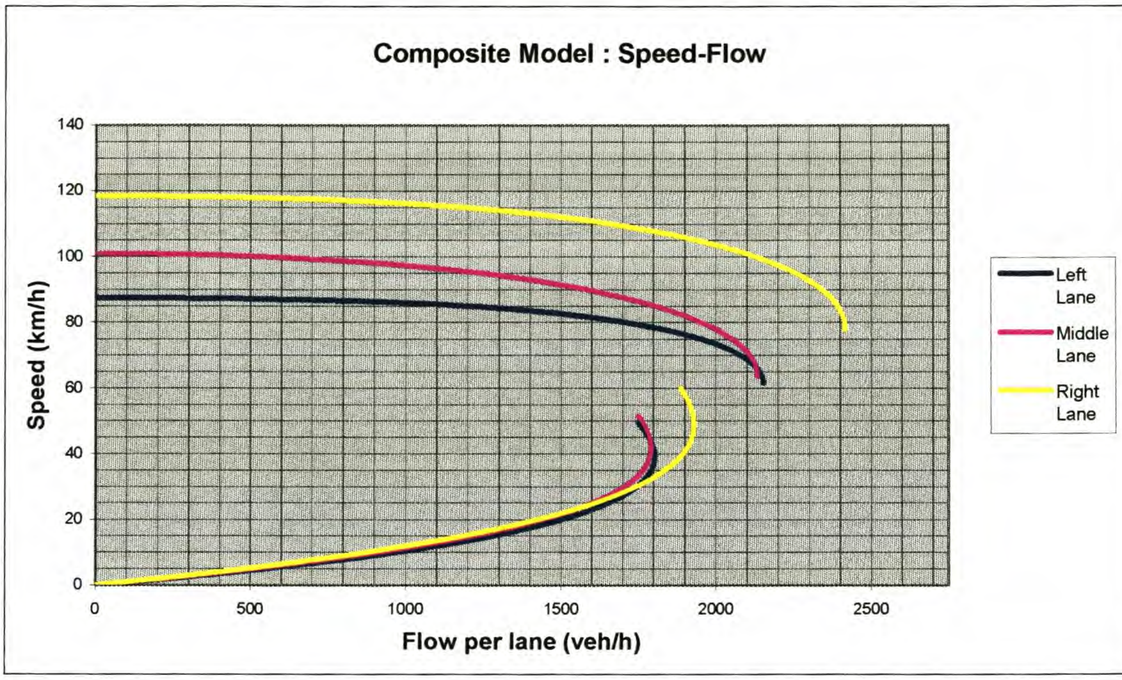

Figure 4.9: Speed-Flow relationship for separate lanes (Section 1, N1 near Century City)

The free-flow speed at zero density in the speed-density model (Figure 4.7) is the maximum attainable speed of vehicles travelling through the section on a particular lane. Therefore, the highest point on the speed-flow graph in Figure 4.9 is the point at free-flow speed and zero flow. Bearing in mind that the flow values are the products of the corresponding speed and density values (Equation 2.6), there will be a second point of zero flow corresponding to zero speed (maximum density). Therefore, the graph in Figure 4.9 must have one point on the speed axis (at the maximum value) and one point on the origin for each lane.

The optimum speed for the right hand lane (78 km/h) is higher than the middle and left hand lane speeds (64 km/h and 61 km/h respectively).

Section 2: N1 near R300

Left lane:

Free-flow curve: $\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.792$, $u_f = 84.08$ km/h, c = 6.41E-04

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 35.86$ km/h, $k_j = 149.45$ veh/km

Overall Variability: $R^2 = 0.923$

Right lane:

Free-flow curve: $\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.760$, $u_f = 97.93$ km/h, c = 7.44E-04

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 35.86$ km/h, $k_j = 149.45$ veh/km

Overall Variability: $R^2 = 0.958$

Figure 4.10 is an example of the Composite model fitted to the right hand lane data of Section 2.

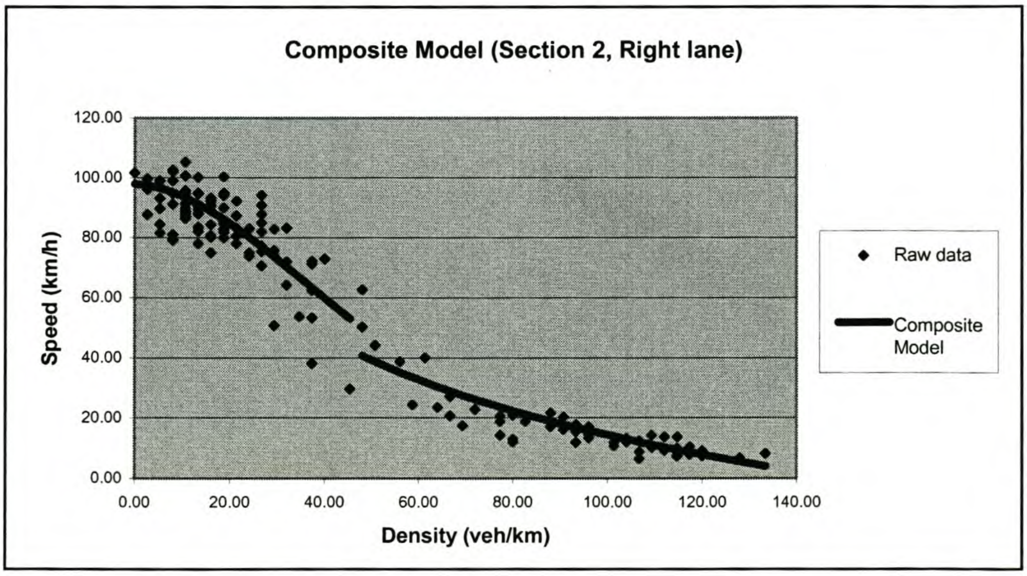

Figure 4.10: Composite model fitted to right hand lane data (Section 2)

Extremely high R^2 values were obtained for each of the two lanes of Section 2. An extremely good fit is obtained for both the congested and uncongested data.

Figure 4.11 is an illustration of the Composite model describing the speed-density relationship for each lane of Section 2.

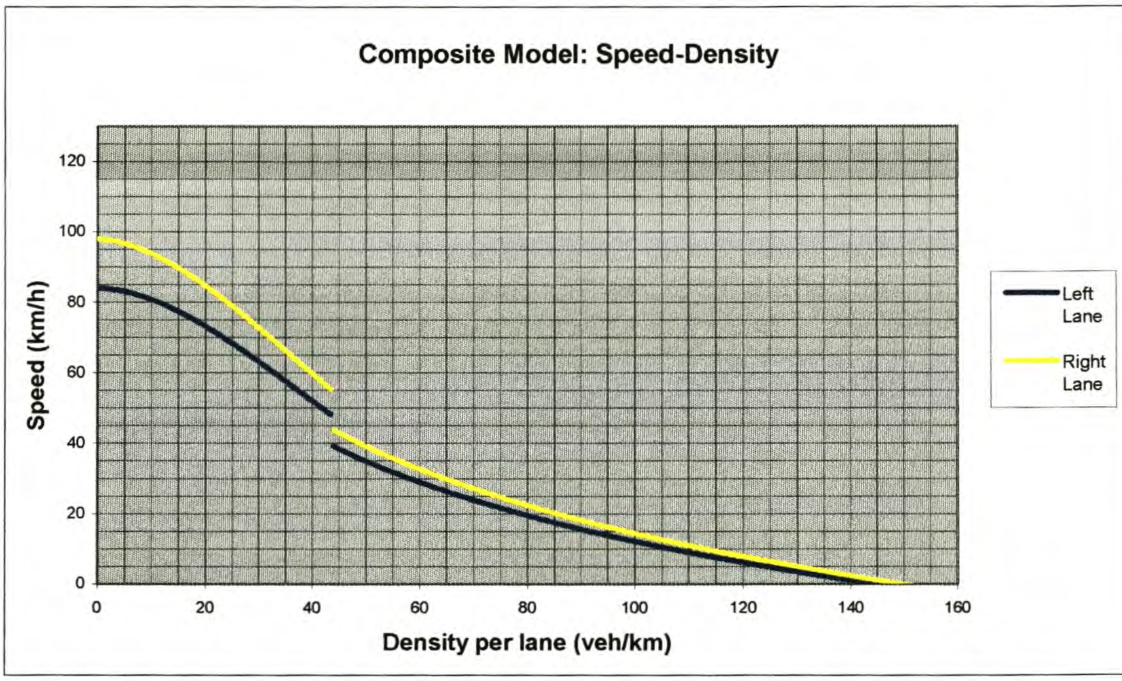

Figure 4.11: Speed-Density relationship for separate lanes (Section 2, N1 near R300)

The average free-flow speed is about 98 km/h for right hand lane vehicles, and about 85 km/h for vehicles in the left hand lane. It is important to note that the free-flow speeds of Section 2 are lower than what was determined for Section 1. This is again due to the travelling speeds on Section 2 being influenced by factors like rolling terrain and fewer lanes (Chapter 3).

Jam-density is estimated at about 150 veh/km for the right hand lane, and about 145 veh/km for the left hand lane. This is much higher than what was estimated for Section 1. Figure 4.12 is an illustration of the flow-density relationship derived from the Composite model for Section 2.

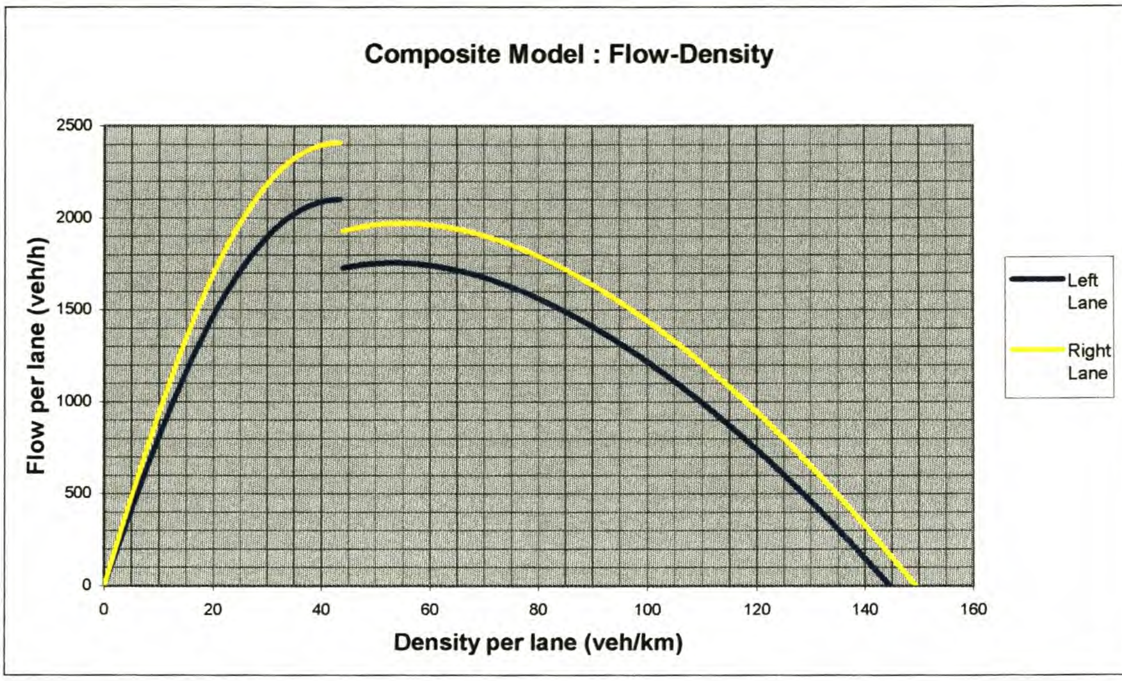

Figure 4.12: Flow-Density relationship for separate lanes (Section 2, N1 near R300)

The right hand lane has the highest uncongested capacity of about 2400 veh/h, while the left hand lane has a capacity of about 2100 veh/h. The optimum density for both the right and left hand lane of Section 2 is about 44 veh/km.

Figure 4.13 is an illustration of the speed-flow relationship derived for Section 2. The optimum speed for the left hand lane (48 km/h) is slightly lower than the optimum speed for the right hand lane (55 km/h). Again, the optimum speeds observed for Section 2 is much lower than the optimum speeds observed for Section 1. However, the capacities are very similar.

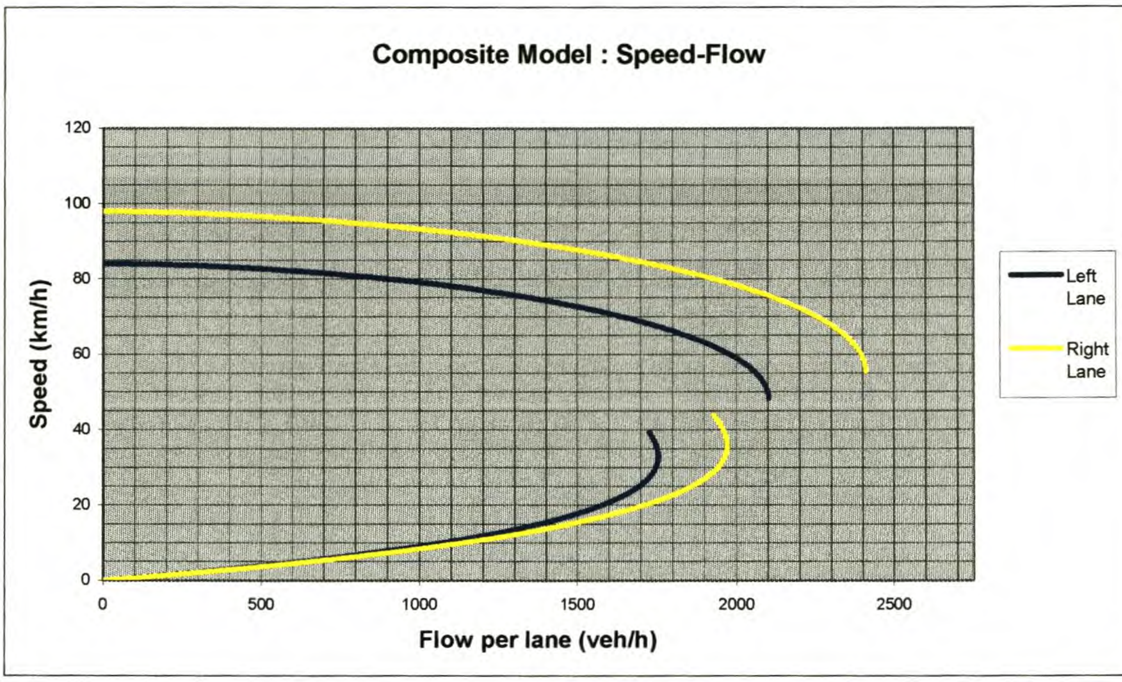

Figure 4.13: Speed-Flow relationship for separate lanes
(Section 2, N1 near R300)

Section 3: N2 near Athlone Power Station

Left lane:

Free-flow curve: $\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.720$, $u_f = 88.42$ km/h, c = 1.23E-03.

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 30.59$ km/h, $k_j = 128.06$ veh/km

Overall Variability: $R^2 = 0.927$

Middle lane:

Free-flow curve: $\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.893$, $u_f = 106.10$ km/h, c = 5.44E-04.

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 44.00$ km/h, $k_j = 123.54$ veh/km

Overall Variability: $R^2 = 0.939$

Right lane:

Free-flow curve:	$\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$	for $m = 1, l > 1$
Variables:	$l = 2.634$, $u_f = 118.77$ km/h, c = 1.74E-03.	
Congested-flow curve:	Greenberg ($m = 0, l = 1$)	
Variables:	$u_0 = 36.17$ km/h, $k_j = 125.88$ veh/km	
Overall Variability:	$R^2 = 0.942$	

Figure 4.14 is an example of the Composite model fitted to the right hand lane data of Section 3.

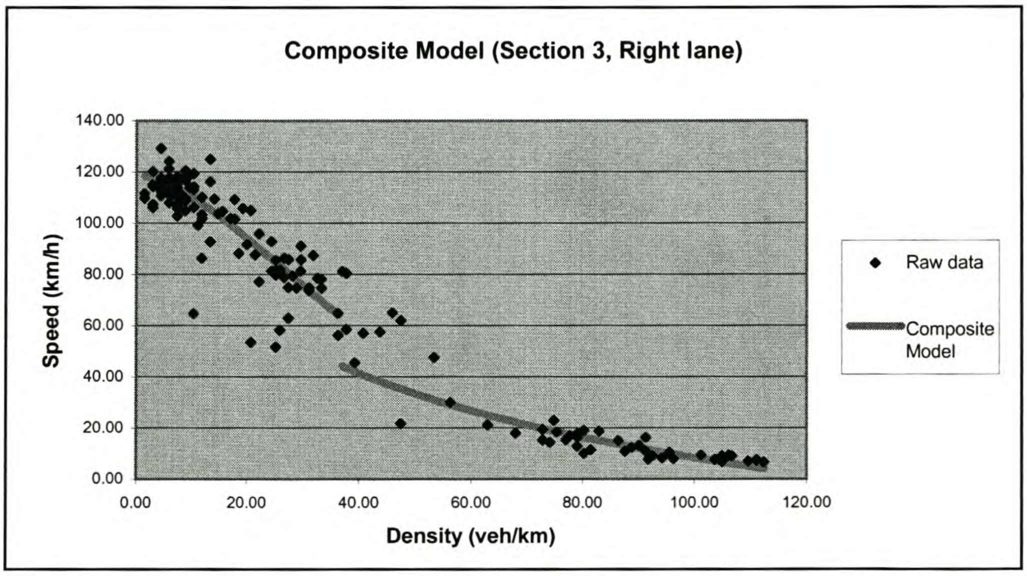

Figure 4.14: Composite model fitted to right hand lane data (Section 3)

An extremely good fit is again obtained for both the congested and uncongested regimes. Figure 4.15 is an illustration of the Composite model describing the speed-density relationship for each lane of Section 3.

The graphs are very similar in nature to the graphs obtained for Section 1. We can estimate a free-flow speed of about 119 km/h for vehicles in the right hand lane, 106 km/h for vehicles in the middle lane, and about 88 km/h for vehicles in the left hand lane.

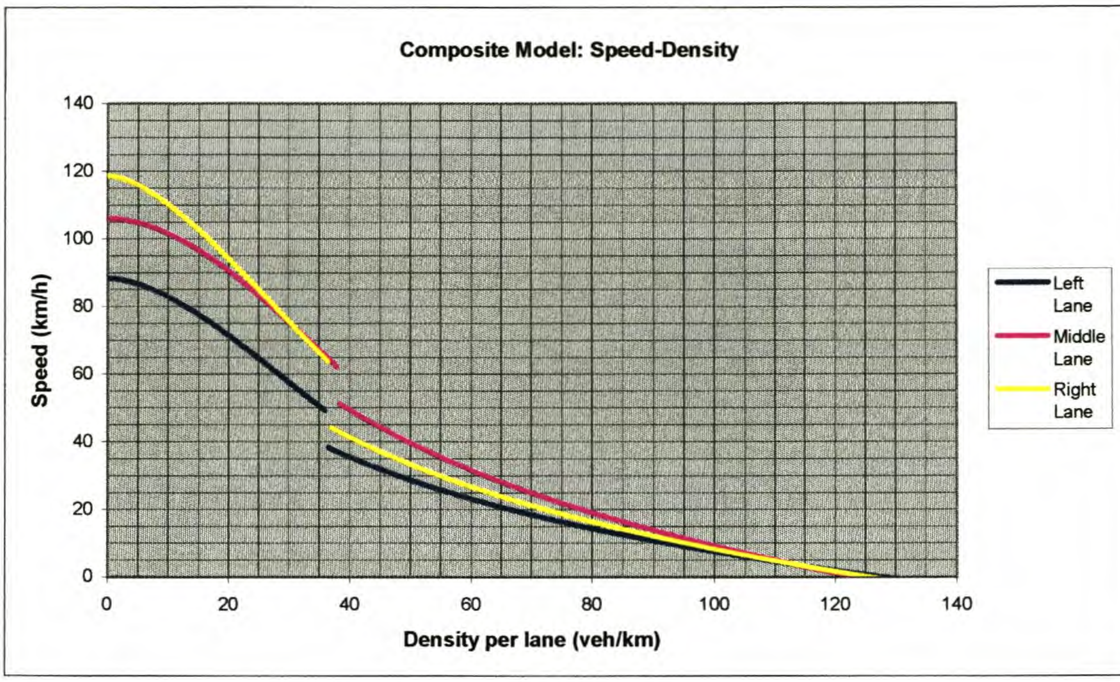

Figure 4.15: Speed-Density relationship for separate lanes (Section 3, N2 near Athlone Power Station)

It is very interesting to note the differences between the middle and left hand lanes for Section 1 and Section 3. A higher free-flow speed is obtained for the middle lane of Section 3, while a lower free-flow speed is obtained for the left hand lane. The portion of fast moving passenger-car drivers obeying the law by travelling on the middle lane (as opposed to the HOV lane), give rise to the higher free-flow speed on this lane.

However, the speed limit for Section 3 is 100 km/h, with the right hand lane reserved exclusively for taxis and buses. A significant number of fast moving passenger-cars illegally travel on the right hand lane. In the ideal situation, with HOV lanes, passenger-cars only travel on the middle and left hand lanes, with the middle lane intended for the faster moving traffic.

We can estimate a jam-density of about 126 veh/km for the right hand lane, 123 veh/km for the middle lane, and about 128 veh/km for the left hand lane.

Figure 4.16 is an illustration of the flow-density relationship derived from the Composite model for Section 3.

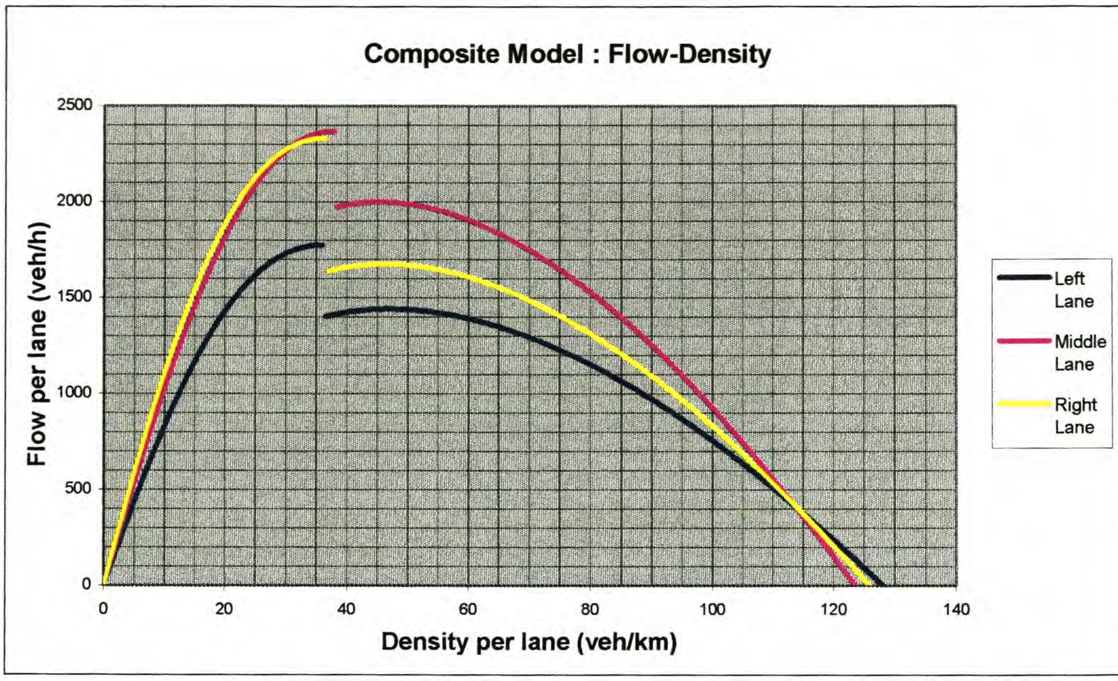

Figure 4.16: Flow-Density relationship for separate lanes (Section 3, N2 near Athlone Power Station)

The middle lane has the highest uncongested capacity of about 2370 veh/h, with the capacity of the right hand lane slightly lower at about 2330 veh/h. An extremely low capacity value of about 1780 veh/h for the left hand lane can be observed from Figure 4.16. This, together with the similar capacity values for the middle and right hand lanes, again indicates that faster moving passenger-cars are divided between the middle and right hand lanes.

For the middle lane, the optimum density is about 38 veh/km, while the optimum density for both the left and right hand lane is about 36 veh/km. Figure 4.17 is an illustration of the speed-flow relationship derived for Section 3.

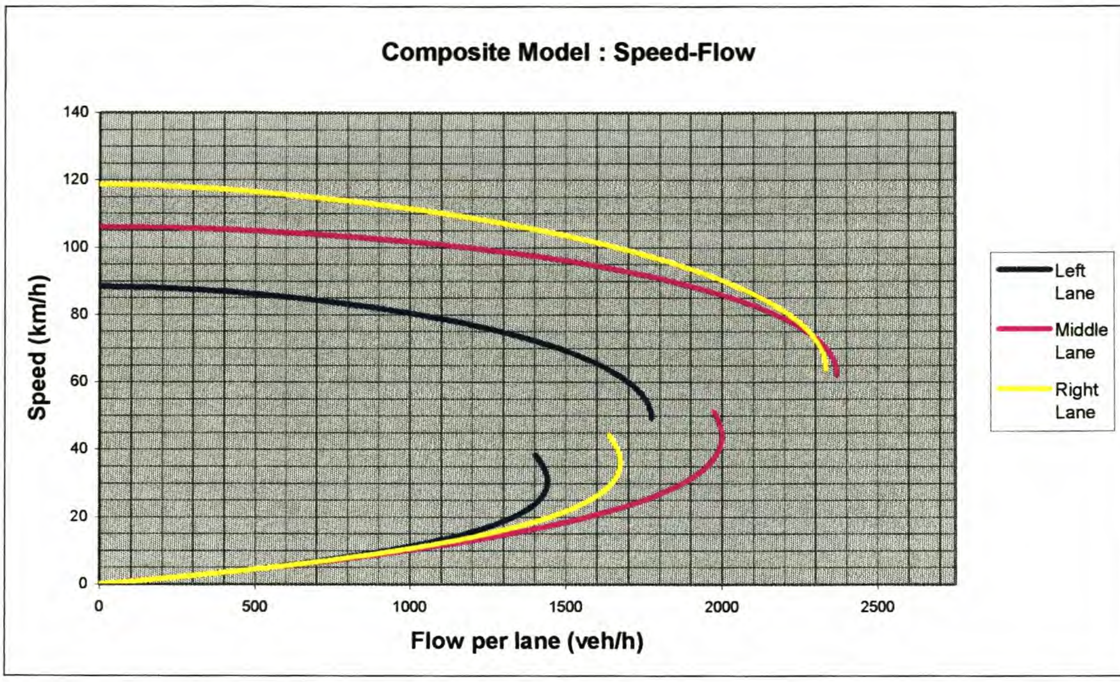

Figure 4.17: Speed-Flow relationship for separate lanes (Section 3, N2 near Athlone Power Station)

The optimum speed (speed at capacity) determined for the middle and right hand lanes are very similar, with the right hand lane having a slightly higher value (62 km/h for the middle lane, 64 km/h for the right hand lane). The optimum speed for the left hand lane is much lower at about 49 km/h, an indication that the left hand lane is occupied by slower moving traffic only.

4.4.2 All Lanes

In this section, models describing speed/flow/density relationships for the average of all freeway lanes were established (a single model is used to describe traffic flow relationships for the average of all the lanes on a particular freeway section). The aim being to compare these models obtained from three South African freeway sections with other models that use average freeway lanes (e.g. HCM models). To this end, different curves were fitted to combined lane data on each section with the use of regression analysis (Section 4.3).

With experience gained in Section 4.4.1, it was decided to utilise the Composite model (consisting of the Multi-regime curve representing uncongested conditions, and the Greenberg curve representing congested conditions) as final model for the whole speed-density range for freeway sections with average lanes.

Regression analysis results for each model are summarised in Table B-4 of Appendix B-2 (page B-28).

- **The Greenberg Model**

The Greenberg Model is represented by Equation 2.17: $u = u_0.\ln\left(\frac{k_j}{k}\right)$

For the Greenberg model, the known parameters are the exponents *m* and *l* ($m = 0$, $l = 1$). The optimum speed, u_0, and jam density, k_j, were defined as unknown variables.

Figures B-49 through B-51 in Appendix B-2 are illustrations of the Greenberg curve fitted to average lane data for each section. Regression analysis yielded the following values:

<u>Section 1: N1 near Century City:</u>

u_0 = 45.81 km/h, k_j = 110.95 veh/km/ln, R^2 = 0.582.

<u>Section 2: N1 near R300</u>

u_0 = 35.04 km/h, k_j = 143.02 veh/km/ln, R^2 = 0.784.

<u>Section 3: N2 near Athlone Power Station</u>

u_0 = 36.43 km/h, k_j = 123.35 veh/km/ln, R^2 = 0.800.

Figure 4.18 is an example of the Greenberg model fitted to combined lane data of Section 3.

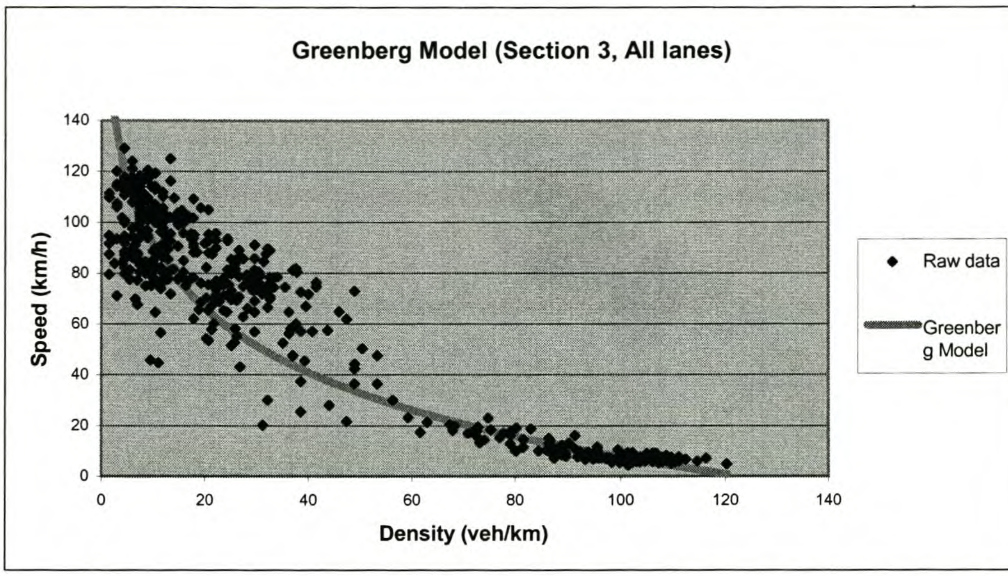

Figure 4.18: Greenberg model fitted to combined lane data (Section 3)

- **The Multi-regime Matrix Model**

For the Multi-regime model, the exponents *m* and *l* together with other variables like U_f, K_0, K_j, and c (depending on the particular equation) were defined as unknown parameters.

Figures B-52 through B-54 in Appendix B-2 are illustrations of the Multi-regime curves that best described the average lane data for each section. Regression analysis yielded the following values:

Section 1: N1 near Century City

Equation: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1, l > 1$

Variables: $m = 1.074$, $l = 3.779$, $u_f = 100.0$ km/h, c = 1.22E-06, $R^2 = 0.828$.

Section 2: N1 near R300

Equation: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.782$, $u_f = 92.13$ km/h, c = 7.09E-04, $R^2 = 0.925$.

Section 3: N2 near Athlone Power Station

Equation: $\text{Ln}\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.959$, $u_f = 103.81$ km/h, c = 4.76E-04, $R^2 = 0.895$.

Figure 4.19 is an example of the Multi-regime Matrix model fitted to combined lane data of Section 3.

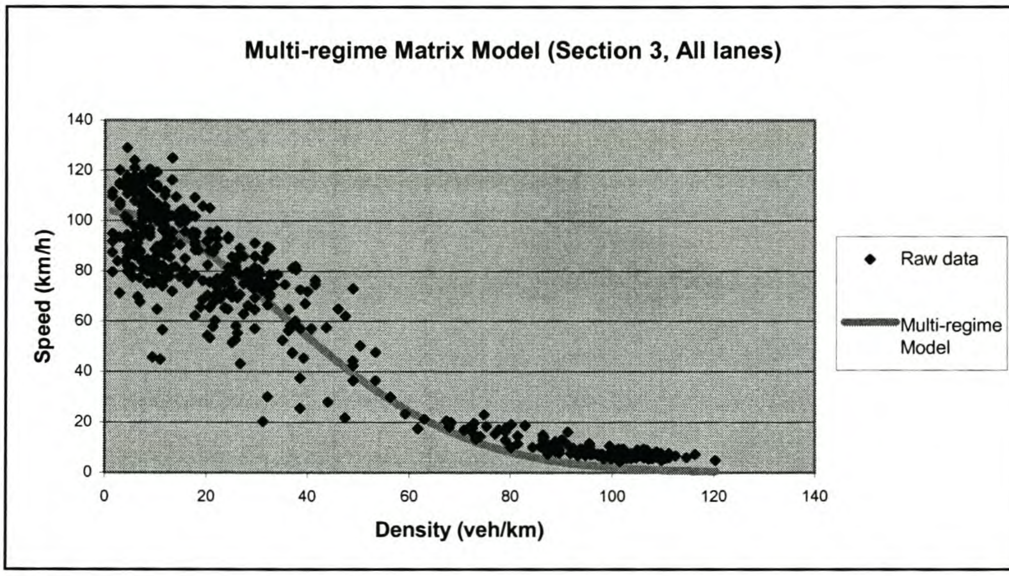

Figure 4.19: Multi-regime model fitted to combined lane data (Section 3)

- **The Composite Model**

Figures B-55 through B-57 in Appendix B-2 are illustrations of the Composite model consisting of separate curves fitted to average lane data of each section. The following values were obtained from regression analysis results of the previous two models:

Section 1: N1 near Century City

Free-flow curve: $U^{1-m} = u_f^{1-m} + c.K^{l-1}$ for $m > 1, l > 1$

Variables: $m = 1.074$, $l = 3.779$, $u_f = 100.0$ km/h, c = 1.22E-06,

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 45.81$ km/h, $k_j = 110.95$ veh/km/ln

Overall Variability: $R^2 = 0.817$

Section 2: N1 near R300

Free-flow curve: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.782$, $u_f = 92.13$ km/h, c = 7.09E-04

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 35.04$ km/h, $k_j = 143.02$ veh/km/ln

Overall Variability: $R^2 = 0.923$

Section 3: N2 near Athlone Power Station

Free-flow curve: $Ln\left(\frac{u_f}{U}\right) = c.K^{l-1}$ for $m = 1, l > 1$

Variables: $l = 2.959$, $u_f = 103.81$ km/h, c = 4.76E-04

Congested-flow curve: Greenberg ($m = 0, l = 1$)

Variables: $u_0 = 36.43$ km/h, $k_j = 123.35$ veh/km/ln

Overall Variability: $R^2 = 0.880$

Figure 4.20 is an example of the Composite model fitted to combined lane data of Section 3.

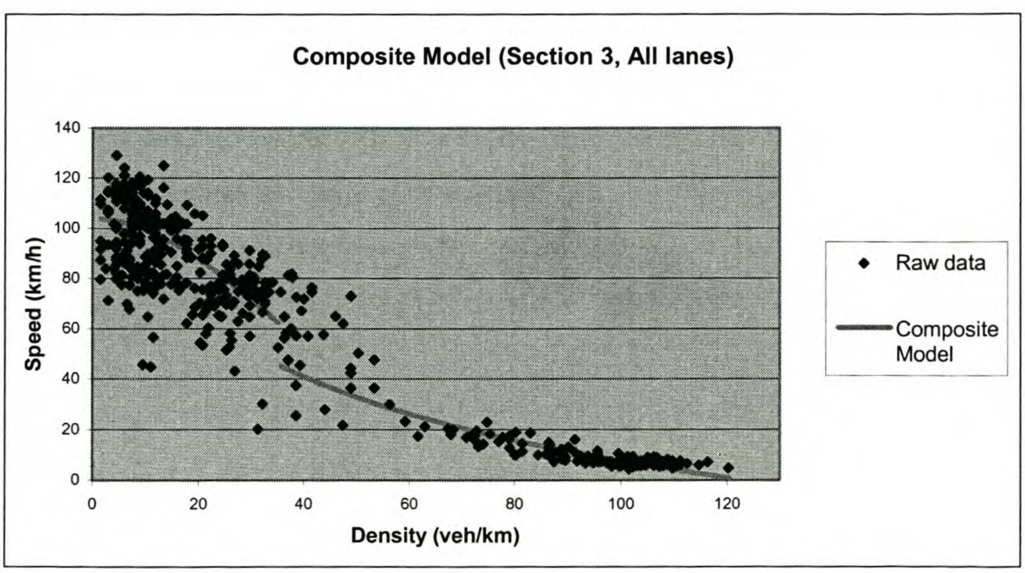

Figure 4.20: Composite model fitted to combined lane data (Section 3)

The R^2 values obtained from the combined lane data are lower than the values obtained for the separate lanes. This is expected, since a single model is used to describe the speed-density relationship of all the lanes on a particular freeway section. Nonetheless, the R^2 values obtained for average lanes in this report are deemed satisfactory.

Figure 4.21 is an illustration of the Composite model describing the speed-density relationship for an average lane of each section.

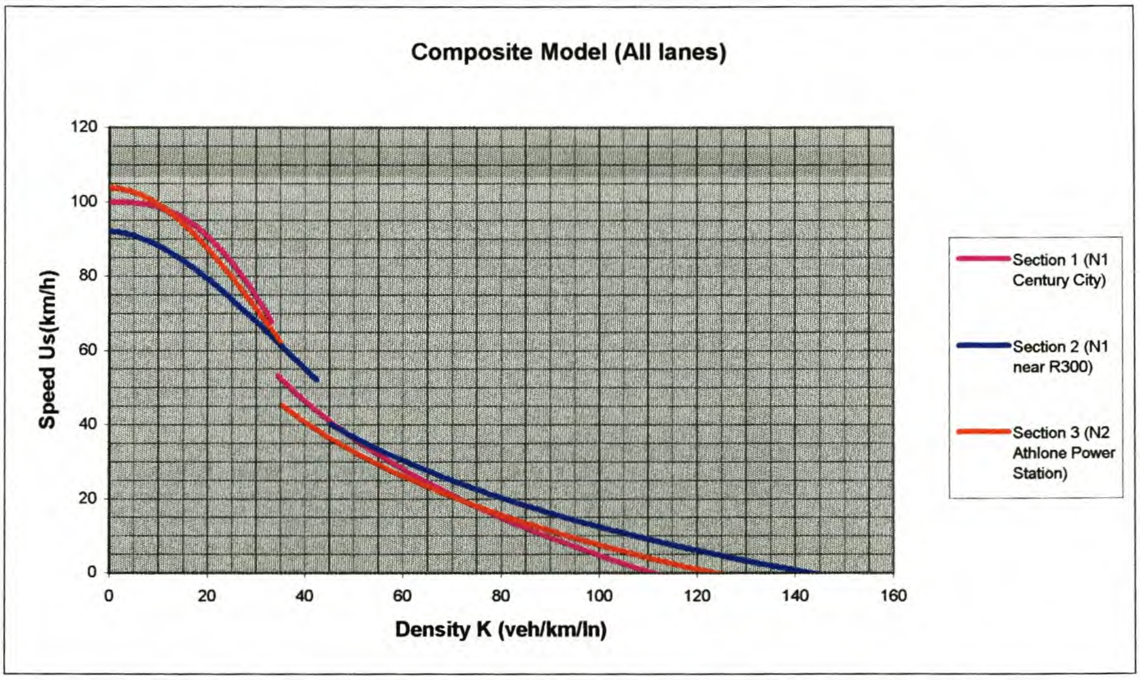

Figure 4.21: Speed-Density relationships for average freeway lanes

The free-flow speed is about 100 km/h for Section 1, about 92 km/h for Section 2, and about 104 km/h for Section 3. It is interesting to note that these values closely correspond to the estimated values for free-flow speed in Chapter 3 (102 km/h for Section 1, 90 km/h for Section 2, 99 km/h for Section 3). The relatively low free-flow speed determined for Section 2 can be ascribed to various factors, one being the rolling terrain of the section influencing the driver's perception of a safe travelling speed. Another factor contributing to this phenomenon may be the fact that Section 2 consists of only two lanes, resulting in a less effective segregation between slower and faster moving vehicles.

The jam-density is about 111 veh/km/ln for Section 1, 143.02 veh/km/ln for Section 2, and about 124 veh/km/ln for Section 3. The average jam-density determined for Section 2 is much higher than the values determined for Sections 1 and 3.

Figure 4.22 is an illustration of the flow-density relationship for an average lane of each section.

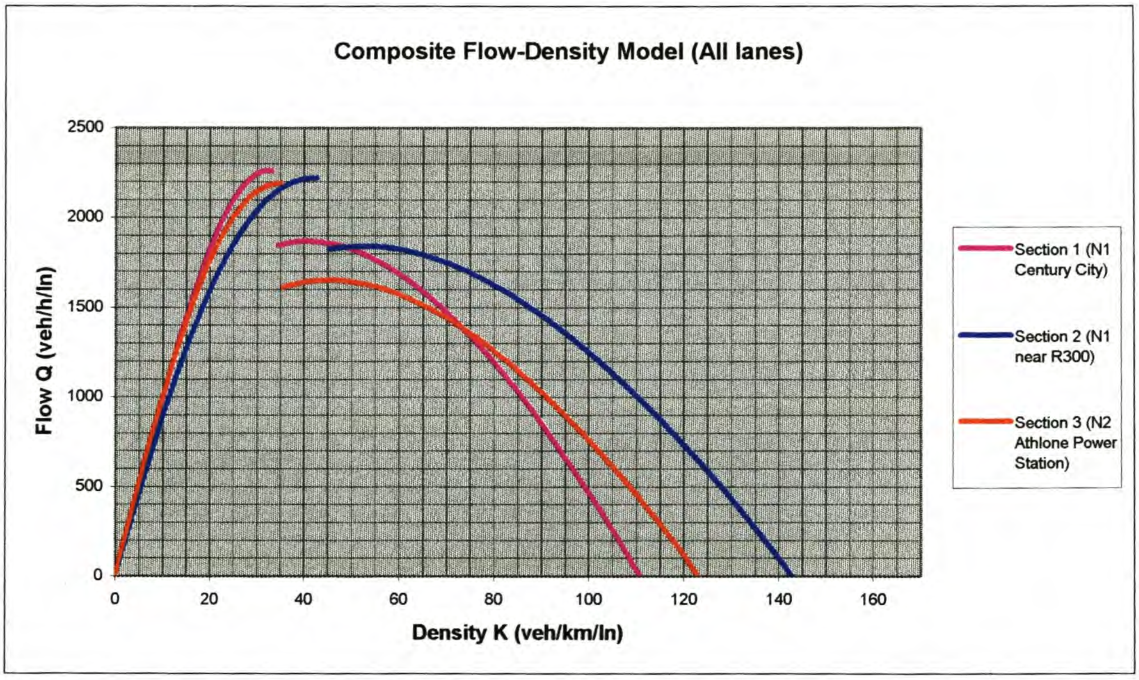

Figure 4.22: Flow-Density relationships for average freeway lanes

The uncongested capacity is estimated at about 2280 veh/h/ln for Section 1, 2220 veh/h/ln for Section 2, and about 2200 veh/h/ln for Section 3. The freeway capacities specified by the HCM are dependent on the free-flow speeds of particular freeway sections. The HCM specifies a capacity of 2350 pc/h/ln for a 110 km/h free-flow speed, 2300 pc/h/ln for 100 km/h, and 2250 pc/h/ln for a 90 km/h free-flow speed. These capacities are slightly higher than the values determined from the Composite curves.

The optimum density is about 33 veh/km/ln for Section 1, 43 veh/km/ln for Section 2, and about 35 veh/km/ln for Section 3.

Figure 4.23 is an illustration of the speed-flow relationship for an average lane of each section.

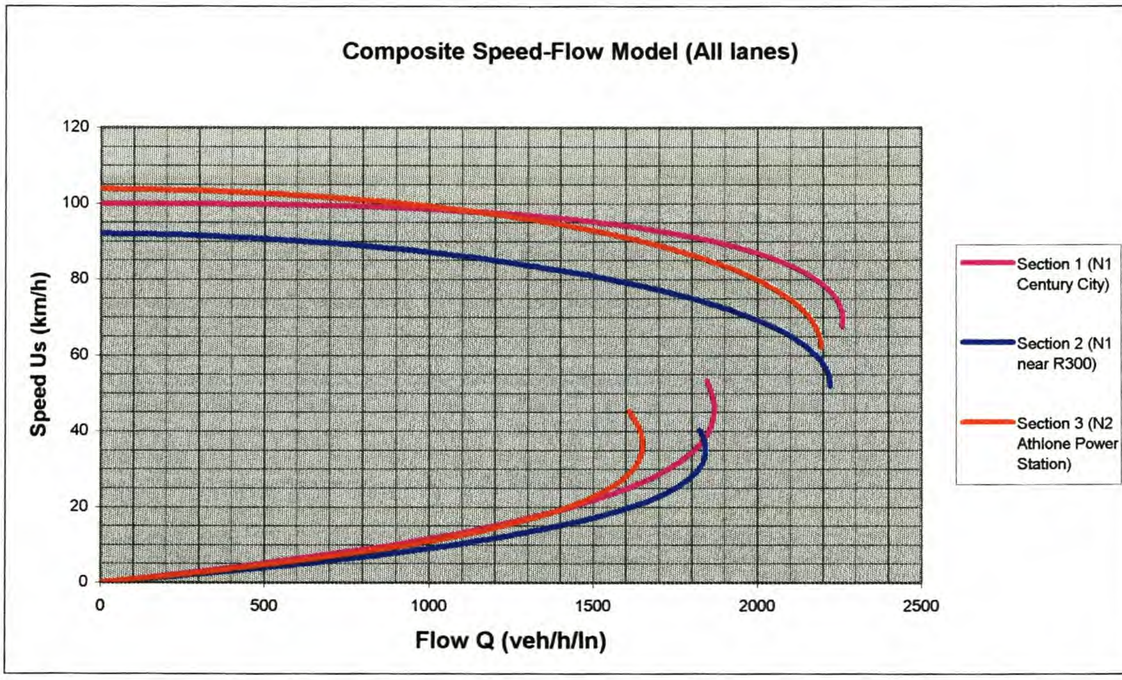

Figure 4.23: Speed-Flow relationships for average freeway lanes

Some early investigators of traffic flow (*Walker (15)*) postulated a linear relationship between flow and speed up to maximum flow (capacity), with a curvilinear segment between maximum flow and the origin. In another model developed by the British Road Research Laboratory, the speed is taken as constant for a substantial range of flow that finally breaks to a linear decrease of speed with increasing flow. Similarly, the *Highway Capacity Manual (1)* (HCM), based on recent freeway studies indicating that speed on freeways is insensitive to flow in the low to moderate range, postulated a constant average speed (equal to the free-flow speed) up to very high flows (up to 1450 pc/h/ln for a 110 km/h free-flow speed, 1600 pc/h/ln for a 100 km/h free-flow speed, and 1750 pc/h/ln for a free-flow speed of 90 km/h). In Figure 4.23, there is also a region for each lane where the speed is relatively insensitive to flow. However, these regions seem shorter than the regions predicted by the HCM for average lanes.

This is an interesting observation bearing in mind that the "level of service" concept defined by the HCM is extensively used around the world (including South Africa) in the design and evaluation of facilities. This concept is however based on traffic flow studies done in the USA and uses the speed-flow curves in the HCM to determine different levels of service.

4.5 Comparison between models

4.5.1 Individual-lane models vs. Average-lane models

In the past, many researchers have examined speed/flow/density relationships on freeways. However, these researchers have concentrated on relationships for the freeway as a whole instead of on individual lanes. In this report, relationships were examined for individual as well as for average freeway lanes.

- Speed-Density models

Figures B-58 through B-60 in Appendix B-3 are illustrations showing the differences between Composite speed-density models of individual lanes and average lanes for each section. There is a marked difference between the individual lane and average lane curves for each section, especially for the uncongested side of the graphs. There is a considerable variation between the speeds at low densities obtained from the individual lane curves for each section.

It is therefore the opinion of the author that separate curves for individual lanes should be used to represent uncongested speed-density data for freeways. On the other hand, the differences between the congested curves for individual and average lanes are relatively small. It is therefore adequate to represent congested speed-density data for freeways by a single curve for average lanes.

- Flow-Density models

Figures B-61 through B-63 in Appendix B-3 are illustrations showing the differences between Composite flow-density models of individual lanes and average lanes for each section. The individual lane and average lane curves differ from each other significantly for each section. For Section 3, where there is a large speed differential between the left hand lane and the other two lanes, the difference in capacity is substantial. There are also significant differences between the congested lane curves for each section. Separate curves for individual lanes should therefore be used to represent both uncongested and congested flow-density data for freeways.

- Speed-Flow models

Figures B-64 through B-66 in Appendix B-3 are illustrations showing the differences between Composite speed-flow models of individual lanes and average lanes for each section. There is a considerable difference between the free-flow speeds as well as the uncongested capacities for the individual lanes of each section. The use of separate uncongested speed-flow curves for individual freeway lanes is therefore again recommended. Conversely, the differences between the congested curves for individual and average lanes are relatively small. It is therefore feasible to represent congested speed-flow data by a single curve for average freeway lanes.

4.5.2 Other Individual-lane models

A study by *Hurdle, Merlo and Robertson (16)* focussed on individual freeway lanes in the USA. The study was based on data collected by the Ontario Ministry of Transportation (OMT) in 1991 and 1992 from two separate locations on Highway 401 (Toronto). The subject of the study was speed-flow relationships in uncongested conditions. Data obtained during congested conditions were therefore separated and removed from the data set. The procedure used for data separation was visual examination of time-traced plots of flow versus density. Both locations, Station 4 and

Station 7, consisted of 3-lane sections with high geometric standards, a speed limit of 100 km/h, and minor grades at the data collection points. Each of the two locations had double loop installations to measure speeds. Travel times and flows were measured with the OMT's COMPASS Advanced Traffic Management System. Average speeds and flows were calculated for 20 sec intervals for each lane.

Simple polynomial functions (as opposed to theoretical car-following functions) were fitted to the individual-lane speed-flow data. The following cubic polynomial function was used:

$$\hat{u}_i = b_0 + b_1 q_i + b_2 q_i^2 + b_3 q_i^3 \qquad (4.6)$$

Where $\hat{u}_i$ = and estimate of the mean speed at the given flow q_i

b_j = parameters estimated from the data set

The regression analysis results for each lane of each station are shown in Table 4.1. The right hand column in Table 4.1 shows the root-mean-square error (RMSE) for each equation. Figures B-67 through B-69 are illustrations showing the differences between the uncongested speed-flow curves (individual lanes) of the Composite model for Section 1 and Section 3 and the polynomial curves obtained for individual lanes of Station 4 and Station 7.

Table 4.1: Regression results for individual lanes (Highway 401)

Lane	Station	Estimated Parameters				RMSE
		b_0	b_1	b_2	b_3	(km/h)
Median lane	4	119.9	-4.58E-04	-2.40E-06	0.34E-09	6.3
	7	129.0	-1.42E-03	-8.26E-06	1.90E-09	9.5
Middle lane	4	110.5	1.98E-03	-3.88E-06	5.49E-10	6.5
	7	103.8	9.88E-03	-1.64E-05	3.80E-09	7.7
Outside lane	4	105.6	2.06E-03	-6.63E-06	1.42E-09	9.2
	7	95.2	4.78E-03	-13.5E-06	3.53E-09	8.3

Figure 4.24 is an example of the uncongested Composite curves compared to the polynomial curves for median freeway lanes (right hand lanes).

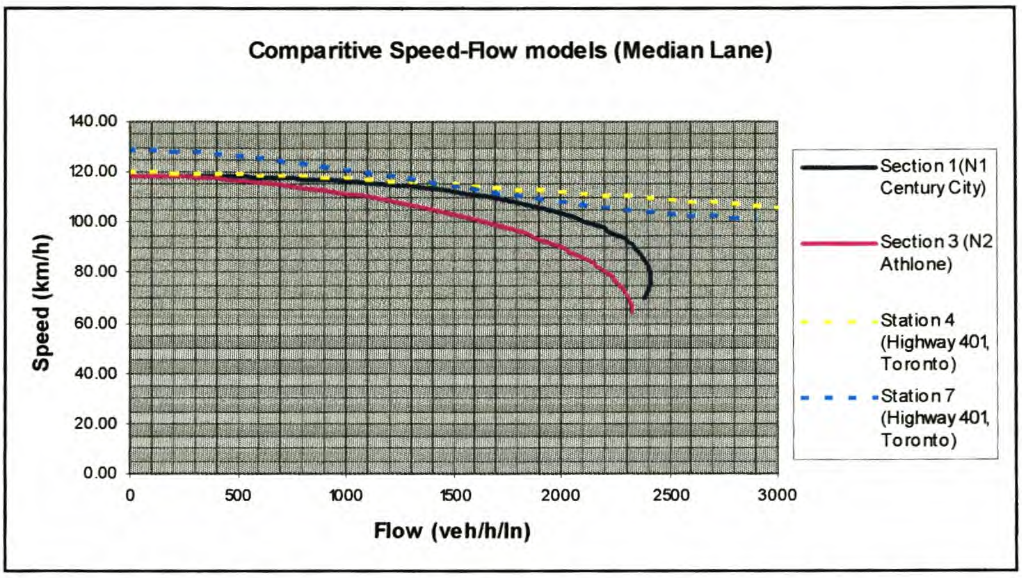

Figure 4.24: Comparative Speed-Flow models for Median freeway lanes

There are certain areas where the polynomial curves (Highway 401, Toronto) are very similar to the uncongested curves taken from the Composite model. It is however interesting to note that higher average speeds are estimated for the lanes of Highway 401 (especially for the outside lane). For each curve of each of the three lanes, the average speed decreases slightly with an increase in flow (for low flows). However, as higher flows are reached, the speeds of the Composite curves decrease more rapidly towards capacity.

Conversely, the slopes of the polynomial curves stay relatively constant, resulting in extremely high flows at relatively high speeds. It must be taken into account that these extremely high flows are averages over periods only 20 sec long. They are events at the extreme end of the probability distribution and cannot be sustained over longer periods. It is therefore expected that the capacities of the individual lanes (Highway 401) will be well back from the ends of the polynomial curves.

4.5.3 Average-lane models for uncongested conditions

- **Highway 401 (Toronto)**

During the study described in Section 4.5.2, the relationship between speed and flow for the entire roadway was also examined. Simple polynomial functions (Equation 4.6) were again fitted to the average lane data obtained from 20 sec analysis results (see Table 4.2).

Table 4.2: Regression results for average lanes (Highway 401)

Station	Estimated Parameters				RMSE
	b_0	b_1	b_2	b_3	(km/h)
4	107.6	6.35E-03	-5.22E-06	6.01E-10	5.4
7	97.6	23.0E-03	-20.95E-06	4.16E-09	7.0

Figure 4.25 is an illustration showing the differences between the uncongested speed-flow curves (average lanes) of the Composite model for Section 1 and Section 3 and the polynomial curves obtained for average lanes of Station 4 and Station 7.

The polynomial curves for average lanes (Highway 401, Toronto) in Figure 4.25 are to a large extent very similar to the uncongested curves taken from the Composite model. Higher average speeds are however estimated for Highway 401. As was experienced for the individual curves, the average lane speed for each average-lane curve decreases slightly with an increase in flow (for low flows). The speeds of the Composite curves again decrease more rapidly towards capacity, while the slopes of the polynomial curves stay relatively constant. It must again be noted that these extremely high flows (polynomial curves) are averages over periods only 20 sec long. They cannot be sustained over longer periods.

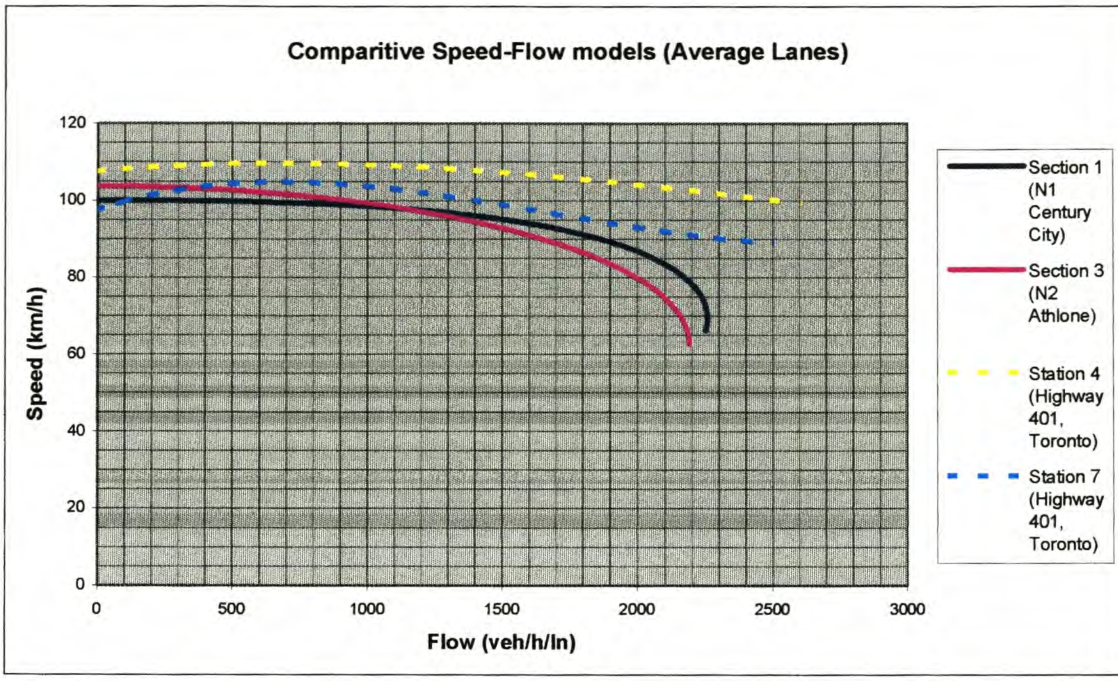

Figure 4.25: Comparative Speed-Flow models for Average lanes

- **Highway Capacity Manual**

Different speed-flow curves for typical basic freeway sections of all widths are given in the HCM depending only on the free-flow speed (FFS) of the particular section. The free-flow speed is measured in the field as the average speed of passenger cars when flow rates are less than 1300 pc/h/ln. The HCM only provides curves for free-flow speeds of 120, 110, 100, and 90 km/h, but allows that a curve representing any free-flow speed between 90 and 120 km/h can be defined by interpolation.

Figure 4.26 is an illustration showing the differences between the uncongested speed-flow curves (average lanes) of the Composite model for each section and the HCM 2000 curves for different free-flow speeds.

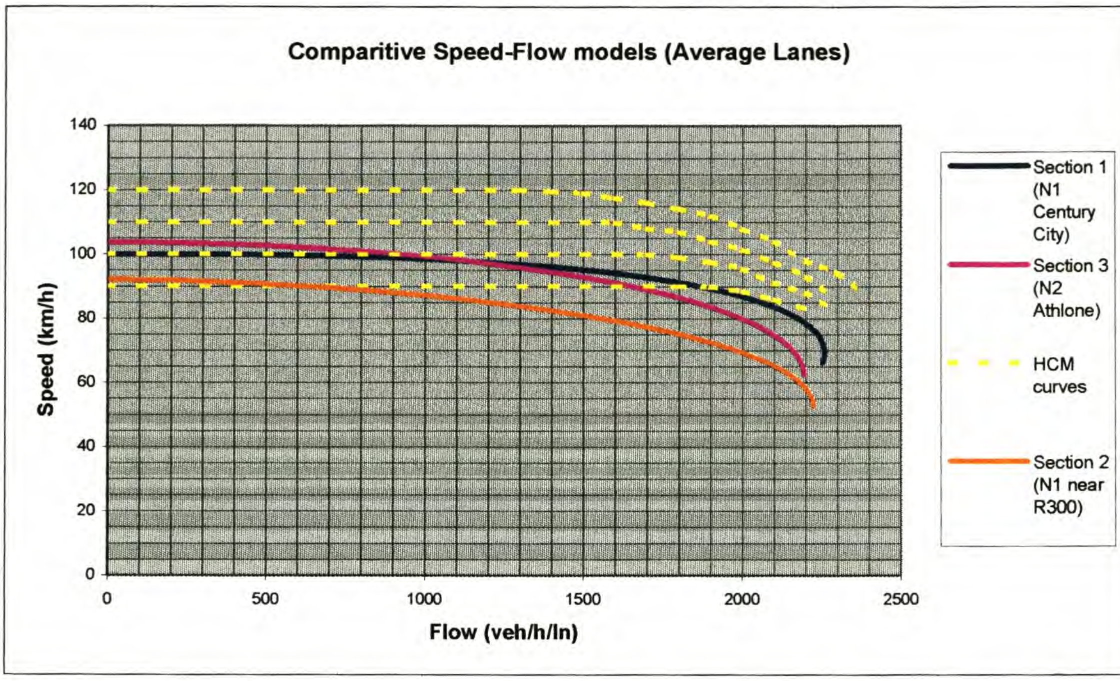

Figure 4.26: Comparison of Composite Speed-Flow curves with 2000 HCM curves (Uncongested)

The Composite uncongested speed-flow curves for Section 1 and Section 3 are very similar to the 100 km/h free-flow speed curve from the 2000 HCM for low flows. For both the Composite curves and the HCM curves, there are regions over which speed is relatively insensitive to flow. For the HCM curves, these regions extend to very high flows (1300 pc/h/ln for 120 km/h FFS, 1450 pc/h/ln for 110 km/h FFS, 1600 pc/h/ln for 100 km/h FFS, and 1750 pc/h/ln for 90 km/h FFS). For each of the Composite curves, these regions are much shorter. For the 3-lane sections (Section 1 and Section 3), with free-flow speeds of about 100 km/h, this region extends up to about 1000 veh/h/ln. For the 2-lane section (Section 2), with a free-flow speed of about 90 km/h, this region is even shorter, extending up to about 600 veh/h/ln (much shorter than the 1750 pc/h/ln predicted by the 2000 HCM curves).

The adequacy of the HCM speed-flow curves obviously depend on the use that is to be made of them. The use of the 2000 HCM curves by the HCM does not require great accuracy and they are therefore deliberately simplified.

Nonetheless, the 2000 HCM curves differ significantly from the Composite curves at high flows, where much higher speeds are predicted by the HCM curves.

- **The National Transport Commission (NTC) Report**

Kruger, Kruger and Stander (17) of Bruinette Kruger Stoffberg Inc. compiled a report in 1988 for the Department of Transport (DOT). This report was commissioned by the National Transport Commission with the purpose of establishing specific speed-flow relationships as guidelines for application to South African conditions. Data was obtained from the Comprehensive Traffic Observation (CTO) project undertaken for the Department of Transport, which covered a number of local urban freeways and provided extensive information on traffic behaviour on these roads.

The DELTRAN model (18) contains nine standard speed-flow curves that relate speed to a specific flow according to the ratio of the assigned flow to the capacity of the specific road section. This ratio is otherwise known as the volume to capacity (v/c) ratio. The capacity applicable to a specific road thus needs to be determined before speed-flow relationships can be obtained from the standard DELTRAN curves. The DELTRAN curves were used to analyse the data obtained from the CTO project.

Different types of roads were categorized for uninterrupted facilities. Two of these types (relevant to this report) covered by data obtained from the CTO project are urban and suburban freeways.

i) Urban freeways

These are freeways close to or directly serving a CBD area, often with lower geometric standards. They are often characterised by a lower speed limit (80 to 100 km/h). An example of this type of freeway, which has been studied in the NTC report, is the M2 (Johannesburg) close to the Mooi Street interchange. This type of freeway corresponds to the N2 (Athlone Power Station) freeway studied in this report.

ii) Suburban freeways

These are freeways that, while close to an urban area and within a metropolitan area, have higher design standards with a probable speed limit of 120 km/h. Speed-flow data have been obtained from observation stations on the N1 between Pretoria and Johannesburg at Halfway House and at Kyalami and on the N1 at Wingfield near Cape Town. This type of freeway corresponds to the N1 freeway near Century City and the N1 freeway near the R300 studied in this report.

The following DELTRAN curve equations were obtained from the CTO project data for the different freeways mentioned above:

DELTRAN 1 (Urban):

$$U = 90 - 27.89(v/c) \quad \text{for } v/c < 0.6 \tag{4.7}$$

$$U = -2.54 + \sqrt{6058.32 - (110.(v/c - 0.44))^2} \tag{4.8}$$

for v/c ≥ 0.6

DELTRAN 2 (Suburban):

$$U = 105 - 12.104(v/c) \quad \text{for } v/c < 0.8 \tag{4.9}$$

$$U = 50.06 + \sqrt{2055.62 - (200.(v/c - 0.786))^2} \tag{4.10}$$

for v/c ≥ 0.8

Figure 4.27 is an illustration containing two separate comparisons. The uncongested speed-flow curves (average lanes) of the Composite model for Section 3 is compared to the DELTRAN 1 model for urban freeways, while the uncongested speed-flow curves for Section 1 and Section 2 are compared to the DELTRAN 2 model for suburban freeways. The Composite speed-flow curves have been converted to equivalent speed-v/c curves for the purpose of comparison.

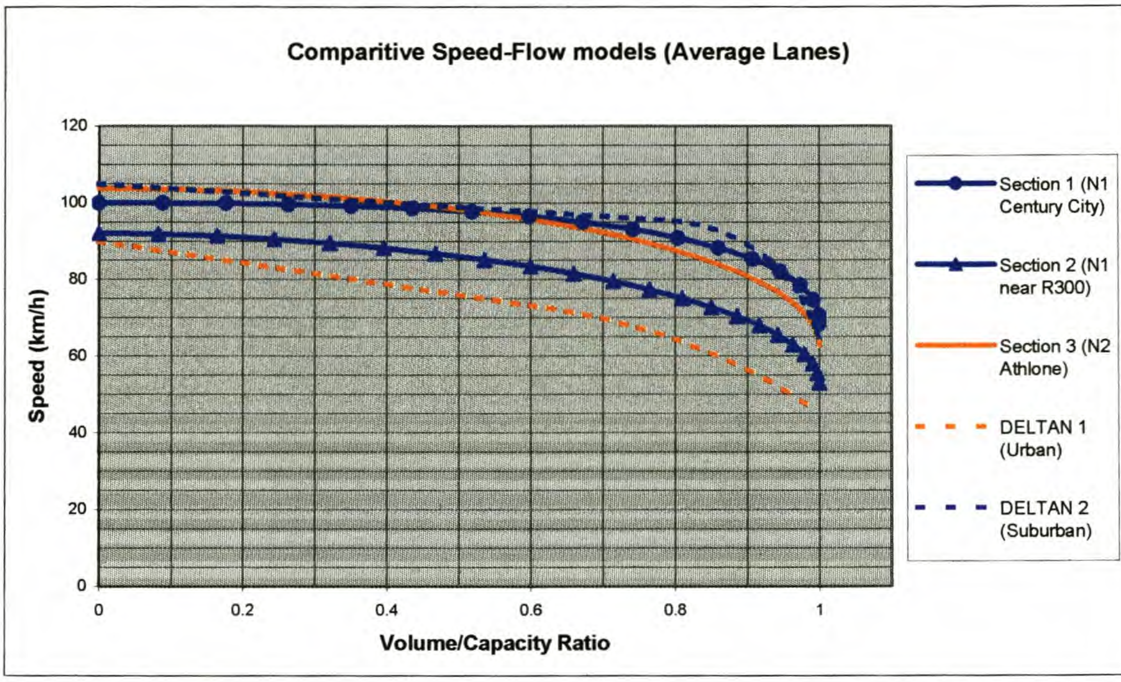

Figure 4.27: Comparison of Composite Speed-v/c curves with DELTRAN curves (Uncongested)

Section 3 curve vs. DELTRAN 1 (Urban) curve:

The Composite curve for Section 3 is very similar in shape to the DELTRAN 1 curve for urban freeways. This is signified by the fact that they are almost parallel to each other. However, there is a large difference in speed between the two curves, notwithstanding the fact that each of the freeway sections from which the two curves have been obtained operates with a speed limit of 100 km/h. It seems as if Section 3 operates more like a suburban freeway with a speed limit of 120 km/h (as opposed to 100 km/h). There is an extremely good correlation between the Composite curve of Section 3 and the DELTRAN 2 curve for suburban freeways.

Section 1 and Section 2 curves vs. DELTRAN 2 (Suburban) curve:

An extremely good correlation can be observed between the Composite curve of Section 1 and the DELTRAN 2 curve for suburban freeways. Although the Composite curve for Section 2 is very similar in shape (parallel) to the DELTRAN 2 curve, there is a large difference in speed between the two curves for the whole v/c range. Bearing in mind that each of the freeway sections from which the Composite and DELTRAN 2 curves have been obtained operates with a speed limit of 120 km/h, it is clear that Section 2 is occupied by slower moving traffic (on average). This can be explained by the fact that average travelling speeds on Section 2 were constrained by a rolling terrain and the fact that the section consisted of only 2 lanes (which resulted in less effective segregation between slower and faster moving traffic).

4.5.4 Average-lane models for congested conditions

- **Flow-Density models (Highway Capacity Manual)**

Different congested flow-density curves for typical basic freeway sections of all widths are given in the HCM depending only on the free-flow speed (FFS) of the particular section. The free-flow speed is again measured in the field as the average speed of passenger cars when flow rates are less than 1300 pc/h/ln. The HCM again only provides flow-density curves for free-flow speeds of 120, 110, 100, and 90 km/h.

Figure 4.28 is an illustration showing the differences between the congested flow-density curves (average lanes) of the Composite model for each section and the 2000 HCM curves for different free-flow speeds.

The Composite curves are consistently steeper than the 2000 HCM curves for high flows. However, there is only a slight difference (although constant) between the composite curve of Section 1, which has a FFS of 100 km/h, and the 2000 HCM curve for the same FFS. The difference between the composite curve of Section 3 (100 km/h FFS) and the corresponding 2000 HCM curve is however more significant. Higher densities are predicted by the composite curves of Section 1 and Section 3 for flows higher than about 1400 veh/h/ln.

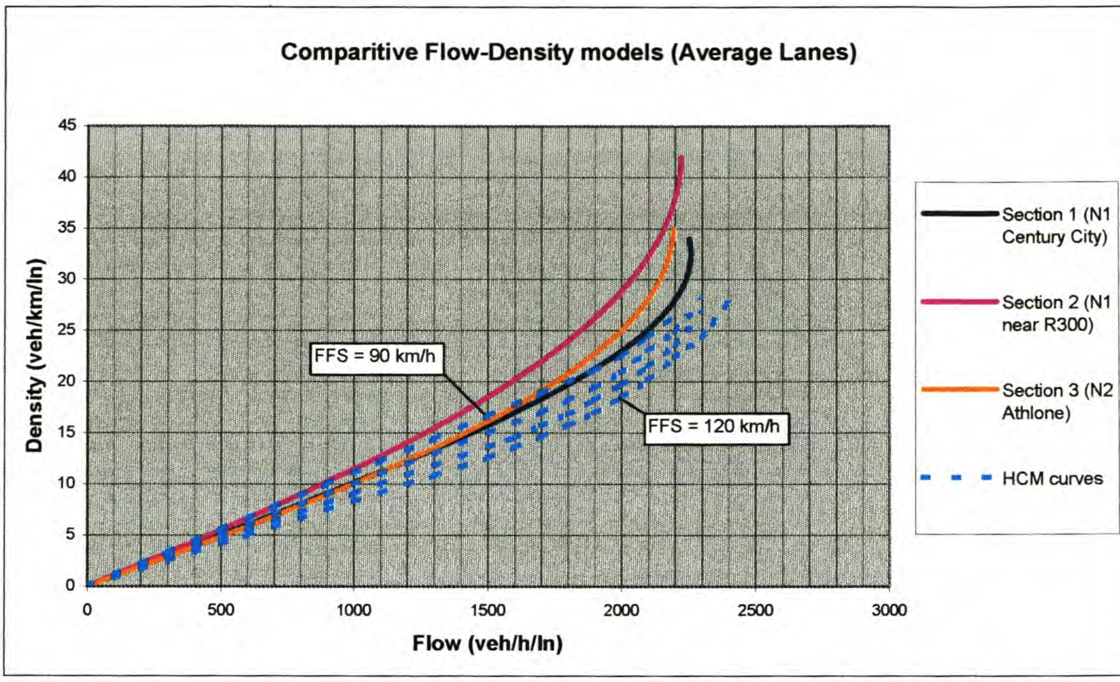

Figure 4.28: Comparison of Composite Flow-Density curves with 2000 HCM curves (Congested)

The difference between the composite curve of Section 2 (90 km/h FFS) and the corresponding 2000 HCM curve is more dramatic. For flows higher than about 1000 veh/h/ln, the composite curve of Section 2 is much steeper which results in much higher densities being predicted by the curve. In general, it seems that the 2000 HCM curves are somewhat optimistic with regards to flows at higher densities during congested conditions.

- **Speed-Flow investigation**

Work was done by *Zhou and Hall (19)* with the purpose of investigating the relationship between speed and flow within congestion, that is, the lower portion of the speed-flow curve. Data were collected on separate days in 1997 and 1998 from the Gardiner Expressway and in 1998 from Highway 401 in Toronto (Ontario). Observations that were from transitions between congested and uncongested conditions were removed from the data set. For the purpose of reducing the random variation inherent in the raw 20 sec data, 5 min averages were used in the analysis. The data were analysed using regression analysis for four types of functions: quadratic, cubic, exponential, and power. The following equations were identified for the different types of functions:

i) Quadratic: $speed = b_0.flow + c_0.flow^2$ (4.11)

ii) Cubic: $speed = b_0.flow + c_0.flow^2 + d_0.flow^3$ (4.12)

iii) Power: $speed = a_0.flow^{b0}$ (4.13)

iv) Exponential: $speed = a_0.e^{b0.flow}$ (4.14)

Parameters a_0, b_0, c_0, and d_0 are constants. The regression analysis results for each function fitted to the Gardiner Expressway data are shown in Table 4.3.

Table 4.3: Regression results for different equations (Gardiner Expressway)

Type	Equation	Estimated Parameters				R^2
		a_0	b_0	c_0	d_0	
Quadratic	4.11	-	0.0049	1.028E-05	-	0.7345
Cubic	4.12	-	0.0283	-2.12E-05	1.04E-08	0.7629
Power	4.13	2.0E-04	1.6579	-	-	0.7789
Exponential	4.14	5.215	0.0012	-	-	0.7806

Figure 4.29 is an illustration showing the differences between the congested speed-flow curves (average lanes) of the Composite model for each section and the curves represented by each of the equations in Table 4.3.

There is a significant difference in shape between the Composite curves and the curves fitted to the Gardiner Expressway. Higher speeds are predicted by the Gardiner Expressway curves for most flows, suggesting that the Gardiner Expressway is a higher-quality facility. Also, when the raw data of Highway 401 and the Gardiner Expressway were compared, higher speeds were observed for the Highway 401 data. Highway 401 also displayed a free-flow speed higher than that of the Gardiner Expressway, which suggested that there might be different congested speed-flow curves for different free-flow speeds.

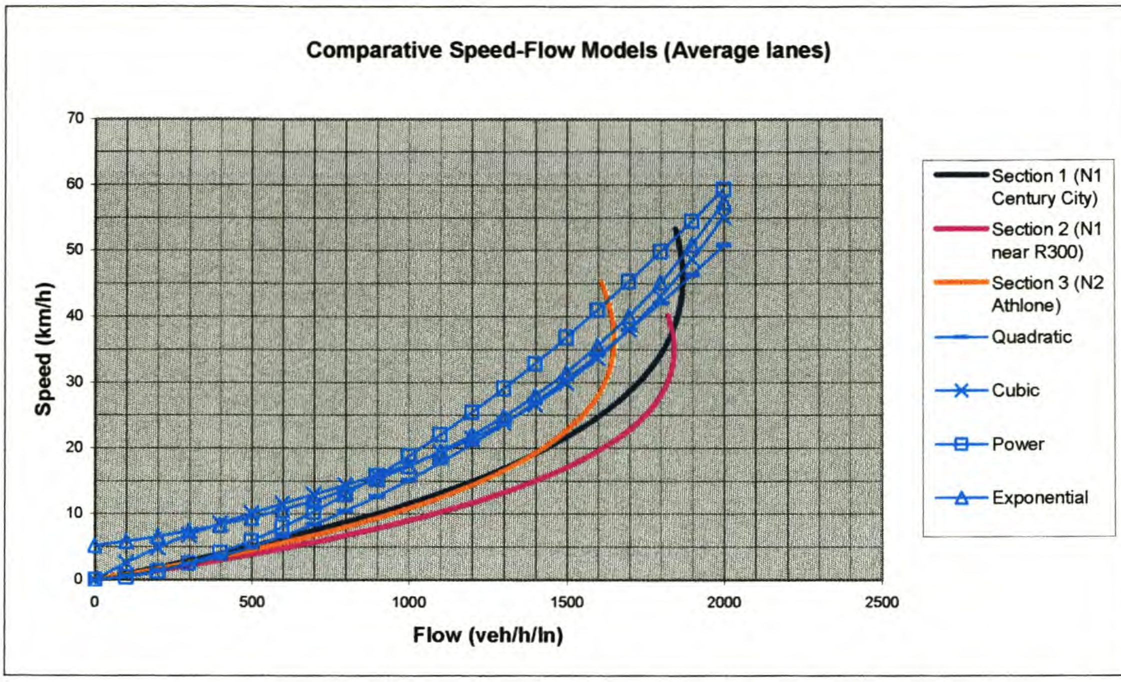

Figure 4.29: Comparison of Composite Speed-Flow curves with Overseas models (Congested)

The idea of different speed-flow curves for different free-flow speeds is supported by the behaviour of the Composite curves. Section 1 and Section 3 predict similar speeds for the same flows. They also have similar free-flow speeds (about 100 km/h). Furthermore, lower speeds are predicted by Section 2 (90 km/h FFS), which suggests that it is a lower quality facility. This makes sense, since Section 2 consists of only two lanes.

In previous versions of the HCM, a variety of different uncongested curves all converge on a single curve within congestion. In later versions (e.g. 2000 HCM) however, different congested speed-flow curves for different free-flow speeds are used (see Figure 4.28).

CHAPTER 5

APPLICATION OF CURVES

5.1 Introduction

Transportation is a crucial element to every part of our society. However, the infrastructure needed to sustain our current system becomes increasingly expensive. Therefore, in order to conserve scarce financial resources, optimum utilisation must be achieved from existing facilities. One way of achieving this is by increasing the capacity of existing facilities such as freeways. This can be done by either increasing the number of passengers per vehicle, or to provide preferential treatment to high occupancy vehicles (HOV's) on freeways. The types of HOV's applicable to South African conditions are taxis and buses. In a paper published by the National Department of Transport (*Moving South Africa (20))*, it was stated that if dedicated infrastructure like HOV lanes can improve speed on dense corridors by 25 %, it could save between 5% and 20% of operating costs.

In this report, the N2 freeway westbound towards Cape Town was investigated during peak morning conditions. The particular section (Section 3) consists of three lanes, with the median lane (right hand lane) reserved for buses and minibus taxis from 06:30 to 09:00. The focus in this chapter is on applying the different speed-flow curves established in Chapter 4 to Section 3, the purpose being to make predictions regarding the influence of the HOV lane on the traffic situation on the particular section. To this end, the current performance of the section was investigated and compared by way of the performance of a number of hypothetical cases. Passenger travel-times and time costs, as well as vehicle operating costs, were used as performance criteria. The different hypothetical cases are:

- Hypothetical Case 1

  An investigation into the traffic situation on the N2 freeway (Section 3) without the influence of the HOV lane.

- Hypothetical Case 2

  An investigation into the traffic situation on the N2 freeway with perfect operation of the HOV lane.

For the first investigation, Section 3 was evaluated in terms of the current operating conditions with regard to travel-times and costs for each lane. This was achieved by applying the speed/flow/density relationships for Section 3 (established in Chapter 4) to average 5 min. data (average data obtained from 5 consecutive 1 min. intervals) in order to convert average vehicular flows to equivalent average speeds for each mode on each lane. Once the speeds were determined, the passenger travel-times, as well as the passenger time costs and vehicle operating costs (dependent on average vehicle speeds), could be determined.

Similar methods were used for investigating each of the two hypothetical cases, the fundamental difference being that speed/flow/density curves established for other freeway sections (Chapter 4) were used to analyse 5 min. vehicle flows on each lane of Section 3. Various assumptions had to be made for each of the hypothetical cases investigated in this report.

5.2 Vehicle Occupancy

As mentioned earlier, the performance of Section 3 (for the Current situation as well as each of the two hypothetical cases) was evaluated in terms of passenger travel-times and time-costs, as well as vehicle operating costs. Information was therefore needed regarding the number of passengers occupying each type of mode observed on Section 3. In this report, distinction was made between passenger cars, minibus taxis, trucks, and buses.

For the passenger car mode, a large number of occupancy observations were made on Section 3 during typical peak morning conditions. Table 5.1 contains occupancy data measured on Section 3.

The first column in Table 5.1 contains the different occupancy levels (persons per vehicle), while the second column consists of the total number of observations made for each occupancy level. The third column consists of the total number of weighted observations (product of column 1 and column 2). Passenger car occupancy was then calculated as 1.831 (passengers/pc) by dividing the total number of weighted observations (column 3) by the total number of observations (column 2). This value was used for analysis throughout the report. A value of 2 passengers/veh (including the driver) was assumed for trucks.

Table 5.1: Passenger-car occupancy observations

Occupancy Class	Number of Cars	Total No. of Passengers
1	317	317
2	251	502
3	87	261
4	39	156
5	11	55
	705	**1291**

In the case of minibus taxis and buses, it was not possible to obtain accurate occupancy levels through simple observation. For minibus taxis, the assumption (based on enquiries from the taxi industry itself) was made that taxis generally operate at passenger capacity. Bearing in mind that the average capacity of a minibus taxi is about 15 passengers (seated), a value of 16 occupants/taxi (including the driver) was assumed for minibus taxi occupancy throughout the report.

The capacity of the average single-storey bus is about 83 passengers (67 seating, 17 standing). However, it is not easy to determine the level of capacity at which buses operate, due to the fact that buses (unlike taxis) operate on fixed time schedules. A capacity value of 85 passengers/veh (including the driver) was assumed for buses in this report. For the purpose of analysis, after numerous observations, it was assumed that buses operate at 90% of capacity during the morning peak period.

5.3 Travel-Time Analysis

5.3.1 Current Situation (N2 freeway)

Description:

The Current situation on the N2 freeway westbound towards Cape Town was investigated during the peak $1^1/_2$ hour (06:32 to 08:01) on a typical weekday. A peak $1^1/_2$ hour was used for analysis, as this was the period during which a very high demand was experienced (discussed in Chapter 3). For the Current situation (and each hypothetical case), flows observed during the study period of Section 3 were used as input data for determining the total passenger travel-time (including the driver) (sec/km) for each mode type.

Method:

The method for calculating the total passenger travel-time for each mode type is indicated in different steps in Tables C-1.1 through C-1.5 in Appendix C. The different steps are:

Step 1: The 1 min. flows observed for each lane during the given study period were converted to average 5 min. flows in pcu/h (pcu = equivalent passenger car unit).

Step 2: From the average 5 min. flows, average 5 min. densities (pcu/km) for each lane were calculated from the flow-density Composite model determined in Chapter 4 for Section 3 (Figure 4.8).

Step 3: However, in the model, one particular flow value has two possible density values, depending on the level of congestion. For uncongested flows, the average density was determined from the uncongested Composite curves (Multi-regime), while the congested Composite curves (Greenberg) were used to determine the density for congested flows.

Therefore, before the model could be applied, the level of congestion for each 5 min. flow of each lane had to be determined. The procedure used to determine whether a particular flow occurred during uncongested or congested conditions, was visual inspection of flow versus density observed over time. In other words, by referring to Figures 3.12 and 3.13, it is quite clear that all flows observed up to about 07:20 occurred during uncongested conditions. For the rest of the particular study period (up to 08:01), congested conditions were observed.

Step 4: Once the average flows and densities were known for each lane, the average pcu speeds (km/h) could easily be determined from the steady state equation Q = U.K (Equation 2.6).

Step 5: The speeds were then converted to average travel-times per kilometre (sec/km/veh) for each 5 min. interval of each lane. In other words, each vehicle (irrespective of the mode) travelling on a specific lane during a specific 5 min. interval, will have the same average speed (and travel-time) as every other vehicle travelling on the same lane during the same 5 min. interval.

Step 6: The vehicle mode data for each 5 min. interval of Section 3 were obtained from Table A-6 in Appendix A.

Step 7: The average travel-times, calculated for each 5 min. interval of each lane, were assigned to each of the observed vehicle modes.

Step 8: Total passenger travel-times in sec/km for each mode were calculated by multiplying the total vehicle travel-time for each 5 min. interval by the relevant occupancy value.

Step 9: The average travel-time per passenger for each mode-type during each 5 min. interval (all lanes) was calculated next. This was done by dividing the total passenger travel-time for each 5 min. interval (each mode) by the total number of passengers observed during the particular 5 min. interval.

It should be noted that the average passenger travel-times are equal to the average vehicle travel-times, as a single passenger travelling on a particular lane during a particular interval has the same speed as the vehicle he/she travels in. Therefore, the average travel-times in Table C-1.5 could also have been computed by dividing the total vehicle travel-time by the total number of vehicles for each case.

The vehicles travelling through the section during the given peak $1^1/_2$-hour period travel in either congested or uncongested conditions (as mentioned earlier). In Table C-1.5, these values are given as percentages of the total number of vehicles observed during the peak $1^1/_2$-hour period for each mode. These values will play an important role in interpreting the average results obtained for each mode (see Section 5.3.4).

The total travel-time of all passengers travelling through Section 3 during the given $1^1/_2$-hour period can easily be determined from Table C-1.4. For the Current situation, this value was calculated as 4,943,851 sec/km (sum of all travel-times for each lane). From this value, the average passenger travel-time for the whole period (irrespective of the mode) can be calculated as 161 sec/km/passenger. Likewise, the average speed can be calculated as 22.33 km/h/passenger. Figure 5.1 is an illustration of the average travel-times of each mode (and passenger) for each 5 min. interval.

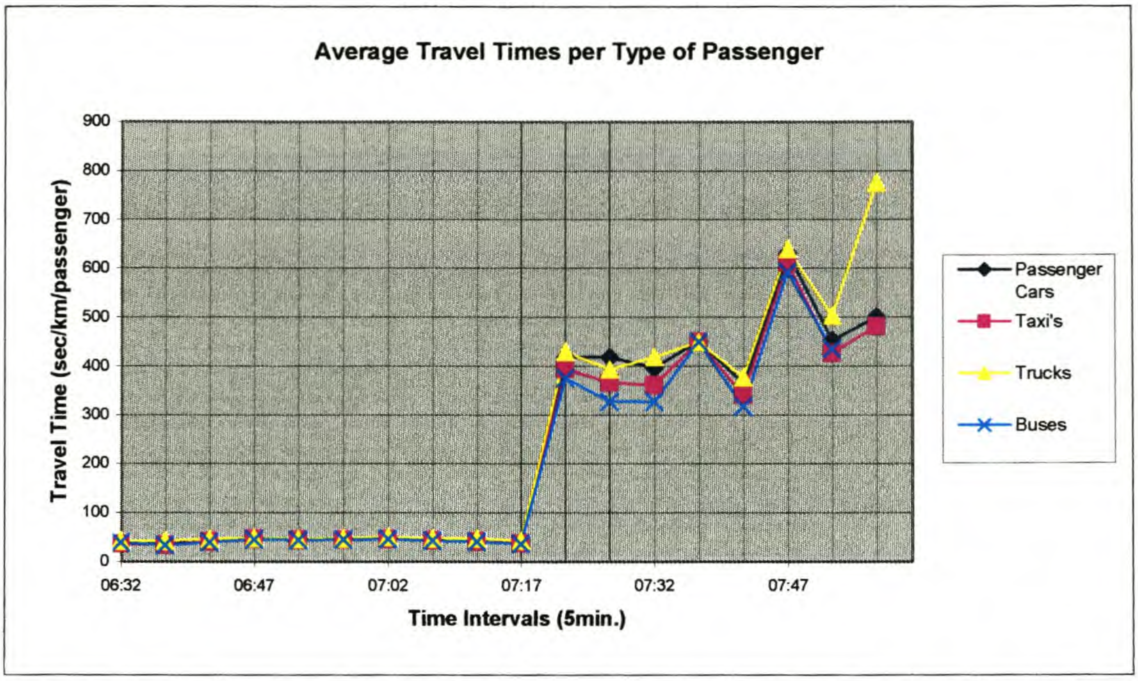

Figure 5.1: Average Passenger travel-time per type of mode (Current situation)

It is easy to distinguish between uncongested and congested conditions. Extremely high average passenger travel-times were calculated for each mode from 07:17 onwards. However, the current performance of Section 3 may be evaluated more effectively by investigating the total average passenger travel-time for each mode type.

Table 5.2 contains data on the total number of vehicles (and passengers) counted for each type of mode during the whole $1^1/_2$-hour peak period. Data were obtained from Table C-1.2 in Appendix C.

Table 5.2: Composition of mode types and passengers for peak $1^1/_2$-hour period

Mode Type	Vehicles		Passengers	
	Total	%	Total	%
Passenger cars	4783	82.2	8758	28.6
Taxis	767	13.2	12272	40.0
Trucks	149	2.6	298	1.0
Buses	122	2.1	9333	30.4

The vast majority of vehicles travelling through Section 3 during the peak $1^1/_2$-hour period are passenger cars. Passenger cars account for over 82 % of the total number of vehicles counted, while carrying only about 29 % of the total number of passengers. In contrast, taxis and buses together carry over 70 % of the total number of passengers, while constituting only about 15 % of the total number of vehicles.

Figure 5.2 is an illustration of the total average passenger travel-time calculated for each type of mode. It is clear that taxis and buses experience the largest amounts of passenger travel-time during the study period. This bearing in mind that passenger cars are by far the greatest contributors to congestion on all three lanes. It is interesting to note that 8758 passengers currently occupying 4783 passenger cars (Table 5.2) can be accommodated by just 115 buses (at 90% of capacity).

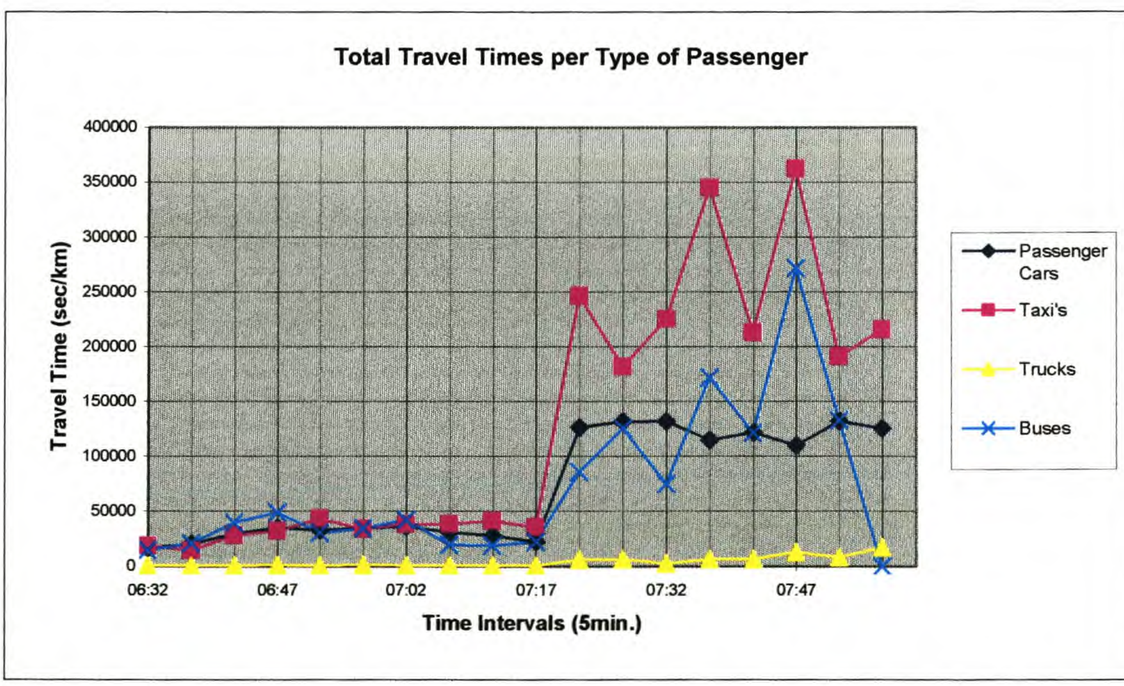

Figure 5.2: Total Passenger travel-time per type of mode (Current situation)

5.3.2 Hypothetical Case 1: N2 freeway without HOV lane

Description:

The first hypothetical case is an investigation into the traffic situation on the N2 freeway (Section 3) without the influence of the HOV lane. To this end, the current traffic-flow data observed on Section 3 during the $1^1/_2$-hour peak period were analysed and converted to equivalent passenger travel-times by applying the Composite curves of Section 1 (N1 freeway near Century City).

The assumption was therefore made that the particular section on the N2 freeway would operate similarly to the three-lane section on the N1 freeway in absence of an HOV lane dedicated to taxis and buses. Therefore, it was assumed that taxi drivers exhibit driver behaviour similar to that of passenger-car drivers on freeways.

Method:

The method used to determine passenger travel-times was very similar to the method used for the Current situation, the fundamental difference being that the 5 min. flows observed for Section 3 had to be redistributed among the three lanes. This had to be done in such a manner that would suggest that the HOV lane did not exist.

The method for calculating the total passenger travel-time for each mode type is indicated in different steps in Tables C-2.1 through C-2.5 in Appendix C. The different steps are:

Step 1: The flows were distributed among the three lanes according to the pcu ratios observed for Section 1 (for each mode). To obtain these ratios, the 1 min. flow data in the "Pcu's" column of Table A-3 (Appendix A) were converted to equivalent 5 min. data, from which the ratios for each lane were determined.

Step 2: The 5 min. pcu data observed for Section 3 were distributed among the three lanes according to the ratios determined in Step 1 and converted to average flows (pcu/h).

Step 3: For uncongested flows, the average speeds were determined directly from the uncongested Composite curves in Figure 4.3 (Section 1), while the congested Composite curves of the same figure were used to determine the congested speeds.

It was again necessary to determine the level of congestion for each 5 min. flow of each lane. The assumption was made that the conditions for the redistributed traffic for Hypothetical Case 1 would be similar to the conditions for the Current situation, as long as none of the lane capacities (relating to the Composite curves of Section 1) were exceeded during uncongested conditions.

In such a case, the redistributed traffic on a particular 5 min. interval would operate at congested conditions. This would mean that some of the vehicles (that would otherwise have been part of the particular 5 min. interval) would have to be carried over to the next 5 min. interval, which would almost certainly result in congested conditions for that particular interval.

For Hypothetical Case 1, none of the lane capacities were exceeded during the proposed uncongested conditions. As a result, the same uncongested and congested periods used for the Current situation were also used for Hypothetical Case 1.

Step 4: The speeds were converted to average travel-times per kilometre (sec/km/veh) for each 5 min. interval of each lane.

Step 5: Vehicle mode data for each 5 min. interval of Section 3 were again obtained from Table A-6 in Appendix A.

Step 6: The vehicles (each mode type) were then distributed among the three lanes according to the ratios calculated in Step 1.

Step 7: Average travel-times (calculated in Step 4) were assigned to each of the redistributed vehicles for each interval.

Step 8: Total passenger travel-times in sec/km for each mode were calculated by multiplying the total vehicle travel-time for each 5 min. interval by the relevant occupancy value.

Step 9: The average travel-time per passenger (and vehicle) for each mode-type was calculated according to the method used for the Current situation.

From the table, it should be noted that the percentages of congested and uncongested vehicles for each mode (Hypothetical Case 1) are equal the percentages calculated for the Current situation (Table C-1.5). This makes sense, since the same 5 min. average flow data that was used for the Current situation was also used for Hypothetical Case 1. Also, no vehicles were carried over from any particular 5 min. interval to the next resulting from the uncongested capacity of a lane being exceeded.

The total travel-time of all passengers was once again determined as the sum of all travel-times for each lane (Table C-2.4). For Hypothetical Case 1, this value was calculated as 4,719,564 sec/km (slightly lower than the 4,943,851 sec/km determined for the Current situation). From this value, the average passenger travel-time for the whole period, irrespective of the mode, can be calculated as 154 sec/km/passenger (vs. 161 sec/km/passenger for Current situation). Likewise, the average speed can be calculated as 23.39 km/h/passenger. Figure 5.3 is an illustration of the total average passenger travel-time calculated for each type of mode (Hypothetical Case 1).

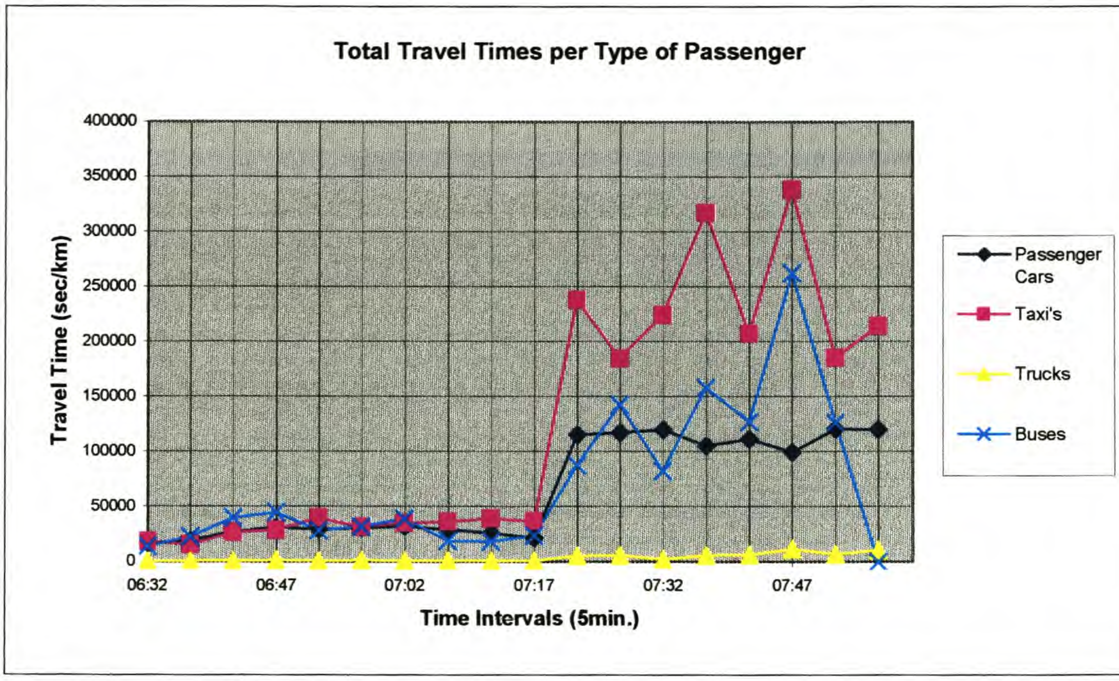

Figure 5.3: Total Passenger travel-time per type of mode (Hypothetical Case 1)

The graphs of each mode in Figure 5.3 are very similar (in shape and value) to the graphs in Figure 5.2. This suggests that the particular section on the N2 freeway (Section 3) currently operates almost exactly like a three lane section without an HOV lane during peak morning conditions. This results from inadequate law enforcement on the particular section, giving rise to a low level of compliance by passenger-car drivers.

5.3.3 Hypothetical Case 2: N2 freeway with perfect HOV lane operation

Description:

The second hypothetical case is an investigation into the traffic situation on the N2 freeway (Section 3) with perfect operation of the HOV lane. For perfect operation, only taxis and buses are allowed to travel on the HOV lane during the allocated period (06:30 to 09:00). Therefore, for Hypothetical Case 2, all taxis and buses were placed on the HOV lane (right hand lane) according to the total 5 min. flows observed for the Current situation on Section 3. These flows were then analysed and converted to equivalent passenger travel-times by applying the Composite curves determined for the HOV lane of Section 3 (N2 Athlone).

Similarly, passenger cars and trucks were placed on the left hand lane and middle lane. Due to the large number of passenger cars, the redistribution of traffic on these two lanes would almost certainly result in flows much higher than the capacity on each lane for every 5 min. interval. Flows much lower than the 5 min. flows observed for the Current situation are therefore expected, with vehicles being carried over to following intervals due to high congestion.

Redistributed traffic-flow data on the left hand lane and middle lane were analysed and converted to equivalent passenger travel-times by applying the Composite curves determined for these two lanes for Section 3 (N2 Athlone). However, before the curves could be applied, the flow and level of congestion for each 5 min. interval (each lane) had to be determined. Various assumptions had to be made before these flows and congestion levels could be determined. The assumptions for Hypothetical Case 2 were:

- All redistributed trucks will travel on the left hand lane only.

- Hypothetical Case 2.A: Passenger cars are expected to travel on the left hand lane and middle lane according to the worst 5 min. flows observed during congested conditions for the Current situation. This is regarded as the worst possible performance that could be expected from the middle and left hand lanes during perfect operation of the HOV lane.

- Hypothetical Case 2.B: Passenger cars are expected to travel on the middle and left hand lanes according to a prescribed level of the uncongested lane capacities. The assumption is therefore that vehicle throughput on Section 3 can be maintained at a high flow level on these two lanes (below capacity), with relatively high vehicle speeds. One way of achieving this is through the use of ramp metering, whereby the number of vehicles entering a freeway mainline at each on-ramp is controlled during the morning peak period. For Hypothetical Case 2.B, a conservative prescribed flow-rate of 50% of the uncongested capacity was used for each lane.

- Hypothetical Case 2.C: The assumptions of Hypothetical Case 2.B apply. A prescribed flow-rate of 85% of the uncongested capacity was used for each lane.

Method: Hypothetical Case 2.A

The method for calculating the total passenger travel-time for each mode type is highlighted in different steps in Tables C-3.1 through C-3.5 in Appendix C. The different steps are:

Step 1: The 1 min. flow data in the "Pcu's" column of Table A-3 (Appendix A) were converted to equivalent 5 min. data for each mode type.

Step 2: The total number of observed pcu's (per 5 min. interval) were distributed between the three lanes. All taxis and buses were placed on the HOV lane (right hand lane). Equivalency factors were used to convert buses to pcu's (1.5 for buses).

All trucks were placed on the left hand lane, while the passenger cars were distributed on the middle and left hand lanes according to congested traffic ratios. The ratios were determined as the average percentages of traffic (pcu's) observed on each lane during congested conditions (Table A-6, Appendix A). These ratios were calculated as 0.484 for the left hand lane, and 0.516 for the middle lane. An equivalency factor of 1.7 was used to convert trucks to pcu's.

Step 3: The average 5 min. flows (in pcu/h) were calculated for each lane. Traffic on the HOV lane (taxis and buses only) was assumed to be operating at uncongested conditions as long as the lane capacity of 2370 pcu/h was not exceeded. Traffic on the middle and left hand lanes were assumed to be operating at congested conditions corresponding to the worst 5 min. flows observed for the Current situation for each lane (471 pcu/h for the left hand lane, and 606 pcu/h for the middle lane).

Step 4: The average speeds were calculated directly from the Composite curves in Figure 5.17 (uncongested curve for the HOV lane, congested curves for the middle and left hand lane). A maximum average speed of 100 km/h was assumed for the HOV lane (taxi and bus speed limit).

Step 5: The speeds were converted to average travel-times per kilometre (sec/km/veh) for each 5 min. interval of each lane.

Step 6: The actual number of trucks and passenger cars expected to travel through Section 3 according to the worst observed 5 min. flows, were redistributed among the middle and left hand lanes according to the congested ratios calculated in Step 2. Very low flows are obtained (worst condition).

Step 7: The average travel-times, calculated for each lane, were assigned to each of the observed vehicle modes.

Step 8: Total passenger travel-times in sec/km for each mode were calculated by multiplying the total vehicle travel-time for each 5 min. interval by the relevant occupancy value.

It must be noted that, due to the high level of congestion in the middle and left hand lanes, a large portion of the total number of passenger cars and trucks were not able to travel through the section during the $1^1/_2$-hour study period. The passenger travel-times of the vehicles falling outside the study period (also travelling according to worst 5 min. flows) were therefore added to the total passenger travel-time.

Step 9: The average travel-time per passenger (and vehicle) for each mode-type was calculated according to the method used for the Current situation.

According to Hypothetical Case 2.A, only 32% of the total number of passenger cars and 34.1% of the trucks travelled through the section during the $1^1/_2$-hour peak period (refer to Table C-3.5). The total number of taxis and buses travelled through the section during uncongested conditions.

The total travel-time of all passengers was calculated from Table C-3.4 as 7,519,762 sec/km (sum of all travel-times for each lane). This very high value is due to a large number of passenger cars experiencing a very high level of congestion. The average passenger travel-time and average speed was calculated as 239.8 sec/km/passenger and 15.01 km/h/passenger respectively.

Figure 5.4 is an illustration of the total average passenger travel-time calculated for each type of mode (Hypothetical Case 2.A). Much lower total passenger travel-times are experienced by the HOV lane vehicles for Hypothetical Case 2.A. The travel-time values for taxis and buses over the whole $1^1/_2$-hour period correspond to the uncongested values obtained for Hypothetical Cases 1 and 2.

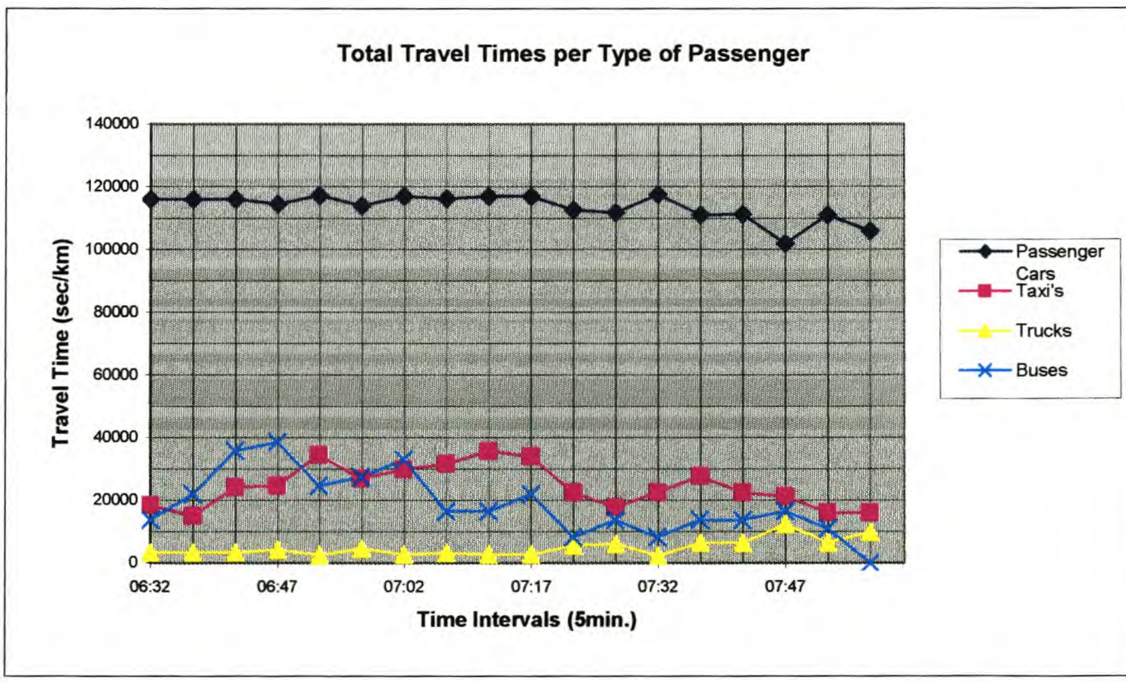

Figure 5.4: Total Passenger travel-time per type of mode (Hypothetical Case 2.A)

Passenger cars experience very high total passenger travel-times over the whole period. Due to a lower occupancy level, these travel-times are not as high as what was experienced in some cases by taxis and buses during the previous two hypothetical cases. However, the passenger car travel-times displayed in Figure 5.4 only account for about 32% of the total passenger travel-times experienced by all passenger cars.

Method: Hypothetical Case 2.B

The method for calculating the total passenger travel-time for each mode type is highlighted in different steps in Tables C-4.1 through C-4.5 in Appendix C. The different steps are:

Step 1: The 1 min. flow data in the "Pcu's" column of Table A-3 (Appendix A) were converted to equivalent 5 min. data for each mode type.

Step 2: The same procedure described in Hypothetical Case 2.A was followed to distribute the total number of observed pcu's among the three lanes. However, passenger cars were distributed among the middle and left hand lanes according to uncongested ratios determined from Table A-6 in Appendix A. These ratios were calculated as 0.373 for the left hand lane, and 0.627 for the middle lane.

Step 3: Average 5 min. flows (in pcu/h) were calculated for each lane. Traffic on the middle and left hand lanes were assumed to be operating at uncongested flows corresponding to 50% of the lane capacities (890 pcu/h for the left hand lane, and 1185 pcu/h for the middle lane).

Step 4: Average speeds were calculated for each lane directly from the uncongested Composite curves in Figure 4.17.

Step 5: The speeds were converted to average travel-times per kilometre (sec/km/veh) for each 5 min. interval of each lane.

Step 6: The actual number of trucks and passengers expected to travel through Section 3 at to 50% of the lane capacities, were distributed among the middle and left hand lanes according to the uncongested ratios calculated in Step 2.

Step 7: The average travel-times calculated in Step 5 were assigned to each of the observed vehicle modes.

Step 8: The same procedure described in Hypothetical Case 2.A was followed to calculate the total passenger travel-times for each mode (in sec/km).

Step 9: The average travel-time per passenger (and vehicle) for each mode-type was calculated according to the method used for the Current situation. According to Hypothetical Case 2.B, 60.6% of the total number of passenger cars and 83.8% of the trucks travelled through the section during the $1^1/_2$-hour peak period.

The total travel-time of all passengers was calculated from Table C-4.4 as 1,129,674 sec/km (sum of all travel-times for each lane). This low value is due to the assumption that a relatively high level of traffic-flow (with high vehicle speeds) can be maintained on the middle and left hand lanes through the use of ramp metering. The average passenger travel-time and average speed was calculated as 36.77 sec/km/passenger and 97.9 km/h/passenger respectively. Figure 5.5 is an illustration of the total average passenger travel-time calculated for each type of mode.

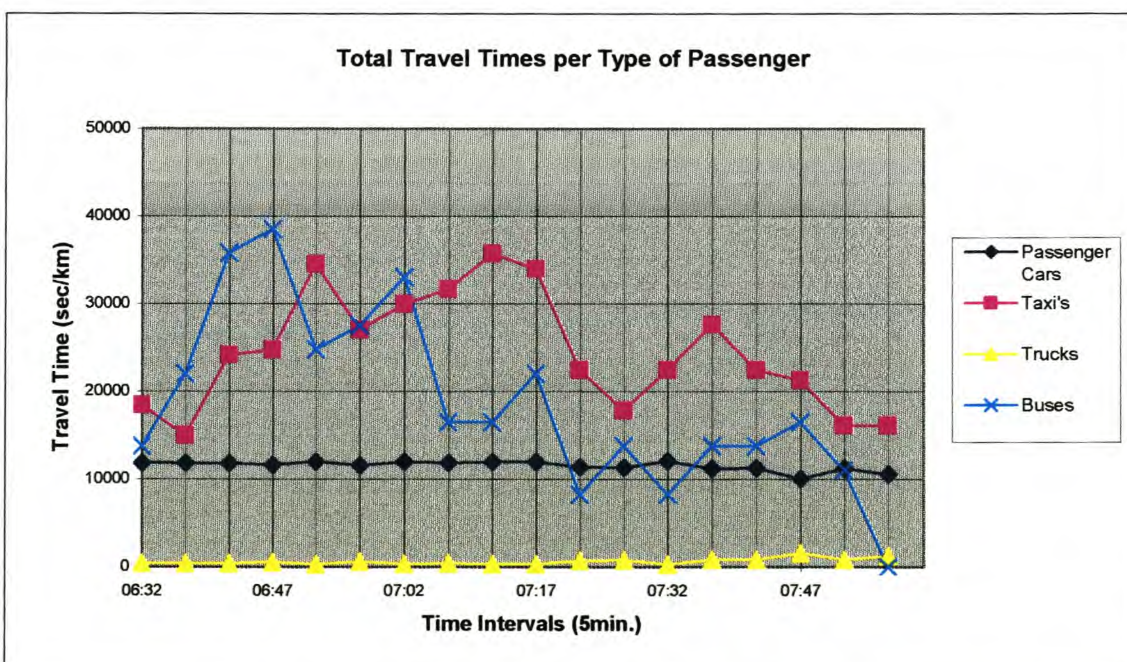

Figure 5.5: Total Passenger travel-time per type of mode (Hypothetical Case 2.B)

Passenger cars experience extremely low total passenger travel-times over the whole period. This is due to the assumption that relatively high flows (with high speeds) can be maintained on the middle and left hand lanes with the use of ramp metering. The passenger car travel-times displayed in Figure 5.5 only account for about 60% of the total passenger travel-times experienced by all passenger cars.

Method: Hypothetical Case 2.C

The only difference between Hypothetical Case 2.B and 2.C was that different flows were prescribed for the middle and left hand lanes. For Hypothetical Case 2.C, traffic on the middle and left hand lanes were assumed to be operating at uncongested flows corresponding to 85% of the lane capacities (1513 pcu/h for the left hand lane, and 2015 pcu/h for the middle lane).

The same method used in Hypothetical Case 2.B was therefore used to calculate the total passenger travel-time for each mode type for Hypothetical Case 2.C. The different steps are highlighted in Tables C-5.1 through C-5.5 in Appendix C.

An interesting observation from Table C-5.5 is that, due to the very high flows prescribed on the middle and left hand lanes, more than the total number of passenger cars and trucks were able to travel through the section during the $1^1/_2$-hour peak period (103.1% of the total number of passenger cars, and 142.5% of the trucks). To compensate, the passenger travel-times of the additional vehicles were subtracted from the total passenger travel-times.

The total travel-time of all passengers was calculated at 1,139,487 sec/km (sum of all travel-times for each lane). The average passenger travel-time and average speed was calculated as 39.14 sec/km/passenger and 91.98 km/h/passenger respectively. Figure 5.6 is an illustration of the total average passenger travel-time calculated for each type of mode.

Higher total passenger travel-times are experienced over the whole period than what was experienced for Hypothetical Case 2.B. This is due to the higher level of flow prescribed on each of the two lanes, resulting in more passenger cars being able to travel through the section during each interval. Also, the travel-times displayed in Figure 5.6 account for passenger travel-times of all the passenger cars (as opposed to about 60% for Hypothetical Case 2.B)

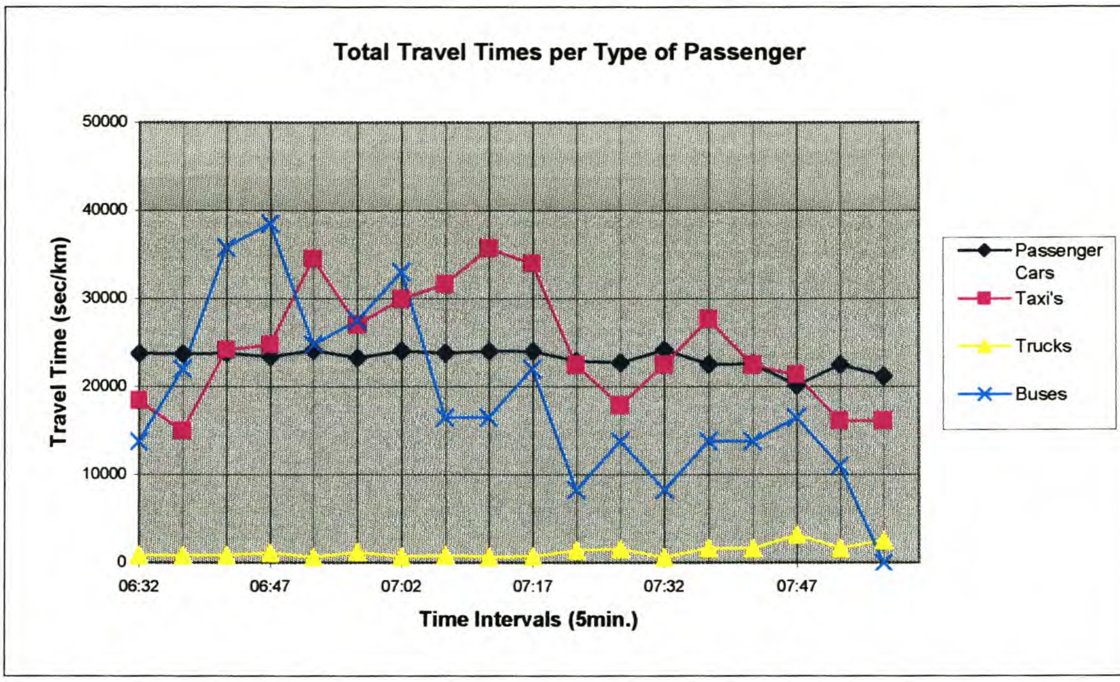

Figure 5.6: Total Passenger travel-time per type of mode (Hypothetical Case 2.C)

5.3.4 Summary and Interpretation of Travel-Time Results

The travel-time results obtained for the Current situation, as well as for each of the hypothetical cases, are summarised in Table 5.3.

The results of the Current situation and Hypothetical Case 1 are very similar, with extremely high average travel-times obtained for each mode type. This suggests that the particular section on the N2 freeway currently operates very much like a three lane freeway section without an HOV lane. In fact, slightly lower average travel-times are predicted by Hypothetical Case 1, which suggests that the current use of the HOV lane has a negative impact on the performance of the section.

Table 5.3: Summary of travel-time results

Summary of Results	Current Situation: N2 with HOV lane	Case 1: N2 without HOV lane	Case 2: Perfect HOV operation		
			Worst 5 min. flows	50% of Capacity	85% of Capacity
Total passenger Travel Time (sec/km)	**4,943,851**	**4,719,564**	**7,519,762**	**1,129,674**	**1,193,487**
Passenger Cars	1,282,243	1,171,467	6,487,915	338,811	400,159
Taxi's	2,308,417	2,218,870	441,792	441,792	441,792
Trucks	73,853	60,770	254,067	13,083	15,548
Buses	1,279,338	1,268,457	335,988	335,988	335,988
Average Passenger Travel Time (sec/km)					
Passenger Cars	146.4	133.7	730.2	39.1	46.2
Taxi's	188.1	180.8	36.0	36.0	36.0
Trucks	247.8	203.9	852.6	43.9	52.2
Buses	137.1	135.9	36.0	36.0	36.0
Average Passenger Speed (km/h)					
Passenger Cars	24.59	26.92	4.93	92.17	78.00
Taxi's	19.14	19.91	100.00	100.00	100.00
Trucks	14.53	17.65	4.22	82.00	69.00
Buses	26.26	26.49	100.00	100.00	100.00
Total Avg. Passenger Travel Time (sec/km/pass.)	**161.2**	**153.9**	**239.8**	**36.8**	**39.1**
Total Avg. Passenger Speed (km/h/pass.)	**22.33**	**23.39**	**15.01**	**97.90**	**91.98**

The results of the Current situation and Hypothetical Case 1 are very similar, with extremely high average travel-times obtained for each mode type. This suggests that the particular section on the N2 freeway currently operates very much like a three lane freeway section without an HOV lane. In fact, slightly lower average travel-times are predicted by Hypothetical Case 1, which suggests that the current use of the HOV lane has a negative impact on the performance of the section.

An interesting observation is that the highest average travel-times are obtained for taxis and trucks for both the Current situation and Hypothetical Case 1. This is a direct result of the percentages of vehicles travelling during either congested or uncongested conditions for each mode (Step 9). A higher percentage of the total number of taxis (38%) and trucks (42%) travel during congested conditions, as opposed to passenger cars (26%) and buses (25%). This gives rise to the higher average travel-times calculated for taxis and trucks.

For both the Current situation and Hypothetical Case 1, passengers travelling in passenger cars account for a relatively low percentage (about 26%) of the total passenger travel-time, while passenger cars account for as much as 82% of the total number of vehicles. In contrast, passengers carried by taxis and buses (constituting 15% of the total number of vehicles) account for about 73% of the total passenger travel-time.

For Hypothetical Case 2.A, passengers travelling in passenger cars account for over 86% of the total passenger travel-time. This is a result of the extremely high level of congestion predicted for the middle and left hand lanes. In contrast, taxis and buses travel in the HOV lane at their desired speeds (100 km/h maximum) during uncongested conditions. A very high speed-differential exists between vehicles in the middle lane (average speed about 5 km/h) and taxis and buses in the HOV lane (100 km/h). Also, taxis and buses are required to weave into and out of the HOV lane in order to enter or leave the freeway. For example, a vehicle travelling on the HOV lane at 100 km/h will have to slow down to a speed of about 5 km/h in order to join the middle lane. It is therefore highly unlikely that the high speeds predicted for the HOV lane by Hypothetical Case 1 will actually occur in practice. One positive aspect of Hypothetical Case 1 is that the extremely high level of congestion in the middle and left hand lanes might force passengers to consider using public transport (as opposed to passenger cars) as their mode of choice.

Extremely low average travel-times are predicted by both Hypothetical Case 2.B and 2.C for each mode type. The different modes travel at similar speeds, resulting in a low speed differential between the middle and right hand lane, thereby facilitating weaving into and out of the HOV lane.

Hypothetical Case 2.B predicts lower average passenger travel-times for passenger cars and trucks than Hypothetical Case 2.C, notwithstanding the fact that higher flow-rates are prescribed by Hypothetical Case 2.C. It must however be borne in mind that the total number of passenger cars and trucks were able to travel through the section during the $1^1/_2$-hour period for Hypothetical Case 2.C. In contrast, only about 60% of the passenger cars and 84% of the trucks were able to do so for Hypothetical Case 2.B. The extra time spent by vehicles outside the $1^1/_2$-hour period before entering the section, was not taken into account while determining the average passenger travel-times.

Due to the lower prescribed flow-rates, longer queues and delays are expected on the on-ramps for Hypothetical Case 2.B. Hypothetical Case 2.C is therefore preferred above Hypothetical Case 2.B.

5.4 Total Cost Analysis

The total costs of using the N2 freeway section (Section 3), under the different circumstances described in Section 5.3, consist of vehicle operating costs and person time costs. The operating cost of a particular vehicle is a function of the average travel speed of the vehicle over a certain length of road. On the other hand, a person time cost is a measure of the value of a particular person's time. The additional time that is spent by a person while travelling is regarded as "lost" time, expressed as R/person hour. The value of a particular person's time is dependent on the nature of his/her journey. For example, persons travelling to or from work (commuters) have lower time values than persons who are working while travelling (e.g. bus and taxi drivers).

5.4.1 Vehicle Operating Costs

Table 5.4 contains operating costs per type of mode for various average travel speeds (expressed in 1999 R/1000 vehicle kilometres). The operating cost data were obtained from the CSIR (Council for Scientific and Industrial Research) (21). Elements incorporated into the costs included fuel, vehicle maintenance, depreciation, tyres, and oil.

Table 5.4: Vehicle Operating Costs

1999 Vehicle Operating Costs (R/1000 veh. km.)				
Travel Speed	**Passenger Cars**	**Taxi's**	**Buses**	**Trucks**
10	1129.51	1306.11	2742.55	3736.91
20	830.41	947.98	1993.61	2619.32
30	713.24	821.22	1734.96	2235.55
40	649.03	759.92	1614.98	2048.17
50	609.87	729.37	1561.72	1951.06
60	586.00	717.96	1551.93	1912.22
70	573.20	720.93	1576.82	1921.41
80	569.41	736.22	1633.38	1976.87
90	573.57	763.04	1721.37	2080.85
100	585.21	801.27	1842.20	2237.85
110	604.14	851.20	1998.42	2453.86
120	630.38	913.44	2193.50	2736.02

The following relationships between vehicle operating costs and average travel speeds were obtained through regression analysis of the data in Table 5.4:

Passenger cars:
$$\text{Cost} = \frac{7178.5}{U} + 0.9316(U) + 424.977 \tag{5.1}$$

Taxis:
$$\text{Cost} = \frac{9342.11}{U} + 3.431(U) + 374.471 \tag{5.2}$$

Buses:
$$\text{Cost} = \frac{21573.64}{U} + 10.670(U) + 595.684 \tag{5.3}$$

Trucks:
$$\text{Cost} = \frac{31311.67}{U} + 13.358(U) + 647.854 \tag{5.4}$$

Where U = Average travel speed of vehicles for a particular time-interval.

Vehicle operating costs were determined for the Current situation, as well as for each of the hypothetical cases described in the previous section. Results are shown in Tables C-6.1 through C-6.5 in Appendix C. The above equations were used to calculate operating costs for each mode type from corresponding 5 min. average speed data. Figure 5.7 is an illustration of the average passenger car operating costs (per 5 min. interval) for each case.

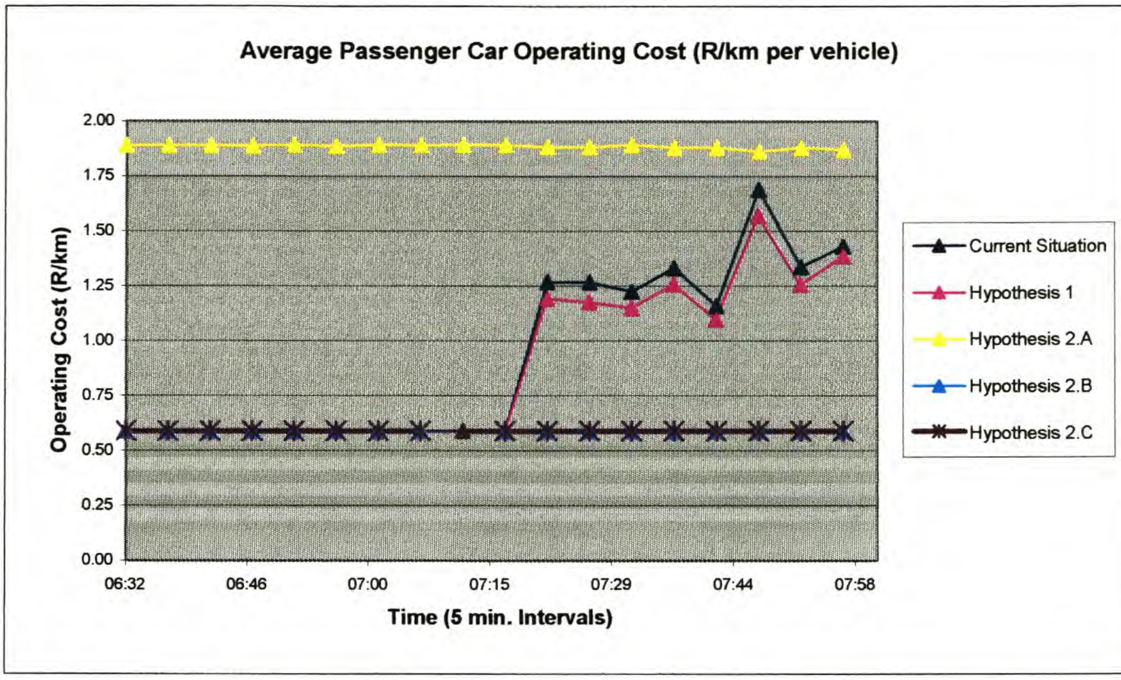

Figure 5.7: Average Passenger car Operating Costs (5 min. Intervals)

Average passenger car operating cost is relatively insensitive to changes in speed during uncongested conditions. The average passenger car speeds for Hypothetical Cases 2.B and 2.C (as well as the uncongested speeds for the Current situation and Hypothetical Case 1) vary between 70 and 100 km/h, while the operating costs stay relatively constant. Conversely, operating costs vary considerably during congested conditions when extremely low speeds occur (speeds lower than 20 km/h). Very high operating costs are experienced during congested conditions (low speed conditions). Slightly higher operating costs are expected for taxis during both congested and uncongested conditions.

Figure 5.8 is an illustration of the average bus operating costs (per 5 min. interval) for each situation.

Average bus operating costs (like passenger car operating costs) are relatively insensitive to changes in speed during uncongested conditions. Bus operating costs are much higher than passenger car and taxi operating costs for similar speeds. Extremely high costs are experienced during congested conditions.

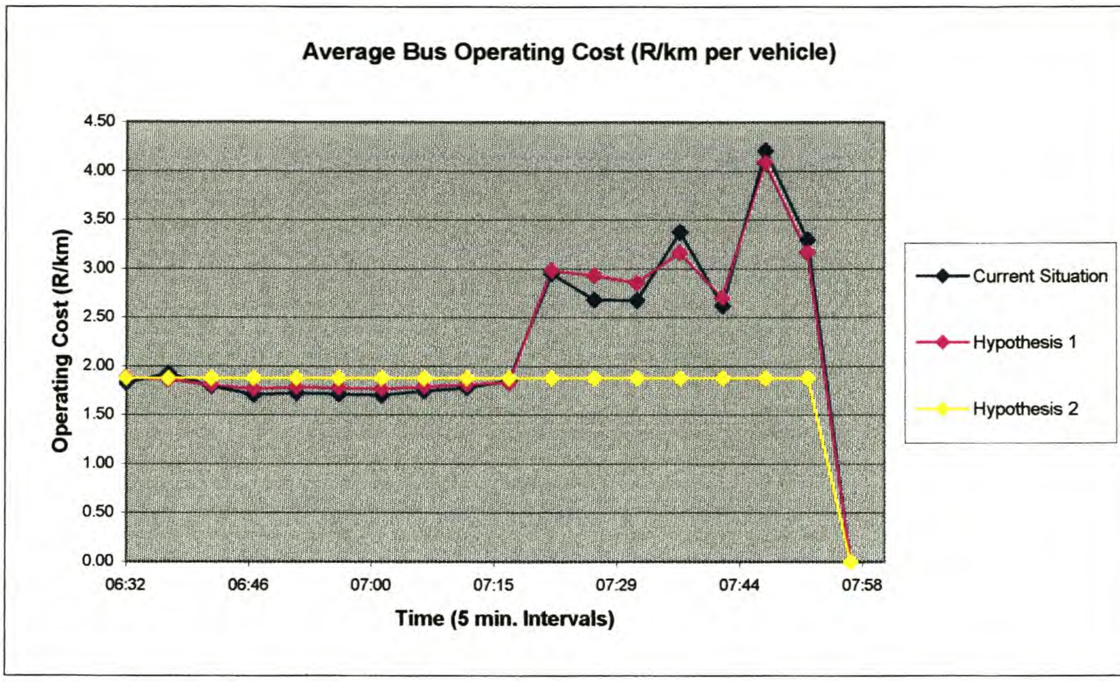

Figure 5.8: Average Bus Operating Costs (5 min. Intervals)

5.4.2 Person Time Costs

The value of a particular person's time is dependent on the nature of his/her journey. In this report, distinction was made between commuter passengers and working passengers (truck passengers and drivers, taxi drivers, and bus drivers). A time-cost value of 5.45 (R/person hour) was assumed for commuter passengers, and 23.89 (R/person hour) for working passengers. These values were obtained from the CSIR (21).

Person time costs were calculated from average travel-time data for each 5 min. interval. These values were converted to equivalent person costs per travel distance (R/km) for each mode type. Time cost results are shown in Tables C-7.1 through C-7.5 in Appendix C.

Figure 5.9 is an illustration of the average person time costs (per 5 min. interval) for passenger car passengers.

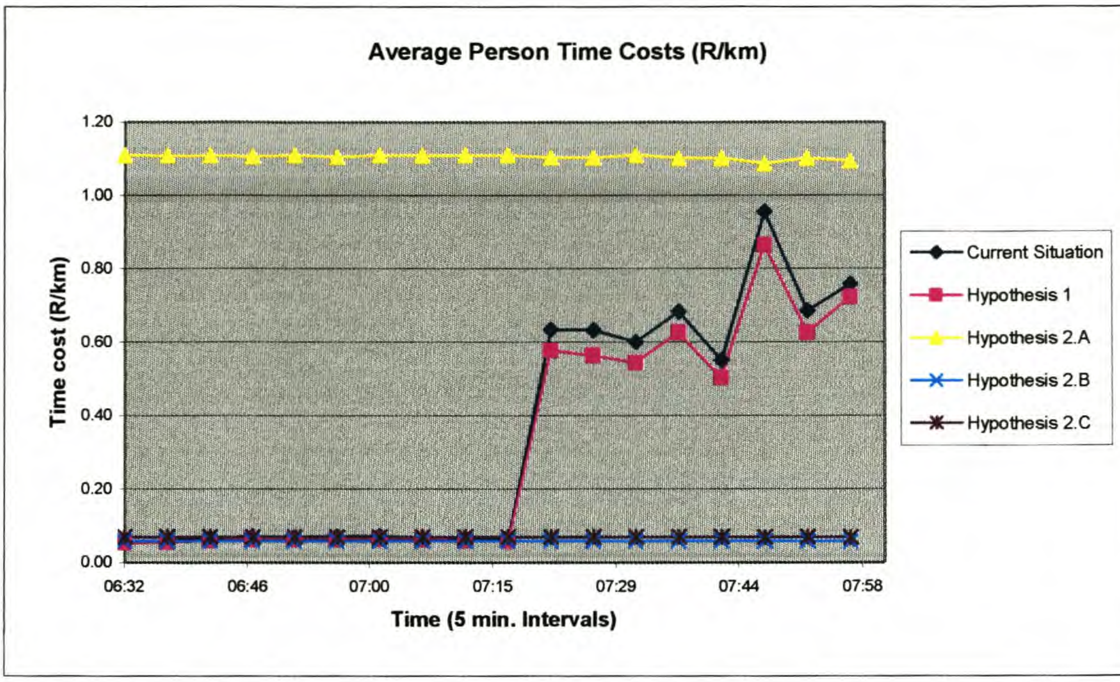

Figure 5.9: Average Person Time Costs (Passenger cars)

Similarly to what was experienced for operating costs, average person time costs (passenger cars) are relatively insensitive to changes in speed during uncongested conditions, with very high time costs experienced during congested conditions. Average person time costs are lower than corresponding vehicle operating costs for both congested and uncongested conditions. These lower costs result from a low passenger time-value for passenger car occupants (commuter).

Figure 5.10 is an illustration of the average person time costs (per 5 min. interval) for bus passengers. Average person time costs for buses are much lower than the corresponding operating costs for both congested and uncongested conditions. However, the total person time costs per bus will be much higher than the operating costs, due to the high occupancy level.

The average person time costs for Hypothetical Case 1, where buses were distributed among all three lanes, were slightly higher than for the Current situation during congested conditions. This is due to the fact that, for the Current situation, 94% of the total number of buses travelled on the HOV lane where the highest congested flow-rate of all three lanes occurred.

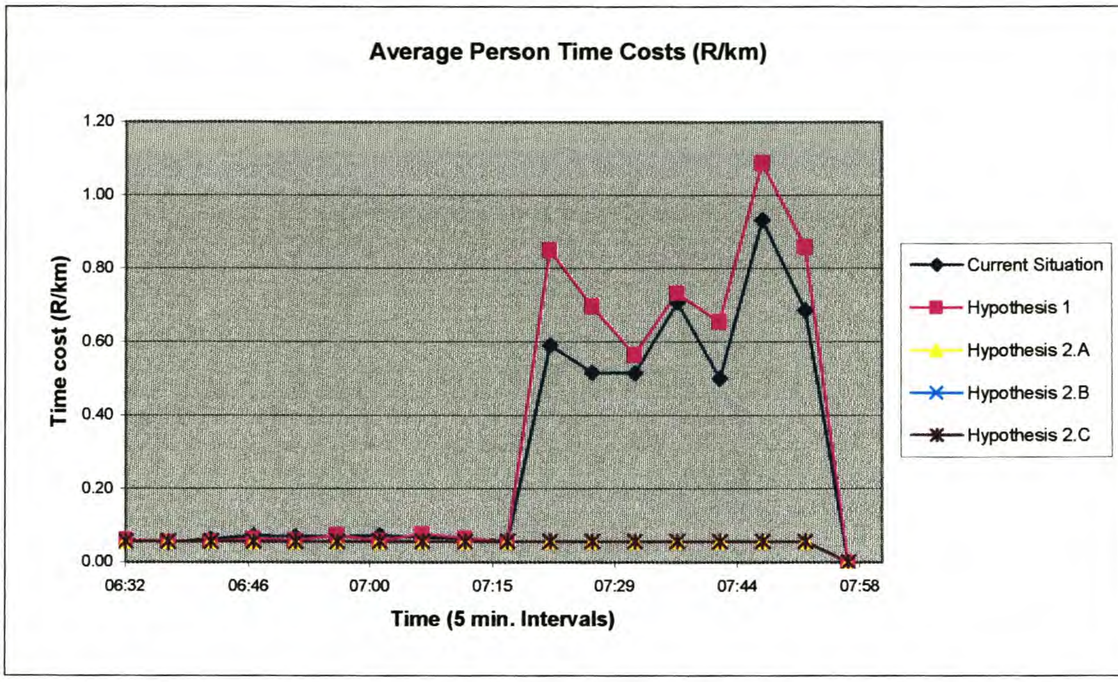

Figure 5.10: Average Person Time Costs (Buses)

5.4.3 Summary and Interpretation of Total Cost Results

The total cost results (operating costs and person time costs) obtained for the Current situation, as well as each of the hypothetical cases, are summarised in Table 5.5. The person time costs are expressed in R/km.

The total costs of the Current situation are very similar to the costs of Hypothetical Case 1. This is again proof that the particular N2 freeway section (Section 3) currently operates very much like a three lane section without an HOV lane. However, the total person time costs for bus passengers were slightly lower for the Current situation (as opposed to that of Hypothetical Case 1). This results from the fact that a large portion of buses (94%) travelled on the HOV lane during the Current situation where the highest congested flow-rate occurred.

For both the Current situation and Hypothetical Case 1, passenger cars account for about 70% of the total operating costs, while passengers travelling in passenger cars only account for about 20% of the total person time costs. In contrast, taxis and buses together account for only 20% of the total operating costs, while accounting for between 73% and 76% of the total person time costs.

Table 5.5: Summary of Total Cost results

Summary of Total Cost Results	Current Situation: N2 with HOV lane	Case 1: N2 without HOV lane	Case 2: Perfect HOV operation		
			Worst 5 min. flows	50% of Capacity	85% of Capacity
Total Vehicle Operating Costs (R/km)	**5,293.99**	**5,158.95**	**11,180.53**	**3,987.74**	**3,975.58**
Passenger Cars	3,710.82	3,618.97	9,119.52	2,819.94	2,822.93
Taxi's	810.38	804.95	622.01	622.01	622.01
Trucks	513.05	472.15	1,209.83	316.63	301.48
Buses	259.73	262.88	229.16	229.16	229.16
Total Person Time Costs (R/km)	**8,902.60**	**9,045.88**	**12,905.92**	**1,997.66**	**2,106.89**
Passenger Cars	1,941.17	1,773.47	9,821.98	512.92	605.80
Taxi's	4,233.70	4,069.47	810.26	810.26	810.26
Trucks	490.10	403.27	1,686.02	86.82	103.18
Buses	2,237.63	2,799.66	587.66	587.66	587.66
Total Costs (R/km)	**14,196.59**	**14,204.83**	**24,086.45**	**5,985.40**	**6,082.48**
Passenger Cars	5,651.99	5,392.44	18,941.50	3,332.86	3,428.73
Taxi's	5,044.09	4,874.42	1,432.27	1,432.27	1,432.27
Trucks	1,003.15	875.43	2,895.85	403.45	404.66
Buses	2,497.37	3,062.54	816.83	816.83	816.83

For Hypothetical Case 2.A, the high level of congestion in the middle and left hand lanes result in extremely high operating costs and person time costs for passenger cars and trucks. On the other hand, total costs (especially person time costs) for taxis and buses are reduced considerably. As mentioned earlier, the extremely high levels of congestion in the middle and left hand lanes, resulting in high costs, might promote a shift to public transport as the optimal mode of transport.

A large reduction in operating costs and person time costs are predicted for all mode types by both Hypothetical Case 2.B and 2.C. However, Hypothetical Case 2.C is preferred above Hypothetical Case 2.B, as the extra costs incurred by vehicles outside the $1^1/_2$-hour period before entering the section (Hypothetical Case 2.B), were not taken into account while determining the total costs. It is however not possible to predict the full impact of the hypothetical case on traffic behaviour. In practice, drivers might alter their travel routines by either changing their trip schedule, or choosing alternative travel routes at greater cost.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions drawn from the Results

1. Speed, flow, and density data were collected with a video camera from fixed vantage points near each section under study. Speed measurements were made from the footage with the aid of a stopwatch. Although accurate results were obtained, this method is extremely time-consuming and not recommended for longer study periods.

2. Various factors influence the capacity of freeway lanes. Some of these factors include the number of freeway lanes, the traffic composition during study, the speed limit, as well as geometric characteristics like the grade and type of terrain.

3. Each of the three freeway sections on the N1 and N2 performed relatively poorly over the morning peak period. Extremely high levels of congestion, with traffic operating at very low speeds (stop-start conditions), were observed in each case for a large portion of the study period.

4. No fixed measure exists for judging whether data are sufficiently represented by a particular model. Confidence limits of parameters were not comparable, as models consisted of different parameter types. Also, the coefficient of determination (R^2) is a singular value representing the overall adequacy of a model, also interpreted as the proportion of the total variability explained by the model. It does not indicate whether the model overestimates (or underestimates) certain areas of the data. The decision on whether a certain model constituted a good fit, was therefore based on visual inspection. In each

case, the models were compared to each other and the "best" model was chosen as the model giving the best overall fit.

5. There is merit for representing the whole range of speed-density data with two separate curves (uncongested regime and congested regime), as the Composite model yielded the best results in each case (based on optimum R^2 values and visual inspection). The bell-shaped curve consistently gave the best results for the uncongested regime, while a logarithmic curve (Greenberg) proved to be the best curve for the congested regime. The use of non-integer values for exponents *m* and *l* (bell-shaped curve) produced slightly better results than other similar bell-shaped models (11).

6. The models obtained in this report are based on data obtained during short time intervals on single days. It must be noted that the curves may vary considerably from time period to time period owing to changes in factors like traffic composition, weather conditions, day-night conditions, etc. Care must be taken in specifying the exact conditions under which particular data were captured.

7. In most cases, the speed-density data are well represented at conditions of high congestion and low congestion. However, it is not possible to achieve an accurate representation the data near capacity, as the data are scattered (breakdown phenomenon). This discontinuity of the data near capacity warrants the use of separate curves to describe the whole speed-density domain. Also, it is believed that a good representation of the data near capacity is not imperative, as flows near capacity do not occur for long periods of time. In many cases, congested conditions ensue before the uncongested capacity of a particular freeway section is reached.

8. Separate lane curves differ considerably from each other (especially for the uncongested regime) for each freeway section. It is therefore the opinion of the author that the usual practice of averaging over all the lanes (e.g. in the HCM) should be re-examined. However, the adequacy of the HCM curves obviously depends on the required level of accuracy.

9. The uncongested curves obtained from the N1 and the N2 freeways were similar in some respects to models obtained from overseas studies (1, 16). However, higher capacities were consistently predicted by the overseas models. On the other hand, extremely good correlation was achieved between the uncongested curves and other curves obtained from South African studies (17). Similarly, overseas models were more optimistic with regards to flow on freeways during congested conditions (1, 19). All in all, it seems that South African freeway conditions differ significantly from conditions in America (for both congested and uncongested regimes). It is therefore the opinion of the author that models obtained from overseas studies are in most cases not readily applicable to South African freeways.

10. The study section on N2 freeway westbound towards Cape Town consists of three lanes, with the median lane reserved for HOV's (buses and taxis) during peak morning conditions. The current performance (travel-times and travel costs) of the particular section was compared to the performances of a number of hypothetical cases. The results of Hypothetical Case 1 suggest that the particular section currently operates very much like a three lane freeway section without an HOV lane. This points to a total disregard for the HOV lane by vehicles (especially passenger cars) operating on the section during morning peak conditions.

11. When perfect operation of the HOV lane was assumed (Hypothetical Case 2), significant improvements in travel-times and travel costs were experienced for both taxis and buses. It is believed that effective law enforcement is one way of achieving perfect operation of the HOV lane. Another way may be to utilize the HOV lane as an express lane (with no enter/exit capability) in order to avoid traffic on the lane being stopped by vehicles trying to exit into the jammed middle lane.

12. Very high passenger car travel-times and costs were predicted by Hypothetical Case 2.A. This is due to extremely high congestion on the middle and left hand lanes of the N2 freeway section. It is expected that the poor performance of

these two lanes will force passengers to consider public transport (as opposed to passenger cars) as the optimal mode of transport.

13. Hypothetical Case 2.A predicts a very high speed-differential between traffic in the middle lane and the HOV lane (median lane). As taxis and buses are required to weave into and out of the HOV lane in order to enter or leave the freeway, it is believed that the high speeds predicted for the median lane (fast lane) will in fact be much lower in practice.

14. A large reduction in both overall travel-times and overall travel costs can be obtained when the flow-rates on the middle and left hand lanes are regulated (Hypothetical Case 2.B and 2.C). This can be achieved by restricting access to the freeway at the on-ramps with the use of ramp metering.

15. Lower flow-rates are prescribed for the middle and left hand lanes for Hypothetical Case 2.B (50% of capacity as opposed to 85% of capacity for Hypothetical Case 2.C). Hypothetical Case 2.C therefore provides the ultimate solution, as longer queues and delays are expected on the on-ramps for Hypothetical Case 2.B.

6.2 Recommendations for Future Studies

1. There is a need for quick and accurate traffic-flow data acquisition on freeways. It would be advantageous if the data collection process could be automated. The data obtained from normal loop detectors and other sensors currently in use are not detailed enough. It is for this reason that the use of technologies such as image processing as a tool for real-time traffic surveillance is being investigated.

2. Various factors affect traffic behaviour on freeways, thereby directly influencing the relationships between traffic-flow parameters (speed, flow, and density). Some of these factors are the traffic composition, the number of lanes, weather conditions, geometric conditions like the type of terrain, the

speed limit, and the time of day. Sections with varying characteristics need to be studied in order to establish the relative influence of each characteristic on the performance of freeway sections.

3. One way of increasing the capacity of existing freeway facilities with minimum resources is by providing preferential treatment to high occupancy vehicles (HOV's). When perfect operation of the HOV lane on the N2 freeway section (Section 3) was assumed, significant improvements in overall travel-times and travel costs were experienced. However, due to poor law enforcement, the section currently operates very much like a three lane section without an HOV lane. Future studies might focus on finding a way to force passenger cars to stay clear of the HOV lane during conditions of high congestion.

4. A large reduction in both overall travel-times and overall travel costs were observed when access to the freeway was restricted at the on-ramps. However, the values did not include delays and costs incurred by vehicles queuing at the on-ramps. Further research is necessary to determine queue lengths and delays experienced by vehicles at on-ramps for different flow-rates.

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Appendix A

Raw Traffic-Flow Data

Table A-1: Passenger-car equivalents on extended general freeway segments

Factor	Type of terrain		
	Level	Rolling	Mountainous
E_T for trucks	1.7	4.0	8.0
E_B for buses	1.5	3.0	5.0
E_R for RV's	1.6	3.0	4.0

Table A-2: Traffic counts during consecutive 1 min. intervals on N1 freeway near Century City

Good weather conditions
Section length = 77 m
Level terrain:
E_T = 1.7
E_B = 1.5

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
06:00	3	0	1	0	7	0	1	0	5	0	0	0	4.7	8.7	5.0	18
06:01	4	0	0	0	8	0	1	0	3	0	0	0	4.0	9.7	3.0	17
06:02	1	0	2	0	7	0	1	0	10	0	1	0	4.4	8.7	11.7	25
06:03	2	0	1	0	3	0	0	0	2	0	0	0	3.7	3.0	2.0	9
06:04	1	0	0	0	6	0	0	0	3	0	0	0	1.0	6.0	3.0	10
06:05	5	0	0	0	8	0	0	0	10	0	0	0	5.0	8.0	10.0	23
06:06	5	0	0	0	5	0	1	0	6	0	0	0	5.0	6.7	6.0	18
06:07	3	0	0	0	14	0	0	0	13	0	0	0	3.0	14.0	13.0	30
06:08	7	0	0	0	8	0	2	0	13	0	0	0	7.0	11.4	13.0	31
06:09	5	0	0	0	11	0	0	0	9	0	0	0	5.0	11.0	9.0	25
06:10	3	0	0	0	10	0	0	0	3	0	0	0	3.0	10.0	3.0	16
06:11	6	0	1	0	12	0	0	0	9	0	0	0	7.7	12.0	9.0	29
06:12	5	0	1	0	9	0	0	0	11	0	0	0	6.7	9.0	11.0	27
06:13	3	0	2	0	12	0	0	0	16	0	0	0	6.4	12.0	16.0	34
06:14	8	0	0	0	13	0	1	0	12	0	0	0	8.0	14.7	12.0	35
06:15	7	0	1	0	19	0	0	0	16	0	0	0	8.7	19.0	16.0	44
06:16	4	0	0	0	17	0	1		21	0	0	0	4.0	18.7	21.0	44
06:17	5	0	0	0	15	0	0	0	19	0	0	0	5.0	15.0	19.0	39
06:18	4	0	1	0	10	0	1	1	20	0	0	0	5.7	13.2	20.0	39
06:19	6	0	1	0	10	0	1	0	17	0	0	0	7.7	11.7	17.0	36
06:20	8	0	1	0	20	0	0	0	22	0	0	0	9.7	20.0	22.0	52
06:21	8	0	0	0	10	0	1	0	19	0	0	0	8.0	11.7	19.0	39
06:22	7	0	1	0	12	0	1	0	29	0	0	0	8.7	13.7	29.0	51

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU'
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
06:23	7	0	2	0	14	0	2	0	20	0	0	0	10.4	17.4	20.0	48
06:24	10	0	1	1	23	0	0	0	33	0	0	0	13.2	23.0	33.0	69
06:25	11	0	0	0	22	0	0	0	26	0	0	0	11.0	22.0	26.0	59
06:26	5	0	1	0	20	0	2	0	30	0	0	0	6.7	23.4	30.0	60
06:27	13	0	1	0	24	0	1	0	30	0	0	0	14.7	25.7	30.0	70
06:28	5	0	0	0	20	0	0	0	30	0	0	0	5.0	20.0	30.0	55
06:29	18	0	0	0	19	0	1	0	44	0	0	0	18.0	20.7	44.0	83
06:30	17	2	1	0	28	1	0	1	41	0	0	0	20.7	30.5	41.0	92
06:31	21	0	0	0	29	1	0	0	37	0	0	0	21.0	30.0	37.0	88
06:32	22	0	0	0	29	1	0	0	37	0	0	0	22.0	30.0	37.0	89
06:33	18	0	3	0	26	1	0	0	33	0	0	0	23.1	27.0	33.0	83
06:34	26	0	0	0	35	1	0	0	47	0	0	0	26.0	36.0	47.0	109
06:35	19	1	0	0	26	0	3	0	46	0	0	0	20.0	31.1	46.0	97
06:36	17	0	2	0	29	2	1	0	31	0	0	0	20.4	32.7	31.0	84
06:37	29	0	2	1	42	0	1	0	44	0	0	0	33.9	43.7	44.0	122
06:38	23	0	1	0	29	1	0	0	43	0	0	0	24.7	30.0	43.0	98
06:39	27	1	0	2	29	3	1	0	38	1	0	0	31.0	33.7	39.0	104
06:40	36	0	0	0	35	1	1	0	42	1	0	0	36.0	37.7	43.0	117
06:41	31	1	0	0	26	1	1	0	37	1	1	0	32.0	28.7	39.7	100
06:42	28	0	1	0	33	0	0	0	35	0	0	0	29.7	33.0	35.0	98
06:43	29	1	0	0	31	1	0	0	21	2	0	0	30.0	32.0	23.0	85
06:44	22	1	2	0	32	0	1	0	34	0	0	0	26.4	33.7	34.0	94
06:45	27	1	0	1	25	0	2	0	35	1	0	0	29.5	28.4	36.0	94
06:46	25	3	0	0	25	2	1	0	33	1	0	0	28.0	28.7	34.0	91
06:47	25	0	1	0	30	1	0	0	35	0	0	0	26.7	31.0	35.0	93
06:48	25	2	0	0	28	0	0	0	33	0	0	0	27.0	28.0	33.0	88
06:49	25	1	2	0	27	1	1	0	36	0	0	0	29.4	29.7	36.0	95
06:50	23	1	0	0	27	2	0	0	37	0	0	0	24.0	29.0	37.0	90
06:51	26	1	0	1	30	1	0	0	33	1	0	0	28.5	31.0	34.0	94
06:52	29	1	0	0	24	2	0	0	31	0	0	0	30.0	26.0	31.0	87
06:53	28	0	0	0	28	2	0	0	23	3	0	0	28.0	30.0	26.0	84
06:54	14	3	2	0	29	0	0	0	31	0	0	0	20.4	29.0	31.0	80
06:55	26	1	1	0	31	0	0	0	30	1	0	0	28.7	31.0	31.0	91

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU'
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
06:56	26	0	0	1	29	0	0	1	29	0	0	0	27.5	30.5	29.0	87
06:57	24	0	1	0	27	0	1	0	30	0	0	0	25.7	28.7	30.0	84
06:58	30	0	2	0	31	0	0	0	36	0	0	0	33.4	31.0	36.0	100
06:59	26	1	2	1	34	0	1	0	35	0	0	0	31.9	35.7	35.0	103
07:00	28	0	0	0	29	1	0	0	36	0	0	0	28.0	30.0	36.0	94
07:01	31	0	0	1	28	1	0	0	35	0	0	0	32.5	29.0	35.0	97
07:02	29	1	0	0	26	0	2	0	31	1	0	0	30.0	29.4	32.0	91
07:03	28	0	0	0	28	0	0	0	32	0	0	0	28.0	28.0	32.0	88
07:04	26	2	1	1	27	2	2	0	34	0	0	0	31.2	32.4	34.0	98
07:05	25	0	2	1	31	1	0	0	30	1	0	0	29.9	32.0	31.0	93
07:06	27	1	0	0	29	0	0	0	31	0	0	0	28.0	29.0	31.0	88
07:07	23	1	2	0	26	0	0	0	26	0	0	0	27.4	26.0	26.0	79
07:08	20	1	0	0	19	1	0	1	25	0	0	0	21.0	21.5	25.0	68
07:09	21	1	2	0	22	0	2	0	23	2	0	0	25.4	25.4	25.0	76
07:10	25	0	0	0	25	1	0	0	26	1	0	0	25.0	26.0	27.0	78
07:11	17	0	2	2	29	0	0	0	17	2	0	0	23.4	29.0	19.0	71
07:12	29	1	0	0	26	0	0	0	31	1	0	0	30.0	26.0	32.0	88
07:13	25	2	0	0	23	0	0	1	30	0	0	0	27.0	24.5	30.0	82
07:14	26	1	2	0	28	0	0	0	35	0	0	0	30.4	28.0	35.0	93
07:15	28	0	0	0	23	0	2	0	31	0	0	0	28.0	26.4	31.0	85
07:16	29	1	1	0	22	1	1	0	28	1	0	0	31.7	24.7	29.0	85
07:17	26	1	0	0	23	1	1	0	30	0	0	0	27.0	25.7	30.0	83
07:18	26	0	1	0	27	0	0	0	30	1	0	0	27.7	27.0	31.0	86
07:19	24	0	0	2	28	1	0	0	29	0	0	0	27.0	29.0	29.0	85
07:20	23	0	1	0	23	0	0	2	16	1	0	0	24.7	26.0	17.0	68
07:21	25	1	1	0	22	0	0	0	18	0	0	0	27.7	22.0	18.0	68
07:22	20	0	0	0	23	0	0	0	26	0	0	0	20.0	23.0	26.0	69
07:23	25	0	0	0	24	0	0	0	27	0	0	0	25.0	24.0	27.0	76
07:24	19	0	0	0	23	0	0	0	21	0	0	0	19.0	23.0	21.0	63
07:25	21	0	0	0	24	0	1	0	23	1	0	0	21.0	25.7	24.0	71
07:26	24	0	0	1	24	2	0	0	27	0	0	0	25.5	26.0	27.0	79
07:27	23	3	0	0	24	1	0	0	26	0	0	0	26.0	25.0	26.0	77
07:28	24	1	0	0	23	0	1	1	22	0	0	0	25.0	26.2	22.0	73

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU'
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
07:29	25	0	2	0	24	0	0	0	27	0	0	0	28.4	24.0	27.0	79
07:30	29	0	0	0	25	0	0	0	24	3	0	0	29.0	25.0	27.0	81
07:31	26	1	0	0	23	0	0	0	23	0	0	0	27.0	23.0	23.0	73
07:32	10	0	0	0	21	1	0	0	16	0	0	0	10.0	22.0	16.0	48
07:33	16	0	0	1	20	0	0	0	19	0	0	0	17.5	20.0	19.0	57
07:34	20	0	1	0	23	0	0	0	17	0	0	0	21.7	23.0	17.0	62
07:35	24	1	1	0	23	1	0	0	26	0	0	0	26.7	24.0	26.0	77
07:36	20	0	2	0	24	0	0	0	30	0	0	0	23.4	24.0	30.0	77
07:37	20	0	3	0	27	0	0	0	25	0	0	0	25.1	27.0	25.0	77
07:38	18	1	2	0	18	0	1	0	14	0	0	0	22.4	19.7	14.0	56
07:39	22	0	2	0	25	0	0	0	21	2	0	0	25.4	25.0	23.0	73
07:40	22	0	1	0	23	0	0	0	27	0	0	0	23.7	23.0	27.0	74
07:41	23	1	0	1	25	0	0	0	26	0	0	0	25.5	25.0	26.0	77
07:42	18	0	3	2	24	0	1	0	24	2	0	0	26.1	25.7	26.0	78
07:43	23	0	2	0	26	0	0	0	24	2	0	0	26.4	26.0	26.0	78
07:44	21	0	2	0	22	0	1	0	25	1	0	0	24.4	23.7	26.0	74
07:45	25	0	1	0	25	0	0	0	27	0	0	0	26.7	25.0	27.0	79
07:46	16	1	2	0	22	1	1	0	28	0	0	0	20.4	24.7	28.0	73
07:47	22	0	2	0	21	0	1	0	25	0	0	0	25.4	22.7	25.0	73
07:48	16	0	3	0	22	4	0	0	25	1	0	0	21.1	26.0	26.0	73
07:49	22	0	1	1	18	2	2	1	20	0	0	0	25.2	24.9	20.0	70
07:50	22	1	0	1	20	1	2	0	27	0	0	0	24.5	24.4	27.0	76
07:51	28	1	0	0	25	0	1	0	24	0	0	0	29.0	26.7	24.0	80
07:52	22	0	0	0	23	0	0	0	21	0	0	0	22.0	23.0	21.0	66
07:53	27	0	1	0	25	1	1	0	34	0	0	0	28.7	27.7	34.0	90
07:54	24	0	1	0	25	0	0	0	28	2	0	0	25.7	25.0	30.0	81
07:55	23	0	2	0	25	0	0	0	29	1	0	0	26.4	25.0	30.0	81
07:56	23	0	3	0	23	1	1	0	29	2	0	0	28.1	25.7	31.0	85
07:57	29	0	1	0	23	0	1	0	29	0	0	0	30.7	24.7	29.0	84
07:58	24	1	0	1	22	0	1	0	27	1	0	0	26.5	23.7	28.0	78
07:59	14	0	4	0	27	1	0	0	22	1	0	0	20.8	28.0	23.0	72
08:00	19	1	3	0	26	1	0	0	29	0	0	0	25.1	27.0	29.0	81
08:06	7	0	4	0	26	1	2	0	29	1	0	0	13.8	30.4	30.0	74

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU'
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
08:07	20	0	2	0	28	1	0	0	26	0	0	1	23.4	29.0	27.5	80
08:08	19	0	1	0	23	1	0	0	30	0	0	0	20.7	24.0	30.0	75
08:09	15	1	2	0	26	0	1	0	31	2	0	0	19.4	27.7	33.0	80
08:10	16	0	2	0	16	2	2	0	34	0	0	0	19.4	21.4	34.0	75
08:11	16	0	0	0	21	1	0	0	29	0	0	0	16.0	22.0	29.0	67
08:12	19	0	0	0	19	1	0	0	22	0	0	0	19.0	20.0	22.0	61
08:13	15	2	2	0	19	1	1	0	24	2	0	0	20.4	21.7	26.0	68
08:14	11	0	2	0	27	0	0	0	28	0	0	0	14.4	27.0	28.0	69
08:15	11	1	2	0	29	1	1	0	28	0	0	0	15.4	31.7	28.0	75
08:16	16	0	1	0	25	1	0	0	20	2	0	0	17.7	26.0	22.0	66
08:17	17	0	1	0	19	0	1	0	26	1	0	0	18.7	20.7	27.0	66
08:18	9	0	2	0	19	0	0	0	22	1	0	0	12.4	19.0	23.0	54
08:19	16	0	1	0	24	1	0	0	22	0	0	0	17.7	25.0	22.0	65
08:20	17	0	3	0	27	0	2	0	33	0	0	0	22.1	30.4	33.0	86
08:21	12	0	2	0	22	1	0	0	19	0	0	0	15.4	23.0	19.0	57
08:22	9	0	1	0	20	0	0	0	27	0	0	0	10.7	20.0	27.0	58
08:23	14	1	3	0	27	0	0	0	24	0	0	0	20.1	27.0	24.0	71
08:24	21	0	0	0	25	1	1	0	30	1	1	0	21.0	27.7	32.7	81
08:25	10	0	2	0	25	0	3	1	23	0	0	0	13.4	31.6	23.0	68
08:26	11	0	1	0	24	0	0	0	31	0	0	0	12.7	24.0	31.0	68
08:27	14	0	1	0	24	0	0	0	28	1	0	0	15.7	24.0	29.0	69
08:28	12	0	2	0	23	1	2	0	26	1	0	0	15.4	27.4	27.0	70
08:29	14	0	3	0	24	0	0	0	20	1	1	0	19.1	24.0	22.7	66
08:30	17	1	2	0	24	0	3	1	44	0	0	1	21.4	30.6	45.5	98
08:31	13	1	1	0	21	0	0	0	31	0	0	0	15.7	21.0	31.0	68
08:32	12	0	4	0	23	1	0	0	21	1	0	0	18.8	24.0	22.0	65
08:33	20	0	1	0	25	0	1	0	38	0	0	0	21.7	26.7	38.0	86
08:34	13	0	2	0	20	0	0	0	29	0	0	0	16.4	20.0	29.0	65
08:35	14	0	2	0	24	0	0	0	32	0	0	0	17.4	24.0	32.0	73
08:36	13	0	0	0	21	1	0	0	25	1	0	0	13.0	22.0	26.0	61
08:37	11	1	1	0	17	0	3	0	20	0	0	0	13.7	22.1	20.0	56
08:38	14	1	3	0	25	2	1	0	33	2	0	0	20.1	28.7	35.0	84
08:39	22	1	1	0	27	1	0	0	34	0	0	0	24.7	28.0	34.0	87

Time	Left Lane				Middle Lane				Right Lane				PCU's			Total PCU'
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Middle	Right	
08:40	14	0	1	0	36	1	0	0	27	0	0	0	15.7	37.0	27.0	80
08:41	12	2	1	0	18	0	0	0	26	1	0	0	15.7	18.0	27.0	61
08:42	10	1	0	1	20	1	0	0	18	0	0	0	12.5	21.0	18.0	52
08:43	15	0	1	0	21	0	2	0	36	0	0	0	16.7	24.4	36.0	77
08:44	11	1	2	0	22	1	0	0	25	0	0	0	15.4	23.0	25.0	63
08:45	5	0	3	0	17	0	0	0	33	0	0	0	10.1	17.0	33.0	60
08:46	10	0	6	0	34	0	2	0	21	1	0	0	20.2	37.4	22.0	80
08:47	8	1	5	1	30	0	1	0	39	1	0	0	19.0	31.7	40.0	91
08:48	14	1	2	0	29	0	1	1	43	0	0	0	18.4	32.2	43.0	94
08:49	14	0	1	0	20	1	1	0	23	0	0	0	15.7	22.7	23.0	61
08:50	17	1	0	0	21	0	0	2	32	0	0	0	18.0	24.0	32.0	74
08:51	8	0	3	0	32	0	1	0	36	0	0	0	13.1	33.7	36.0	83
08:52	9	0	2	0	27	0	1	0	29	0	0	0	12.4	28.7	29.0	70
08:53	13	1	3	0	18	1	1	0	21	1	0	0	19.1	20.7	22.0	62
08:54	12	0	5	0	19	1	3	0	35	2	0	0	20.5	25.1	37.0	83
08:55	18	0	2	0	26	0	1	0	26	0	0	0	21.4	27.7	26.0	75
08:56	16	0	6	0	30	0	2	0	40	1	0	0	26.2	33.4	41.0	101
08:57	8	0	1	0	23	1	0	0	16	0	0	0	9.7	24.0	16.0	50
08:58	19	0	1	0	26	0	1	0	37	0	0	0	20.7	27.7	37.0	85
08:59	17	1	1	0	22	2	0	0	28	0	0	0	19.7	24.0	28.0	72

Table A-3: Speed/Flow/Density measurements made during consecutive 1 min. intervals on the N1 freeway (Century City)

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)			Average PCU's per distance (77m)			Average Density (veh/km/lane)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes
06:00	4.70	8.70	5.00	282	522	300	4.59	3.17	2.49	61.22	88.47	112.64	0.20	0.20	0.40	2.56	2.56	5.13	3.42
06:01	4.00	9.70	3.00	240	582	180	4.33	3.57	2.62	64.80	78.59	107.18	0.20	0.60	0.40	2.56	7.69	5.13	5.13
06:02	4.40	8.70	11.70	264	522	702	4.01	3.70	2.94	69.97	75.83	95.38	0.64	1.28	0.60	8.21	16.41	7.69	10.77
06:03	3.70	3.00	2.00	222	180	120	4.12	3.48	2.63	68.24	80.69	106.77	0.20	0.40	0.00	2.56	5.13	0.00	2.56
06:04	1.00	6.00	3.00	60	360	180	4.07	3.85	2.80	69.08	73.01	100.47	0.40	0.80	0.20	5.13	10.26	2.56	5.98
06:05	5.00	8.00	10.00	300	480	600	3.53	3.32	2.85	79.55	84.50	98.46	0.60	0.20	0.80	7.69	2.56	10.26	6.84
06:06	5.00	6.70	6.00	300	402	360	3.81	3.22	2.56	73.64	87.20	109.52	0.60	0.40	0.60	7.69	5.13	7.69	6.84
06:07	3.00	14.00	13.00	180	840	780	4.58	3.59	2.86	61.38	78.30	98.11	0.60	1.00	0.60	7.69	12.82	7.69	9.40
06:08	7.00	11.40	13.00	420	684	780	3.80	3.23	2.59	73.99	86.99	108.25	0.20	0.60	0.40	2.56	7.69	5.13	5.13
06:09	5.00	11.00	9.00	300	660	540	3.57	3.54	2.79	78.66	79.32	100.79	0.20	0.60	0.60	2.56	7.69	7.69	5.98
06:10	3.00	10.00	3.00	180	600	180	3.56	3.06	2.28	78.81	91.88	123.16	0.20	0.60	0.20	2.56	7.69	2.56	4.27
06:11	7.70	12.00	9.00	462	720	540	3.78	3.22	2.49	74.23	87.26	112.68	0.94	1.00	0.20	12.05	12.82	2.56	9.15
06:12	6.70	9.00	11.00	402	540	660	3.49	3.37	2.83	80.39	83.37	99.29	0.00	0.40	0.40	0.00	5.13	5.13	3.42
06:13	6.40	12.00	16.00	384	720	960	3.40	3.33	2.62	82.66	84.32	107.26	0.40	0.60	1.80	5.13	7.69	23.08	11.97
06:14	8.00	14.70	12.00	480	882	720	3.87	2.99	2.62	72.65	93.98	107.26	0.80	1.00	0.80	10.26	12.82	10.26	11.11
06:15	8.70	19.00	16.00	522	1140	960	3.95	3.17	2.57	71.18	88.64	109.43	0.60	1.00	0.40	7.69	12.82	5.13	8.55
06:16	4.00	18.70	21.00	240	1122	1260	3.37	3.29	2.84	83.40	85.35	98.94	0.80	1.20	1.20	10.26	15.38	15.38	13.68
06:17	5.00	15.00	19.00	300	900	1140	3.70	3.24	2.59	75.95	86.72	108.33	0.40	0.80	0.80	5.13	10.26	10.26	8.55
06:18	5.70	13.20	20.00	342	792	1200	4.23	3.41	2.71	66.38	82.30	103.77	0.20	1.30	1.20	2.56	16.67	15.38	11.54
06:19	7.70	11.70	17.00	462	702	1020	3.62	3.10	2.80	77.57	90.64	100.14	0.40	1.64	0.80	5.13	21.03	10.26	12.14
06:20	9.70	20.00	22.00	582	1200	1320	4.52	3.53	2.79	62.15	79.55	100.65	1.14	1.80	1.20	14.62	23.08	15.38	17.69
06:21	8.00	11.70	19.00	480	702	1140	3.51	3.64	2.90	80.09	77.25	96.76	0.74	1.00	0.40	9.49	12.82	5.13	9.15
06:22	8.70	13.70	29.00	522	822	1740	3.60	3.29	2.90	78.00	85.40	96.76	0.80	1.14	1.00	10.26	14.62	12.82	12.56
06:23	10.40	17.40	20.00	624	1044	1200	3.72	3.67	2.88	75.57	76.47	97.64	0.60	0.94	1.00	7.69	12.05	12.82	10.85
06:24	13.20	23.00	33.00	792	1380	1980	3.67	3.60	2.98	76.47	78.04	94.16	1.10	1.60	1.20	14.10	20.51	15.38	16.67
06:25	11.00	22.00	26.00	660	1320	1560	3.59	3.79	3.25	78.13	74.09	86.45	1.00	1.40	2.00	12.82	17.95	25.64	18.80
06:26	6.70	23.40	30.00	402	1404	1800	5.15	3.54	3.02	54.52	79.23	92.86	0.74	1.80	1.40	9.49	23.08	17.95	16.84
06:27	14.70	25.70	30.00	882	1542	1800	3.49	3.92	3.37	80.57	71.67	83.22	0.80	1.40	1.60	10.26	17.95	20.51	16.24

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)			Average PCU's per distance (77m)			Average Density (veh/km/lane)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes
06:28	5.00	20.00	30.00	300	1200	1800	3.83	3.66	2.99	73.26	76.64	93.85	0.60	1.20	1.40	7.69	15.38	17.95	13.68
06:29	18.00	20.70	44.00	1080	1242	2640	3.62	3.26	3.11	77.53	86.24	90.35	1.60	1.54	1.60	20.51	19.74	20.51	20.26
06:30	20.70	30.50	41.00	1242	1830	2460	3.25	2.93	2.53	86.35	95.77	110.99	1.54	1.40	2.20	19.74	17.95	28.21	21.97
06:31	21.00	30.00	37.00	1260	1800	2220	3.02	2.76	2.53	93.04	101.59	110.90	1.20	1.40	2.20	15.38	17.95	28.21	20.51
06:32	22.00	30.00	37.00	1320	1800	2220	3.59	3.15	2.93	78.13	89.09	95.97	2.00	1.60	2.60	25.64	20.51	33.33	26.50
06:33	23.10	27.00	33.00	1386	1620	1980	3.58	2.91	2.42	78.39	96.63	115.94	1.54	2.40	2.00	19.74	30.77	25.64	25.38
06:34	26.00	36.00	47.00	1560	2160	2820	3.41	3.10	2.81	82.44	90.58	100.07	2.20	1.80	1.80	28.21	23.08	23.08	24.79
06:35	20.00	31.10	46.00	1200	1866	2760	3.36	3.17	2.83	83.62	88.47	99.08	1.20	1.54	2.20	15.38	19.74	28.21	21.11
06:36	20.40	32.70	31.00	1224	1962	1860	3.67	3.25	2.65	76.43	86.29	106.12	0.80	1.60	2.40	10.26	20.51	30.77	20.51
06:37	33.90	43.70	44.00	2034	2622	2640	3.51	3.59	3.18	80.09	78.17	88.25	1.50	2.14	2.80	19.23	27.44	35.90	27.52
06:38	24.70	30.00	43.00	1482	1800	2580	3.30	3.40	3.19	85.09	82.59	87.97	1.90	1.74	3.00	24.36	22.31	38.46	28.38
06:39	31.00	33.70	39.00	1860	2022	2340	3.83	3.64	3.37	73.32	77.19	83.22	1.80	2.34	2.20	23.08	30.00	28.21	27.09
06:40	36.00	37.70	43.00	2160	2262	2580	3.96	4.21	3.70	70.98	66.73	75.81	2.80	2.74	2.60	35.90	35.13	33.33	34.79
06:41	32.00	28.70	39.70	1920	1722	2382	5.39	5.67	4.66	52.10	49.56	60.23	3.20	2.94	3.54	41.03	37.69	45.38	41.37
06:42	29.70	33.00	35.00	1782	1980	2100	5.06	4.67	4.40	55.47	60.15	63.76	2.60	2.60	2.80	33.33	33.33	35.90	34.19
06:43	30.00	32.00	23.00	1800	1920	1380	4.63	5.11	5.09	60.70	54.99	55.19	2.60	2.80	2.80	33.33	35.90	35.90	35.04
06:44	26.40	33.70	34.00	1584	2022	2040	4.41	4.20	3.81	63.62	66.79	73.74	2.48	2.80	3.00	31.79	35.90	38.46	35.38
06:45	29.50	28.40	36.00	1770	1704	2160	4.30	4.40	3.94	65.36	63.79	71.23	2.00	1.80	2.60	25.64	23.08	33.33	27.35
06:46	28.00	28.70	34.00	1680	1722	2040	4.62	4.43	4.06	60.75	63.41	69.16	2.40	2.60	2.40	30.77	33.33	30.77	31.62
06:47	26.70	31.00	35.00	1602	1860	2100	4.58	4.45	4.50	61.34	63.04	62.34	2.20	2.60	2.00	28.21	33.33	25.64	29.06
06:48	27.00	28.00	33.00	1620	1680	1980	4.47	4.55	4.36	62.79	61.66	64.34	2.60	2.00	2.60	33.33	25.64	33.33	30.77
06:49	29.40	29.70	36.00	1764	1782	2160	4.58	4.50	4.30	61.34	62.37	65.36	2.60	2.14	2.60	33.33	27.44	33.33	31.37
06:50	24.00	29.00	37.00	1440	1740	2220	4.58	4.98	4.55	61.31	56.43	61.71	2.20	2.40	2.40	28.21	30.77	30.77	29.91
06:51	28.50	31.00	34.00	1710	1860	2040	4.77	4.46	3.93	58.87	62.96	71.52	2.40	2.60	2.40	30.77	33.33	30.77	31.62
06:52	30.00	26.00	31.00	1800	1560	1860	4.45	4.12	4.16	63.07	68.22	67.44	2.40	2.00	2.80	30.77	25.64	35.90	30.77
06:53	28.00	30.00	26.00	1680	1800	1560	4.60	4.23	4.00	61.02	66.41	70.13	2.60	2.20	2.40	33.33	28.21	30.77	30.77
06:54	20.40	29.00	31.00	1224	1740	1860	4.64	4.50	4.75	60.54	62.46	59.09	2.00	3.20	2.80	25.64	41.03	35.90	34.19
06:55	28.70	31.00	31.00	1722	1860	1860	5.11	4.72	4.87	54.95	59.52	57.68	2.54	2.40	2.40	32.56	30.77	30.77	31.37
06:56	27.50	30.50	29.00	1650	1830	1740	4.71	4.87	4.72	59.57	57.61	59.52	2.60	2.60	2.00	33.33	33.33	25.64	30.77
06:57	25.70	28.70	30.00	1542	1722	1800	5.44	5.59	6.17	51.66	50.23	45.48	2.60	2.60	2.80	33.33	33.33	35.90	34.19
06:58	33.40	31.00	36.00	2004	1860	2160	5.20	5.07	5.44	54.04	55.41	51.64	3.14	3.00	3.20	40.26	38.46	41.03	39.91

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)			Average PCU's per distance (77m)			Average Density (veh/km/lane)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes
06:59	31.90	35.70	35.00	1914	2142	2100	5.33	5.31	5.10	52.72	52.84	55.02	2.60	3.00	3.20	33.33	38.46	41.03	37.61
07:00	28.00	30.00	36.00	1680	1800	2160	4.61	4.38	4.21	60.96	64.05	66.67	2.40	2.00	2.00	30.77	25.64	25.64	27.35
07:01	32.50	29.00	35.00	1950	1740	2100	4.95	4.31	4.24	56.75	65.12	66.23	2.80	2.60	3.20	35.90	33.33	41.03	36.75
07:02	30.00	29.40	32.00	1800	1764	1920	4.97	4.28	4.04	56.52	65.58	69.57	2.80	2.80	2.20	35.90	35.90	28.21	33.33
07:03	28.00	28.00	32.00	1680	1680	1920	5.42	4.97	4.63	51.81	56.45	60.65	2.60	3.20	2.20	33.33	41.03	28.21	34.19
07:04	31.20	32.40	34.00	1872	1944	2040	4.94	4.86	4.68	56.82	57.83	59.97	2.70	3.00	3.00	34.62	38.46	38.46	37.18
07:05	29.90	32.00	31.00	1794	1920	1860	4.89	5.40	4.67	57.45	51.98	60.15	2.14	3.00	2.40	27.44	38.46	30.77	32.22
07:06	28.00	29.00	31.00	1680	1740	1860	6.13	6.20	5.16	45.84	45.32	54.44	2.80	3.20	2.60	35.90	41.03	33.33	36.75
07:07	27.40	26.00	26.00	1644	1560	1560	17.17	10.21	11.54	16.35	27.51	24.34	6.20	5.00	5.80	79.49	64.10	74.36	72.65
07:08	21.00	21.50	25.00	1260	1290	1500	13.50	12.26	10.51	20.81	22.90	26.72	6.00	5.10	5.40	76.92	65.38	69.23	70.51
07:09	25.40	25.40	25.00	1524	1524	1500	10.08	8.41	10.67	27.86	33.41	26.32	4.94	3.74	5.80	63.33	47.95	74.36	61.88
07:10	25.00	26.00	27.00	1500	1560	1620	7.81	9.08	8.70	35.97	30.91	32.28	3.80	4.60	4.40	48.72	58.97	56.41	54.70
07:11	23.40	29.00	19.00	1404	1740	1140	7.08	7.01	6.31	39.68	40.07	44.47	3.04	3.80	3.40	38.97	48.72	43.59	43.76
07:12	30.00	26.00	32.00	1800	1560	1920	6.56	6.88	6.32	42.83	40.81	44.40	3.90	3.00	4.00	50.00	38.46	51.28	46.58
07:13	27.00	24.50	30.00	1620	1470	1800	7.04	6.70	6.49	39.90	41.90	43.25	3.00	3.30	3.80	38.46	42.31	48.72	43.16
07:14	30.40	28.00	35.00	1824	1680	2100	6.39	6.59	6.22	43.92	42.61	45.16	3.34	3.80	3.60	42.82	48.72	46.15	45.90
07:15	28.00	26.40	31.00	1680	1584	1860	6.76	8.16	8.56	41.51	34.43	32.82	3.94	4.28	4.80	50.51	54.87	61.54	55.64
07:16	31.70	24.70	29.00	1902	1482	1740	7.21	6.83	8.08	38.92	41.14	34.77	3.80	3.94	4.20	48.72	50.51	53.85	51.03
07:17	27.00	25.70	30.00	1620	1542	1800	7.04	6.85	7.95	39.88	41.00	35.31	3.80	3.14	4.60	48.72	40.26	58.97	49.32
07:18	27.70	27.00	31.00	1662	1620	1860	8.11	7.52	10.76	34.64	37.32	26.10	4.14	4.00	5.60	53.08	51.28	71.79	58.72
07:19	27.00	29.00	29.00	1620	1740	1740	8.48	8.82	9.31	33.11	31.84	30.18	4.10	4.60	5.20	52.56	58.97	66.67	59.40
07:20	24.70	26.00	17.00	1482	1560	1020	10.81	12.10	27.05	25.98	23.22	10.38	5.04	5.60	7.60	64.62	71.79	97.44	77.95
07:21	27.70	22.00	18.00	1662	1320	1080	14.63	16.29	21.33	19.19	17.24	13.17	5.74	6.50	6.60	73.59	83.33	84.62	80.51
07:22	20.00	23.00	26.00	1200	1380	1560	9.89	10.11	8.69	28.39	27.77	32.33	4.20	5.20	3.80	53.85	66.67	48.72	56.41
07:23	25.00	24.00	27.00	1500	1440	1620	8.62	7.54	6.66	32.56	37.25	42.19	3.80	3.94	3.40	48.72	50.51	43.59	47.61
07:24	19.00	23.00	21.00	1140	1380	1260	20.53	10.72	15.77	13.68	26.19	17.81	6.00	4.54	6.40	76.92	58.21	82.05	72.39
07:25	21.00	25.70	24.00	1260	1542	1440	13.11	10.13	12.68	21.43	27.71	22.15	5.20	4.80	5.20	66.67	61.54	66.67	64.96
07:26	25.50	26.00	27.00	1530	1560	1620	8.91	10.46	9.20	31.50	26.86	30.51	4.00	4.80	4.60	51.28	61.54	58.97	57.26
07:27	26.00	25.00	26.00	1560	1500	1560	8.44	8.06	8.42	33.29	34.82	33.33	3.40	4.60	3.80	43.59	58.97	48.72	50.43
07:28	25.00	26.20	22.00	1500	1572	1320	8.46	8.63	13.71	33.18	32.54	20.48	4.00	4.50	5.20	51.28	57.69	66.67	58.55
07:29	28.40	24.00	27.00	1704	1440	1620	7.45	6.60	7.35	37.67	42.53	38.19	4.54	3.80	3.60	58.21	48.72	46.15	51.03

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)			Average PCU's per distance (77m)			Average Density (veh/km/lane)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes
07:30	27.00	23.00	23.00	1620	1380	1380	16.79	10.53	20.44	16.72	26.67	13.74	7.00	4.00	6.60	89.74	51.28	84.62	75.21
07:31	10.00	22.00	16.00	600	1320	960	41.35	15.43	18.55	6.79	18.20	15.14	8.40	6.00	6.80	107.69	76.92	87.18	90.60
07:32	17.50	20.00	19.00	1050	1200	1140	14.10	12.01	16.48	19.91	23.37	17.04	5.80	6.00	5.00	74.36	76.92	64.10	71.79
07:33	21.70	23.00	17.00	1302	1380	1020	13.96	14.31	16.09	20.11	19.62	17.45	5.60	5.60	5.80	71.79	71.79	74.36	72.65
07:34	26.70	24.00	26.00	1602	1440	1560	9.57	7.81	7.60	29.34	35.94	36.93	4.14	3.80	3.60	53.08	48.72	46.15	49.32
07:35	23.40	24.00	30.00	1404	1440	1800	7.84	7.24	6.62	35.80	38.80	42.39	3.74	3.00	3.40	47.95	38.46	43.59	43.33
07:36	25.10	27.00	25.00	1506	1620	1500	11.22	9.81	13.47	25.03	28.62	20.85	4.96	4.60	3.80	63.59	58.97	48.72	57.09
07:37	22.40	19.70	14.00	1344	1182	840	19.44	18.87	24.93	14.44	14.88	11.27	6.48	5.80	6.60	83.08	74.36	84.62	80.68
07:38	25.40	25.00	23.00	1524	1500	1380	13.86	10.86	9.55	20.26	25.86	29.42	6.54	4.80	3.80	83.85	61.54	48.72	64.70
07:39	23.70	23.00	27.00	1422	1380	1620	12.54	10.66	9.64	22.39	26.35	29.13	5.40	5.40	4.20	69.23	69.23	53.85	64.10
07:40	25.50	25.00	26.00	1530	1500	1560	9.45	7.80	8.15	29.71	36.02	34.46	4.30	3.60	3.80	55.13	46.15	48.72	50.00
07:41	26.10	25.70	26.00	1566	1542	1560	9.51	8.44	8.99	29.53	33.26	31.22	4.74	4.00	4.40	60.77	51.28	56.41	56.15
07:42	26.40	26.00	26.00	1584	1560	1560	9.20	9.68	8.98	30.53	29.02	31.26	4.74	4.60	4.40	60.77	58.97	56.41	58.72
07:43	24.40	23.70	26.00	1464	1422	1560	10.91	11.12	9.52	25.73	25.24	29.50	4.88	4.60	4.40	62.56	58.97	56.41	59.32
07:44	26.70	25.00	27.00	1602	1500	1620	10.61	9.77	8.52	26.47	28.73	32.98	5.40	4.00	4.00	69.23	51.28	51.28	57.26
07:45	20.40	24.70	28.00	1224	1482	1680	10.23	12.00	10.60	27.45	23.41	26.50	4.08	4.74	4.60	52.31	60.77	58.97	57.35
07:46	25.40	22.70	25.00	1524	1362	1500	9.85	10.31	8.41	28.51	27.25	33.39	5.08	4.14	4.20	65.13	53.08	53.85	57.35
07:47	21.10	26.00	26.00	1266	1560	1560	9.33	9.18	7.93	30.11	30.60	35.41	4.42	4.00	4.00	56.67	51.28	51.28	53.08
07:48	25.20	24.90	20.00	1512	1494	1200	13.08	9.07	13.76	21.47	30.97	20.40	6.28	4.10	6.80	80.51	52.56	87.18	73.42
07:49	24.50	24.40	27.00	1470	1464	1620	13.32	8.90	8.22	21.08	31.56	34.18	6.00	3.70	4.40	76.92	47.44	56.41	60.26
07:50	29.00	26.70	24.00	1740	1602	1440	8.39	8.46	7.42	33.46	33.18	37.87	5.00	3.80	3.40	64.10	48.72	43.59	52.14
07:51	22.00	23.00	21.00	1320	1380	1260	12.08	8.56	8.11	23.25	32.80	34.63	5.80	4.00	3.20	74.36	51.28	41.03	55.56
07:52	28.70	27.70	34.00	1722	1662	2040	7.77	6.93	6.06	36.16	40.54	46.37	4.34	3.54	3.20	55.64	45.38	41.03	47.35
07:53	25.70	25.00	30.00	1542	1500	1800	8.06	7.27	5.85	34.83	38.62	48.03	3.74	3.94	3.20	47.95	50.51	41.03	46.50
07:54	26.40	25.00	30.00	1584	1500	1800	7.02	6.83	6.03	40.01	41.09	46.54	3.74	3.20	3.60	47.95	41.03	46.15	45.04
07:55	28.10	25.70	31.00	1686	1542	1860	7.00	6.39	6.38	40.11	43.96	44.00	3.40	3.00	3.60	43.59	38.46	46.15	42.74
07:56	30.70	24.70	29.00	1842	1482	1740	7.63	6.68	6.43	36.80	42.02	43.70	4.40	2.80	3.70	56.41	35.90	47.44	46.58
07:57	26.50	23.70	28.00	1590	1422	1680	8.84	8.02	7.36	31.77	35.01	38.18	4.40	3.34	3.80	56.41	42.82	48.72	49.32
07:58	20.80	28.00	23.00	1248	1680	1380	9.06	9.36	6.22	30.99	29.99	45.17	4.02	4.40	2.60	51.54	56.41	33.33	47.09
07:59	25.10	27.00	29.00	1506	1620	1740	9.11	8.23	6.61	30.84	34.11	42.49	3.88	4.00	3.60	49.74	51.28	46.15	49.06
08:00	13.80	30.40	30.00	828	1824	1800	4.05	3.26	2.73	69.33	86.24	102.93	1.28	1.94	1.40	16.41	24.87	17.95	19.74

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)			Average PCU's per distance (77m)			Average Density (veh/km/lane)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes
08:06	23.40	29.00	27.50	1404	1740	1650	3.43	3.39	3.44	81.96	82.93	81.68	1.74	2.00	1.30	22.31	25.64	16.67	21.54
08:07	20.70	24.00	30.00	1242	1440	1800	3.14	3.13	2.51	89.37	89.66	111.78	2.34	1.40	2.00	30.00	17.95	25.64	24.53
08:08	19.40	27.70	33.00	1164	1662	1980	3.22	3.34	2.68	87.20	84.12	104.78	1.48	1.40	1.60	18.97	17.95	20.51	19.15
08:09	19.40	21.40	34.00	1164	1284	2040	3.27	3.13	3.01	85.77	89.60	93.23	1.48	1.00	2.40	18.97	12.82	30.77	20.85
08:10	16.00	22.00	29.00	960	1320	1740	3.02	2.80	2.51	93.13	100.14	111.69	1.94	1.00	2.20	24.87	12.82	28.21	21.97
08:11	19.00	20.00	22.00	1140	1200	1320	2.67	2.48	2.57	105.09	113.41	109.09	1.40	1.40	1.20	17.95	17.95	15.38	17.09
08:12	20.40	21.70	26.00	1224	1302	1560	2.77	2.76	2.43	101.37	101.74	115.37	0.94	1.00	1.20	12.05	12.82	15.38	13.42
08:13	14.40	27.00	28.00	864	1620	1680	2.77	2.54	2.57	101.56	110.38	109.26	1.08	1.20	1.60	13.85	15.38	20.51	16.58
08:14	15.40	31.70	28.00	924	1902	1680	3.57	3.14	2.65	78.77	89.48	105.88	0.94	1.40	1.40	12.05	17.95	17.95	15.98
08:15	17.70	26.00	22.00	1062	1560	1320	3.20	2.82	2.31	87.80	99.72	121.66	1.00	1.40	0.80	12.82	17.95	10.26	13.68
08:16	18.70	20.70	27.00	1122	1242	1620	2.74	2.43	2.33	102.33	115.65	120.31	1.74	2.00	1.20	22.31	25.64	15.38	21.11
08:17	12.40	19.00	23.00	744	1140	1380	3.01	2.71	2.26	93.29	103.77	124.25	1.88	1.60	0.80	24.10	20.51	10.26	18.29
08:18	17.70	25.00	22.00	1062	1500	1320	2.74	2.69	2.38	102.33	104.54	117.98	1.34	1.00	0.80	17.18	12.82	10.26	13.42
08:19	22.10	30.40	33.00	1326	1824	1980	3.40	3.03	2.44	82.54	92.67	114.89	1.48	1.20	1.40	18.97	15.38	17.95	17.44
08:20	15.40	23.00	19.00	924	1380	1140	3.28	3.03	2.46	85.51	92.55	114.05	0.60	1.00	0.60	7.69	12.82	7.69	9.40
08:21	10.70	20.00	27.00	642	1200	1620	3.09	2.66	2.27	90.82	105.41	123.48	0.20	1.20	1.20	2.56	15.38	15.38	11.11
08:22	20.10	27.00	24.00	1206	1620	1440	3.05	2.62	2.46	91.94	107.18	114.05	1.00	1.00	1.40	12.82	12.82	17.95	14.53
08:23	21.00	27.70	32.70	1260	1662	1962	2.93	3.01	2.59	95.97	93.29	108.25	1.80	1.70	2.20	23.08	21.79	28.21	24.36
08:24	13.40	31.60	23.00	804	1896	1380	3.01	2.69	2.42	93.17	104.23	116.13	1.20	1.70	1.00	15.38	21.79	12.82	16.67
08:25	12.70	24.00	31.00	762	1440	1860	2.81	2.83	2.22	99.86	99.36	126.26	0.60	1.60	1.00	7.69	20.51	12.82	13.68
08:26	15.70	24.00	29.00	942	1440	1740	2.92	2.71	2.41	96.10	103.77	116.61	0.60	1.40	1.00	7.69	17.95	12.82	12.82
08:27	15.40	27.40	27.00	924	1644	1620	3.26	2.82	2.24	86.13	99.50	125.58	0.80	1.10	1.00	10.26	14.10	12.82	12.39
08:28	19.10	24.00	22.70	1146	1440	1362	2.90	2.75	2.20	96.89	102.03	127.52	1.08	1.54	1.00	13.85	19.74	12.82	15.47
08:29	21.40	30.60	45.50	1284	1836	2730	3.08	2.76	2.53	91.23	101.74	111.08	1.74	2.28	2.20	22.31	29.23	28.21	26.58
08:30	15.70	21.00	31.00	942	1260	1860	3.13	2.59	2.35	89.77	108.58	119.49	1.14	1.20	1.80	14.62	15.38	23.08	17.69
08:31	18.80	24.00	22.00	1128	1440	1320	3.04	2.62	2.23	92.25	107.01	125.69	1.28	1.00	0.80	16.41	12.82	10.26	13.16
08:32	21.70	26.70	38.00	1302	1602	2280	3.08	3.15	2.51	91.17	89.20	112.05	1.20	0.80	2.40	15.38	10.26	30.77	18.80
08:33	16.40	20.00	29.00	984	1200	1740	3.19	2.65	2.24	88.08	105.80	125.47	0.80	1.00	1.20	10.26	12.82	15.38	12.82
08:34	17.40	24.00	32.00	1044	1440	1920	3.01	2.84	2.34	93.17	98.80	120.21	1.54	1.40	1.60	19.74	17.95	20.51	19.40
08:35	13.00	22.00	26.00	780	1320	1560	3.42	2.97	2.18	82.20	94.55	129.04	1.14	1.40	0.60	14.62	17.95	7.69	13.42
08:36	13.70	22.10	20.00	822	1326	1200	2.83	2.72	2.28	99.36	103.24	123.16	1.00	1.74	1.40	12.82	22.31	17.95	17.69
08:37	20.10	28.70	35.00	1206	1722	2100	3.44	2.91	2.35	81.68	96.63	119.49	1.20	2.08	2.00	15.38	26.67	25.64	22.56
08:38	24.70	28.00	34.00	1482	1680	2040	3.22	2.89	2.51	87.26	97.23	111.87	0.94	2.54	2.20	12.05	32.56	28.21	24.27

Table A-4: Traffic counts during consecutive 1 min. intervals on N1 freeway near R300

Good weather conditions
Section length = 75 m
Rolling terrain: E_T = 4.0
E_B = 3.0

Time	Left Lane				Right Lane				PCU's		Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Right	
06:00	12	0	0	0	5	0	0	0	12.0	5.0	17
06:01	5	0	1	0	5	0	0	0	9.0	5.0	14
06:02	7	0	1	0	8	0	0	0	11.0	8.0	19
06:03	6	0	1	0	6	0	0	0	10.0	6.0	16
00:00	5	0	1	0	4	0	0	0	9.0	4.0	13
06:05	3	0	2	0	7	0	0	0	11.0	7.0	18
06:06	11	0	0	0	10	0	0	0	11.0	10.0	21
06:07	8	0	2	0	8	0	0	0	16.0	8.0	24
06:08	10	0	0	0	12	0	0	0	10.0	12.0	22
06:09	5	1	3	0	16	1	0	0	18.0	17.0	35
06:10	7	0	0	1	9	0	0	0	10.0	9.0	19
06:11	7	0	3	1	11	0	0	0	22.0	11.0	33
06:12	9	0	2	0	17	0	0	0	17.0	17.0	34
06:13	9	0	1	0	22	0	0	0	13.0	22.0	35
06:14	9	0	0	0	9	0	0	0	9.0	9.0	18
06:15	13	0	0	0	19	0	1	0	13.0	23.0	36
06:16	11	0	1	0	11	0	0	0	15.0	11.0	26
06:17	11	0	1	0	17	0	0	0	15.0	17.0	32
06:18	11	0	0	0	17	0	0	0	11.0	17.0	28
06:19	12	0	0	0	17	0	0	0	12.0	17.0	29
06:20	12	0	1	0	21	0	0	0	16.0	21.0	37
06:21	8	0	4	0	25	0	1	0	24.0	29.0	53
06:22	15	0	1	0	18	0	0	0	19.0	18.0	37
06:23	12	0	0	0	25	0	0	0	12.0	25.0	37
06:24	9	0	4	0	30	0	0	0	25.0	30.0	55

Time	Left Lane				Right Lane				PCU's		Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Right	
06:25	17	0	0	0	25	0	0	0	17.0	25.0	42
06:26	11	0	1	0	30	1	0	0	15.0	31.0	46
06:27	16	0	2	0	32	0	0	0	24.0	32.0	56
06:28	13	1	2	0	25	0	0	0	22.0	25.0	47
06:29	8	0	2	0	25	0	0	1	16.0	28.0	44
06:30	12	0	2	1	29	2	0	0	23.0	31.0	54
06:31	14	0	0	0	26	1	0	0	14.0	27.0	41
06:32	14	0	3	0	39	0	0	0	26.0	39.0	65
06:33	13	0	4	0	33	1	0	0	29.0	34.0	63
06:34	14	0	1	0	19	0	0	0	18.0	19.0	37
06:35	10	1	3	0	33	0	0	0	23.0	33.0	56
06:36	16	1	1	0	35	0	0	0	21.0	35.0	56
06:37	21	0	0	0	27	0	1	0	21.0	31.0	52
06:38	19	0	0	0	36	0	0	0	19.0	36.0	55
06:39	15	1	0	0	34	1	0	0	16.0	35.0	51
06:40	20	0	0	0	32	0	0	0	20.0	32.0	52
06:41	11	2	3	0	37	0	0	0	25.0	37.0	62
06:42	15	0	1	1	29	0	0	0	22.0	29.0	51
06:43	14	1	0	0	32	0	0	0	15.0	32.0	47
06:44	22	0	5	0	38	0	1	0	42.0	42.0	84
06:45	18	1	4	0	29	0	1	0	35.0	33.0	68
06:46	19	0	0	1	30	1	1	0	22.0	35.0	57
06:47	13	0	2	0	35	0	0	0	21.0	35.0	56
06:48	16	0	3	0	31	0	0	0	28.0	31.0	59
06:49	16	0	0	0	30	0	0	0	16.0	30.0	46
06:50	19	1	2	0	39	0	0	0	28.0	39.0	67
06:51	28	0	0	0	19	0	0	0	28.0	19.0	47
06:52	13	0	2	1	20	0	0	0	24.0	20.0	44
06:53	17	0	2	0	20	0	0	0	25.0	20.0	45
06:54	18	0	2	0	22	0	0	0	26.0	22.0	48
06:55	16	0	0	2	24	0	0	0	22.0	24.0	46
06:56	15	0	2	0	24	0	1	0	23.0	28.0	51
06:57	28	0	1	0	29	0	1	0	32.0	33.0	65

Time	Left Lane				Right Lane				PCU's		Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Right	
06:58	23	0	1	0	25	0	0	0	27.0	25.0	52
06:59	16	0	1	0	21	0	0	0	20.0	21.0	41
07:00	15	0	2	0	27	0	1	0	23.0	31.0	54
07:01	17	0	2	0	25	0	0	0	25.0	25.0	50
07:02	18	1	2	0	20	0	1	0	27.0	24.0	51
07:03	14	0	1	0	17	0	0	0	18.0	17.0	35
07:04	7	0	2	0	15	0	0	0	15.0	15.0	30
07:05	13	0	1	0	13	0	0	0	17.0	13.0	30
07:06	10	0	0	0	13	0	0	0	10.0	13.0	23
07:07	17	0	2	0	25	0	0	0	25.0	25.0	50
07:08	21	0	1	0	23	0	0	0	25.0	23.0	48
07:09	14	0	1	0	19	0	0	0	18.0	19.0	37
07:10	16	0	1	1	23	0	0	0	23.0	23.0	46
07:11	14	0	2	0	19	0	0	0	22.0	19.0	41
07:12	9	0	0	1	20	0	0	0	12.0	20.0	32
07:13	16	0	2	0	14	0	0	0	24.0	14.0	38
07:14	19	0	1	0	17	0	0	0	23.0	17.0	40
07:15	18	0	0	0	21	0	0	0	18.0	21.0	39
07:16	18	1	1	0	19	0	0	0	23.0	19.0	42
07:17	21	0	0	0	15	0	0	0	21.0	15.0	36
07:18	16	0	2	0	20	0	0	0	24.0	20.0	44
07:19	15	0	2	0	17	0	0	0	23.0	17.0	40
07:20	10	0	3	1	19	0	0	0	25.0	19.0	44
07:21	16	0	2	0	15	0	0	0	24.0	15.0	39
07:22	15	0	0	0	16	0	0	0	15.0	16.0	31
07:23	17	0	3	0	21	0	0	0	29.0	21.0	50
07:24	14	0	1	0	21	0	0	0	18.0	21.0	39
07:25	12	0	2	0	14	0	0	0	20.0	14.0	34
07:26	17	1	1	0	15	0	0	1	22.0	18.0	40
07:27	19	0	0	0	19	0	0	0	19.0	19.0	38
07:28	15	1	3	0	21	0	0	0	28.0	21.0	49
07:29	16	2	1	0	16	0	0	0	22.0	16.0	38
07:30	14	0	1	0	18	0	0	0	18.0	18.0	36
07:31	17	0	2	0	20	0	0	0	25.0	20.0	45
07:32	17	1	2	0	24	0	0	1	26.0	27.0	53
07:33	21	1	2	0	25	0	0	0	30.0	25.0	55
07:34	20	0	1	0	18	0	0	0	24.0	18.0	42

Time	Left Lane				Right Lane				PCU's		Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Right	
07:35	17	1	2	2	29	0	0	0	32.0	29.0	61
07:36	17	0	0	3	23	0	0	0	26.0	23.0	49
07:37	16	0	0	1	15	0	0	0	19.0	15.0	34
07:38	19	1	0	0	19	0	0	0	20.0	19.0	39
07:39	15	0	1	1	20	0	0	0	22.0	20.0	42
07:40	20	1	0	0	29	0	0	0	21.0	29.0	50
07:41	16	0	2	0	15	0	0	0	24.0	15.0	39
07:42	13	0	1	1	27	0	0	0	20.0	27.0	47
07:43	22	0	2	0	18	0	0	0	30.0	18.0	48
07:44	12	0	2	0	17	0	0	0	20.0	17.0	37
07:45	21	0	0	0	18	0	0	0	21.0	18.0	39
07:46	15	0	0	0	16	0	0	0	15.0	16.0	31
07:47	16	0	1	0	18	0	0	0	20.0	18.0	38
07:48	8	0	5	0	23	0	0	0	28.0	23.0	51
07:49	14	0	1	0	17	0	0	0	18.0	17.0	35
07:50	13	0	0	0	11	0	0	0	13.0	11.0	24
07:51	13	0	3	0	11	0	0	0	25.0	11.0	36
07:52	13	0	0	0	16	0	0	0	13.0	16.0	29
07:53	9	0	1	0	11	0	0	0	13.0	11.0	24
07:54	14	0	4	0	24	0	0	0	30.0	24.0	54
07:55	8	0	4	0	16	0	0	0	24.0	16.0	40
07:56	9	0	1	0	16	0	0	0	13.0	16.0	29
07:57	8	0	0	0	15	0	0	0	8.0	15.0	23
07:58	7	0	2	0	13	0	0	0	15.0	13.0	28
07:59	11	0	3	0	17	0	0	0	23.0	17.0	40
08:00	7	0	2	0	21	0	0	0	15.0	21.0	36
08:01	15	0	0	0	14	0	0	0	15.0	14.0	29
08:02	13	0	3	0	13	0	0	0	25.0	13.0	38
08:03	15	0	1	0	20	0	0	0	19.0	20.0	39
08:04	12	1	0	0	11	0	0	0	13.0	11.0	24
08:05	12	0	3	0	23	0	0	0	24.0	23.0	47
08:06	10	0	1	0	20	0	0	0	14.0	20.0	34
08:07	11	0	4	0	23	0	0	0	27.0	23.0	50
08:08	9	0	1	0	12	0	0	0	13.0	12.0	25
08:09	12	0	3	0	16	0	0	0	24.0	16.0	40
08:10	9	0	2	0	21	0	1	0	17.0	25.0	42
08:11	14	0	0	0	19	0	0	0	14.0	19.0	33

Time	Left Lane				Right Lane				PCU's		Total PCU's
	Passenger	Taxi's	Trucks	Busses	Passenger	Taxi's	Trucks	Busses	Left	Right	
08:12	9	1	2	0	11	0	0	0	18.0	11.0	29
08:13	18	0	1	0	24	0	0	0	22.0	24.0	46
08:14	8	0	1	0	12	0	0	0	12.0	12.0	24
08:15	12	0	3	0	21	0	0	0	24.0	21.0	45
08:16	9	0	1	0	10	0	0	0	13.0	10.0	23
08:17	11	0	2	0	14	0	0	0	19.0	14.0	33
08:18	14	0	1	0	15	0	0	0	18.0	15.0	33
08:19	5	0	2	0	24	0	0	0	13.0	24.0	37
08:20	12	0	4	0	27	0	0	0	28.0	27.0	55
08:21	10	0	5	0	27	0	0	0	30.0	27.0	57
08:22	12	1	2	0	28	0	0	0	21.0	28.0	49
08:23	15	0	0	0	13	0	0	0	15.0	13.0	28
08:24	12	0	1	0	13	0	0	0	16.0	13.0	29
08:25	9	0	4	0	28	0	0	0	25.0	28.0	53
08:26	9	1	2	1	22	0	0	0	21.0	22.0	43
08:27	10	1	4	0	22	0	0	0	27.0	22.0	49
08:28	14	0	2	0	11	0	0	0	22.0	11.0	33
08:29	11	0	2	0	21	0	0	0	19.0	21.0	40
08:30	17	0	2	0	15	0	0	0	25.0	15.0	40
08:31	8	1	0	0	15	0	0	0	9.0	15.0	24
08:32	12	0	1	0	12	0	1	0	16.0	16.0	32
08:33	6	0	2	0	20	0	0	0	14.0	20.0	34
08:34	6	0	5	1	22	0	1	0	29.0	26.0	55
08:35	16	0	1	0	25	0	0	0	20.0	25.0	45
08:36	9	0	5	0	24	0	0	0	29.0	24.0	53
08:37	16	0	2	0	19	0	0	0	24.0	19.0	43
08:38	12	0	3	0	20	0	0	0	24.0	20.0	44
08:39	12	0	2	1	11	0	0	0	23.0	11.0	34

Table A-5: Speed/Flow/Density measurements made during consecutive 1 min. intervals on section 2 (N1 near R300)

Time	PCU's		Average Flow (veh/h)		Average Travel Time (s)		Average Macroscopic Speed (km/h)			Average PCU's per distance		Average Density (veh/km)		
	Left	Right	Left	Right	Left	Right	Left	Right	All lanes	Left	Right	Left	Right	All lanes
06:00	12	5	720.0	300.0	2.934	2.727	92.02	99.01	95.52	0.6	0.4	8.00	5.33	6.67
06:01	9	5	540.0	300.0	3.256	2.81	82.92	96.09	89.50	1	0.2	13.33	2.67	8.00
06:02	11	8	660.0	480.0	3.124	2.9	86.43	93.10	89.77	0.8	0.4	10.67	5.33	8.00
06:03	10	6	600.0	360.0	3.15	2.71	85.71	99.63	92.67	0.4	0.2	5.33	2.67	4.00
00:00	9	4	540.0	240.0	3.09	2.657	87.38	101.62	94.50	0.4	0	5.33	0.00	2.67
06:05	11	7	660.0	420.0	3.573	2.788	75.57	96.84	86.21	0.4	0.4	5.33	5.33	5.33
06:06	11	10	660.0	600.0	2.894	2.63	93.30	102.66	97.98	0.6	0.6	8.00	8.00	8.00
06:07	16	8	960.0	480.0	3.444	2.86	78.40	94.41	86.40	1.4	0.8	18.67	10.67	14.67
06:08	10	12	600.0	720.0	3.074	2.564	87.83	105.30	96.57	0.2	0.8	2.67	10.67	6.67
06:09	18	17	1080.0	1020.0	3.234	2.866	83.49	94.21	88.85	1.8	1.4	24.00	18.67	21.33
06:10	10	9	600.0	540.0	3.214	2.648	84.01	101.96	92.99	0.8	0.6	10.67	8.00	9.33
06:11	22	11	1320.0	660.0	3.732	2.852	72.35	94.67	83.51	1.2	1	16.00	13.33	14.67
06:12	17	17	1020.0	1020.0	3.296	2.962	81.92	91.15	86.54	1.4	0.8	18.67	10.67	14.67
06:13	13	22	780.0	1320.0	3.356	2.846	80.45	94.87	87.66	0.4	1.4	5.33	18.67	12.00
06:14	9	9	540.0	540.0	3.358	2.856	80.41	94.54	87.47	0.8	0.8	10.67	10.67	10.67
06:15	13	23	780.0	1380.0	3.164	2.98	85.34	90.60	87.97	0.8	1	10.67	13.33	12.00
06:16	15	11	900.0	660.0	3.015	2.836	89.55	95.20	92.38	1.2	0.8	16.00	10.67	13.33
06:17	15	17	900.0	1020.0	3.622	3.125	74.54	86.40	80.47	1.2	0.8	16.00	10.67	13.33
06:18	11	17	660.0	1020.0	2.882	2.948	93.68	91.59	92.64	0.8	0.8	10.67	10.67	10.67
06:19	12	17	720.0	1020.0	3.4	2.852	79.41	94.67	87.04	1	1.4	13.33	18.67	16.00
06:20	16	21	960.0	1260.0	3.656	2.974	73.85	90.79	82.32	0.6	1	8.00	13.33	10.67
06:21	24	29	1440.0	1740.0	3.858	3.294	69.98	81.97	75.98	1.8	2	24.00	26.67	25.33
06:22	19	18	1140.0	1080.0	3.278	3.1	82.37	87.10	84.73	1.4	0.8	18.67	10.67	14.67
06:23	12	25	720.0	1500.0	3.274	3.066	82.47	88.06	85.27	0.8	0.8	10.67	10.67	10.67
06:24	25	30	1500.0	1800.0	4.322	3.252	62.47	83.03	72.75	2.4	1.4	32.00	18.67	25.33
06:25	17	25	1020.0	1500.0	3.454	3.244	78.17	83.23	80.70	1	1	13.33	13.33	13.33
06:26	15	31	900.0	1860.0	3.354	2.868	80.50	94.14	87.32	1	2	13.33	26.67	20.00
06:27	24	32	1440.0	1920.0	3.644	3.178	74.09	84.96	79.53	1.2	2	16.00	26.67	21.33
06:28	22	25	1320.0	1500.0	3.634	3.242	74.30	83.28	78.79	1.4	2.4	18.67	32.00	25.33

Time	PCU's		Average Flow (veh/h)		Average Travel Time (s)		Average Macroscopic Speed (km/h)			Average PCU's per distance		Average Density (veh/km)		
	Left	Right	Left	Right	Left	Right	Left	Right	All lanes	Left	Right	Left	Right	All lanes
06:29	16	28	960.0	1680.0	3.972	3.376	67.98	79.98	73.98	2.4	1.4	32.00	18.67	25.33
06:30	23	31	1380.0	1860.0	4.486	3.562	60.19	75.80	67.99	1.8	2.2	24.00	29.33	26.67
06:31	14	27	840.0	1620.0	3.314	3.256	81.47	82.92	82.20	1.2	1.8	16.00	24.00	20.00
06:32	26	39	1560.0	2340.0	4.464	4.31	60.48	62.65	61.56	2	3.6	26.67	48.00	37.33
06:33	29	34	1740.0	2040.0	3.762	3.744	71.77	72.12	71.94	2.2	2.8	29.33	37.33	33.33
06:34	18	19	1080.0	1140.0	3.438	2.93	78.53	92.15	85.34	1	1.6	13.33	21.33	17.33
06:35	23	33	1380.0	1980.0	3.874	3.582	69.70	75.38	72.54	2.4	2	32.00	26.67	29.33
06:36	21	35	1260.0	2100.0	3.638	3.604	74.22	74.92	74.57	1.4	1.8	18.67	24.00	21.33
06:37	21	31	1260.0	1860.0	3.552	3.262	76.01	82.77	79.39	1.4	2.2	18.67	29.33	24.00
06:38	19	36	1140.0	2160.0	3.912	3.494	69.02	77.28	73.15	1.8	2	24.00	26.67	25.33
06:39	16	35	960.0	2100.0	3.232	3.752	83.54	71.96	77.75	1	2.4	13.33	32.00	22.67
06:40	20	32	1200.0	1920.0	3.314	3.35	81.47	80.60	81.03	1.2	1.6	16.00	21.33	18.67
06:41	25	37	1500.0	2220.0	3.774	3.644	71.54	74.09	72.82	2.8	2.2	37.33	29.33	33.33
06:42	22	29	1320.0	1740.0	3.916	3.824	68.95	70.61	69.78	1	2	13.33	26.67	20.00
06:43	15	32	900.0	1920.0	3.845	3.654	70.22	73.89	72.06	1.8	1.8	24.00	24.00	24.00
06:44	42	42	2520.0	2520.0	8.015	6.125	33.69	44.08	38.88	6.6	3.8	88.00	50.67	69.33
06:45	35	33	2100.0	1980.0	8.408	6.964	32.11	38.77	35.44	5.4	4.2	72.00	56.00	64.00
06:46	22	35	1320.0	2100.0	5.71	6.75	47.29	40.00	43.64	2.8	4.6	37.33	61.33	49.33
06:47	21	35	1260.0	2100.0	3.81	3.702	70.87	72.93	71.90	1.2	3	16.00	40.00	28.00
06:48	28	31	1680.0	1860.0	4.25	3.794	63.53	71.16	67.35	2.4	2.8	32.00	37.33	34.67
06:49	16	30	960.0	1800.0	3.436	4.324	78.58	62.44	70.51	1.8	2.8	24.00	37.33	30.67
06:50	28	39	1680.0	2340.0	4.95	5.374	54.55	50.24	52.39	3.2	3.6	42.67	48.00	45.33
06:51	28	19	1680.0	1140.0	12.21	20.715	22.11	13.03	17.57	6	6	80.00	80.00	80.00
06:52	24	20	1440.0	1200.0	11.813	19.69	22.86	13.71	18.28	5	8.6	66.67	114.67	90.67
06:53	25	20	1500.0	1200.0	11.937	20.11	22.62	13.43	18.02	5.6	7.2	74.67	96.00	85.33
06:54	26	22	1560.0	1320.0	12.083	11.055	22.35	24.42	23.38	6	4.4	80.00	58.67	69.33
06:55	22	24	1320.0	1440.0	10.138	11.803	26.63	22.88	24.75	4.6	5.4	61.33	72.00	66.67
06:56	23	28	1380.0	1680.0	11.04	14.283	24.46	18.90	21.68	4.8	5.8	64.00	77.33	70.67
06:57	32	33	1920.0	1980.0	7.835	9.477	34.46	28.49	31.48	4.6	5	61.33	66.67	64.00
06:58	27	25	1620.0	1500.0	8.814	14.343	30.63	18.82	24.73	4.8	6.2	64.00	82.67	73.33
06:59	20	21	1200.0	1260.0	12.1	12.843	22.31	21.02	21.67	4.8	6	64.00	80.00	72.00
07:00	23	31	1380.0	1860.0	14.237	15.17	18.96	17.80	18.38	6.2	7	82.67	93.33	88.00
07:01	25	25	1500.0	1500.0	12.307	15.707	21.94	17.19	19.56	5.2	6.6	69.33	88.00	78.67

Time	PCU's		Average Flow (veh/h)		Average Travel Time (s)		Average Macroscopic Speed (km/h)			Average PCU's per distance		Average Density (veh/km)		
	Left	Right	Left	Right	Left	Right	Left	Right	All lanes	Left	Right	Left	Right	All lanes
07:02	27	24	1620.0	1440.0	12.447	16.637	21.69	16.23	18.96	6.4	6.8	85.33	90.67	88.00
07:03	18	17	1080.0	1020.0	32.875	36.095	8.21	7.48	7.85	9.2	8.6	122.67	114.67	118.67
07:04	15	15	900.0	900.0	36.265	41.72	7.45	6.47	6.96	9	8	120.00	106.67	113.33
07:05	17	13	1020.0	780.0	35.16	39.78	7.68	6.79	7.23	10.4	9.6	138.67	128.00	133.33
07:06	10	13	600.0	780.0	32.515	30.655	8.30	8.81	8.56	8.4	8	112.00	106.67	109.33
07:07	25	25	1500.0	1500.0	17	17.403	15.88	15.51	15.70	7	7	93.33	93.33	93.33
07:08	25	23	1500.0	1380.0	14.953	15.863	18.06	17.02	17.54	6	7.2	80.00	96.00	88.00
07:09	18	19	1080.0	1140.0	18.265	36.56	14.78	7.39	11.08	6	8.6	80.00	114.67	97.33
07:10	23	23	1380.0	1380.0	16	21.655	16.88	12.47	14.67	6.6	8	88.00	106.67	97.33
07:11	22	19	1320.0	1140.0	18	25.13	15.00	10.74	12.87	6.6	7.6	88.00	101.33	94.67
07:12	12	20	720.0	1200.0	28.45	25.515	9.49	10.58	10.04	5.4	8.2	72.00	109.33	90.67
07:13	24	14	1440.0	840.0	14.155	31.015	19.07	8.71	13.89	4.6	9	61.33	120.00	90.67
07:14	23	17	1380.0	1020.0	20.475	29.48	13.19	9.16	11.17	7.8	9	104.00	120.00	112.00
07:15	18	21	1080.0	1260.0	23.705	19.643	11.39	13.75	12.57	7.4	8.4	98.67	112.00	105.33
07:16	23	19	1380.0	1140.0	15.737	34.405	17.16	7.85	12.50	6.4	8.8	85.33	117.33	101.33
07:17	21	15	1260.0	900.0	15.27	31.175	17.68	8.66	13.17	6.2	8.8	82.67	117.33	100.00
07:18	24	20	1440.0	1200.0	16.485	28.505	16.38	9.47	12.93	7.6	8.4	101.33	112.00	106.67
07:19	23	17	1380.0	1020.0	21.685	22.545	12.45	11.98	12.21	8.6	7.6	114.67	101.33	108.00
07:20	25	19	1500.0	1140.0	18.515	31.03	14.58	8.70	11.64	7.4	8.6	98.67	114.67	106.67
07:21	24	15	1440.0	900.0	17.45	32.92	15.47	8.20	11.84	7.6	10	101.33	133.33	117.33
07:22	15	16	900.0	960.0	18.92	32.905	14.27	8.21	11.24	5.8	9	77.33	120.00	98.67
07:23	29	21	1740.0	1260.0	17.56	20.3	15.38	13.30	14.34	7	7.8	93.33	104.00	98.67
07:24	18	21	1080.0	1260.0	21.39	21.625	12.62	12.49	12.55	8.2	8	109.33	106.67	108.00
07:25	20	14	1200.0	840.0	28.845	36.2	9.36	7.46	8.41	8.2	9	109.33	120.00	114.67
07:26	22	18	1320.0	1080.0	15.753	29.28	17.14	9.22	13.18	5.4	8.4	72.00	112.00	92.00
07:27	19	19	1140.0	1140.0	19.905	25.97	13.56	10.40	11.98	7	8.8	93.33	117.33	105.33
07:28	28	21	1680.0	1260.0	18.405	22.61	14.67	11.94	13.31	7.4	7	98.67	93.33	96.00
07:29	22	16	1320.0	960.0	26.115	26.295	10.34	10.27	10.30	7.4	8.2	98.67	109.33	104.00
07:30	18	18	1080.0	1080.0	27.535	22.465	9.81	12.02	10.91	7.2	7.8	96.00	104.00	100.00
07:31	25	20	1500.0	1200.0	18.95	18.36	14.25	14.71	14.48	8.8	7.2	117.33	96.00	106.67
07:32	26	27	1560.0	1620.0	14.75	13.27	18.31	20.35	19.33	6.6	6.8	88.00	90.67	89.33
07:33	30	25	1800.0	1500.0	12.463	18.977	21.66	14.23	17.95	7	8.2	93.33	109.33	101.33
07:34	24	18	1440.0	1080.0	16.02	16.55	16.85	16.31	16.58	5.8	7.2	77.33	96.00	86.67

Time	PCU's		Average Flow (veh/h)		Average Travel Time (s)		Average Macroscopic Speed (km/h)			Average PCU's per distance		Average Density (veh/km)		
	Left	Right	Left	Right	Left	Right	Left	Right	All lanes	Left	Right	Left	Right	All lanes
07:35	32	29	1920.0	1740.0	13.123	9.945	20.57	27.15	23.86	6.6	5	88.00	66.67	77.33
07:36	26	23	1560.0	1380.0	15.105	16.217	17.87	16.65	17.26	7.4	7.2	98.67	96.00	97.33
07:37	19	15	1140.0	900.0	15.533	26.84	17.38	10.06	13.72	6	8.6	80.00	114.67	97.33
07:38	20	19	1200.0	1140.0	6.898	13.053	39.14	20.68	29.91	3	5.8	40.00	77.33	58.67
07:39	22	20	1320.0	1200.0	5.788	5.03	46.65	53.68	50.16	2.6	2.6	34.67	34.67	34.67
07:40	21	29	1260.0	1740.0	4.726	5.068	57.13	53.28	55.20	1.8	2.8	24.00	37.33	30.67
07:41	24	15	1440.0	900.0	4.922	7.078	54.86	38.15	46.50	1.6	2.8	21.33	37.33	29.33
07:42	20	27	1200.0	1620.0	7.473	12.44	36.13	21.70	28.92	3.6	6.6	48.00	88.00	68.00
07:43	30	18	1800.0	1080.0	7.303	13	36.97	20.77	28.87	3	5	40.00	66.67	53.33
07:44	20	17	1200.0	1020.0	7.905	9.103	34.16	29.66	31.91	4	3.4	53.33	45.33	49.33
07:45	21	18	1260.0	1080.0	13.783	18.807	19.59	14.36	16.97	5	5.8	66.67	77.33	72.00
07:46	15	16	900.0	960.0	29.06	22.465	9.29	12.02	10.65	6.8	6	90.67	80.00	85.33
07:47	20	18	1200.0	1080.0	24.935	15.45	10.83	17.48	14.15	6.6	5.2	88.00	69.33	78.67
07:48	28	23	1680.0	1380.0	14.313	11.457	18.86	23.57	21.22	5.4	4.8	72.00	64.00	68.00
07:49	18	17	1080.0	1020.0	5.345	5.326	50.51	50.69	50.60	2	2.2	26.67	29.33	28.00
07:50	13	11	780.0	660.0	3.54	3.415	76.27	79.06	77.67	0.6	0.6	8.00	8.00	8.00
07:51	25	11	1500.0	660.0	3.958	3.31	68.22	81.57	74.89	1	0.4	13.33	5.33	9.33
07:52	13	16	780.0	960.0	3.568	3.406	75.67	79.27	77.47	0.6	0.6	8.00	8.00	8.00
07:53	13	11	780.0	660.0	4.008	3.2	67.37	84.38	75.87	0.4	0.4	5.33	5.33	5.33
07:54	30	24	1800.0	1440.0	4.288	3.252	62.97	83.03	73.00	1.4	1.8	18.67	24.00	21.33
07:55	24	16	1440.0	960.0	3.594	3.188	75.13	84.69	79.91	2	1.4	26.67	18.67	22.67
07:56	13	16	780.0	960.0	3.76	3.368	71.81	80.17	75.99	1	1.2	13.33	16.00	14.67
07:57	8	15	480.0	900.0	3.3	3.03	81.82	89.11	85.46	0.2	1.2	2.67	16.00	9.33
07:58	15	13	900.0	780.0	4.193	2.982	64.39	90.54	77.47	1.8	1.2	24.00	16.00	20.00
07:59	23	17	1380.0	1020.0	3.716	3.182	72.66	84.85	78.76	1.8	1.4	24.00	18.67	21.33
08:00	15	21	900.0	1260.0	4.563	2.844	59.17	94.94	77.05	1.2	1	16.00	13.33	14.67
08:01	15	14	900.0	840.0	3.44	3.024	78.49	89.29	83.89	2.2	1	29.33	13.33	21.33
08:02	25	13	1500.0	780.0	4.045	3.462	66.75	77.99	72.37	3	1	40.00	13.33	26.67
08:03	19	20	1140.0	1200.0	3.576	3.202	75.50	84.32	79.91	1.6	1.2	21.33	16.00	18.67
08:04	13	11	780.0	660.0	3.654	3.078	73.89	87.72	80.81	0.6	0.2	8.00	2.67	5.33
08:05	24	23	1440.0	1380.0	4.232	3.07	63.80	87.95	75.87	1.8	1	24.00	13.33	18.67
08:06	14	20	840.0	1200.0	3.353	3.332	80.52	81.03	80.78	1.2	0.6	16.00	8.00	12.00
08:07	27	23	1620.0	1380.0	4.006	3.094	67.40	87.27	77.33	2.8	1.6	37.33	21.33	29.33

Time	PCU's		Average Flow (veh/h)		Average Travel Time (s)		Average Macroscopic Speed (km/h)			Average PCU's per distance		Average Density (veh/km)		
	Left	Right	Left	Right	Left	Right	Left	Right	All lanes	Left	Right	Left	Right	All lanes
08:08	13	12	780.0	720.0	3.582	2.696	75.38	100.15	87.76	0.8	1	10.67	13.33	12.00
08:09	24	16	1440.0	960.0	3.87	3.146	69.77	85.82	77.80	2.6	1.4	34.67	18.67	26.67
08:10	17	25	1020.0	1500.0	5.173	3.288	52.19	82.12	67.16	1.6	1	21.33	13.33	17.33
08:11	14	19	840.0	1140.0	3.288	2.868	82.12	94.14	88.13	0.8	1.4	10.67	18.67	14.67
08:12	18	11	1080.0	660.0	3.702	3.008	72.93	89.76	81.35	0.8	0.4	10.67	5.33	8.00
08:13	22	24	1320.0	1440.0	3.968	3.602	68.04	74.96	71.50	0.6	1.2	8.00	16.00	12.00
08:14	12	12	720.0	720.0	3.578	3.004	75.46	89.88	82.67	0.4	0.8	5.33	10.67	8.00
08:15	24	21	1440.0	1260.0	4.138	3.158	65.25	85.50	75.37	2.2	1.4	29.33	18.67	24.00
08:16	13	10	780.0	600.0	3.387	2.684	79.72	100.60	90.16	1	0.8	13.33	10.67	12.00
08:17	19	14	1140.0	840.0	3.253	2.82	83.00	95.74	89.37	1	0.8	13.33	10.67	12.00
08:18	18	15	1080.0	900.0	3.656	2.85	73.85	94.74	84.29	1.4	0.6	18.67	8.00	13.33
08:19	13	24	780.0	1440.0	4.378	3.304	61.67	81.72	71.70	1.4	1.4	18.67	18.67	18.67
08:20	28	27	1680.0	1620.0	4.074	3.462	66.27	77.99	72.13	1.8	1.6	24.00	21.33	22.67
08:21	30	27	1800.0	1620.0	4.882	3.244	55.31	83.23	69.27	1.2	1.6	16.00	21.33	18.67
08:22	21	28	1260.0	1680.0	5.142	4.208	52.51	64.16	58.34	1.6	2.4	21.33	32.00	26.67
08:23	15	13	900.0	780.0	3.396	3.048	79.51	88.58	84.04	0.4	0.8	5.33	10.67	8.00
08:24	16	13	960.0	780.0	3.488	2.896	77.41	93.23	85.32	0.8	1.2	10.67	16.00	13.33
08:25	25	28	1500.0	1680.0	5.278	3.234	51.16	83.49	67.32	1	1	13.33	13.33	13.33
08:26	21	22	1260.0	1320.0	3.762	2.974	71.77	90.79	81.28	1.6	2	21.33	26.67	24.00
08:27	27	22	1620.0	1320.0	3.856	3	70.02	90.00	80.01	2	1.4	26.67	18.67	22.67
08:28	22	11	1320.0	660.0	3.422	2.728	78.90	98.97	88.94	1.4	0.6	18.67	8.00	13.33
08:29	19	21	1140.0	1260.0	3.816	3.036	70.75	88.93	79.84	1.4	0.8	18.67	10.67	14.67
08:30	25	15	1500.0	900.0	3.562	2.692	75.80	100.30	88.05	2.2	1.4	29.33	18.67	24.00
08:31	9	15	540.0	900.0	3.48	2.962	77.59	91.15	84.37	0.8	0.6	10.67	8.00	9.33
08:32	16	16	960.0	960.0	4.315	2.973	62.57	90.82	76.69	1.2	1.2	16.00	16.00	16.00
08:33	14	20	840.0	1200.0	4.032	2.924	66.96	92.34	79.65	1	1.2	13.33	16.00	14.67
08:34	29	26	1740.0	1560.0	4.37	3.346	61.78	80.69	71.24	1.4	1.2	18.67	16.00	17.33
08:35	20	25	1200.0	1500.0	3.826	3.266	70.57	82.67	76.62	1.2	1.4	16.00	18.67	17.33
08:36	29	24	1740.0	1440.0	4.714	3.074	57.28	87.83	72.55	2.6	2	34.67	26.67	30.67
08:37	24	19	1440.0	1140.0	4.108	2.924	65.73	92.34	79.03	2.6	1.2	34.67	16.00	25.33
08:38	24	20	1440.0	1200.0	3.792	3.112	71.20	86.76	78.98	1.4	0.8	18.67	10.67	14.67
08:39	23	11	1380.0	660.0	3.52	2.97	76.70	90.91	83.81	2.2	1.2	29.33	16.00	22.67

Table A-6: Traffic counts during consecutive 1 min. intervals on N2 freeway near Athlone Power Station

Good weather conditions
Section length = 135 m
Level terrain: E_T = 1.7
E_B = 1.5

Time	Left Lane				Middle Lane				HOV Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Left	Middle	Right	
06:30	10	0	2	0	16	2	0	0	10	3	0	1	13.4	18.0	14.5	46
06:31	10	1	0	0	15	0	1	0	7	4	0	0	11.0	16.7	11.0	39
06:32	9	3	0	1	18	1	1	0	17	2	0	0	13.5	20.7	19.0	53
06:33	9	2	1	1	22	1	0	0	12	3	0	0	14.2	23.0	15.0	52
06:34	9	1	1	1	37	2	0	0	15	2	0	1	13.2	39.0	18.5	71
06:35	8	1	2	0	24	3	0	0	18	5	0	1	12.4	27.0	24.5	64
06:36	8	1	1	0	24	0	0	0	18	5	0	0	10.7	24.0	23.0	58
06:37	16	0	0	0	20	2	0	0	16	2	0	2	16.0	22.0	21.0	59
06:38	15	0	2	0	34	0	1	0	16	5	0	1	18.4	35.7	22.5	77
06:39	15	0	1	0	27	1	1	0	14	2	0	3	16.7	29.7	20.5	67
06:40	10	1	0	0	26	1	1	0	14	4	0	0	11.0	28.7	18.0	58
06:41	15	0	1	0	31	1	0	1	14	7	0	1	16.7	33.5	22.5	73
06:42	18	2	1	0	43	3	0	0	20	4	0	3	21.7	46.0	28.5	96
06:43	15	0	1	0	29	3	0	0	18	5	0	3	16.7	32.0	27.5	76
06:44	19	1	2	0	37	2	3	0	35	2	0	1	23.4	44.1	38.5	106
06:45	11	0	0	0	23	2	0	1	27	6	0	3	11.0	26.5	37.5	75
06:46	19	0	2	0	34	3	0	0	21	9	0	2	22.4	37.0	33.0	92
06:47	11	2	1	0	28	3	1	0	20	2	0	4	14.7	32.7	28.0	75
06:48	23	1	0	0	34	2	1	0	32	4	0	2	24.0	37.7	39.0	101
06:49	20	0	2	0	33	3	2	0	33	10	0	2	23.4	39.4	46.0	109
06:50	21	1	3	0	37	2	0	0	31	4	1	1	27.1	39.0	38.2	104
06:51	21	2	2	0	40	0	0	0	21	7	0	5	26.4	40.0	35.5	102
06:52	14	3	1	0	34	1	0	0	21	13	0	3	18.7	35.0	38.5	92
06:53	15	0	2	0	36	2	0	0	31	4	0	2	18.4	38.0	38.0	94

Time	Left Lane				Middle Lane				HOV Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Left	Middle	Right	
06:54	16	0	0	0	28	2	2	0	17	11	0	2	16.0	33.4	31.0	80
06:55	17	6	0	0	37	1	0	0	25	8	1	1	23.0	38.0	36.2	97
06:56	24	0	1	0	43	1	0	0	30	8	0	1	25.7	44.0	39.5	109
06:57	20	1	1	0	42	1	0	0	23	5	2	3	22.7	43.0	35.9	102
06:58	15	0	2	0	38	1	1	0	25	9	0	2	18.4	40.7	37.0	96
06:59	18	1	2	0	31	0	1	0	24	12	0	2	22.4	32.7	39.0	94
07:00	17	0	3	0	35	3	1	0	27	9	1	2	22.1	39.7	40.7	103
07:01	25	1	0	0	33	1	0	0	28	3	0	1	26.0	34.0	32.5	93
07:02	19	1	1	0	35	2	0	0	31	3	0	2	21.7	37.0	37.0	96
07:03	23	0	0	0	31	4	0	0	25	12	0	3	23.0	35.0	41.5	100
07:04	19	1	2	0	38	1	0	0	27	5	0	0	23.4	39.0	32.0	94
07:05	23	0	1	0	36	2	1	0	20	11	0	1	24.7	39.7	32.5	97
07:06	25	0	2	1	34	0	1	0	26	10	0	5	29.9	35.7	43.5	109
07:07	13	1	1	0	29	0	2	0	28	11	0	0	15.7	32.4	39.0	87
07:08	17	3	1	0	31	3	0	0	22	10	0	3	21.7	34.0	36.5	92
07:09	26	2	1	0	35	0	0	0	28	9	0	0	29.7	35.0	37.0	102
07:10	17	1	3	0	38	0	0	0	24	6	0	3	23.1	38.0	34.5	96
07:11	20	2	1	0	30	2	0	0	27	5	0	0	23.7	32.0	32.0	88
07:12	13	2	2	0	28	2	0	0	26	8	0	1	18.4	30.0	35.5	84
07:13	18	2	1	0	30	4	0	0	23	9	0	2	21.7	34.0	35.0	91
07:14	18	0	2	0	31	2	0	0	17	12	0	0	21.4	33.0	29.0	83
07:15	20	2	0	0	27	0	0	0	24	8	0	2	22.0	27.0	35.0	84
07:16	22	2	1	0	32	0	1	0	27	9	0	1	25.7	33.7	37.5	97
07:17	21	0	0	0	31	1	0	0	17	13	0	1	21.0	32.0	31.5	85
07:18	17	3	0	0	26	1	0	0	19	6	1	1	20.0	27.0	28.2	75
07:19	13	1	2	0	26	2	0	0	18	8	1	1	17.4	28.0	29.2	75
07:20	13	1	2	0	27	3	0	0	16	8	0	4	17.4	30.0	30.0	77
07:21	19	0	0	0	25	2	0	0	16	10	0	1	19.0	27.0	27.5	74
07:22	14	1	3	0	17	1	0	0	11	3	0	1	20.1	18.0	15.5	54
07:23	11	0	0	0	8	2	1	0	4	6	0	2	11.0	11.7	13.0	36
07:24	11	1	0	0	10	2	0	0	12	7	0	0	12.0	12.0	19.0	43
07:25	12	1	1	0	12	1	0	0	13	6	0	0	14.7	13.0	19.0	47
07:26	9	1	1	0	10	1	1	0	11	6	0	0	11.7	12.7	17.0	41

Time	Left Lane				Middle Lane				HOV Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Left	Middle	Right	
07:27	14	1	0	0	11	1	0	0	2	5	2	2	15.0	12.0	13.4	40
07:28	4	2	1	0	9	1	0	0	10	3	2	0	7.7	10.0	16.4	34
07:29	9	1	0	0	11	1	0	0	11	6	0	1	10.0	12.0	18.5	41
07:30	7	1	3	0	12	1	0	0	15	5	0	0	13.1	13.0	20.0	46
07:31	19	0	0	0	20	0	0	0	18	3	0	2	19.0	20.0	24.0	63
07:32	12	1	0	0	11	2	0	0	13	8	0	1	13.0	13.0	22.5	49
07:33	11	0	1	0	7	2	0	0	10	4	0	1	12.7	9.0	15.5	37
07:34	6	1	1	0	8	2	0	0	6	8	0	0	8.7	10.0	14.0	33
07:35	15	1	0	0	12	1	0	0	12	5	0	0	16.0	13.0	17.0	46
07:36	22	1	0	0	18	0	1	0	19	3	0	1	23.0	19.7	23.5	66
07:37	10	1	1	0	13	2	0	0	6	8	0	1	12.7	15.0	15.5	43
07:38	9	7	0	0	8	2	0	0	8	5	0	0	16.0	10.0	13.0	39
07:39	7	1	2	0	6	1	1	0	3	5	0	2	11.4	8.7	11.0	31
07:40	9	1	0	0	11	1	1	0	6	4	0	1	10.0	13.7	11.5	35
07:41	14	1	1	0	17	1	1	0	12	8	0	1	16.7	19.7	21.5	58
07:42	18	1	1	0	14	2	1	0	9	7	0	2	20.7	17.7	19.0	57
07:43	16	0	1	0	12	3	0	0	16	4	0	0	17.7	15.0	20.0	53
07:44	12	0	1	0	14	1	1	0	10	8	0	2	13.7	16.7	21.0	51
07:45	7	2	2	0	10	1	0	0	16	4	0	0	12.4	11.0	20.0	43
07:46	10	1	1	0	10	1	1	0	9	4	0	1	12.7	12.7	14.5	40
07:47	9	1	1	0	4	2	2	0	3	6	1	0	11.7	9.4	10.7	32
07:48	9	2	0	0	11	2	0	0	2	5	0	2	11.0	13.0	10.0	34
07:49	7	2	1	0	8	2	0	0	5	5	0	2	10.7	10.0	13.0	34
07:50	4	1	1	0	3	1	2	0	6	5	0	0	6.7	7.4	11.0	25
07:51	8	0	1	0	8	1	1	0	8	2	0	2	9.7	10.7	13.0	33
07:52	7	1	2	1	13	1	0	0	11	1	0	2	12.9	14.0	15.0	42
07:53	11	0	1	0	13	0	0	0	15	2	0	0	12.7	13.0	17.0	43
07:54	13	2	0	0	9	1	3	0	13	7	0	0	15.0	15.1	20.0	50
07:55	7	1	1	0	13	2	0	0	10	4	0	1	9.7	15.0	15.5	40
07:56	5	0	1	0	12	1	0	0	7	5	0	0	6.7	13.0	12.0	32
07:57	4	1	1	0	9	2	0	0	9	3	0	0	6.7	11.0	12.0	30
07:58	8	0	2	0	11	3	0	0	9	7	0	0	11.4	14.0	16.0	41
07:59	1	1	1	0	8	1	0	0	9	3	0	0	3.7	9.0	12.0	25

Time	Left Lane				Middle Lane				HOV Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Left	Middle	Right	
08:00	3	0	2	0	14	1	1	0	14	2	0	0	6.4	16.7	16.0	39
08:01	5	1	3	0	17	1	1	0	16	2	0	0	11.1	19.7	18.0	49
08:02	2	0	3	0	8	3	1	0	5	4	0	0	7.1	12.7	9.0	29
08:03	4	0	1	0	17	1	0	0	8	6	0	1	5.7	18.0	15.5	39
08:04	7	0	0	0	10	1	1	0	12	0	0	0	7.0	12.7	12.0	32
08:05	6	0	1	0	14	1	0	0	6	3	0	0	7.7	15.0	9.0	32
08:06	3	0	4	0	9	0	4	0	13	8	0	0	9.8	15.8	21.0	47
08:07	9	0	1	0	16	1	0	0	8	4	0	0	10.7	17.0	12.0	40
08:08	6	0	1	0	16	1	0	0	16	4	0	0	7.7	17.0	20.0	45
08:09	6	1	0	0	17	0	0	0	5	1	0	0	7.0	17.0	6.0	30
08:10	7	1	0	0	14	1	1	0	3	8	0	1	8.0	16.7	12.5	37
08:11	7	0	1	0	18	0	0	0	8	4	0	0	8.7	18.0	12.0	39
08:12	10	0	0	0	24	0	0	0	18	3	0	0	10.0	24.0	21.0	55
08:13	6	0	2	0	16	2	0	0	10	3	0	0	9.4	18.0	13.0	40
08:14	3	1	0	0	13	1	0	0	11	0	0	0	4.0	14.0	11.0	29
08:15	6	0	2	0	21	1	0	0	11	7	0	0	9.4	22.0	18.0	49
08:16	5	0	2	0	11	1	0	0	11	3	0	0	8.4	12.0	14.0	34
08:17	8	0	1	0	10	0	2	0	5	1	0	0	9.7	13.4	6.0	29
08:18	7	1	0	0	10	1	2	0	7	4	0	0	8.0	14.4	11.0	33
08:19	6	0	2	0	18	0	0	0	5	2	0	0	9.4	18.0	7.0	34
08:20	5	1	0	0	16	2	2	0	12	6	0	0	6.0	21.4	18.0	45
08:21	8	0	1	0	18	1	0	0	7	2	0	0	9.7	19.0	9.0	38
08:22	4	1	1	0	15	0	1	0	15	2	0	1	6.7	16.7	18.5	42
08:23	5	0	2	0	17	1	0	0	12	1	0	0	8.4	18.0	13.0	39
08:24	4	2	2	0	20	0	0	0	15	5	0	0	9.4	20.0	20.0	49
08:25	6	1	0	0	18	2	0	0	5	7	0	1	7.0	20.0	13.5	41
08:26	9	0	1	0	12	1	1	0	10	5	0	0	10.7	14.7	15.0	40
08:27	8	1	0	0	17	3	0	0	8	3	0	0	9.0	20.0	11.0	40
08:28	2	0	3	0	16	0	1	0	9	7	0	0	7.1	17.7	16.0	41
08:29	6	0	3	0	16	2	0	0	13	3	1	0	11.1	18.0	17.7	47
08:30	11	0	0	0	25	0	0	0	7	4	0	0	11.0	25.0	11.0	47
08:31	2	2	2	0	14	2	1	0	9	3	0	0	7.4	17.7	12.0	37
08:32	7	0	0	0	15	1	1	0	6	2	0	0	7.0	17.7	8.0	33

Time	Left Lane				Middle Lane				HOV Lane				PCU's			Total PCU's
	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Passenger	Taxi's	Trucks	Buses	Left	Middle	Right	
08:33	9	1	1	0	18	0	0	0	6	1	0	0	11.7	18.0	7.0	37
08:34	8	1	0	0	15	1	0	0	6	1	0	0	9.0	16.0	7.0	32
08:35	6	0	2	0	15	1	2	0	14	4	0	0	9.4	19.4	18.0	47
08:36	10	0	0	0	20	1	0	0	8	5	0	0	10.0	21.0	13.0	44
08:37	4	0	1	0	18	1	0	0	17	2	0	0	5.7	19.0	19.0	44
08:38	7	1	0	0	18	0	0	0	9	7	0	0	8.0	18.0	16.0	42
08:39	4	0	1	0	19	1	0	0	7	2	0	0	5.7	20.0	9.0	35
08:40	8	0	1	0	21	0	1	0	7	3	0	0	9.7	22.7	10.0	42
08:41	8	1	0	0	17	2	1	0	13	1	0	0	9.0	20.7	14.0	44
08:42	9	0	2	0	15	1	0	0	5	3	0	0	12.4	16.0	8.0	36
08:43	8	1	2	0	21	0	0	0	11	4	0	0	12.4	21.0	15.0	48
08:44	4	0	3	0	19	0	0	0	8	3	0	0	9.1	19.0	11.0	39
08:45	7	0	0	0	14	2	1	0	8	1	0	0	7.0	17.7	9.0	34
08:46	7	1	2	0	18	0	1	0	13	2	0	0	11.4	19.7	15.0	46
08:47	7	0	1	0	17	0	0	0	12	1	0	0	8.7	17.0	13.0	39
08:48	6	0	2	0	24	1	2	0	9	0	0	0	9.4	28.4	9.0	47
08:49	6	0	1	0	18	1	0	0	8	4	0	0	7.7	19.0	12.0	39
08:50	7	0	3	0	16	1	0	0	4	3	0	0	12.1	17.0	7.0	36
08:51	6	0	1	0	15	0	0	0	7	2	0	0	7.7	15.0	9.0	32
08:52	4	1	1	0	19	0	2	0	13	2	0	0	6.7	22.4	15.0	44
08:53	4	1	0	0	12	1	0	0	8	1	0	1	5.0	13.0	10.5	29
08:54	8	1	1	0	15	0	1	0	14	5	0	0	10.7	16.7	19.0	46
08:55	8	0	3	0	16	1	3	0	10	3	0	0	13.1	22.1	13.0	48
08:56	6	0	3	0	18	3	0	0	17	2	0	0	11.1	21.0	19.0	51
08:57	6	1	2	0	11	0	1	0	12	0	0	0	10.4	12.7	12.0	35
08:58	9	1	2	0	15	0	1	0	7	2	0	0	13.4	16.7	9.0	39
08:59	8	0	0	0	22	1	2	0	7	2	0	0	8.0	26.4	9.0	43

Table A-7: Speed/Flow/Density measurements made during consecutive 1 min. intervals on section 3 (N2 near Athlone Power Station)

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)				Average PCU's/distance			Average Density (pcu/km)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes	Left	Middle	Right	Left	Middle	Right	All lanes
06:30	13.4	18.0	14.5	804	1080	870	5.98	4.86	4.438	81.27	100.00	109.51	96.93	1.8	2	1.9	13.33	14.81	14.07	14.07
06:31	11.0	16.7	11.0	660	1002	660	5.975	5.353	4.26	81.34	90.79	114.08	95.40	1.4	1.54	1.3	10.37	11.41	9.63	10.47
06:32	13.5	20.7	19.0	810	1242	1140	6.062	5.182	4.596	80.17	93.79	105.74	93.23	1.6	2.34	2.6	11.85	17.33	19.26	16.15
06:33	14.2	23.0	15.0	852	1380	900	6.04	5.373	4.633	80.46	90.45	104.90	91.94	2.14	2.4	1.2	15.85	17.78	8.89	14.17
06:34	13.2	39.0	18.5	792	2340	1110	6.463	5.456	4.78	75.20	89.08	101.67	88.65	1.3	3.6	2.4	9.63	26.67	17.78	18.02
06:35	12.4	27.0	24.5	744	1620	1470	6.225	5.518	4.628	78.07	88.08	105.01	90.39	1.34	2.8	2.8	9.93	20.74	20.74	17.14
06:36	10.7	24.0	23.0	642	1440	1380	5.953	4.842	4.578	81.64	100.37	106.16	96.06	1.88	2	1.4	13.93	14.81	10.37	13.04
06:37	16.0	22.0	21.0	960	1320	1260	6.475	5.186	4.644	75.06	93.71	104.65	91.14	1.14	2.4	2.1	8.44	17.78	15.56	13.93
06:38	18.4	35.7	22.5	1104	2142	1350	5.835	5.4	4.684	83.29	90.00	103.76	92.35	1.34	3	2	9.93	22.22	14.81	15.65
06:39	16.7	29.7	20.5	1002	1782	1230	5.898	5.463	4.898	82.40	88.96	99.22	90.20	2.74	4.4	1.5	20.30	32.59	11.11	21.33
06:40	11.0	28.7	18.0	660	1722	1080	5.415	5.25	4.772	89.75	92.57	101.84	94.72	1.4	2.8	1.6	10.37	20.74	11.85	14.32
06:41	16.7	33.5	22.5	1002	2010	1350	6.353	5.192	4.77	76.50	93.61	101.89	90.66	1.6	3.3	2.3	11.85	24.44	17.04	17.78
06:42	21.7	46.0	28.5	1302	2760	1710	6.454	6.028	5.55	75.30	80.62	87.57	81.16	2.2	4.1	2.9	16.30	30.37	21.48	22.72
06:43	16.7	32.0	27.5	1002	1920	1650	6.203	5.42	5.294	78.35	89.67	91.80	86.61	2.4	4.34	2.7	17.78	32.15	20.00	23.31
06:44	23.4	44.1	38.5	1404	2646	2310	6.226	5.932	5.334	78.06	81.93	91.11	83.70	2.14	5.08	4	15.85	37.63	29.63	27.70
06:45	11.0	26.5	37.5	660	1590	2250	7.813	5.738	5.072	62.20	84.70	95.82	80.91	2.4	4.24	3	17.78	31.41	22.22	23.80
06:46	22.4	37.0	33.0	1344	2220	1980	6.515	5.8	5.234	74.60	83.79	92.85	83.75	3	3.5	3.3	22.22	25.93	24.44	24.20
06:47	14.7	32.7	28.0	882	1962	1680	6.258	6.106	5.506	77.66	79.59	88.27	81.84	2	3.94	2.5	14.81	29.19	18.52	20.84
06:48	24.0	37.7	39.0	1440	2262	2340	7.43	6.168	5.976	65.41	78.79	81.33	75.18	3.2	4.14	3.3	23.70	30.67	24.44	26.27
06:49	23.4	39.4	46.0	1404	2364	2760	6.438	6.63	5.554	75.49	73.30	87.50	78.77	3.34	4	4.3	24.74	29.63	31.85	28.74
06:50	27.1	39.0	38.2	1626	2340	2292	7	6.506	5.942	69.43	74.70	81.79	75.31	3.54	5.6	3.5	26.22	41.48	25.93	31.21
06:51	26.4	40.0	35.5	1584	2400	2130	7.335	6.688	6.206	66.26	72.67	78.31	72.41	3.82	5.2	4.5	28.30	38.52	33.33	33.38
06:52	18.7	35.0	38.5	1122	2100	2310	7.043	6.184	6.112	69.00	78.59	79.52	75.70	3.08	4.6	3.8	22.81	34.07	28.15	28.35
06:53	18.4	38.0	38.0	1104	2280	2280	6.244	6.338	6.192	77.83	76.68	78.49	77.67	2.34	4	4.4	17.33	29.63	32.59	26.52
06:54	16.0	33.4	31.0	960	2004	1860	6.435	6.23	5.683	75.52	78.01	85.52	79.68	2.8	3.8	3.4	20.74	28.15	25.19	24.69
06:55	23.0	38.0	36.2	1380	2280	2172	6.82	6.514	5.624	71.26	74.61	86.42	77.43	3.2	4.8	3.6	23.70	35.56	26.67	28.64
06:56	25.7	44.0	39.5	1542	2640	2370	6.978	6.356	5.976	69.65	76.46	81.33	75.81	3.4	5.6	4	25.19	41.48	29.63	32.10
06:57	22.7	43.0	35.9	1362	2580	2154	6.865	6.656	6.484	70.79	73.02	74.95	72.92	3.6	6.6	3.7	26.67	48.89	27.41	34.32
06:58	18.4	40.7	37.0	1104	2442	2220	6.563	6.768	5.664	74.05	71.81	85.81	77.22	1.54	5.4	4	11.41	40.00	29.63	27.01
06:59	22.4	32.7	39.0	1344	1962	2340	6.94	6.218	6.04	70.03	78.16	80.46	76.22	2.94	3.2	5.1	21.78	23.70	37.78	27.75

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)				Average PCU's/distance			Average Density (pcu/km)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes	Left	Middle	Right	Left	Middle	Right	All lanes
07:00	22.1	39.7	40.7	1326	2382	2442	7.085	6.374	5.982	68.60	76.25	81.24	75.36	2.6	4.4	5	19.26	32.59	37.04	29.63
07:01	26.0	34.0	32.5	1560	2040	1950	6.608	6.448	5.662	73.55	75.37	85.84	78.25	3	3.2	3.7	22.22	23.70	27.41	24.44
07:02	21.7	37.0	37.0	1302	2220	2220	5.088	6.642	6.306	95.52	73.17	77.07	81.92	2.34	3.4	3	17.33	25.19	22.22	21.58
07:03	23.0	35.0	41.5	1380	2100	2490	6.87	6.948	6.518	70.74	69.95	74.56	71.75	3	4.4	4.5	22.22	32.59	33.33	29.38
07:04	23.4	39.0	32.0	1404	2340	1920	6.908	6.868	5.954	70.35	70.76	81.63	74.25	2.74	4.4	3.4	20.30	32.59	25.19	26.02
07:05	24.7	39.7	32.5	1482	2382	1950	6.86	7.242	6.6	70.85	67.11	73.64	70.53	3.4	5.34	4.2	25.19	39.56	31.11	31.95
07:06	29.9	35.7	43.5	1794	2142	2610	8.078	8.5	7.48	60.16	57.18	64.97	60.77	5.08	5.2	6.2	37.63	38.52	45.93	40.69
07:07	15.7	32.4	39.0	942	1944	2340	7.4	7.293	7.832	65.68	66.64	62.05	64.79	2.54	4.34	6.4	18.81	32.15	47.41	32.79
07:08	21.7	34.0	36.5	1302	2040	2190	8.935	10.955	8.43	54.39	44.36	57.65	52.14	2.74	6.6	5.9	20.30	48.89	43.70	37.63
07:09	29.7	35.0	37.0	1782	2100	2220	8.338	11.437	10.203	58.29	42.49	47.63	49.47	4.94	6.6	7.2	36.59	48.89	53.33	46.27
07:10	23.1	38.0	34.5	1386	2280	2070	9.203	9.64	7.492	52.81	50.41	64.87	56.03	3.48	6.8	4.9	25.78	50.37	36.30	37.48
07:11	23.7	32.0	32.0	1422	1920	1920	9.248	13.33	8.633	52.55	36.46	56.30	48.44	4.74	7.2	4.9	35.11	53.33	36.30	41.58
07:12	18.4	30.0	35.5	1104	1800	2130	8.773	13.32	8.282	55.40	36.49	58.68	50.19	3.54	6.6	5.1	26.22	48.89	37.78	37.63
07:13	21.7	34.0	35.0	1302	2040	2100	7.493	10.255	8.515	64.86	47.39	57.08	56.44	3.28	5	5.5	24.30	37.04	40.74	34.02
07:14	21.4	33.0	29.0	1284	1980	1740	7.22	7.018	6.084	67.31	69.25	79.88	72.15	2.88	4	3.4	21.33	29.63	25.19	25.38
07:15	22.0	27.0	35.0	1320	1620	2100	6.318	6.38	6.162	76.92	76.18	78.87	77.32	3	2.6	3.6	22.22	19.26	26.67	22.72
07:16	25.7	33.7	37.5	1542	2022	2250	6.606	6.623	6.506	73.57	73.38	74.70	73.88	4.34	3.94	3.9	32.15	29.19	28.89	30.07
07:17	21.0	32.0	31.5	1260	1920	1890	6.8	6.744	6.49	71.47	72.06	74.88	72.81	3	4.2	4.2	22.22	31.11	31.11	28.15
07:18	20.0	27.0	28.2	1200	1620	1692	7.423	7.508	7.718	65.47	64.73	62.97	64.39	2.8	4	3.7	20.74	29.63	27.41	25.93
07:19	17.4	28.0	29.2	1044	1680	1752	8.378	8.508	8.35	58.01	57.12	58.20	57.78	2.88	4	3.5	21.33	29.63	25.93	25.63
07:20	17.4	30.0	30.0	1044	1800	1800	11.24	10.18	10.668	43.24	47.74	45.56	45.51	3.62	5	5.3	26.81	37.04	39.26	34.37
07:21	19.0	27.0	27.5	1140	1620	1650	12.977	20.893	21.153	37.45	23.26	22.98	27.90	5.2	8	10.1	38.52	59.26	74.81	57.53
07:22	20.1	18.0	15.5	1206	1080	930	23.67	57.67	46.2	20.53	8.43	10.52	13.16	9.1	12	12.9	67.41	88.89	95.56	83.95
07:23	11.0	11.7	13.0	660	702	780	74.62	71.06	53.7	6.51	6.84	9.05	7.47	13.78	13.14	14.4	102.07	97.33	106.67	102.02
07:24	12.0	12.0	19.0	720	720	1140	81.13	60	37.12	5.99	8.10	13.09	9.06	15	13.57	12.17	111.11	100.52	90.15	100.59
07:25	14.7	13.0	19.0	882	780	1140	66.47	55.4	32.28	7.31	8.77	15.06	10.38	14.67	13.57	11.67	108.67	100.52	86.44	98.54
07:26	11.7	12.7	17.0	702	762	1020	65.78	68.63	39.41	7.39	7.08	12.33	8.93	13.23	15.03	12	98.00	111.33	88.89	99.41
07:27	15.0	12.0	13.4	900	720	804	66	84.97	31.7	7.36	5.72	15.33	9.47	13	14.57	10.4	96.30	107.93	77.04	93.75
07:28	7.7	10.0	16.4	462	600	984	86.25	99.56	63.19	5.63	4.88	7.69	6.07	14.9	16.23	12.4	110.37	120.22	91.85	107.48
07:29	10.0	12.0	18.5	600	720	1110	67.47	67.03	26.5	7.20	7.25	18.34	10.93	11.8	15.7	10.17	87.41	116.30	75.33	93.01
07:30	13.1	13.0	20.0	786	780	1200	50.71	46.16	22.825	9.58	10.53	21.29	13.80	11.7	13.43	8.5	86.67	99.48	62.96	83.04
07:31	19.0	20.0	24.0	1140	1200	1440	36.485	33.425	16.17	13.32	14.54	30.06	19.31	9.88	11	7.6	73.19	81.48	56.30	70.32
07:32	13.0	13.0	22.5	780	780	1350	63.6	72.22	25.97	7.64	6.73	18.71	11.03	14.8	12.6	11.2	109.63	93.33	82.96	95.31

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)				Average PCU's/distance			Average Density (pcu/km)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes	Left	Middle	Right	Left	Middle	Right	All lanes
07:33	12.7	9.0	15.5	762	540	930	81.19	98.03	53.62	5.99	4.96	9.06	6.67	15.47	13.67	14.17	114.59	101.26	104.96	106.94
07:34	8.7	10.0	14.0	522	600	840	67.46	67.78	44.15	7.20	7.17	11.01	8.46	12.93	14	12.33	95.78	103.70	91.33	96.94
07:35	16.0	13.0	17.0	960	780	1020	28.76	42.61	37.72	16.90	11.41	12.88	13.73	9.57	12	10.67	70.89	88.89	79.04	79.60
07:36	23.0	19.7	23.5	1380	1182	1410	27.82	27.81	25.5	17.47	17.48	19.06	18.00	8.33	9.67	10.83	61.70	71.63	80.22	71.19
07:37	12.7	15.0	15.5	762	900	930	67.56	55.53	63.47	7.19	8.75	7.66	7.87	13.9	14.33	15	102.96	106.15	111.11	106.74
07:38	16.0	10.0	13.0	960	600	780	80.5	77.78	68.06	6.04	6.25	7.14	6.48	14.03	14.67	15	103.93	108.67	111.11	107.90
07:39	11.4	8.7	11.0	684	522	660	88.12	92.03	73	5.52	5.28	6.66	5.82	13.27	14.47	15.17	98.30	107.19	112.37	105.95
07:40	10.0	13.7	11.5	600	822	690	66	53.71	52.53	7.36	9.05	9.25	8.55	13.13	13.8	14.33	97.26	102.22	106.15	101.88
07:41	16.7	19.7	21.5	1002	1182	1290	24.39	37.31	30.015	19.93	13.03	16.19	16.38	9.23	11.67	12.33	68.37	86.44	91.33	82.05
07:42	20.7	17.7	19.0	1242	1062	1140	27.315	41.91	24.89	17.79	11.60	19.53	16.30	9.8	12.9	9.83	72.59	95.56	72.81	80.32
07:43	17.7	15.0	20.0	1062	900	1200	46.92	50.67	26.97	10.36	9.59	18.02	12.66	11.6	12.67	9.17	85.93	93.85	67.93	82.57
07:44	13.7	16.7	21.0	822	1002	1260	70.16	59.09	27.655	6.93	8.22	17.57	10.91	14.23	14.67	10.67	105.41	108.67	79.04	97.70
07:45	12.4	11.0	20.0	744	660	1200	68.97	65	28.575	7.05	7.48	17.01	10.51	13.47	14.57	10.5	99.78	107.93	77.78	95.16
07:46	12.7	12.7	14.5	762	762	870	66.59	82.4	51.66	7.30	5.90	9.41	7.53	13.93	14.13	13.67	103.19	104.67	101.26	103.04
07:47	11.7	9.4	10.7	702	564	642	66.82	83.53	70	7.27	5.82	6.94	6.68	13.4	14.33	14.8	99.26	106.15	109.63	105.01
07:48	11.0	13.0	10.0	660	780	600	80.22	74.85	58.87	6.06	6.49	8.26	6.94	13.47	14.33	12.73	99.78	106.15	94.30	100.07
07:49	10.7	10.0	13.0	642	600	780	84.53	86.09	48.81	5.75	5.65	9.96	7.12	13.9	14	10.83	102.96	103.70	80.22	95.63
07:50	6.7	7.4	11.0	402	444	660	88.87	99.44	71.41	5.47	4.89	6.81	5.72	13.47	14.8	14.17	99.78	109.63	104.96	104.79
07:51	9.7	10.7	13.0	582	642	780	70.88	65.09	53.47	6.86	7.47	9.09	7.80	12.8	13.7	12.5	94.81	101.48	92.59	96.30
07:52	12.9	14.0	15.0	774	840	900	54	50.22	33.805	9.00	9.68	14.38	11.02	12.1	12.47	10	89.63	92.37	74.07	85.36
07:53	12.7	13.0	17.0	762	780	1020	62.41	59.5	31.82	7.79	8.17	15.27	10.41	12.1	13.67	9.83	89.63	101.26	72.81	87.90
07:54	15.0	15.1	20.0	900	906	1200	51.82	34.575	29.75	9.38	14.06	16.34	13.26	13.8	11.7	10.67	102.22	86.67	79.04	89.31
07:55	9.7	15.0	15.5	582	900	930	89.97	47.575	44.66	5.40	10.22	10.88	8.83	13.8	10.8	11.83	102.22	80.00	87.63	89.95
07:56	6.7	13.0	12.0	402	780	720	108.66	59.44	63.35	4.47	8.18	7.67	6.77	13.7	13.67	14	101.48	101.26	103.70	102.15
07:57	6.7	11.0	12.0	402	660	720	85.06	74.94	61	5.71	6.49	7.97	6.72	13.5	14	13	100.00	103.70	96.30	100.00
07:58	11.4	14.0	16.0	684	840	960	48.19	46.68	42.34	10.09	10.41	11.48	10.66	11.4	12	11	84.44	88.89	81.48	84.94
07:59	3.7	9.0	12.0	222	540	720	24.01	19.015	22.36	20.24	25.56	21.74	22.51	4.22	5.2	6.4	31.26	38.52	47.41	39.06
08:00	6.4	16.7	16.0	384	1002	960	10.605	16.143	9.078	45.83	30.11	53.54	43.16	1.28	4.34	2.8	9.48	32.15	20.74	20.79
08:01	11.1	19.7	18.0	666	1182	1080	8.59	17.343	9.417	56.58	28.02	51.61	45.40	1.54	5.94	3.4	11.41	44.00	25.19	26.86
08:02	7.1	12.7	9.0	426	762	540	10.825	8.063	7.51	44.90	60.28	64.71	56.63	1.48	2.94	1.4	10.96	21.78	10.37	14.37
08:03	5.7	18.0	15.5	342	1080	930	6.957	5.5	5.624	69.86	88.36	86.42	81.55	0.88	2.4	1.6	6.52	17.78	11.85	12.05
08:04	7.0	12.7	12.0	420	762	720	5.287	5.683	5.243	91.92	85.52	92.70	90.05	0.6	1.74	1.8	4.44	12.89	13.33	10.22
08:05	7.7	15.0	9.0	462	900	540	6.033	4.862	4.598	80.56	99.96	105.70	95.40	1	1.4	1	7.41	10.37	7.41	8.40

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)				Average PCU's/distance			Average Density (pcu/km)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes	Left	Middle	Right	Left	Middle	Right	All lanes
08:06	9.8	15.8	21.0	588	948	1260	6.263	5.19	4.704	77.60	93.64	103.32	91.52	0.74	1.68	1.6	5.48	12.44	11.85	9.93
08:07	10.7	17.0	12.0	642	1020	720	6.827	4.808	4.124	71.19	101.08	117.85	96.71	0.4	1	0.8	2.96	7.41	5.93	5.43
08:08	7.7	17.0	20.0	462	1020	1200	5.42	4.77	4.182	89.67	101.89	116.21	102.59	0.8	1.2	1.8	5.93	8.89	13.33	9.38
08:09	7.0	17.0	6.0	420	1020	360	5.637	4.96	4.387	86.22	97.98	110.78	98.33	0.8	1.6	0.6	5.93	11.85	4.44	7.41
08:10	8.0	16.7	12.5	480	1002	750	4.975	4.835	4.098	97.69	100.52	118.59	105.60	0.8	1.6	1.3	5.93	11.85	9.63	9.14
08:11	8.7	18.0	12.0	522	1080	720	5.97	5.303	4.37	81.41	91.65	111.21	94.76	0.74	2.4	1.1	5.48	17.78	8.15	10.47
08:12	10.0	24.0	21.0	600	1440	1260	5.7	5.228	4.45	85.26	92.96	109.21	95.81	1.34	3	2.4	9.93	22.22	17.78	16.64
08:13	9.4	18.0	13.0	564	1080	780	5.887	4.832	4.258	82.55	100.58	114.14	99.09	1.2	2	1.4	8.89	14.81	10.37	11.36
08:14	4.0	14.0	11.0	240	840	660	5.125	5.113	4.378	94.83	95.05	111.01	100.30	0.2	1.2	0.8	1.48	8.89	5.93	5.43
08:15	9.4	22.0	18.0	564	1320	1080	6.427	4.768	4.188	75.62	101.93	116.05	97.86	1.28	1.8	0.6	9.48	13.33	4.44	9.09
08:16	8.4	12.0	14.0	504	720	840	6.188	4.47	4.322	78.54	108.72	112.45	99.90	1.34	1.2	0.6	9.93	8.89	4.44	7.75
08:17	9.7	13.4	6.0	582	804	360	5.83	4.813	4.228	83.36	100.98	114.95	99.76	1	0.6	0.4	7.41	4.44	2.96	4.94
08:18	8.0	14.4	11.0	480	864	660	5.14	4.758	4.124	94.55	102.14	117.85	104.85	0.8	1.68	0.8	5.93	12.44	5.93	8.10
08:19	9.4	18.0	7.0	564	1080	420	5.558	4.808	4.308	87.44	101.08	112.81	100.45	1.48	2.14	0.8	10.96	15.85	5.93	10.91
08:20	6.0	21.4	18.0	360	1284	1080	5.787	4.676	4.544	83.98	103.93	106.95	98.29	0.54	1.2	1	4.00	8.89	7.41	6.77
08:21	9.7	19.0	9.0	582	1140	540	6	5.158	4.725	81.00	94.22	102.86	92.69	1.14	1	1	8.44	7.41	7.41	7.75
08:22	6.7	16.7	18.5	402	1002	1110	5.74	4.348	4.142	84.67	111.78	117.33	104.59	1.14	1.6	1.1	8.44	11.85	8.15	9.48
08:23	8.4	18.0	13.0	504	1080	780	4.775	4.612	4.258	101.78	105.38	114.14	107.10	0.54	1.4	1	4.00	10.37	7.41	7.26
08:24	9.4	20.0	20.0	564	1200	1200	5.56	5.044	4.412	87.41	96.35	110.15	97.97	0.2	1.6	1.6	1.48	11.85	11.85	8.40
08:25	7.0	20.0	13.5	420	1200	810	5.77	4.85	4.526	84.23	100.21	107.38	97.27	1	1.4	0.4	7.41	10.37	2.96	6.91
08:26	10.7	14.7	15.0	642	882	900	5.48	4.6	4.428	88.69	105.65	109.76	101.36	1.34	1.6	1.2	9.93	11.85	8.89	10.22
08:27	9.0	20.0	11.0	540	1200	660	5.68	4.542	4.158	85.56	107.00	116.88	103.15	0.6	1.4	0.8	4.44	10.37	5.93	6.91
08:28	7.1	17.7	16.0	426	1062	960	7.173	5.018	4.218	67.75	96.85	115.22	93.28	0.94	1.2	1	6.96	8.89	7.41	7.75
08:29	11.1	18.0	17.7	666	1080	1062	6.357	5.142	4.542	76.45	94.52	107.00	92.66	1.48	0.6	1	10.96	4.44	7.41	7.60
08:30	11.0	25.0	11.0	660	1500	660	5.77	4.718	4.15	84.23	103.01	117.11	101.45	1	2.2	0.6	7.41	16.30	4.44	9.38
08:31	7.4	17.7	12.0	444	1062	720	5.518	4.858	4.044	88.08	100.04	120.18	102.76	0.74	1.6	0.4	5.48	11.85	2.96	6.77
08:32	7.0	17.7	8.0	420	1062	480	5.567	5.09	4.158	87.30	95.48	116.88	99.89	0.6	1.8	1.2	4.44	13.33	8.89	8.89
08:33	11.7	18.0	7.0	702	1080	420	5.78	4.756	4.338	84.08	102.19	112.03	99.43	1.34	1.4	0.8	9.93	10.37	5.93	8.74
08:34	9.0	16.0	7.0	540	960	420	5.495	4.668	4.36	88.44	104.11	111.47	101.34	0.6	1.6	0.2	4.44	11.85	1.48	5.93
08:35	9.4	19.4	18.0	564	1164	1080	5.907	4.878	4.3	82.28	99.63	113.02	98.31	1.54	2.14	0.8	11.41	15.85	5.93	11.06
08:36	10.0	21.0	13.0	600	1260	780	5.753	5	4.32	84.48	97.20	112.50	98.06	1	1	0.8	7.41	7.41	5.93	6.91
08:37	5.7	19.0	19.0	342	1140	1140	5.298	4.86	4.5	91.73	100.00	108.00	99.91	0.2	0.6	0.8	1.48	4.44	5.93	3.95
08:38	8.0	18.0	16.0	480	1080	960	4.573	4.766	4.415	106.28	101.97	110.08	106.11	0.4	1.4	1	2.96	10.37	7.41	6.91

Time	PCU's			Average Flow (veh/h)			Average Travel Time (s)			Average Macroscopic Speed (km/h)				Average PCU's/distance			Average Density (pcu/km)			
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	All lanes	Left	Middle	Right	Left	Middle	Right	All lanes
08:39	5.7	20.0	9.0	342	1200	540	6.247	5.053	4.253	77.80	96.18	114.27	96.08	0.74	1.6	0.4	5.48	11.85	2.96	6.77
08:40	9.7	22.7	10.0	582	1362	600	5.568	5.178	4.427	87.28	93.86	109.78	96.97	0.94	1.2	0.2	6.96	8.89	1.48	5.78
08:41	9.0	20.7	14.0	540	1242	840	5.735	4.856	4.18	84.74	100.08	116.27	100.36	0.94	2	1	6.96	14.81	7.41	9.73
08:42	12.4	16.0	8.0	744	960	480	5.42	4.596	4.37	89.67	105.74	111.21	102.21	1.68	1.4	0.8	12.44	10.37	5.93	9.58
08:43	12.4	21.0	15.0	744	1260	900	5.905	4.976	3.888	82.30	97.67	125.00	101.66	1.2	1	1.8	8.89	7.41	13.33	9.88
08:44	9.1	19.0	11.0	546	1140	660	5.918	4.874	4.248	82.12	99.71	114.41	98.75	0.6	1	0.6	4.44	7.41	4.44	5.43
08:45	7.0	17.7	9.0	420	1062	540	5.198	4.742	3.764	93.50	102.49	129.12	108.37	0.4	1.14	0.6	2.96	8.44	4.44	5.28
08:46	11.4	19.7	15.0	684	1182	900	5.795	5.72	4.325	83.87	84.97	112.37	93.73	0.34	2.14	1	2.52	15.85	7.41	8.59
08:47	8.7	17.0	13.0	522	1020	780	6.103	5.366	4.032	79.63	90.57	120.54	96.91	0.2	2	1.2	1.48	14.81	8.89	8.40
08:48	9.4	28.4	9.0	564	1704	540	5.526	5.096	4.108	87.95	95.37	118.31	100.54	0.74	2.8	1	5.48	20.74	7.41	11.21
08:49	7.7	19.0	12.0	462	1140	720	5.33	4.812	4.3	91.18	101.00	113.02	101.73	0.88	1.2	1.4	6.52	8.89	10.37	8.59
08:50	12.1	17.0	7.0	726	1020	420	6.08	5.074	4.176	79.93	95.78	116.38	97.37	1.14	1.6	0.8	8.44	11.85	5.93	8.74
08:51	7.7	15.0	9.0	462	900	540	6.09	4.716	4.127	79.80	103.05	117.76	100.21	0.6	2	0.6	4.44	14.81	4.44	7.90
08:52	6.7	22.4	15.0	402	1344	900	5.187	4.756	4.07	93.70	102.19	119.41	105.10	0.94	1	1.4	6.96	7.41	10.37	8.25
08:53	5.0	13.0	10.5	300	780	630	5.218	5.168	4.387	93.14	94.04	110.78	99.32	0.6	1	0.6	4.44	7.41	4.44	5.43
08:54	10.7	16.7	19.0	642	1002	1140	6.765	5.426	4.446	71.84	89.57	109.31	90.24	1.8	1.74	1.2	13.33	12.89	8.89	11.70
08:55	13.1	22.1	13.0	786	1326	780	6.23	5.11	4.474	78.01	95.11	108.63	93.91	0.74	2.42	1.2	5.48	17.93	8.89	10.77
08:56	11.1	21.0	19.0	666	1260	1140	6.285	4.905	4.296	77.33	99.08	113.13	96.51	0.94	2	0.8	6.96	14.81	5.93	9.23
08:57	10.4	12.7	12.0	624	762	720	5.523	5.05	3.916	88.00	96.24	124.11	102.78	0.94	1.54	0.8	6.96	11.41	5.93	8.10
08:58	13.4	16.7	9.0	804	1002	540	6.25	4.68	4.58	77.76	103.85	106.11	95.91	1.74	1	0.4	12.89	7.41	2.96	7.75
08:59	8.0	26.4	9.0	480	1584	540	6.318	5.074	4.01	76.92	95.78	121.20	97.97	1.54	2.14	0.8	11.41	15.85	5.93	11.06

Appendix B

Regression Analysis Data and Graphs

Table B-1: Regression Analysis data for Section 1 (N1 near Century City)

Model	Equation	Lane	*m*	*l*	U_0	K_0	C	U_f	K_j	R^2
Greenshields	$U = U_f(1-K/K_j)$	left	0	2				100.55	81.5	0.824
		middle	0	2				119.30	72.23	0.836
		right	0	2				138.04	72.06	0.833
Greenberg	$U = U_0.Ln(K_j/K)$	left	0	1	39.16				125.19	0.602
		middle	0	1	41.87				116.38	0.712
		right	0	1	48.95				107.18	0.560
Underwood	$U = U_f.e^{-(K/Ko)}$	left	1	2		43.85		114.72		0.773
		middle	1	2		36.68		144.06		0.792
		right	1	2		26.87		237.65		0.729
Drake et al.	$U = U_f.e^{-0.5(K/Ko)^2}$	left	1	3		36.32		91.52		0.859
		middle	1	3		32.84		106.32		0.863
		right	1	3		31.17		127.05		0.869
Multi-regime	$Ln(U_f/U) = C.K^{L-1}$	left	1	3.812			1.60E-05	87.42		0.865
	$U^{1-M} = U_f^{1-M}+C.K^{L-1}$	middle	1.009	3.169			1.952E-06	101.00		0.861
	$U^{1-M} = U_f^{1-M}+C.K^{L-1}$	right	1.076	3.44			5.171E-06	118.48		0.872
Composite	Low Densities: Multi-regime Matrix	left								0.867
		middle								0.863
	High Densities: Greenberg	right								0.865

Table B-2: Regression Analysis data for Section 2 (N1 near R300)

Model	Equation	Lane	*m*	*l*	U_0	K_0	C	U_f	K_j	R^2
Greenshields	$U = U_f(1-K/K_j)$	left	0	2				88.65	105.87	0.897
		right	0	2				101.51	111.79	0.930
Greenberg	$U = U_0.Ln(K_j/K)$	left	0	1	32.99				144.67	0.842
		right	0	1	35.86				149.45	0.759
Underwood	$U = U_f.e^{-(K/Ko)}$	left	1	2		49.14		104.40		0.896
		right	1	2		49.18		119.68		0.929
Drake et al.	$U = U_f.e^{-0.5(K/Ko)^2}$	left	1	3		43.39		82.09		0.922
		right	1	3		42.77		95.51		0.959
Multi-regime	$Ln(U_f/U) = C.K^{L-1}$	left	1	2.792			6.41E-04	84.08		0.923
	$Ln(U_f/U) = C.K^{L-1}$	right	1	2.760			7.44E-04	97.93		0.960
Composite	Low Densities: Multi-regime	left								0.923
	High Densities: Greenberg	right								0.958

Table B-3: Regression Analysis data for Section 3 (N2 near Athlone Power Station)

Model	Equation	Lane	*m*	*l*	U_0	K_0	C	U_f	K_j	R^2
Greenshields	$U = U_f(1-K/Kj)$	left	0	2				90.29	99.54	0.921
		middle	0	2				110.41	101.78	0.928
		right	0	2				119.90	94.44	0.926
Greenberg	$U = U_0.Ln(Kj/K)$	left	0	1	30.59				128.06	0.839
		middle	0	1	44.00				123.54	0.883
		right	0	1	40.31				132.56	0.862
Underwood	$U = U_f.e^{-(K/Ko)}$	left	1	2		42.73		103.73		0.908
		middle	1	2		43.44		134.77		0.915
		right	1	2		42.83		137.70		0.929
Drake et al.	$U = U_f.e^{-0.5(K/Ko)^2}$	left	1	3		34.36		86.47		0.932
		middle	1	3		37.42		104.99		0.948
		right	1	3		31.17		127.05		0.930
Multi-regime	$Ln(U_f/U) = C.K^{L-1}$	left	1	2.720			1.23E-03	88.42		0.934
	$Ln(U_f/U) = C.K^{L-1}$	middle	1	2.893			5.44E-04	106.10		0.948
	$Ln(U_f/U) = C.K^{L-1}$	right	1	2.634			1.74E-03	118.77		0.953
Composite	Low Densities: Multi-regime Matrix	left								0.927
		middle								0.939
	High Densities: Greenberg	right								0.942

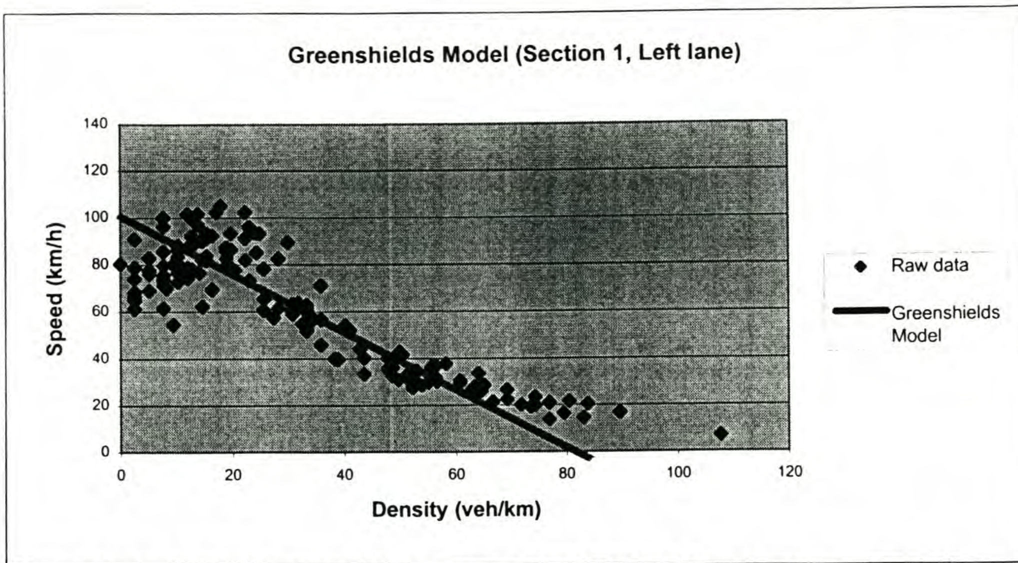

Figure B-1: Greenshields curve fitted to left lane data (section 1)

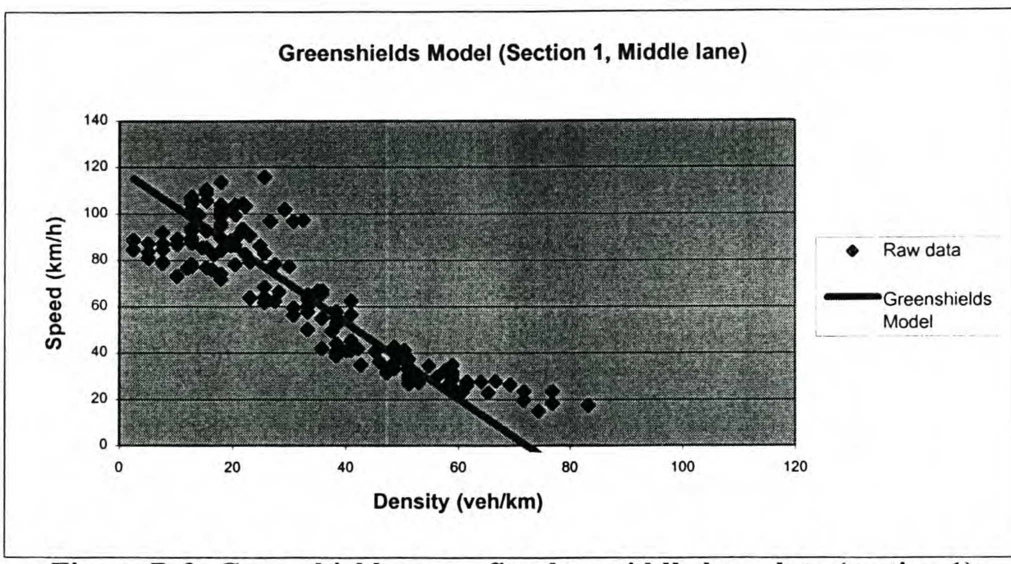

Figure B-2: Greenshields curve fitted to middle lane data (section 1)

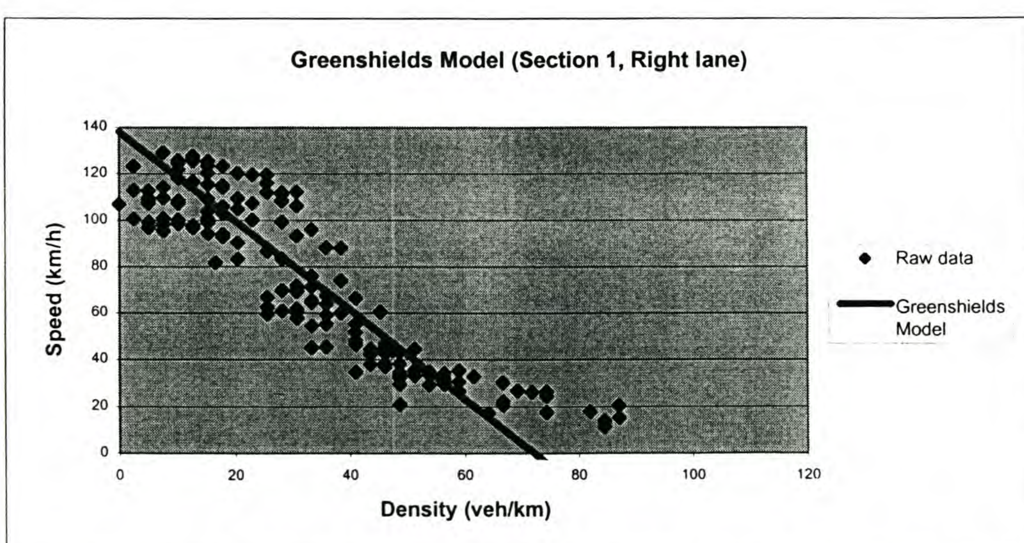

Figure B-3: Greenshields curve fitted to right lane data (section 1)

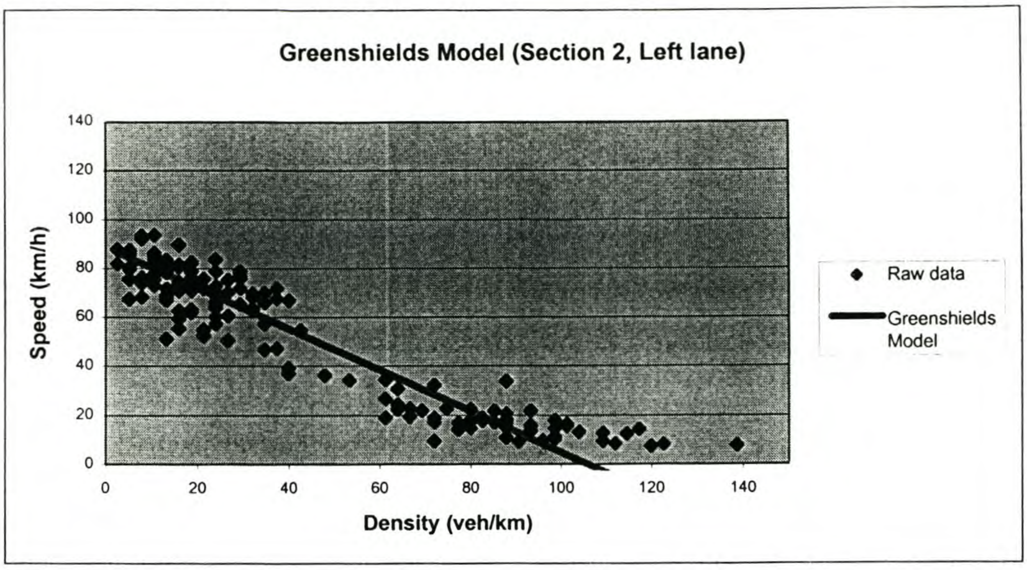

Figure B-4: Greenshields curve fitted to left lane data (section 2)

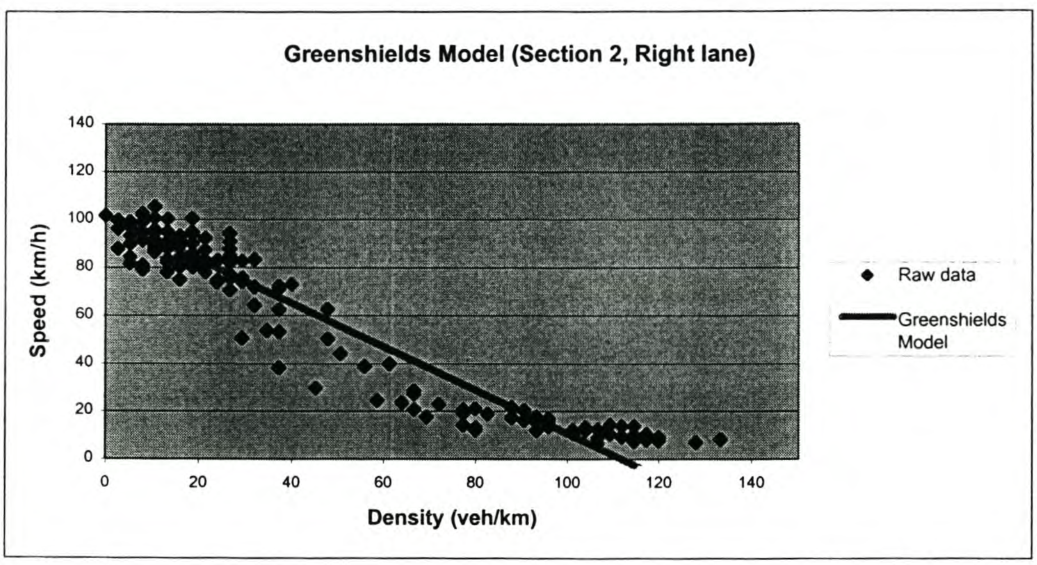

Figure B-5: Greenshields curve fitted to right lane data (section 2)

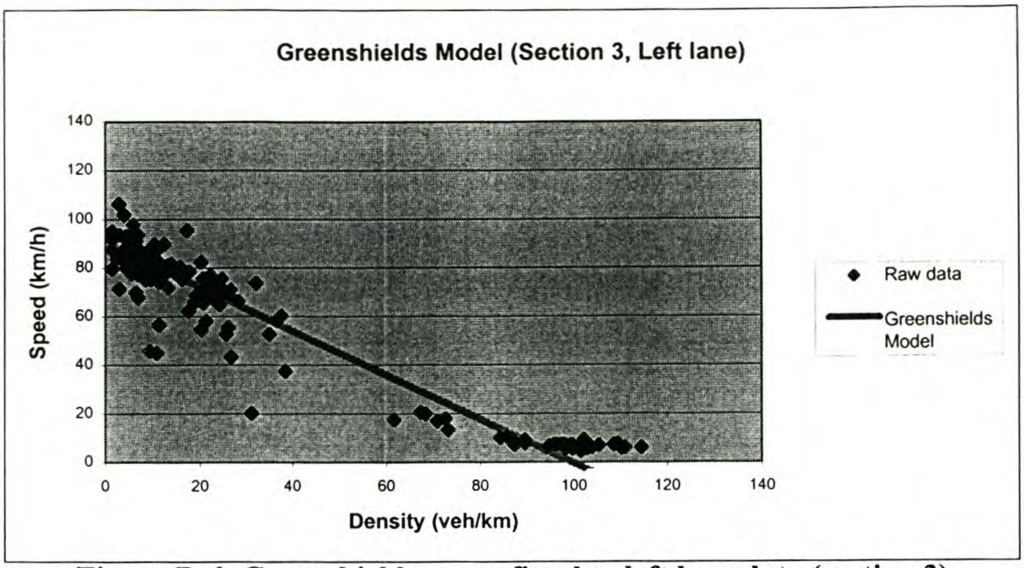

Figure B-6: Greenshields curve fitted to left lane data (section 3)

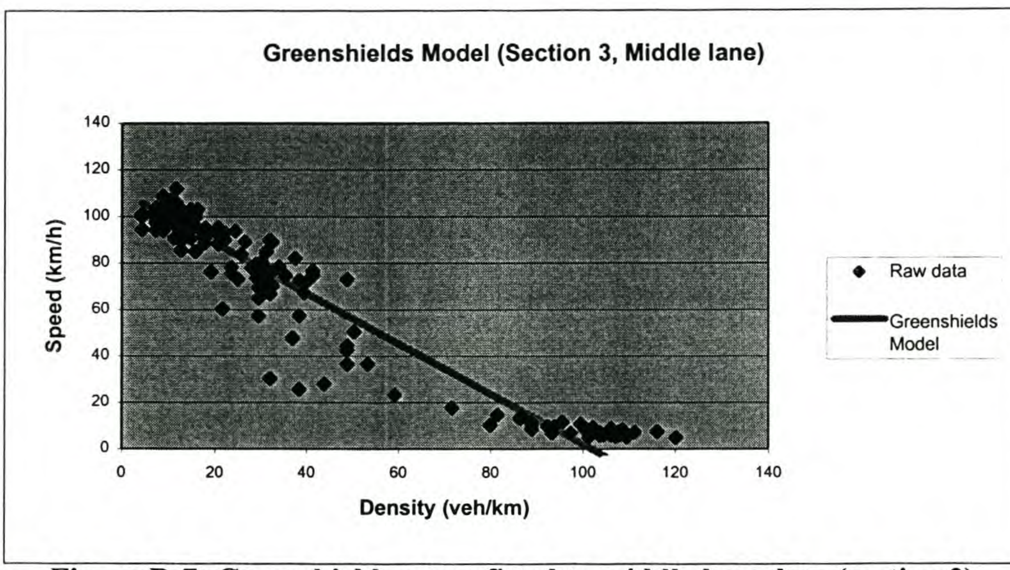

Figure B-7: Greenshields curve fitted to middle lane data (section 3)

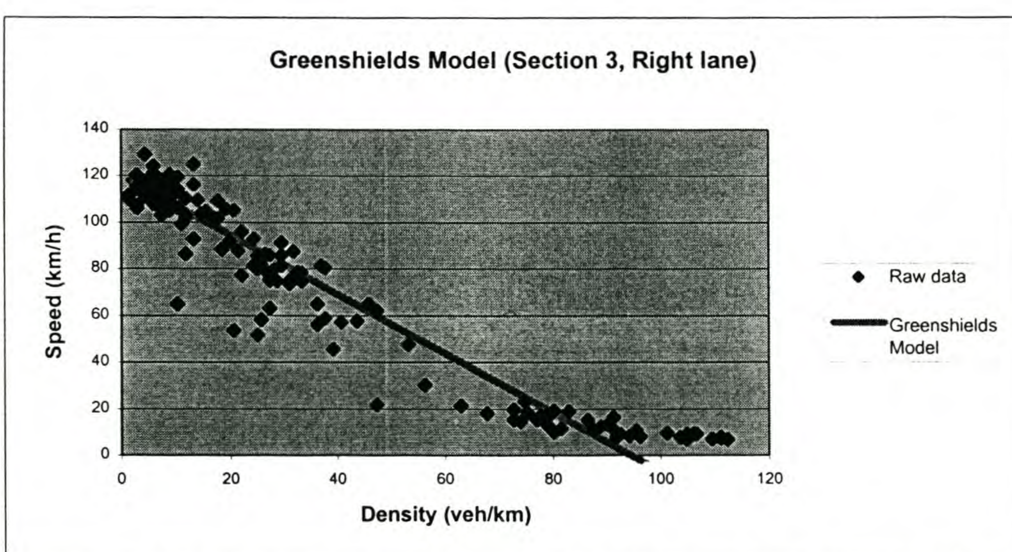

Figure B-8: Greenshields curve fitted to right lane data (section 3)

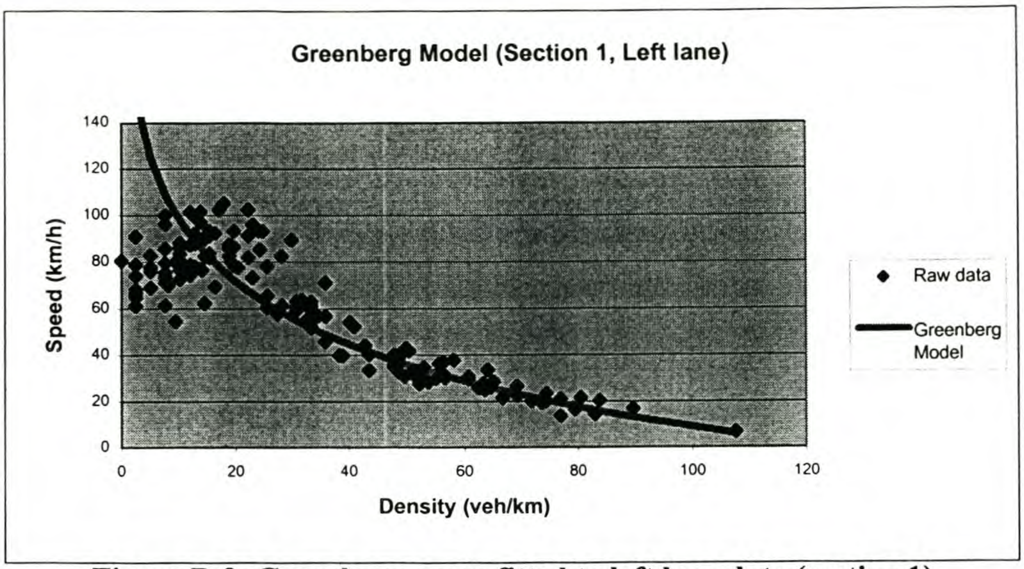

Figure B-9: Greenberg curve fitted to left lane data (section 1)

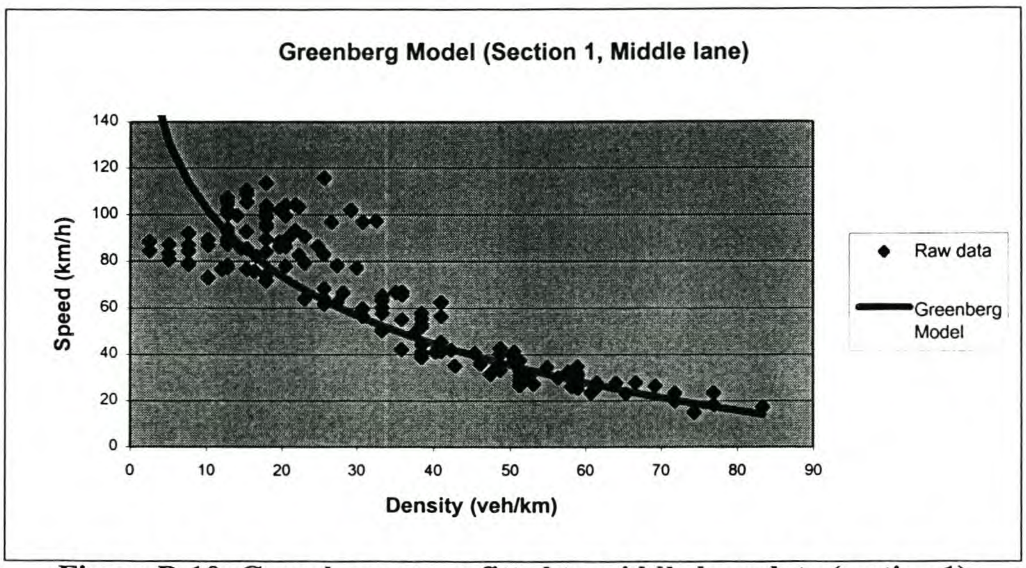

Figure B-10: Greenberg curve fitted to middle lane data (section 1)

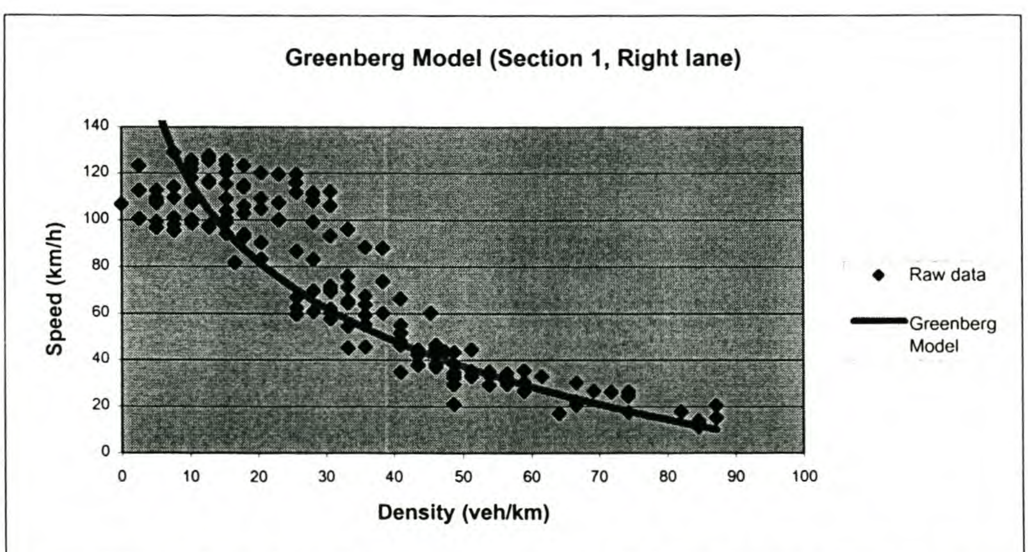

Figure B-11: Greenberg curve fitted to right lane data (section 1)

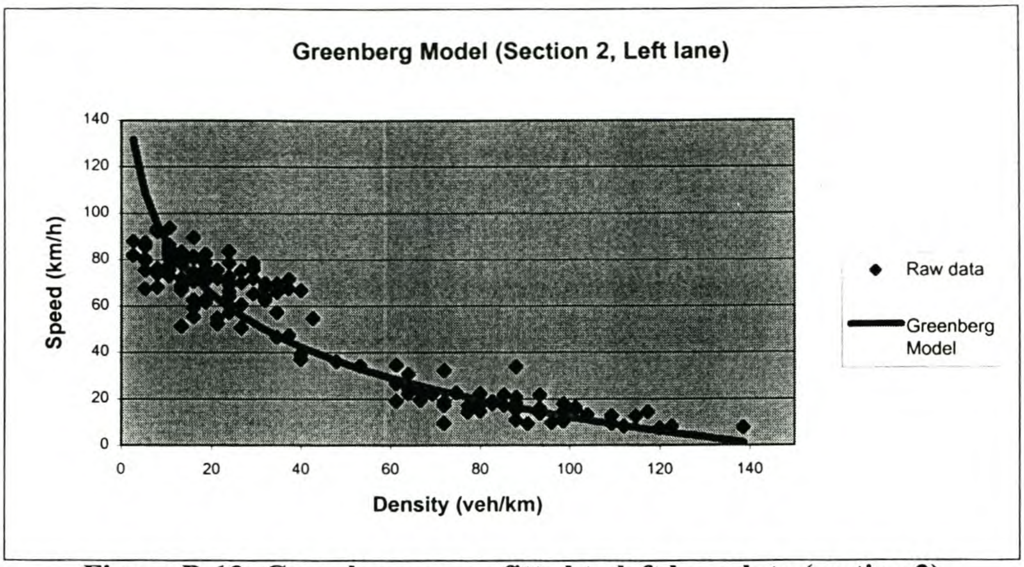

Figure B-12: Greenberg curve fitted to left lane data (section 2)

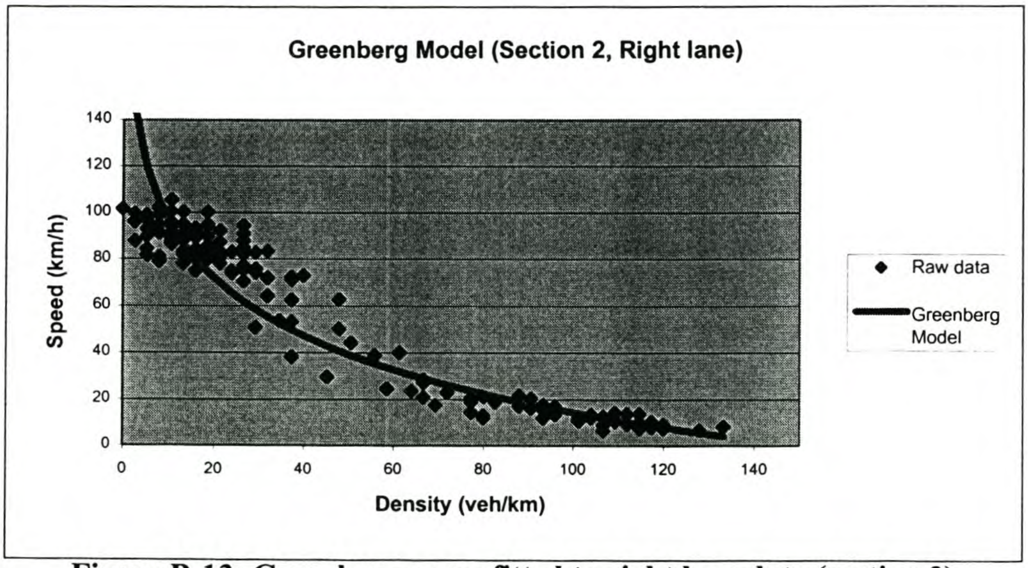

Figure B-13: Greenberg curve fitted to right lane data (section 2)

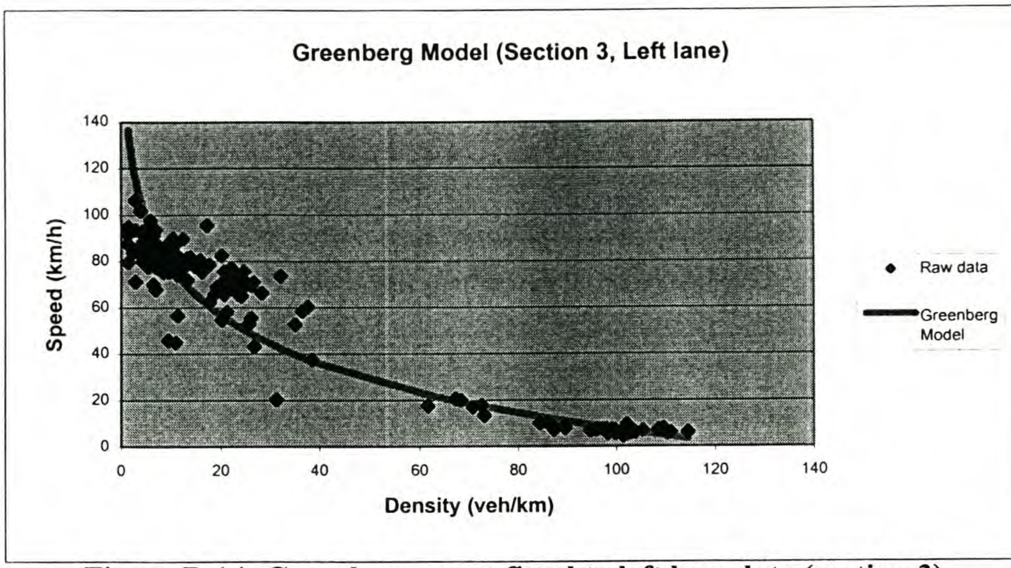

Figure B-14: Greenberg curve fitted to left lane data (section 3)

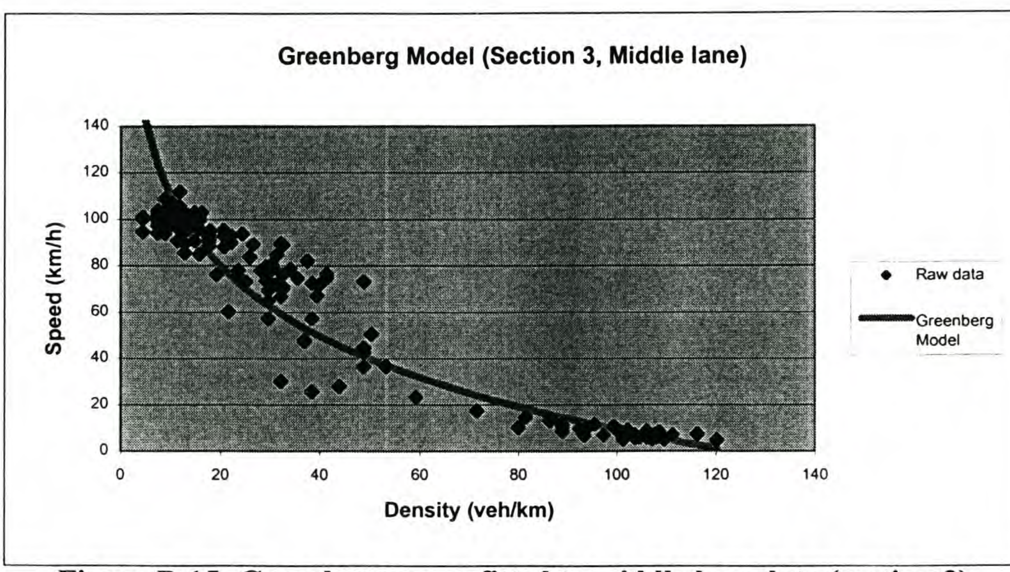

Figure B-15: Greenberg curve fitted to middle lane data (section 3)

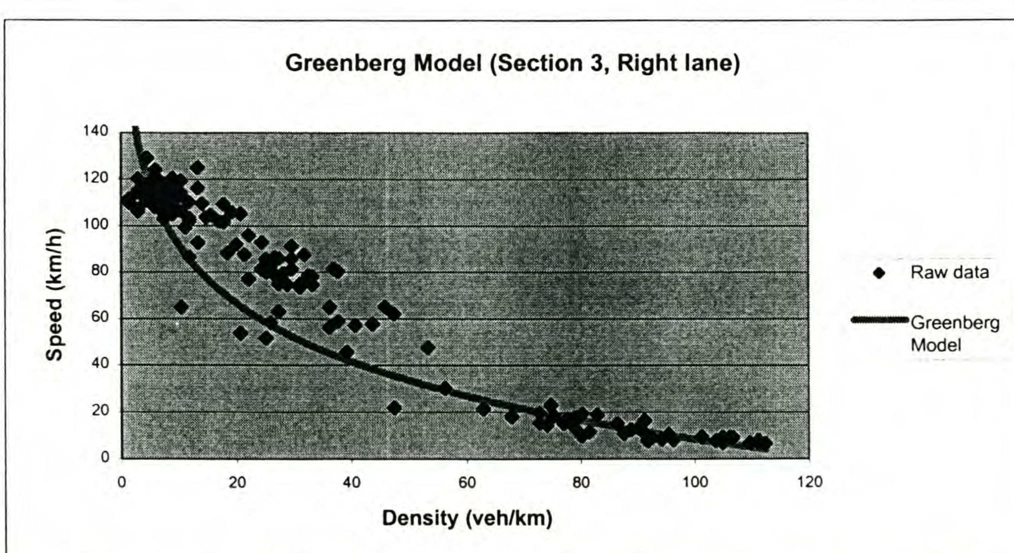

Figure B-16: Greenberg curve fitted to right lane data (section 3)

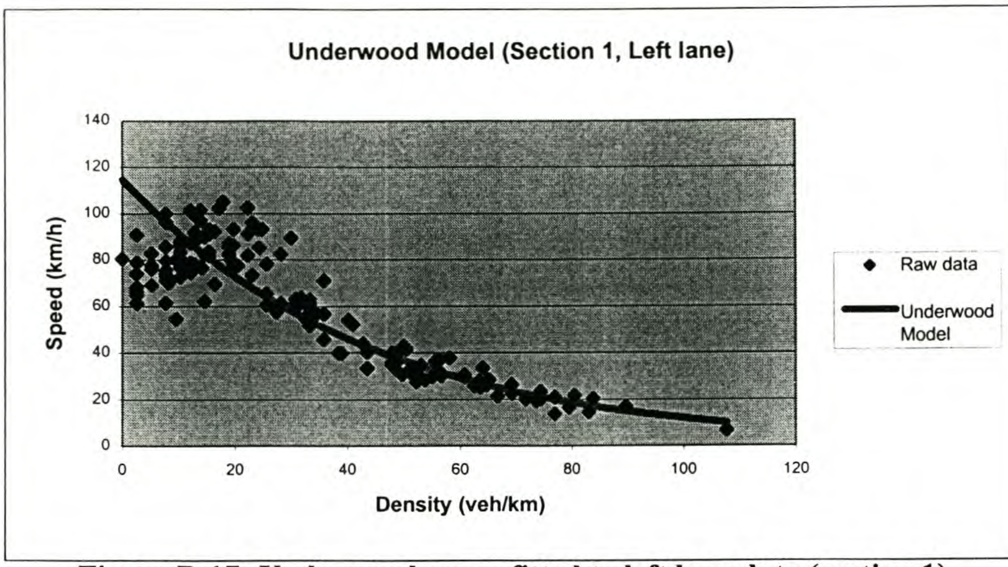

Figure B-17: Underwood curve fitted to left lane data (section 1)

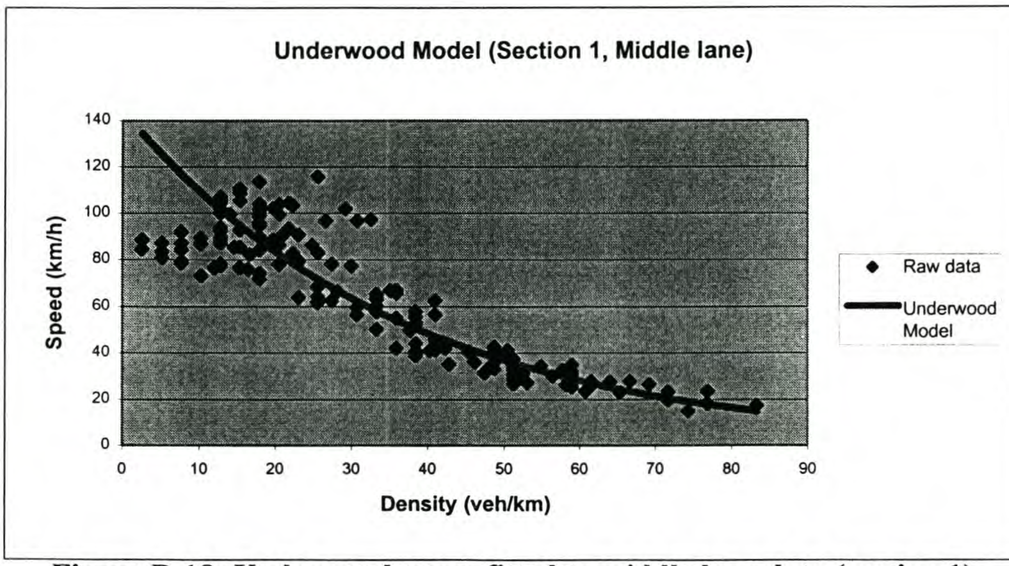

Figure B-18: Underwood curve fitted to middle lane data (section 1)

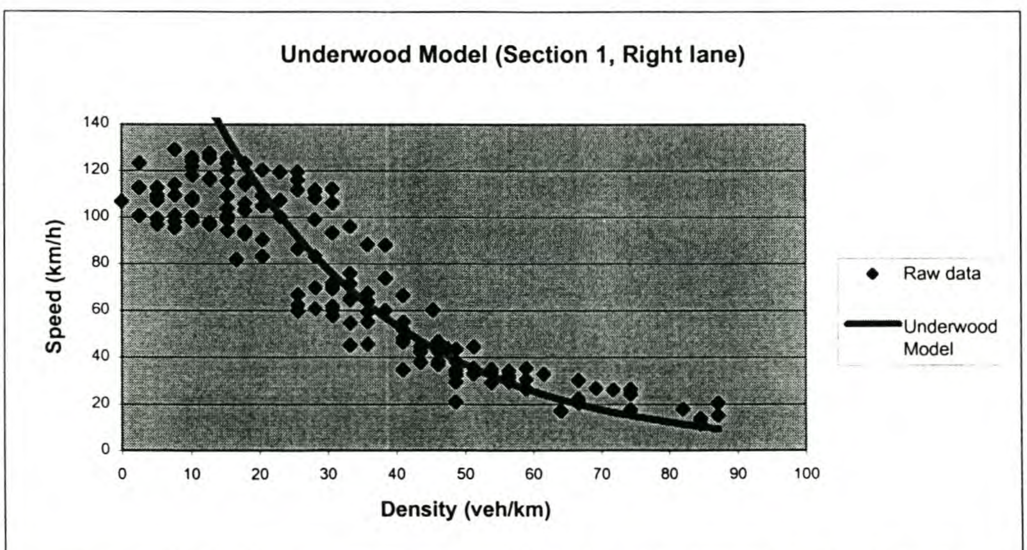

Figure B-19: Underwood curve fitted to right lane data (section 1)

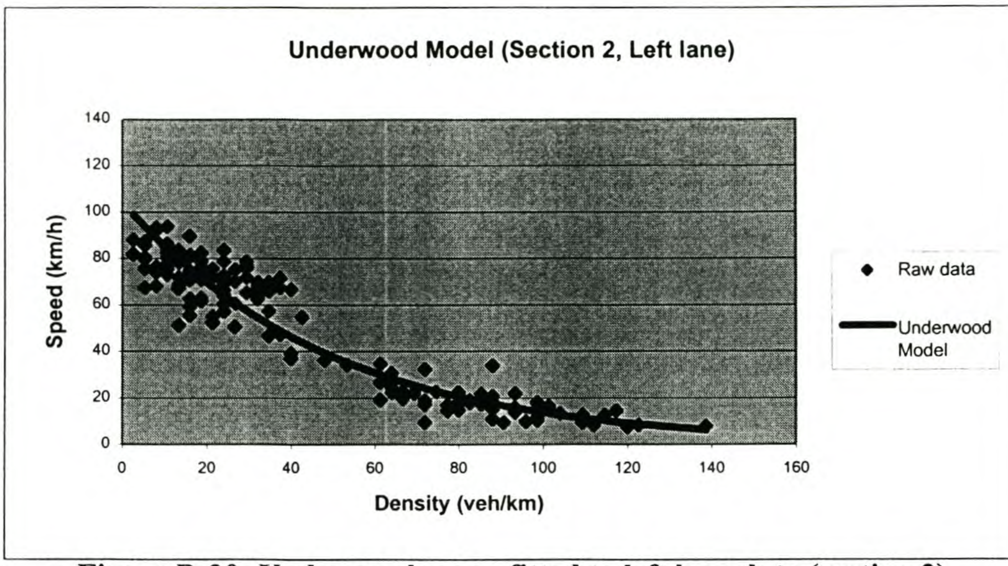

Figure B-20: Underwood curve fitted to left lane data (section 2)

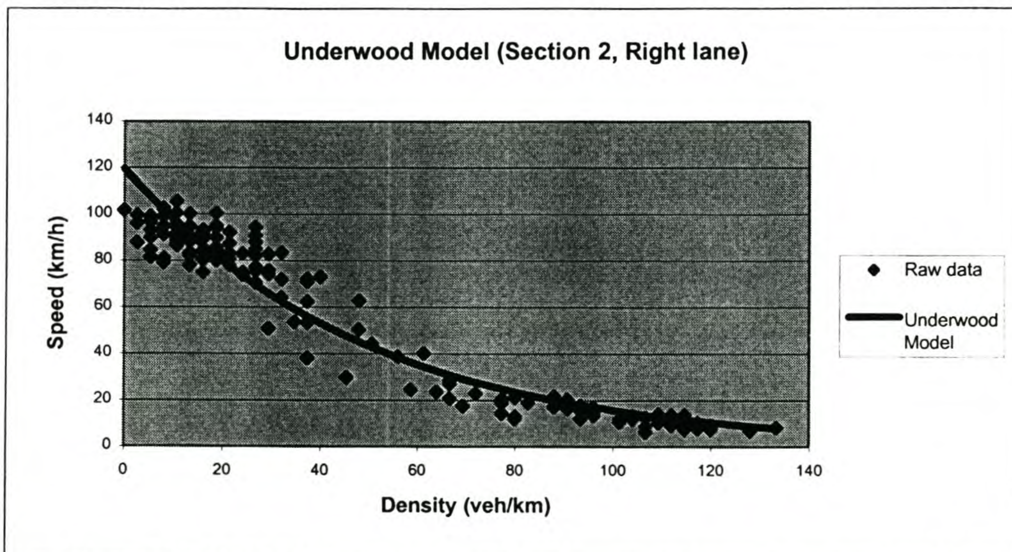

Figure B-21: Underwood curve fitted to right lane data (section 2)

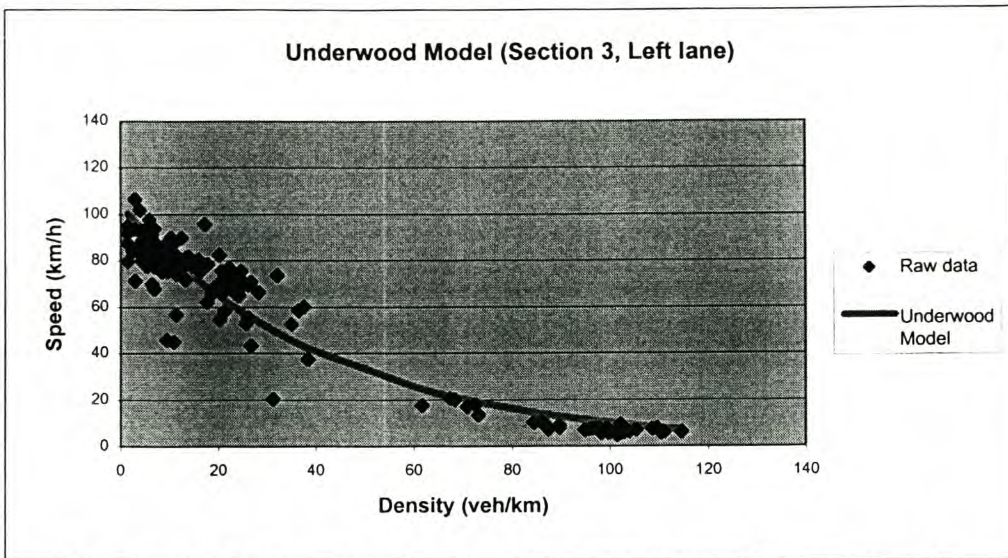

Figure B-22: Underwood curve fitted to left lane data (section 3)

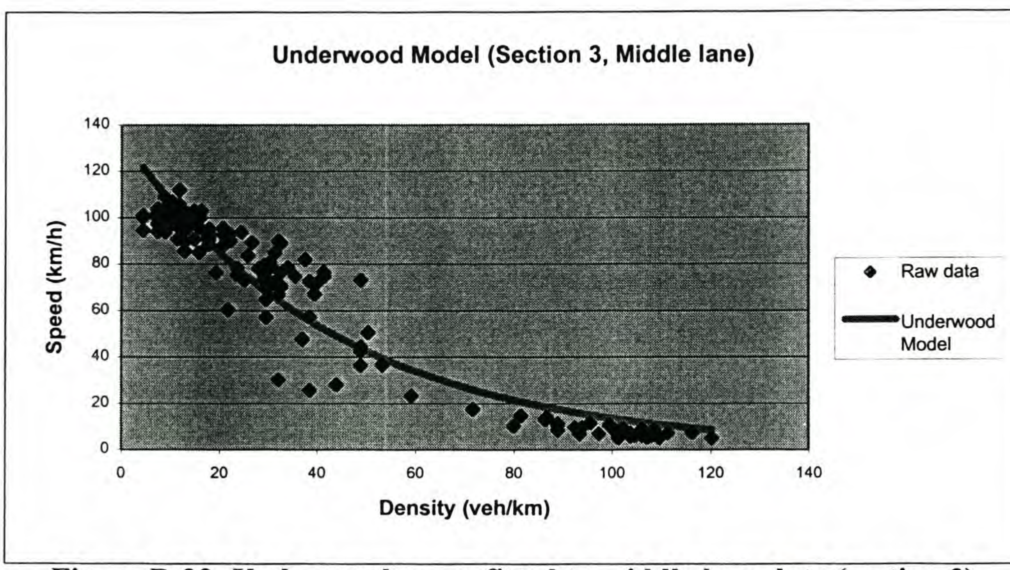

Figure B-23: Underwood curve fitted to middle lane data (section 3)

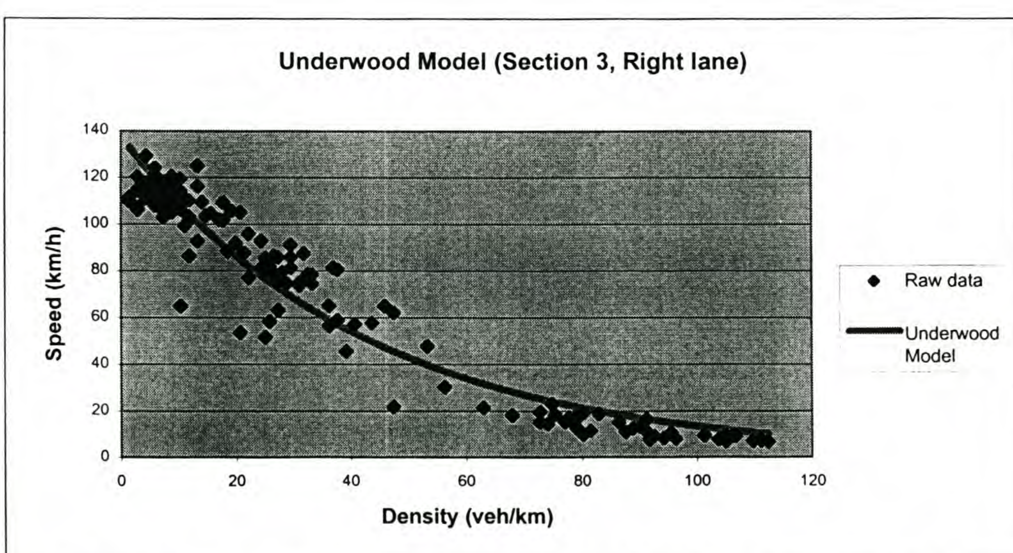

Figure B-24: Underwood curve fitted to right lane data (section 3)

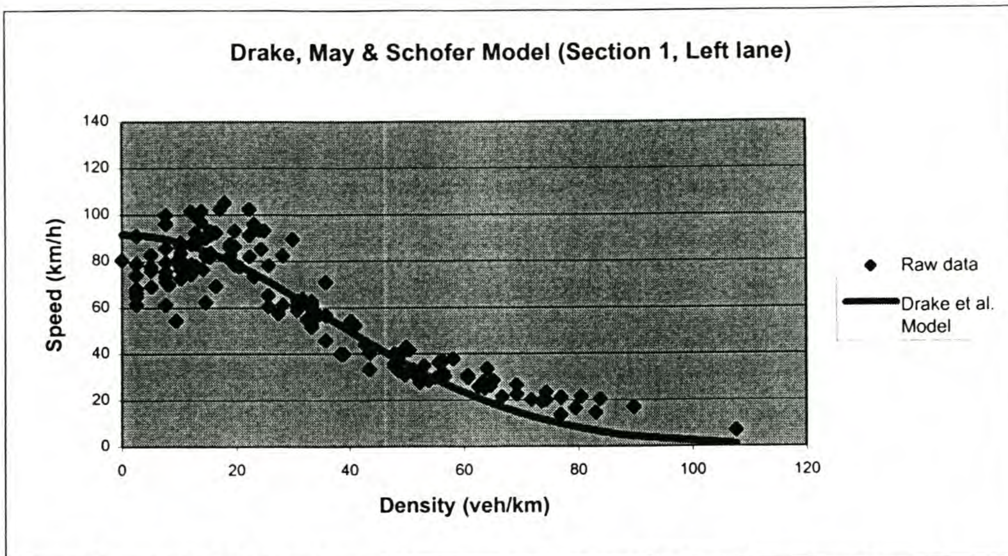

Figure B-25: Drake et al. curve fitted to left lane data (section 1)

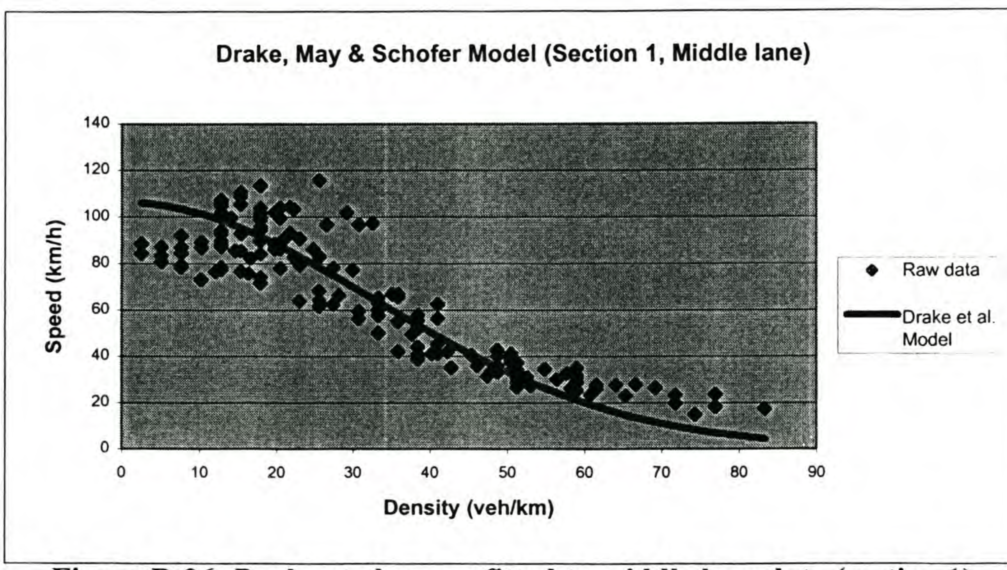

Figure B-26: Drake et al. curve fitted to middle lane data (section 1)

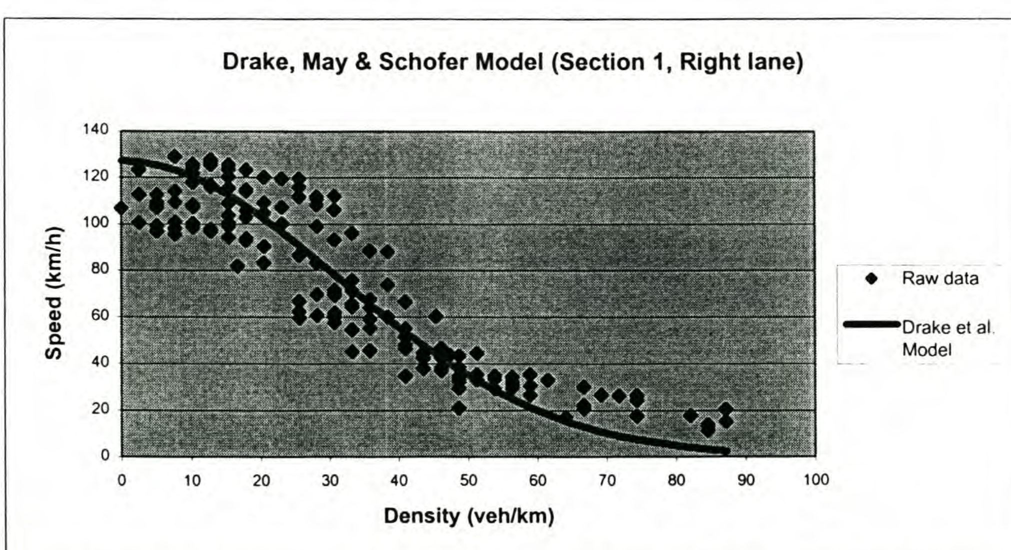

Figure B-27: Drake et al. curve fitted to right lane data (section 1)

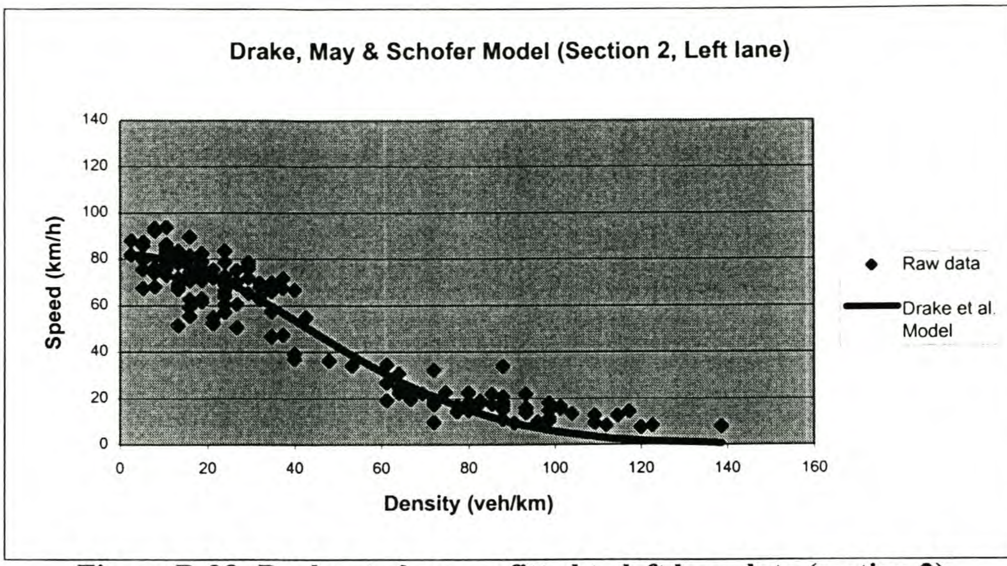

Figure B-28: Drake et al. curve fitted to left lane data (section 2)

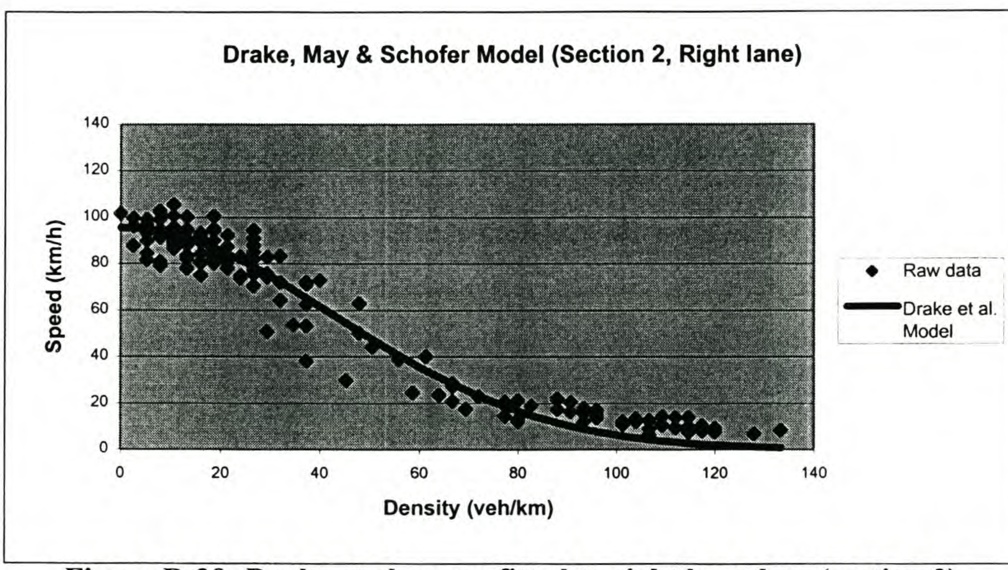

Figure B-29: Drake et al. curve fitted to right lane data (section 2)

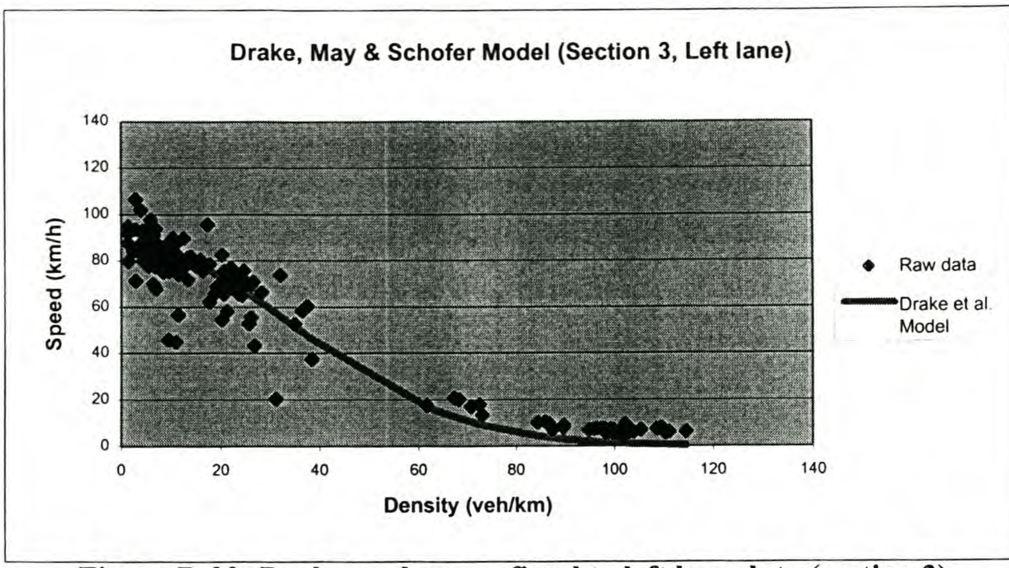

Figure B-30: Drake et al. curve fitted to left lane data (section 3)

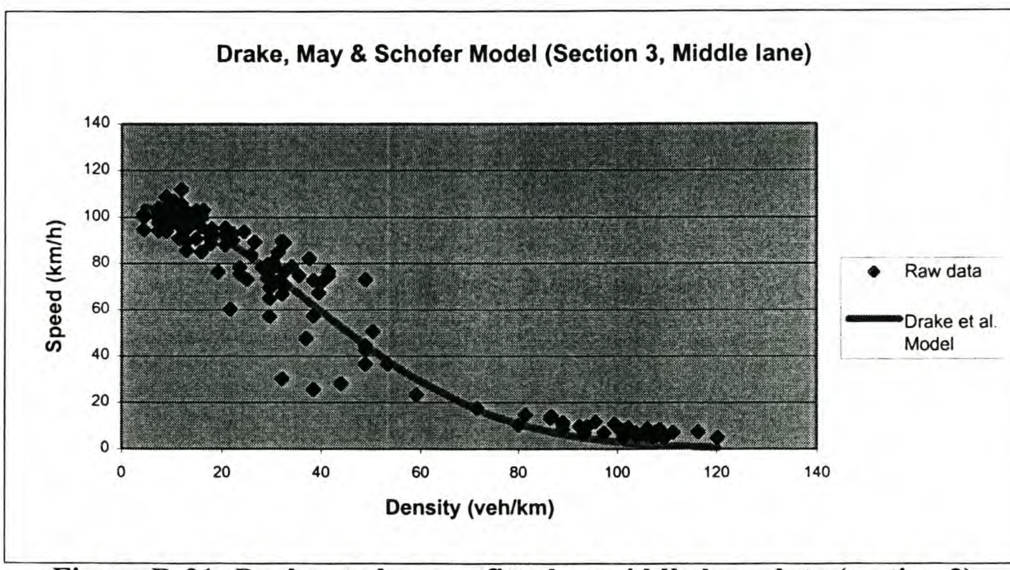

Figure B-31: Drake et al. curve fitted to middle lane data (section 3)

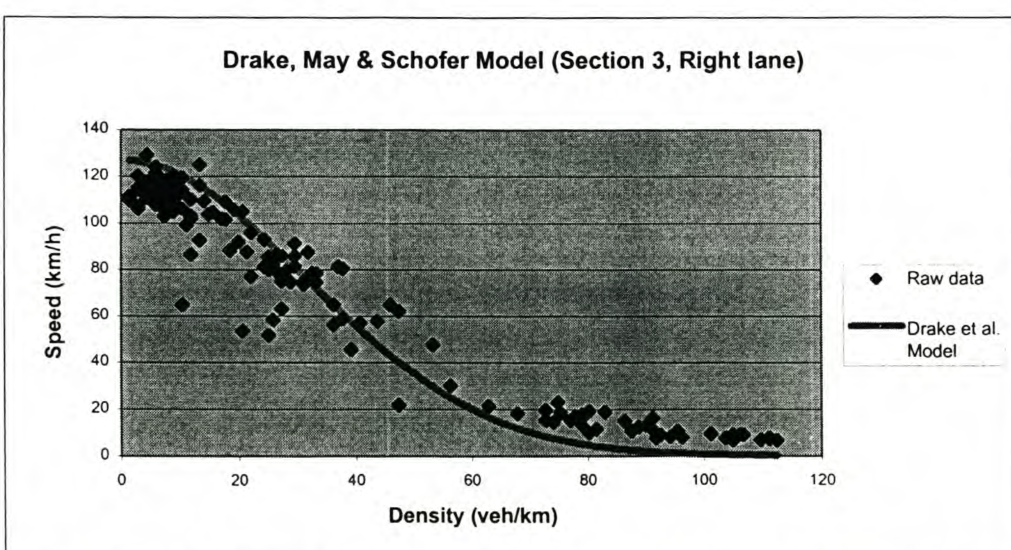

Figure B-32: Drake et al. curve fitted to right lane data (section 3)

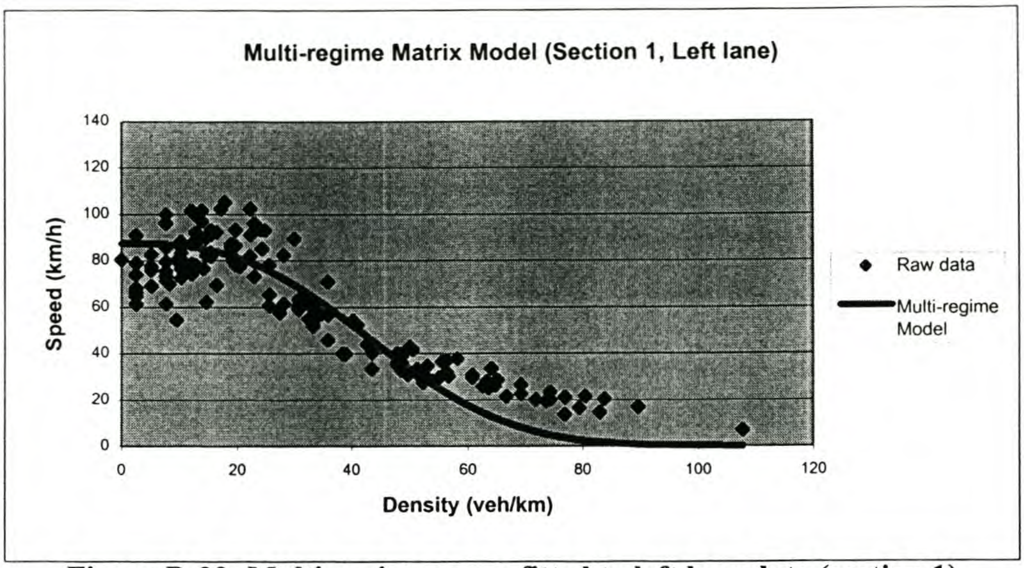

Figure B-33: Multi-regime curve fitted to left lane data (section 1)

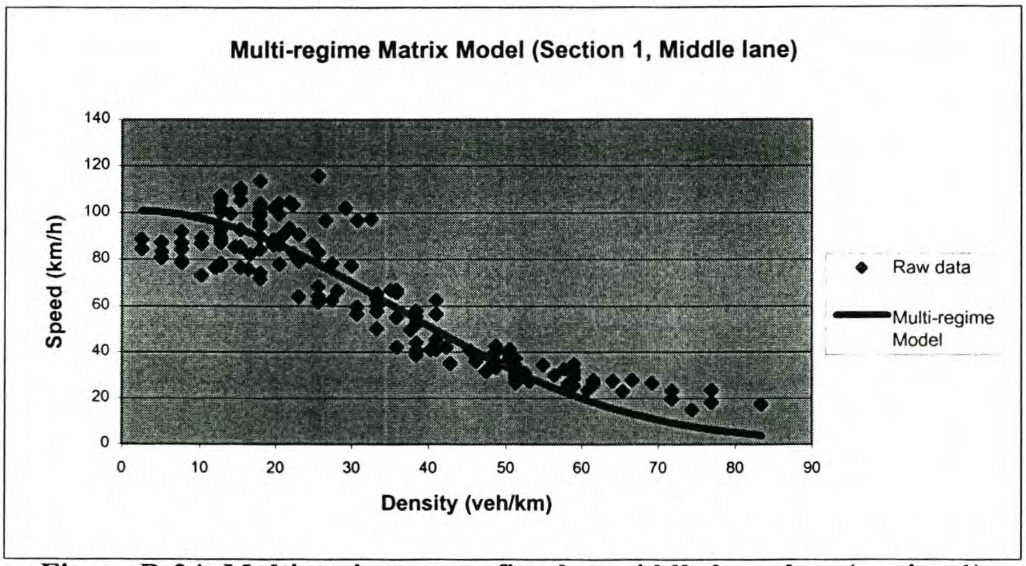

Figure B-34: Multi-regime curve fitted to middle lane data (section 1)

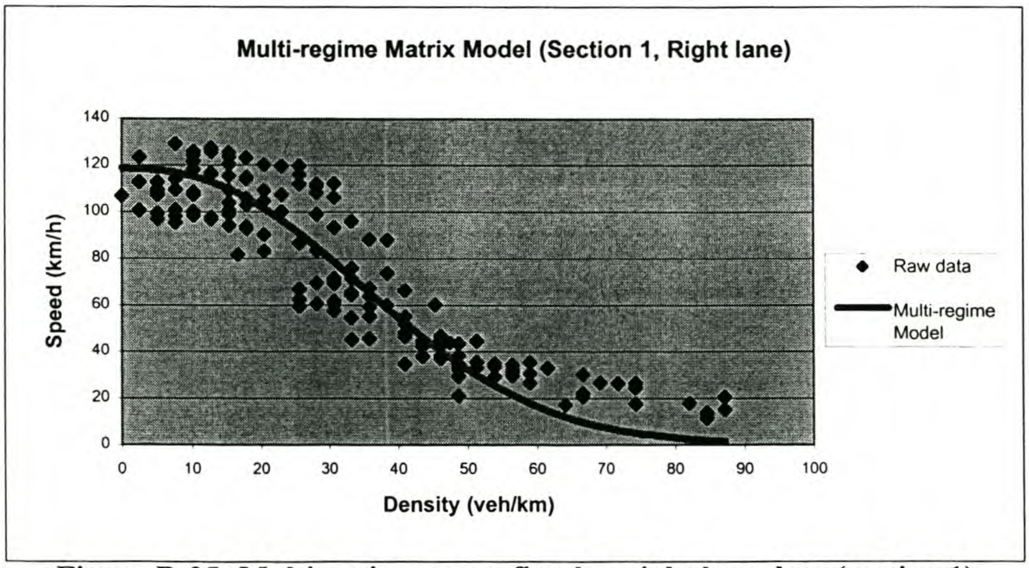

Figure B-35: Multi-regime curve fitted to right lane data (section 1)

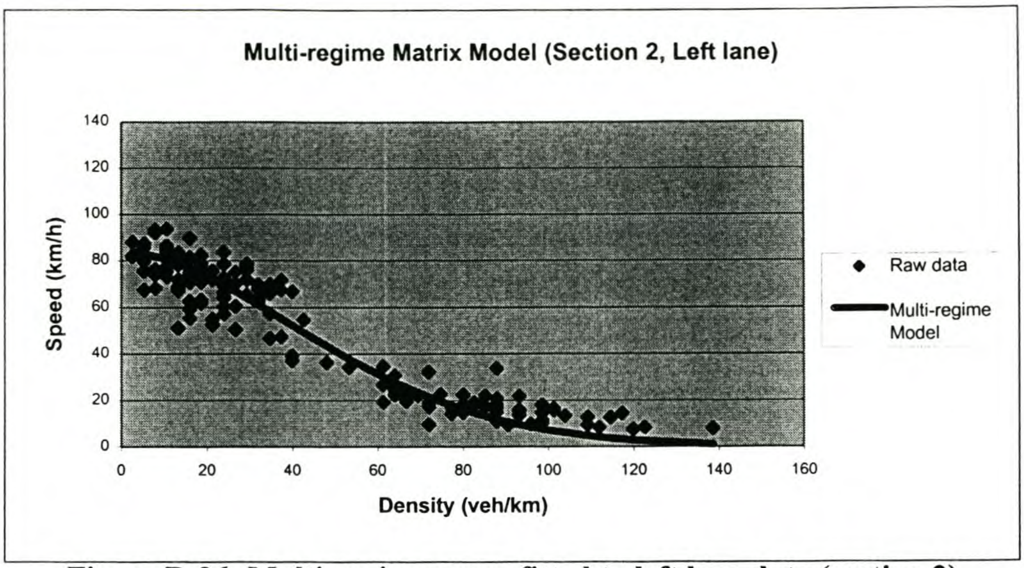

Figure B-36: Multi-regime curve fitted to left lane data (section 2)

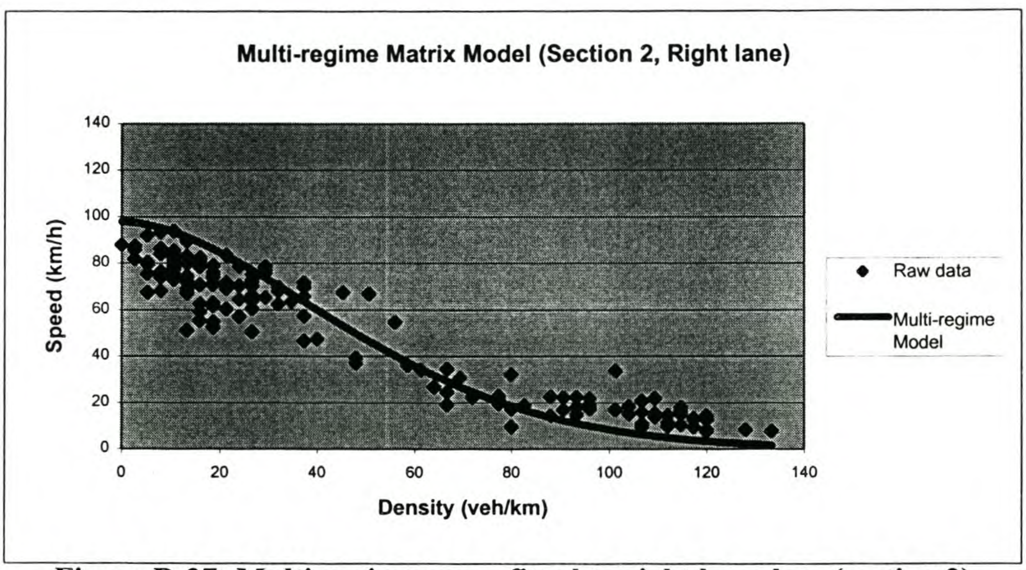

Figure B-37: Multi-regime curve fitted to right lane data (section 2)

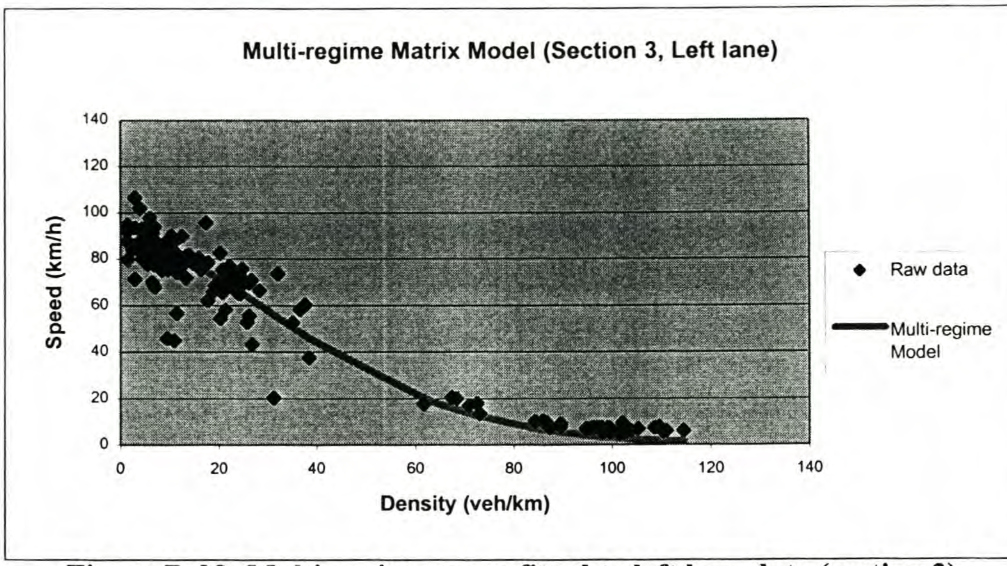

Figure B-38: Multi-regime curve fitted to left lane data (section 3)

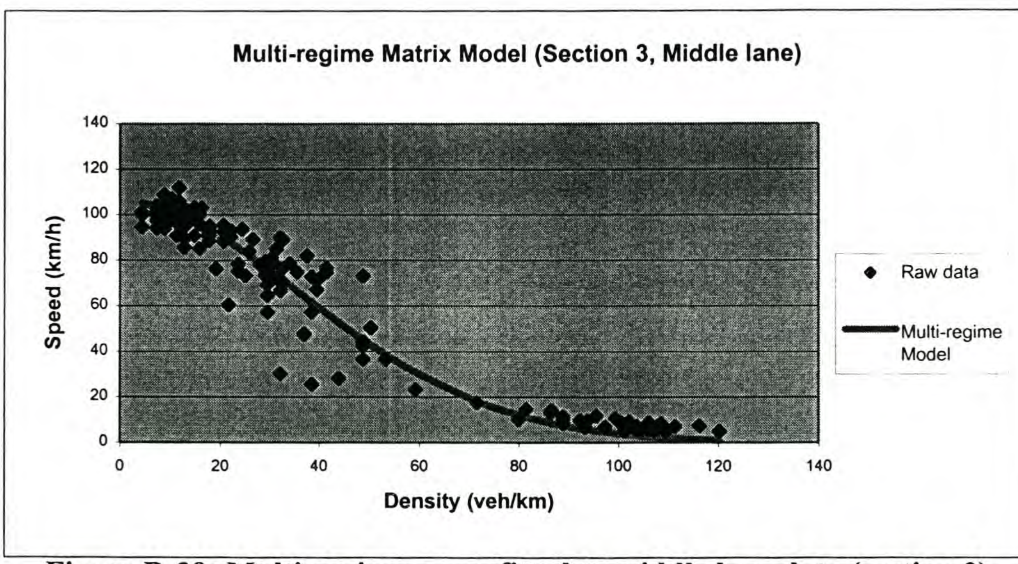

Figure B-39: Multi-regime curve fitted to middle lane data (section 3)

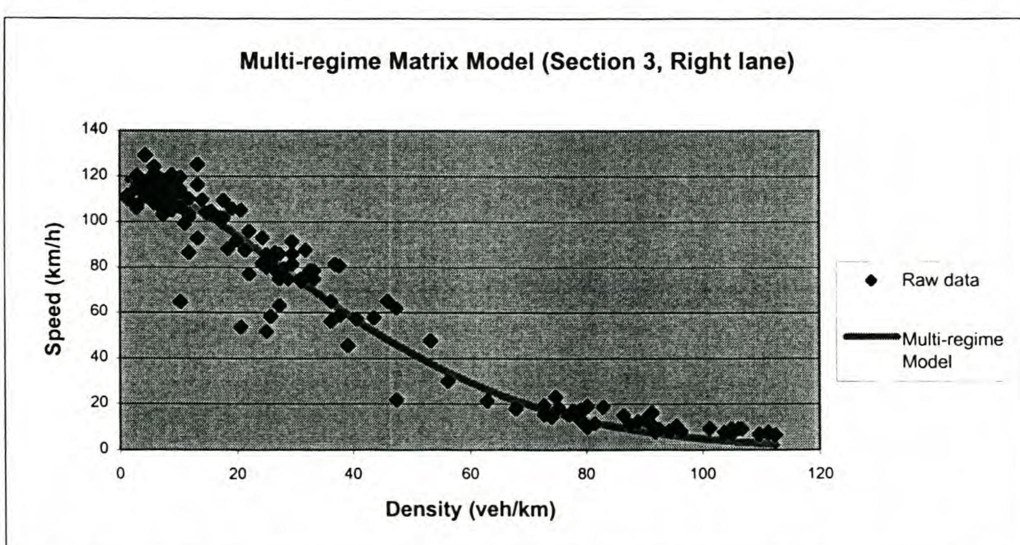

Figure B-40: Multi-regime curve fitted to right lane data (section 3)

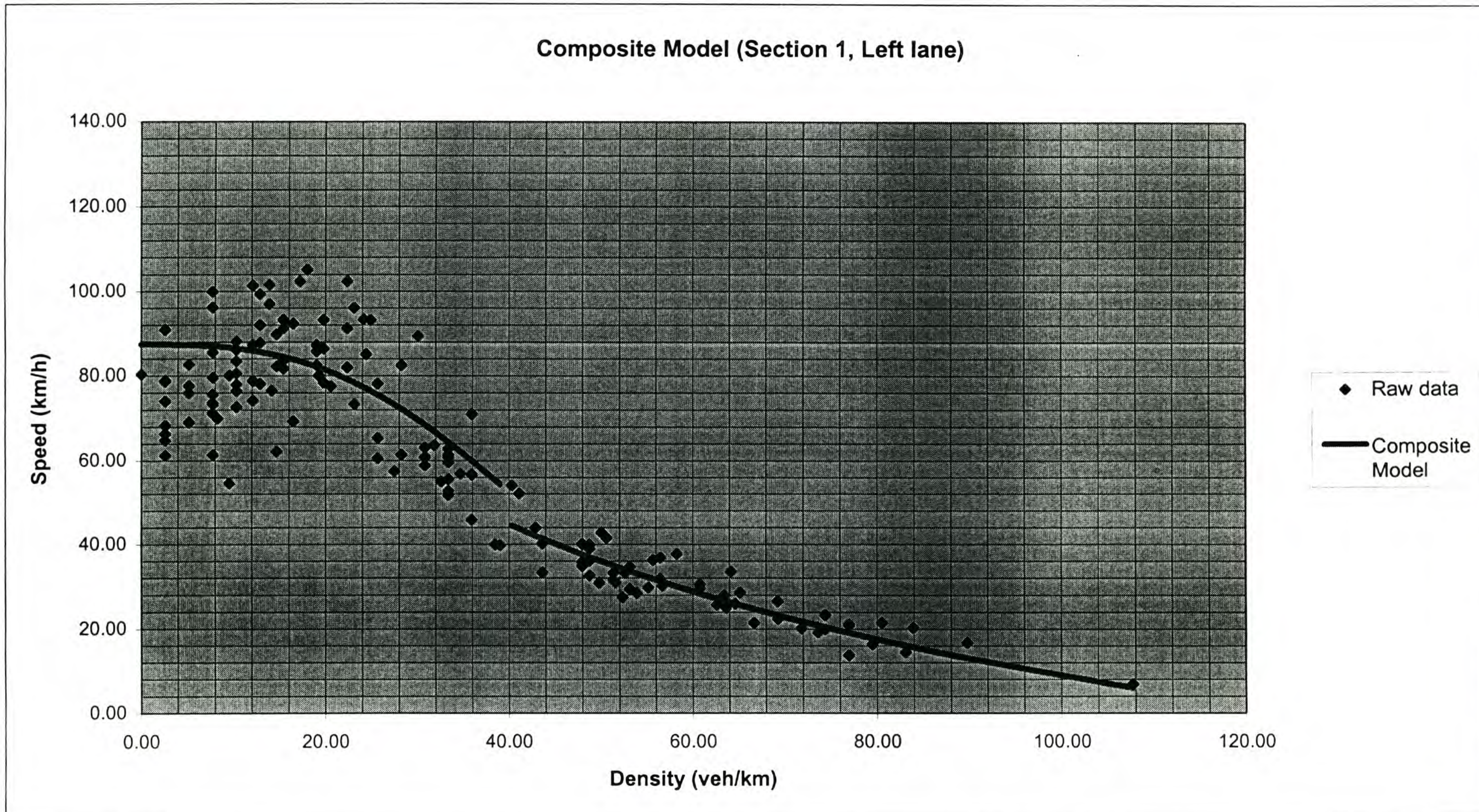

Figure B-41: Composite curve fitted to left lane data (section 1)

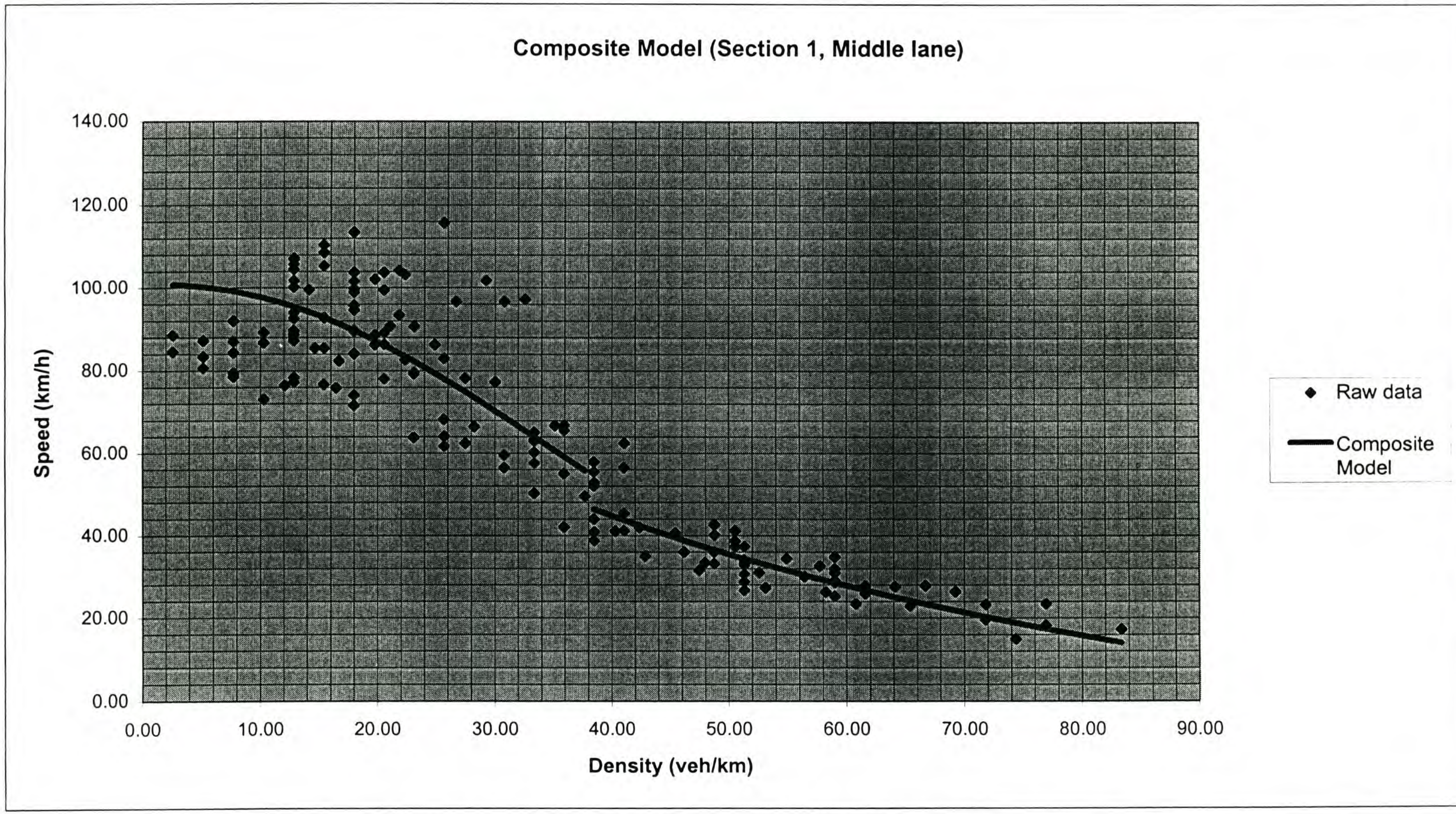

Figure B-42: Composite curve fitted to middle lane data (section 1)

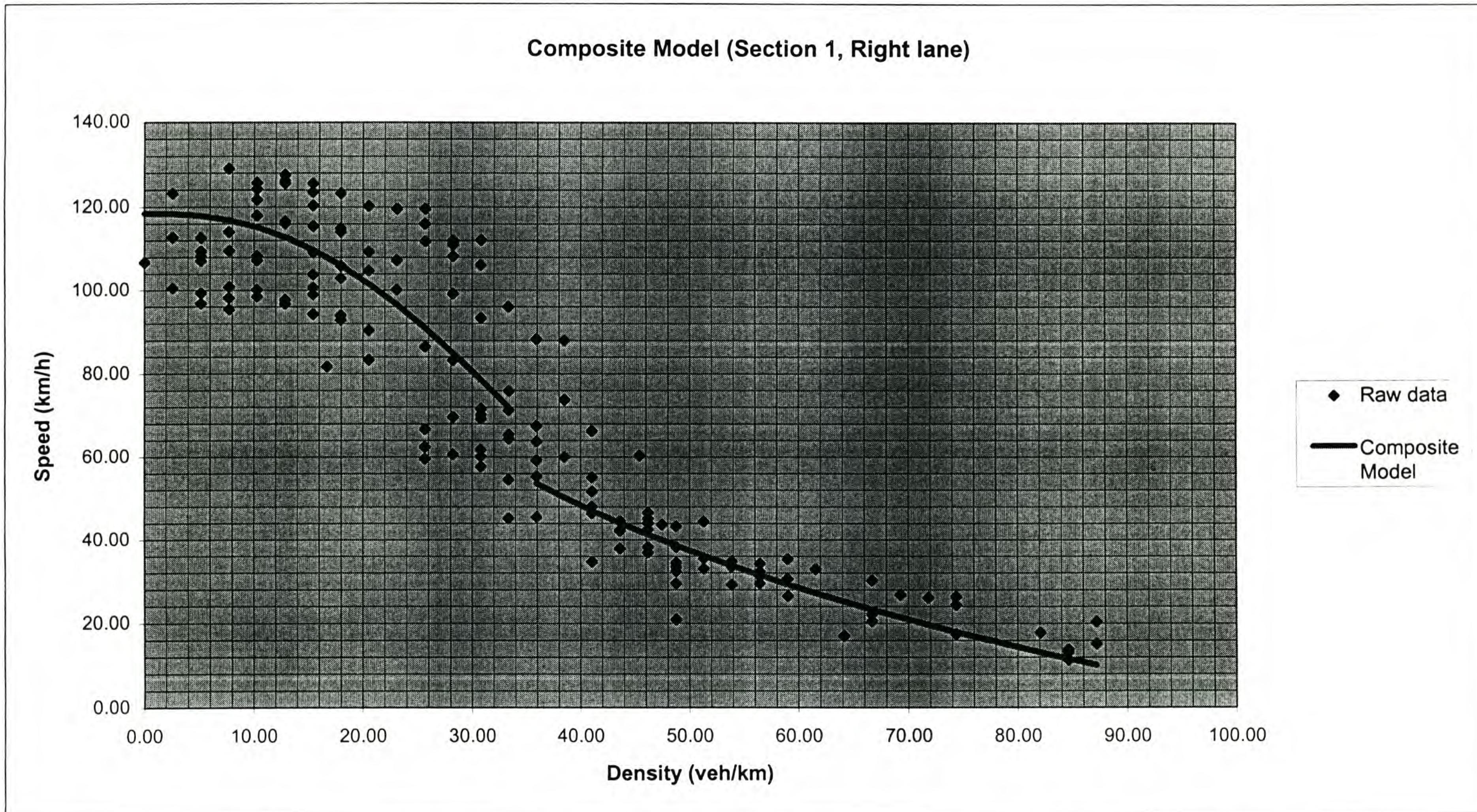

Figure B-43: Composite curve fitted to right lane data (section 1)

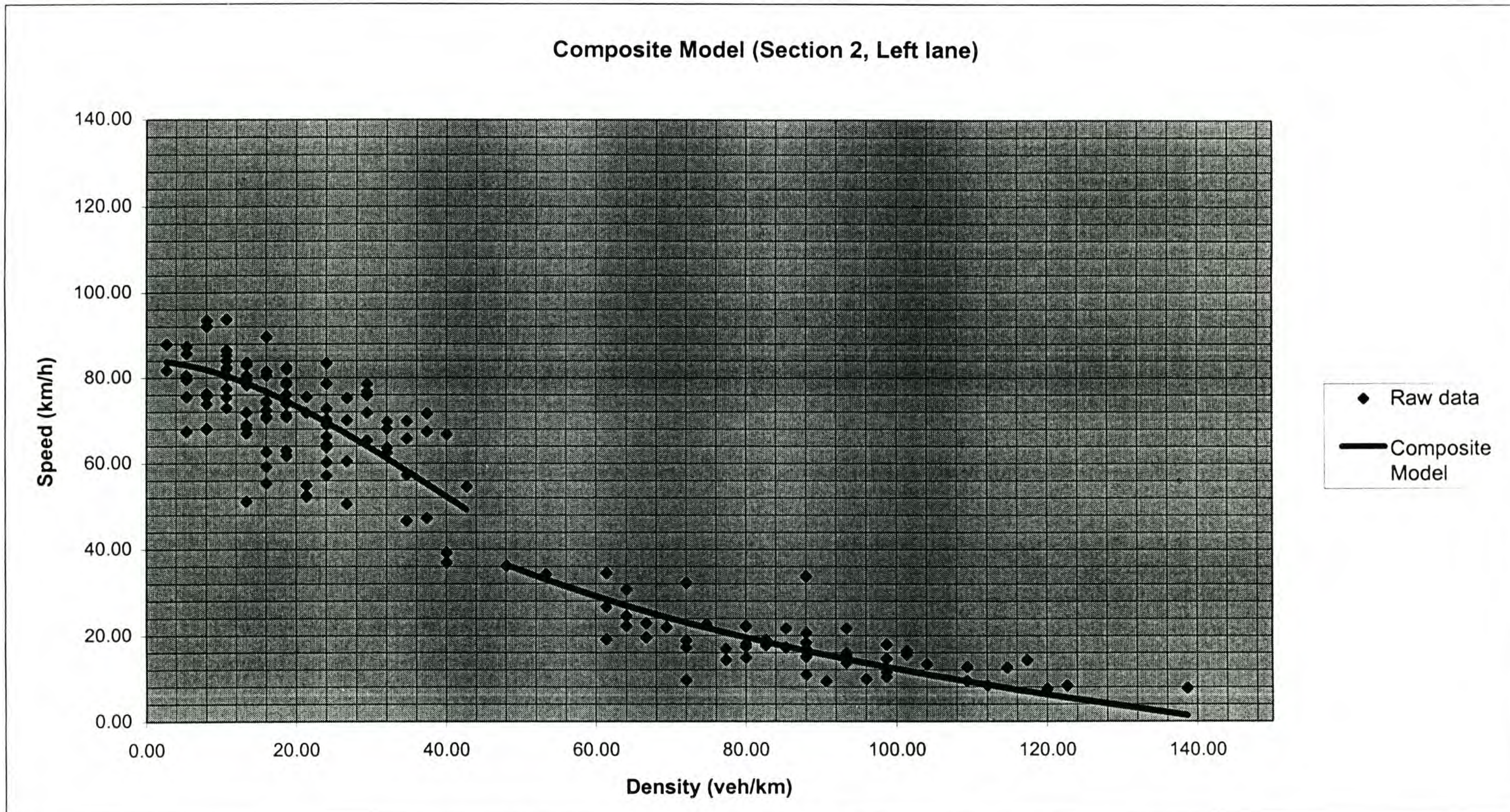

Figure B-44: Composite curve fitted to left lane data (section 2)

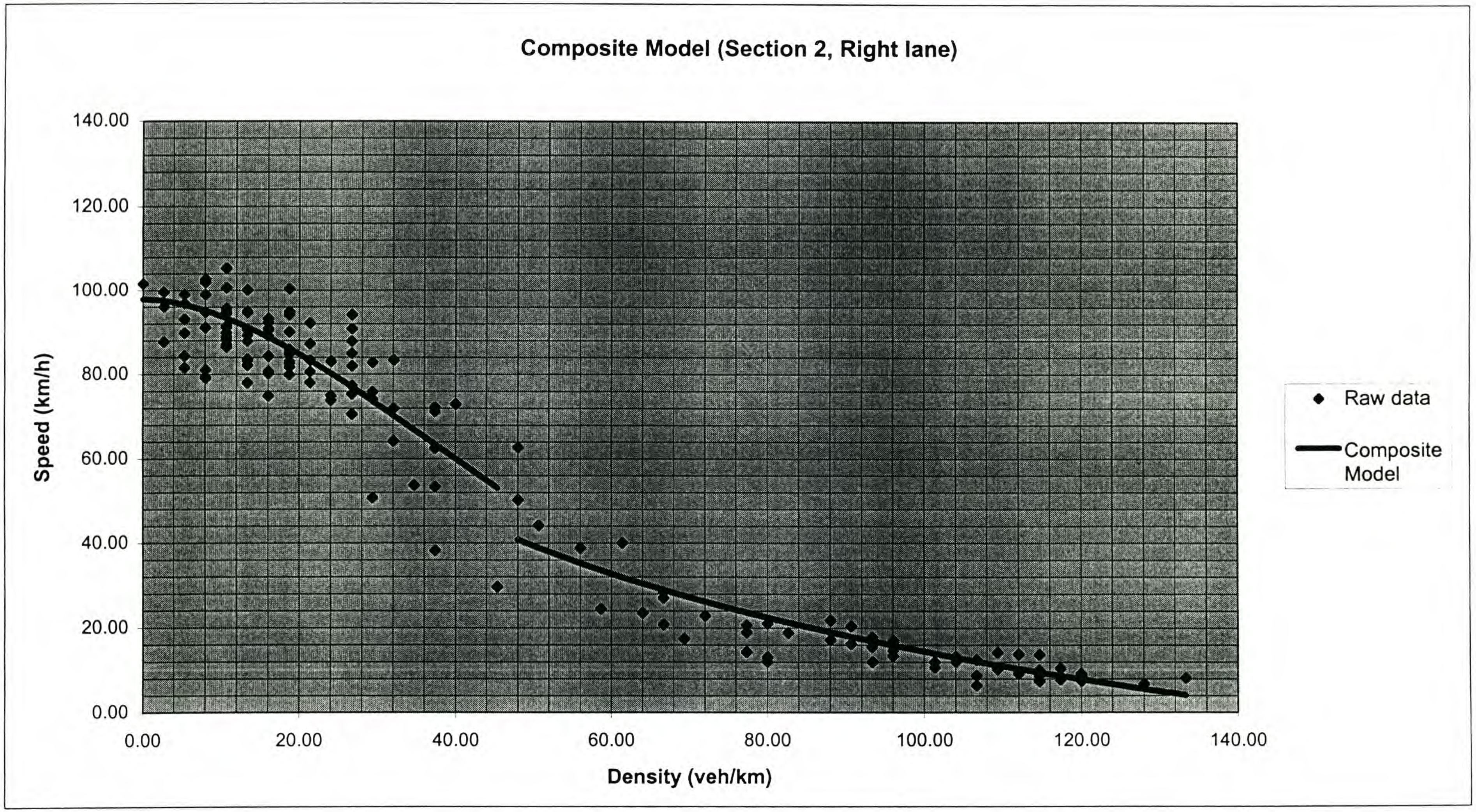

Figure B-45: Composite curve fitted to right lane data (section 2)

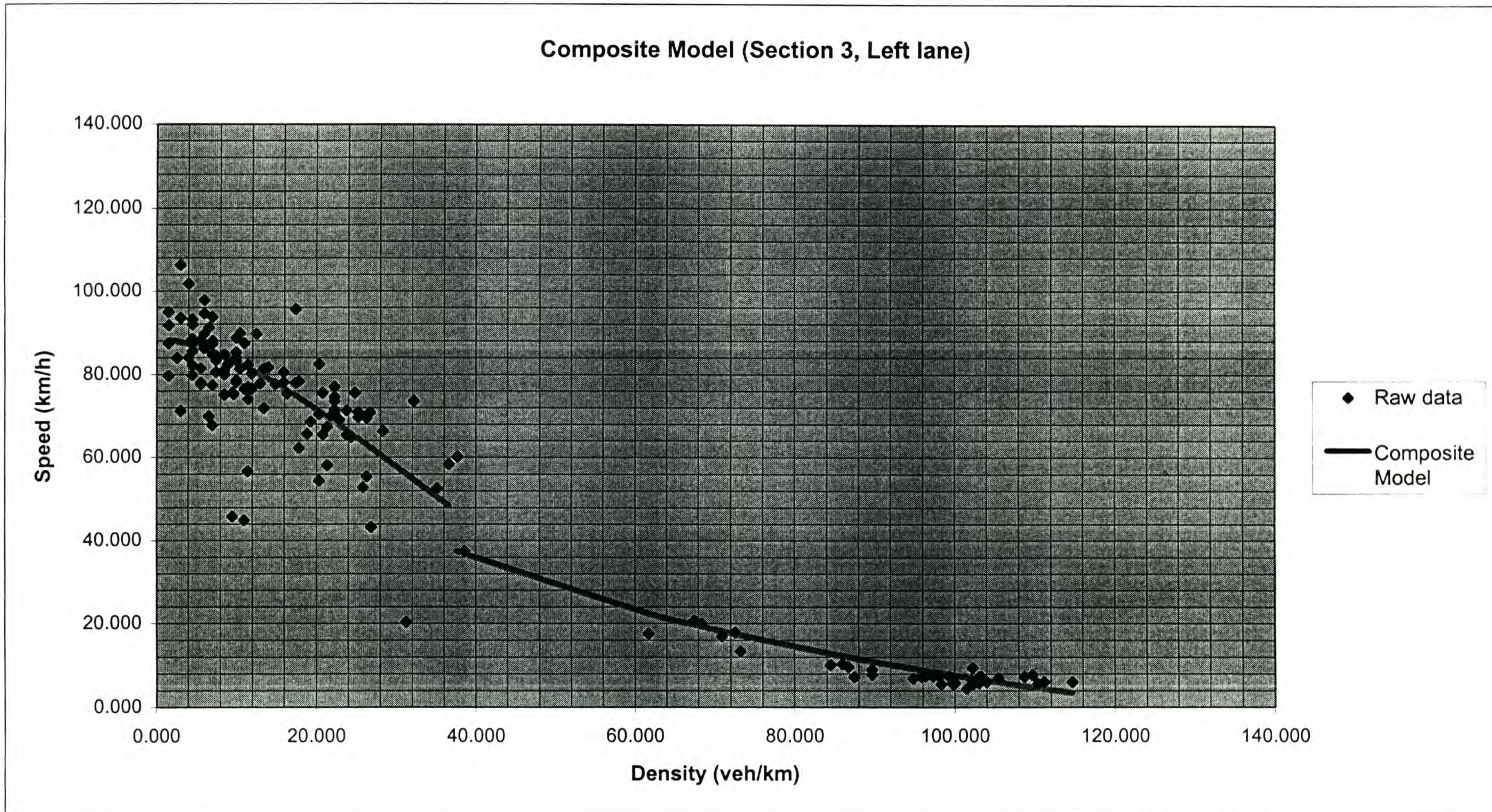

Figure B-46: Composite curve fitted to left lane data (section 3)

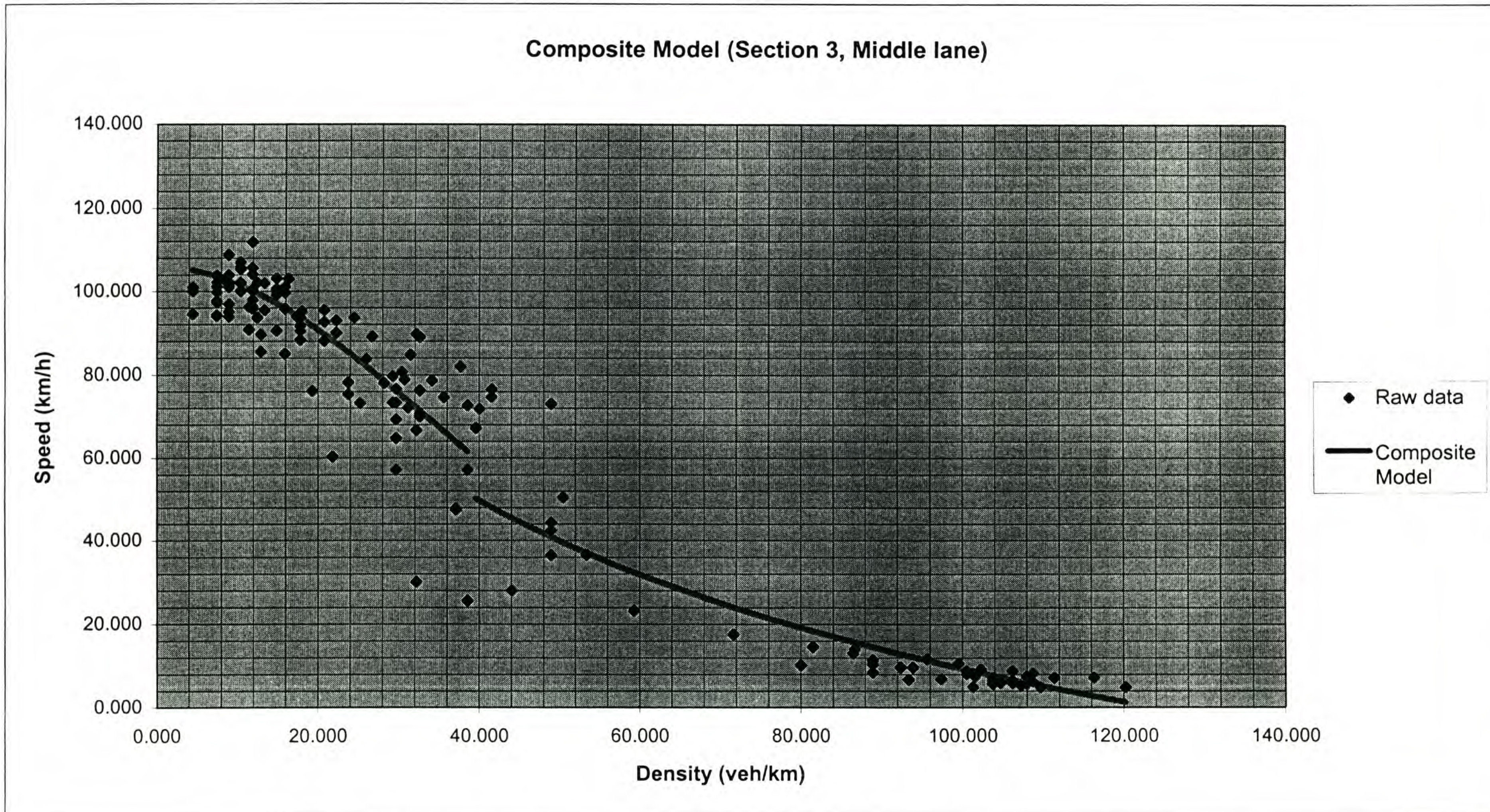

Figure B-47: Composite curve fitted to middle lane data (section 3)

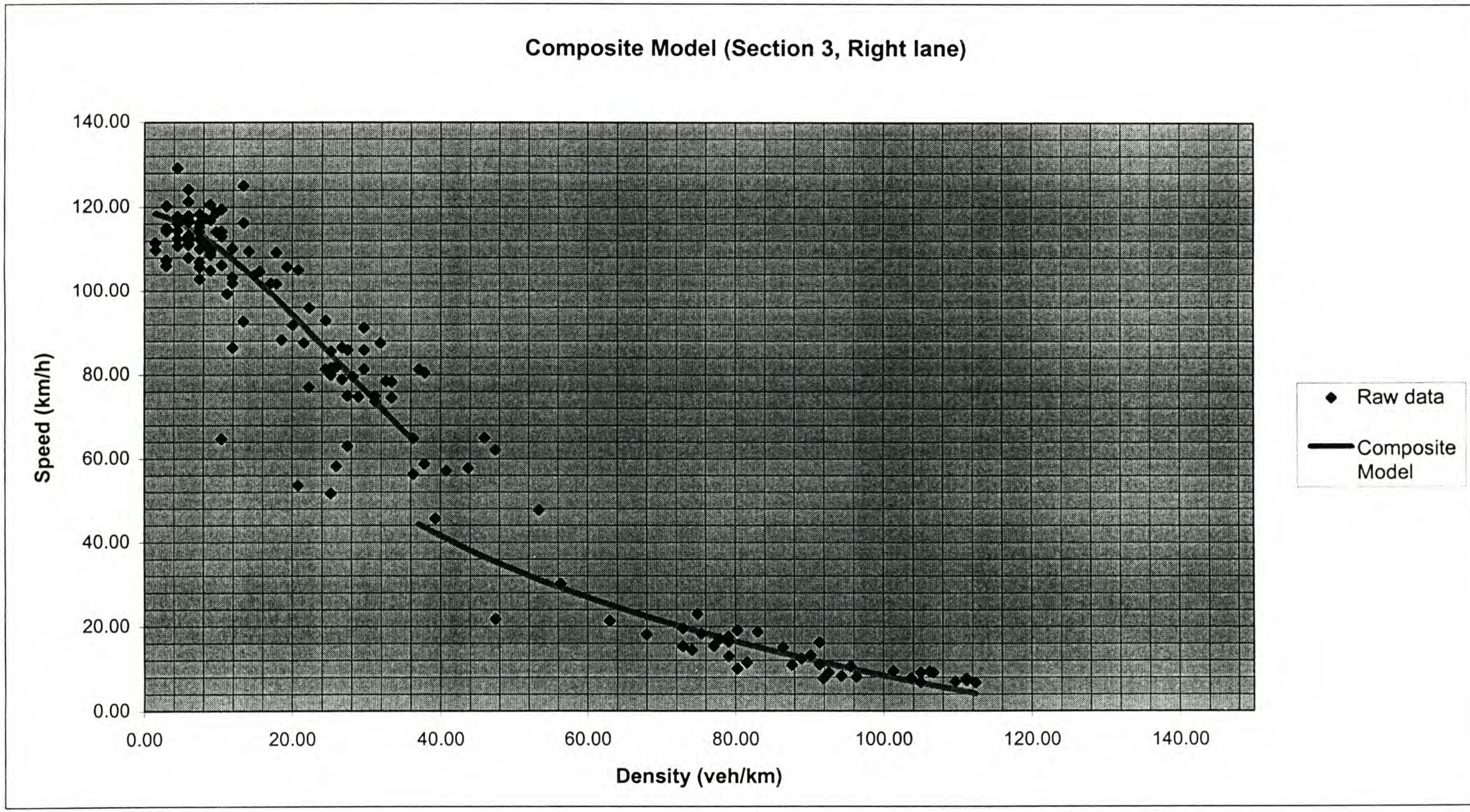

Figure B-48: Composite curve fitted to right lane data (section 3)

Table B-4: Regression Analysis data for average lanes

Regression Analysis data for average lanes (Section 1 - N1 near Century City)									
Model	**Equation**	***m***	***l***	**U_0**	**K_0**	**C**	**U_f**	**K_j**	**R^2**
Greenberg	$U = U_0.Ln(K_j/K)$	0	1	45.81				110.95	0.582
Multi-regime	$U^{1-M} = U_f^{1-M}+C.K^{L-1}$	1.074	3.779			1.22E-06	100.00		0.828
Composite	Low Densities: Multi-regime / High Densities: Greenberg								0.817
Regression Analysis data for average lanes (Section 2 - N1 near R300)									
Model	**Equation**	***m***	***l***	**U_0**	**K_0**	**C**	**U_f**	**K_j**	**R^2**
Greenberg	$U = U_0.Ln(K_j/K)$	0	1	35.04				143.02	0.784
Multi-regime	$Ln(U_f/U) = C.K^{L-1}$	1	2.782			7.09E-04	92.13		0.925
Composite	Low Densities: Multi-regime / High Densities: Greenberg								0.923
Regression Analysis data for average lanes (Section 3 - N2 near Athlone Power Station)									
Model	**Equation**	***m***	***l***	**U_0**	**K_0**	**C**	**U_f**	**K_j**	**R^2**
Greenberg	$U = U_0.Ln(K_j/K)$	0	1	36.43				123.35	0.800
Multi-regime	$Ln(U_f/U) = C.K^{L-1}$	1	2.959			4.76E-04	103.81		0.895
Composite	Low Densities: Multi-regime / High Densities: Greenberg								0.880

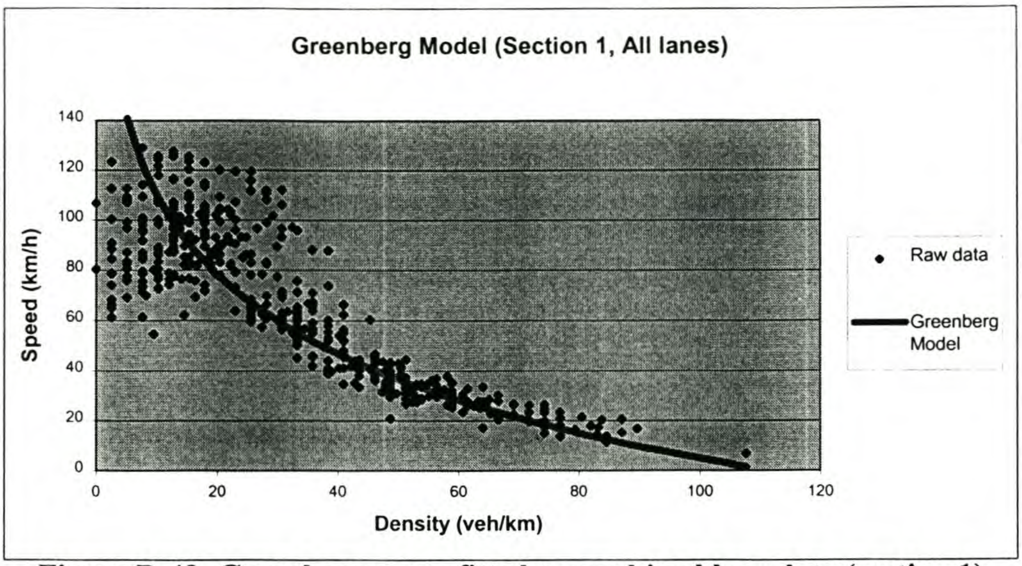

Figure B-49: Greenberg curve fitted to combined lane data (section 1)

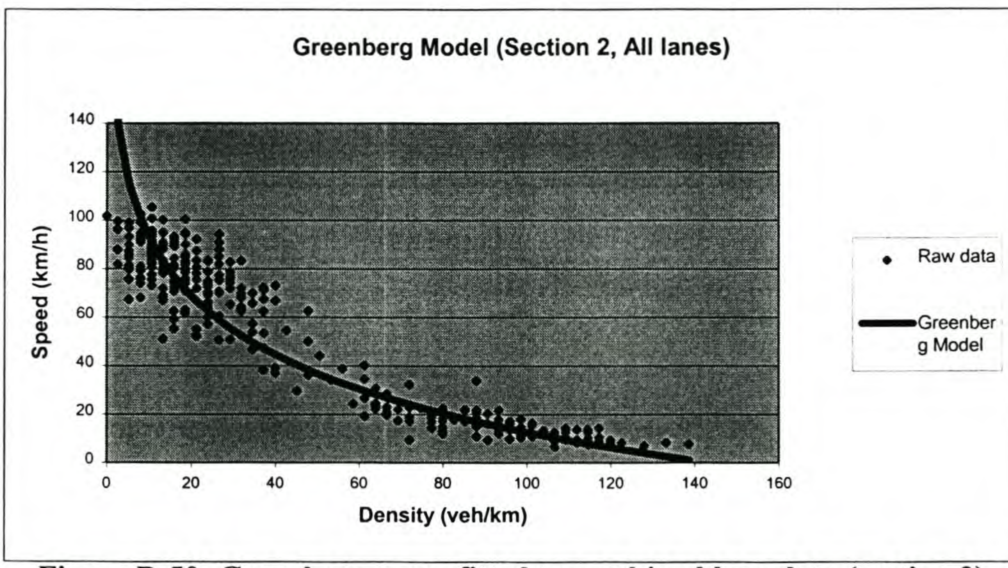

Figure B-50: Greenberg curve fitted to combined lane data (section 2)

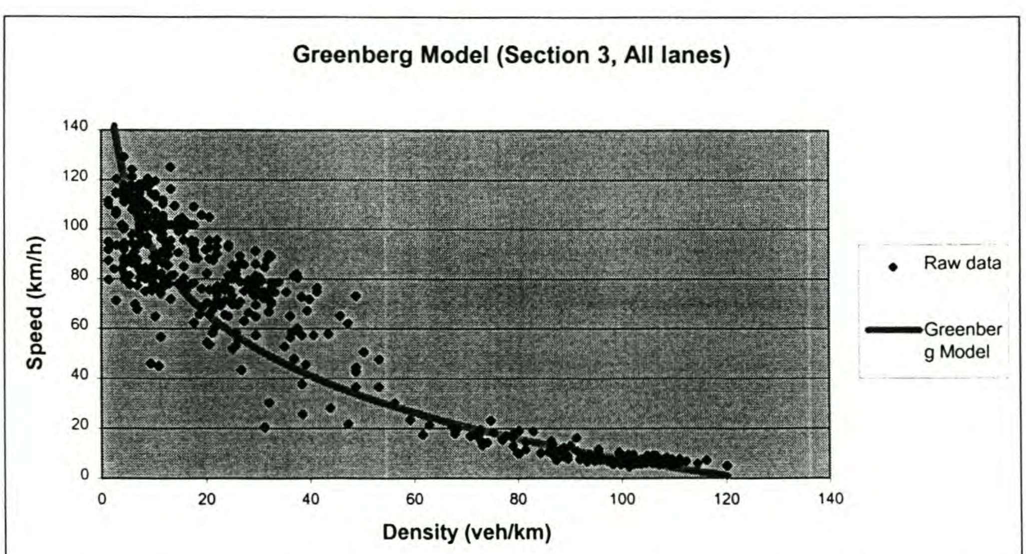

Figure B-51: Greenberg curve fitted to combined lane data (section 3)

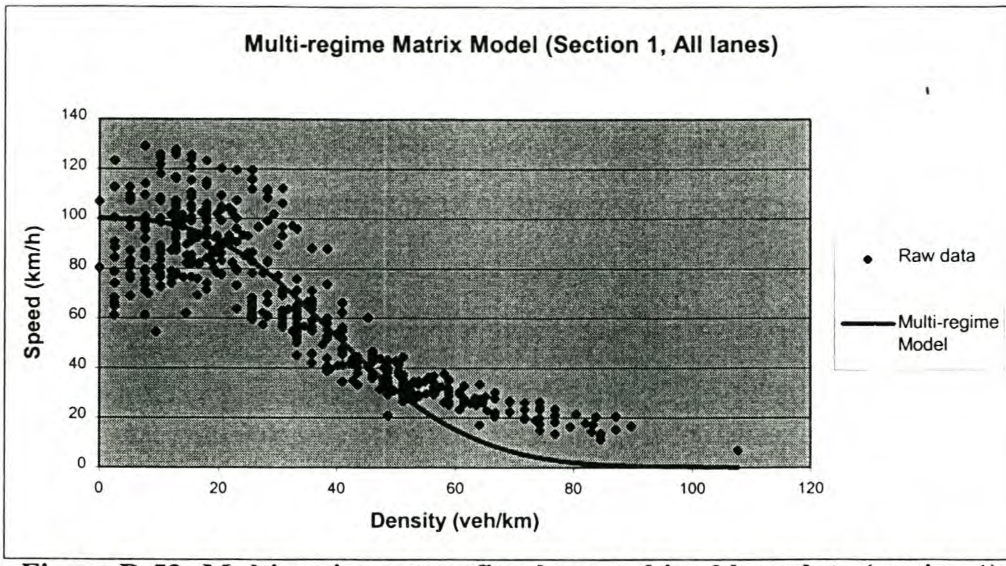

Figure B-52: Multi-regime curve fitted to combined lane data (section 1)

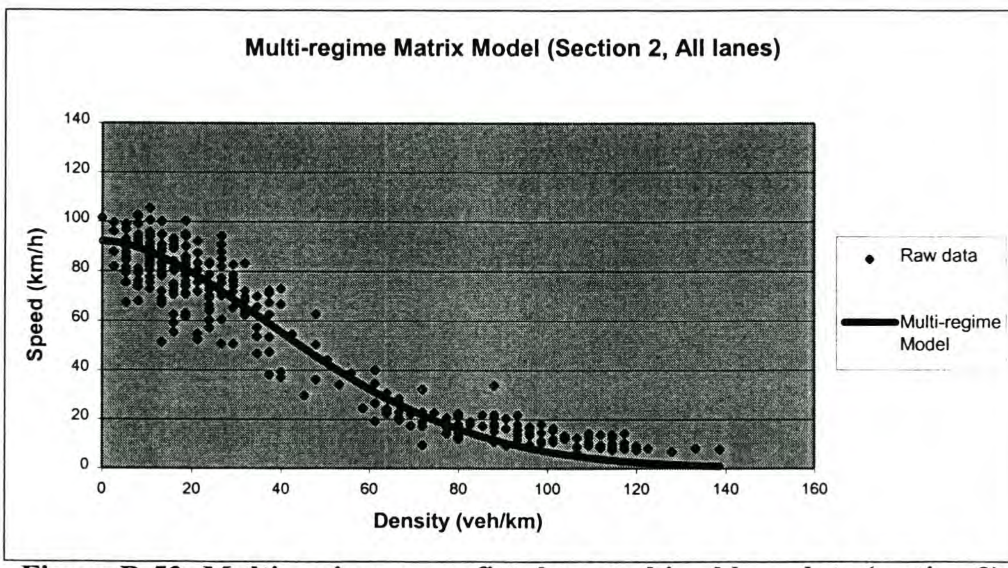

Figure B-53: Multi-regime curve fitted to combined lane data (section 2)

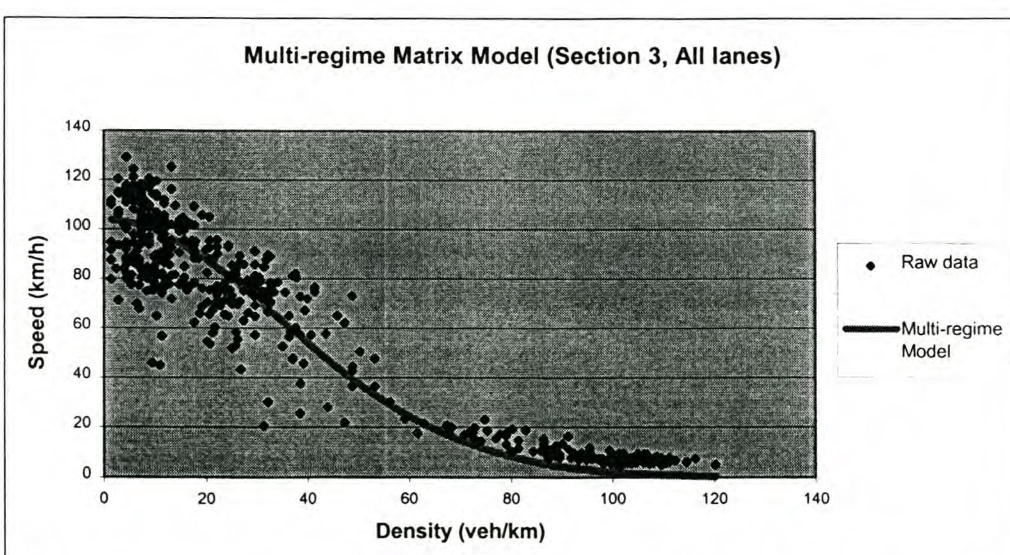

Figure B-54: Multi-regime curve fitted to combined lane data (section 3)

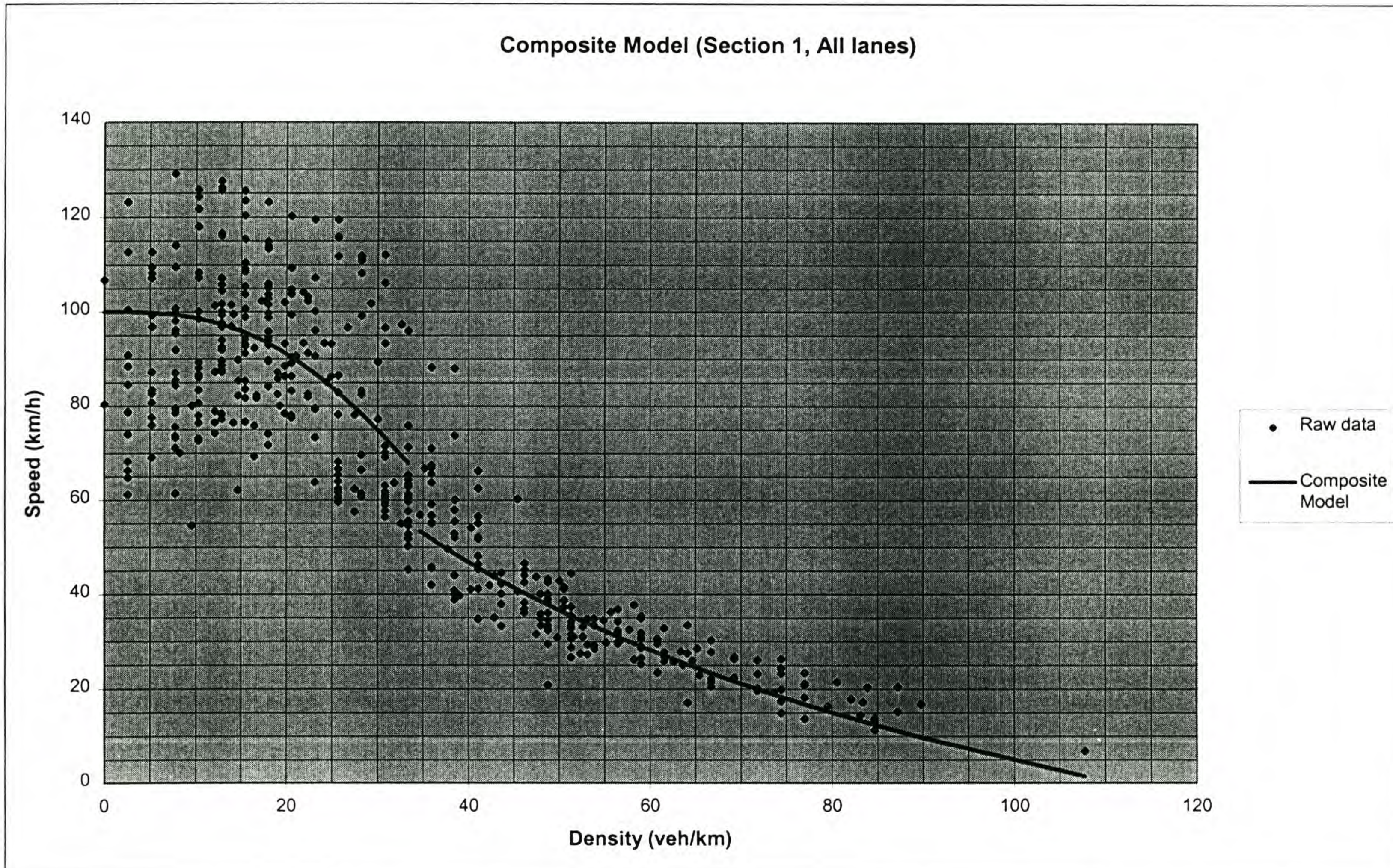

Figure B-55: Composite curve fitted to combined lane data (section 1)

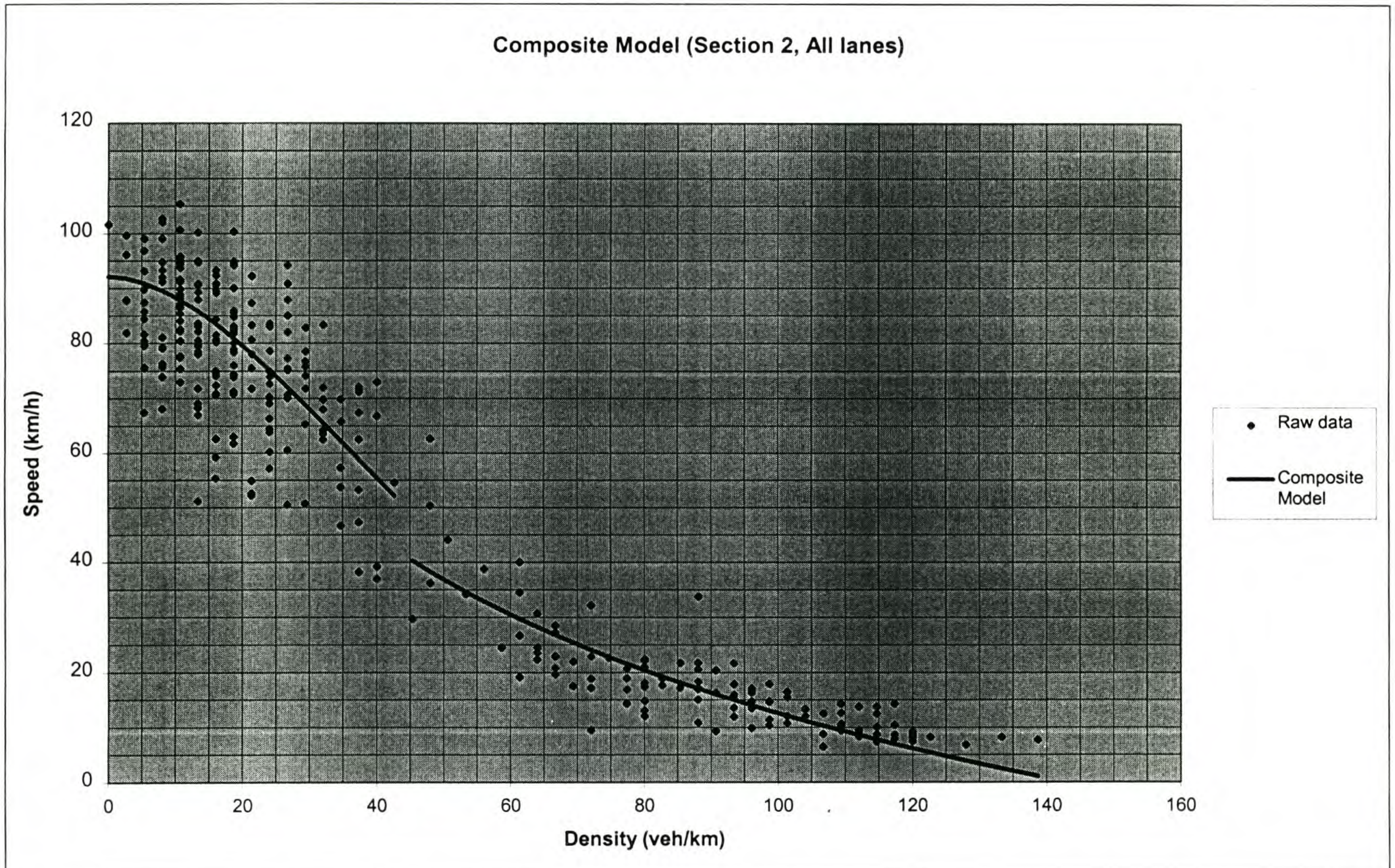

Figure B-56: Composite curve fitted to combined lane data (section 2)

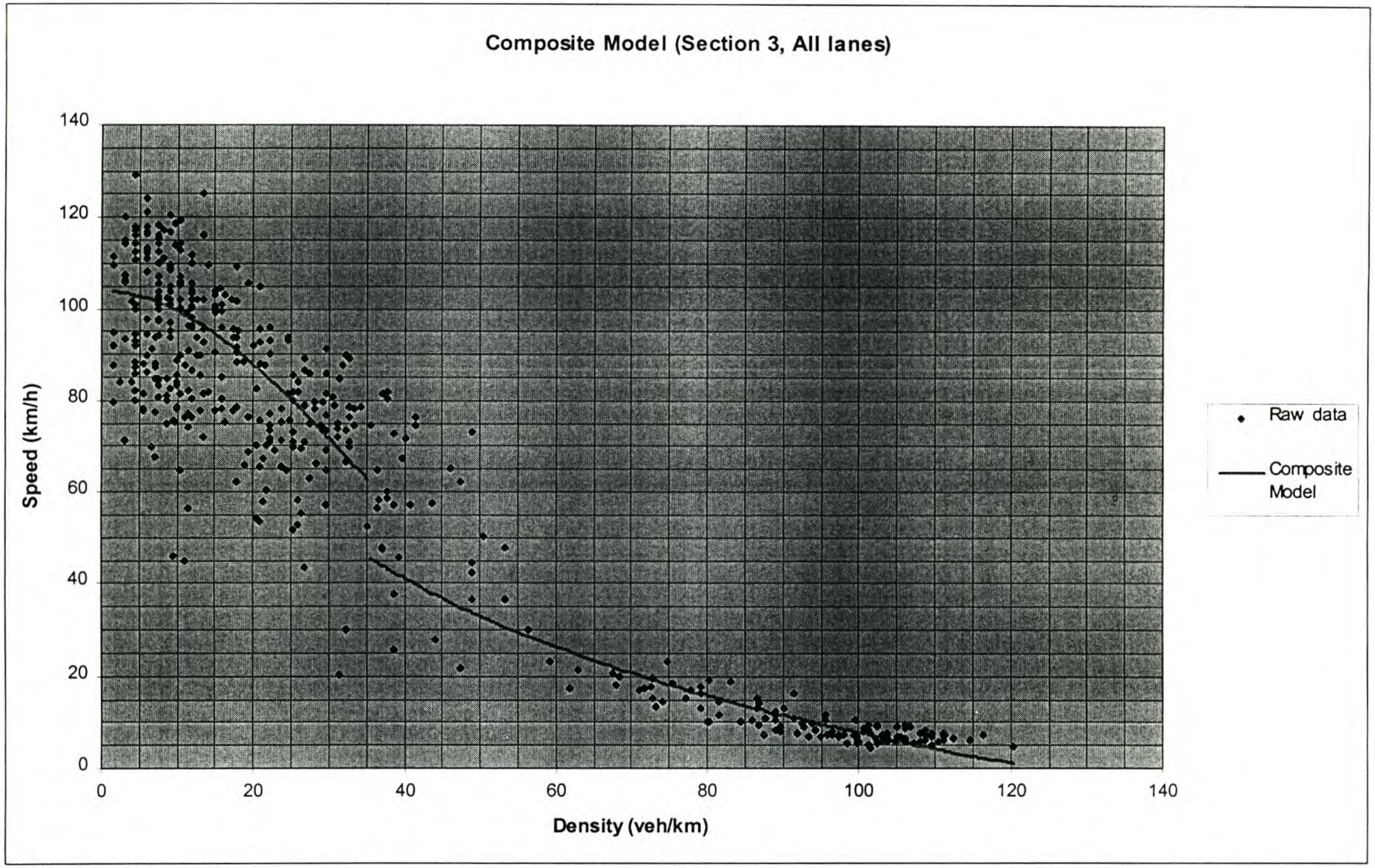

Figure B-57: Composite curve fitted to combined lane data (section 3)

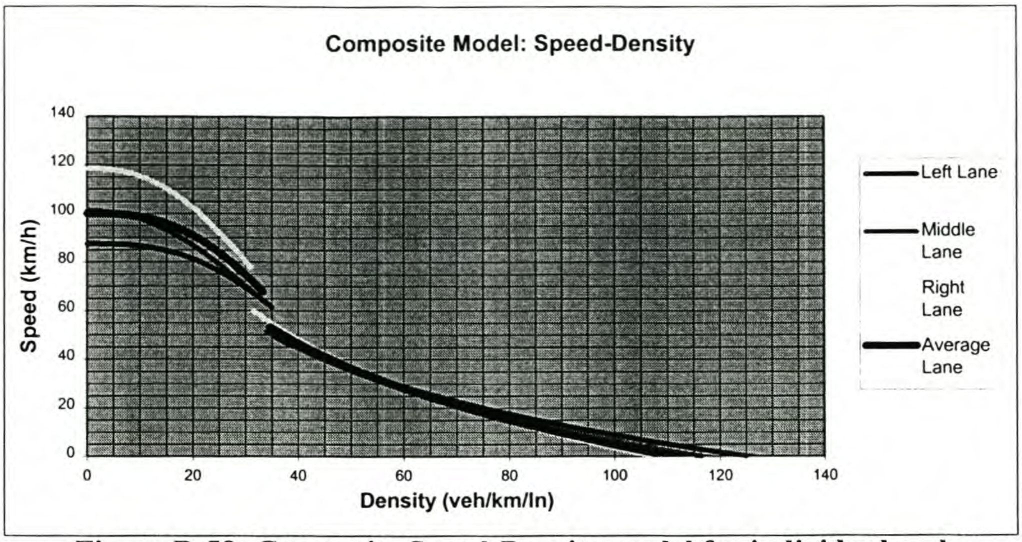

Figure B-58: Composite Speed-Density model for individual and average lane data (Section 1)

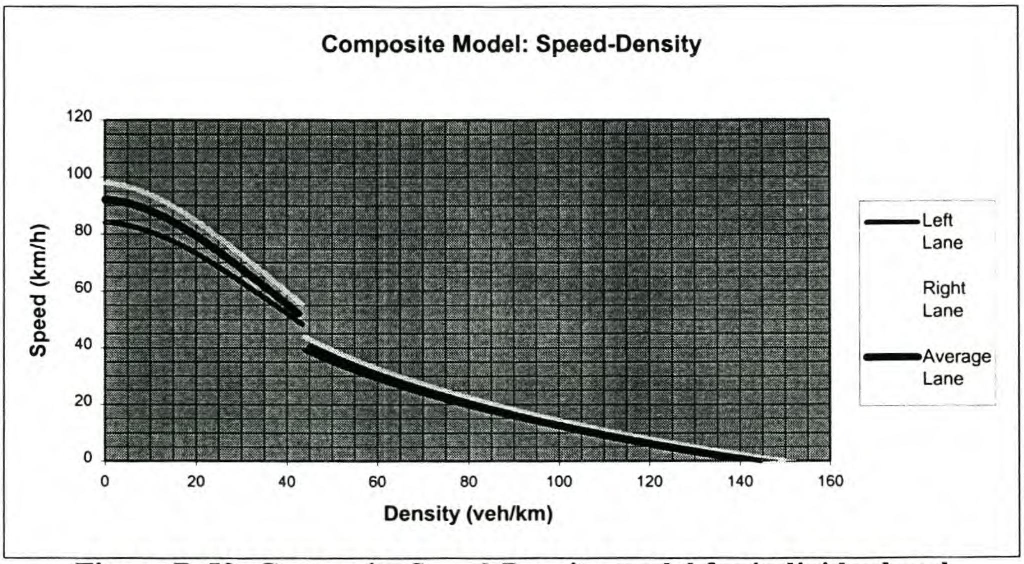

Figure B-59: Composite Speed-Density model for individual and average lane data (Section 2)

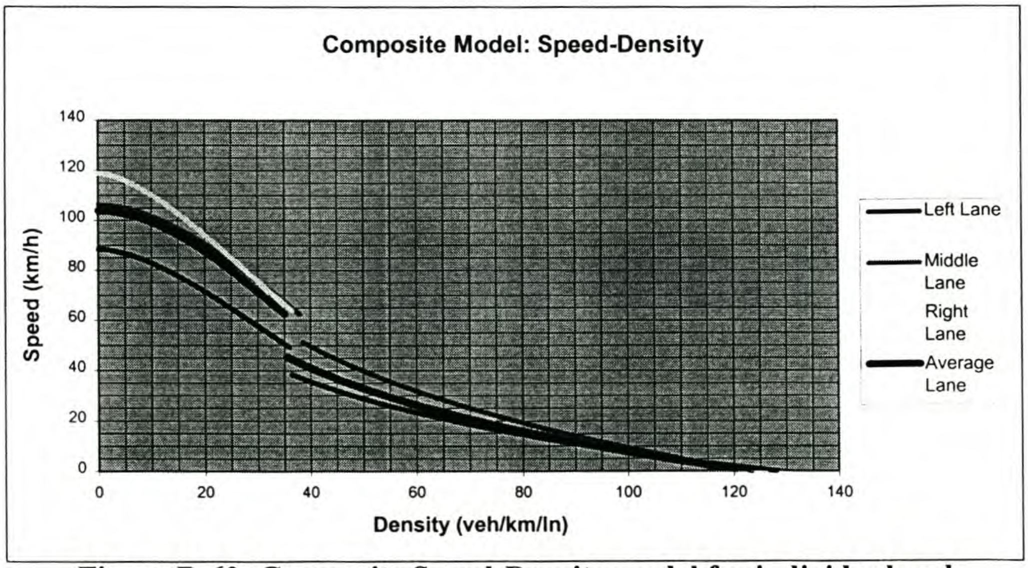

Figure B-60: Composite Speed-Density model for individual and average lane data (Section 3)

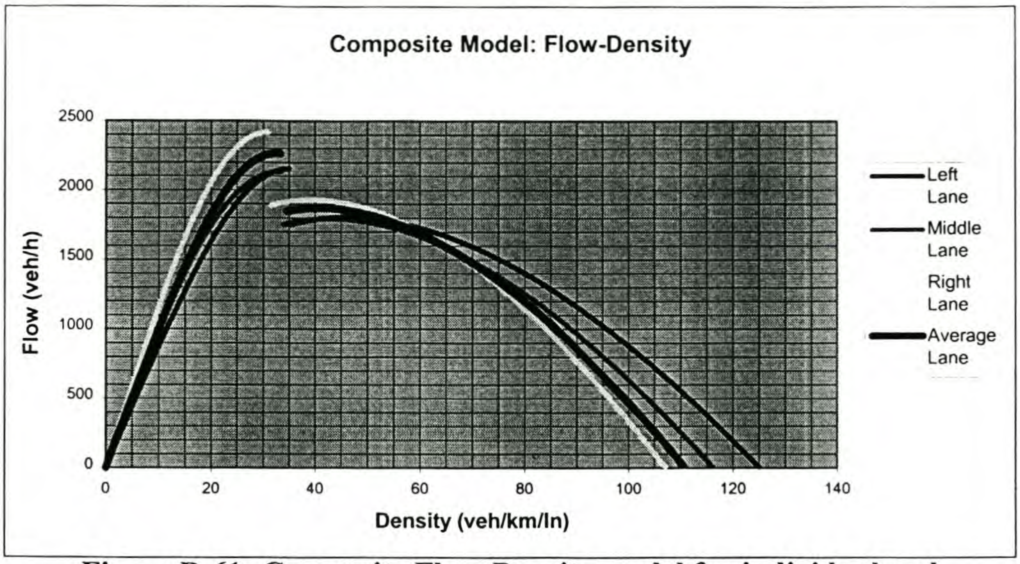

Figure B-61: Composite Flow-Density model for individual and average lane data (Section 1)

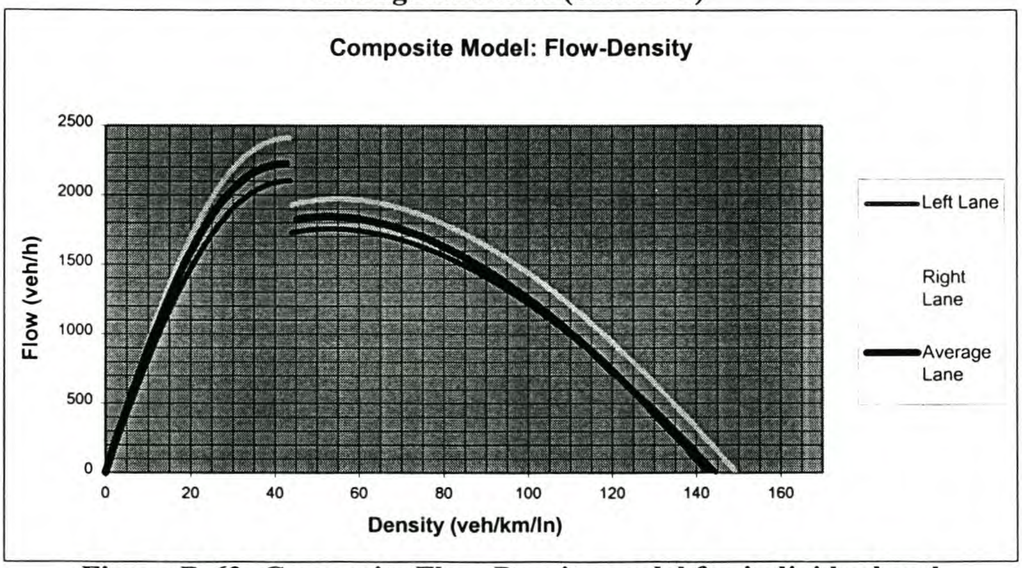

Figure B-62: Composite Flow-Density model for individual and average lane data (Section 2)

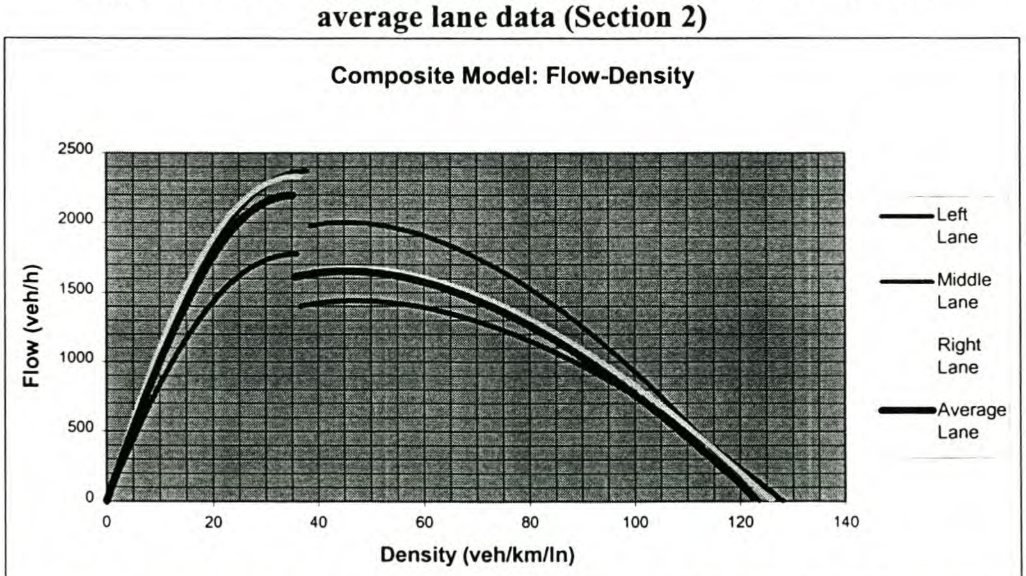

Figure B-63: Composite Flow-Density model for individual and average lane data (Section 3)

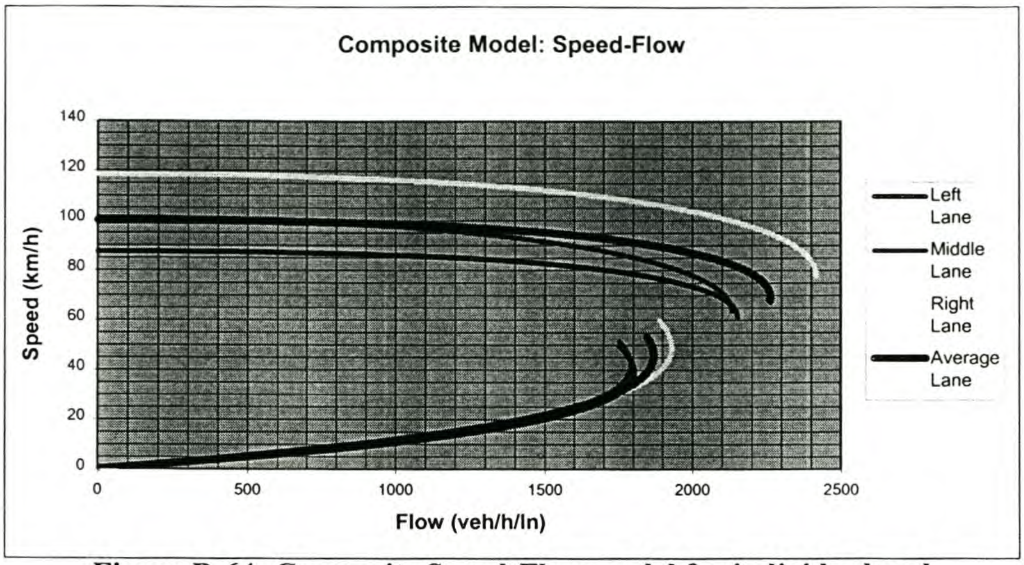

Figure B-64: Composite Speed-Flow model for individual and average lane data (Section 1)

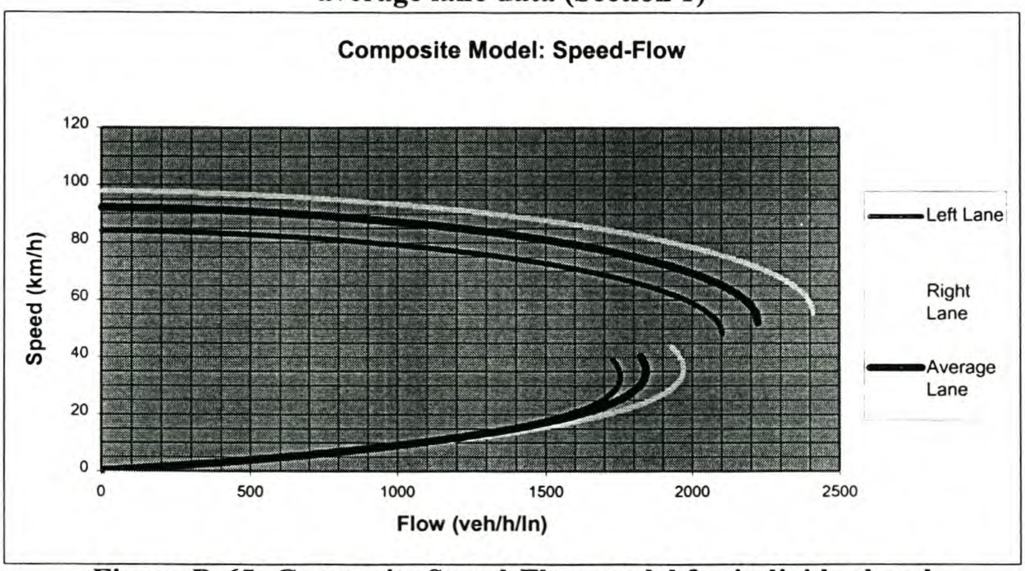

Figure B-65: Composite Speed-Flow model for individual and average lane data (Section 2)

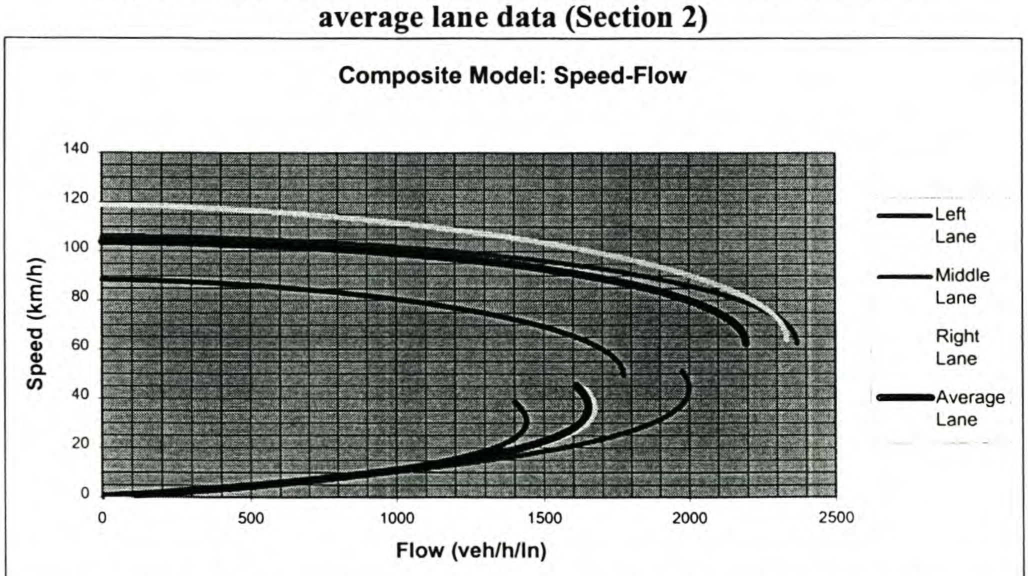

Figure B-66: Composite Speed-Flow model for individual and average lane data (Section 3)

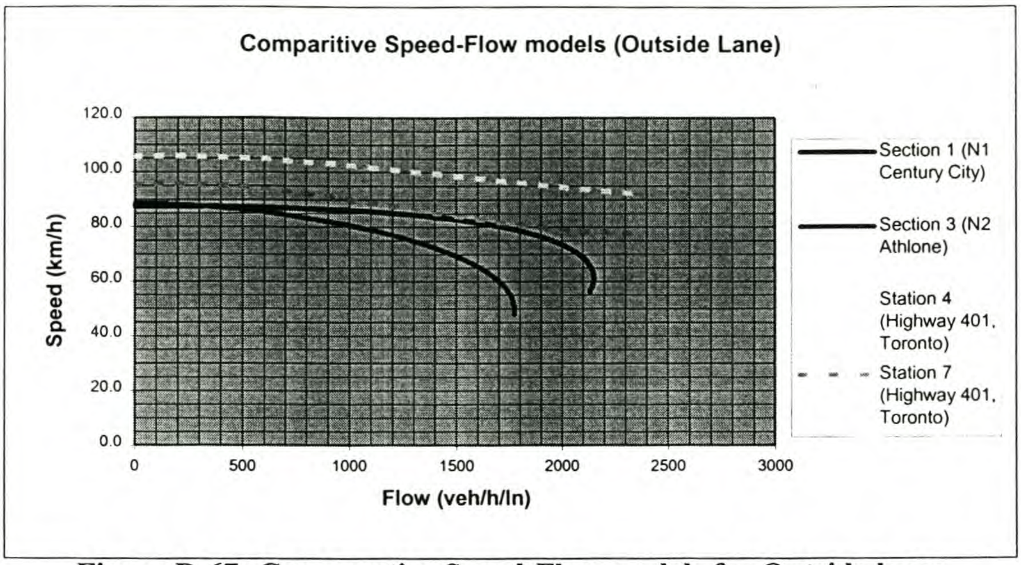

Figure B-67: Comparative Speed-Flow models for Outside lanes

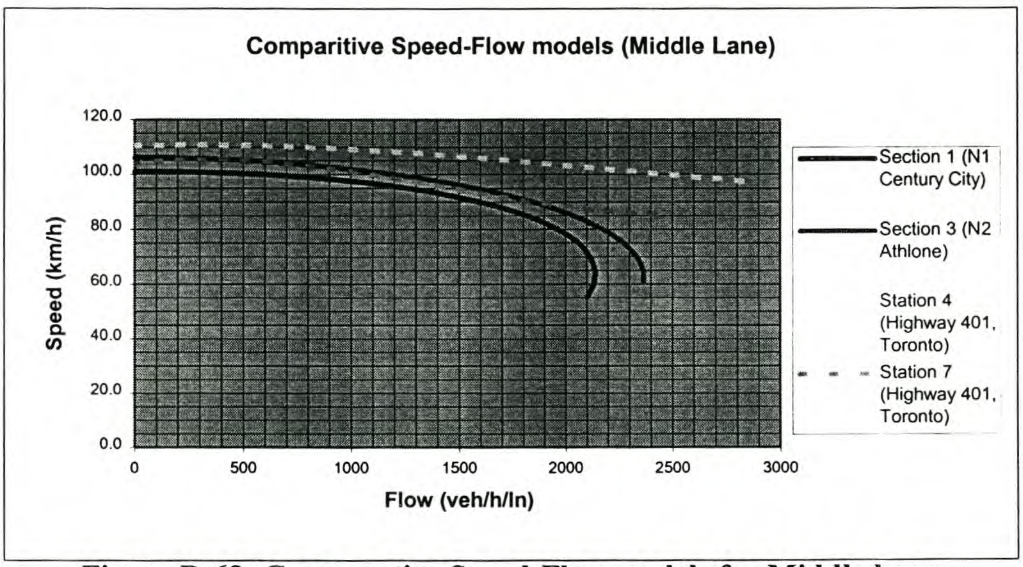

Figure B-68: Comparative Speed-Flow models for Middle lanes

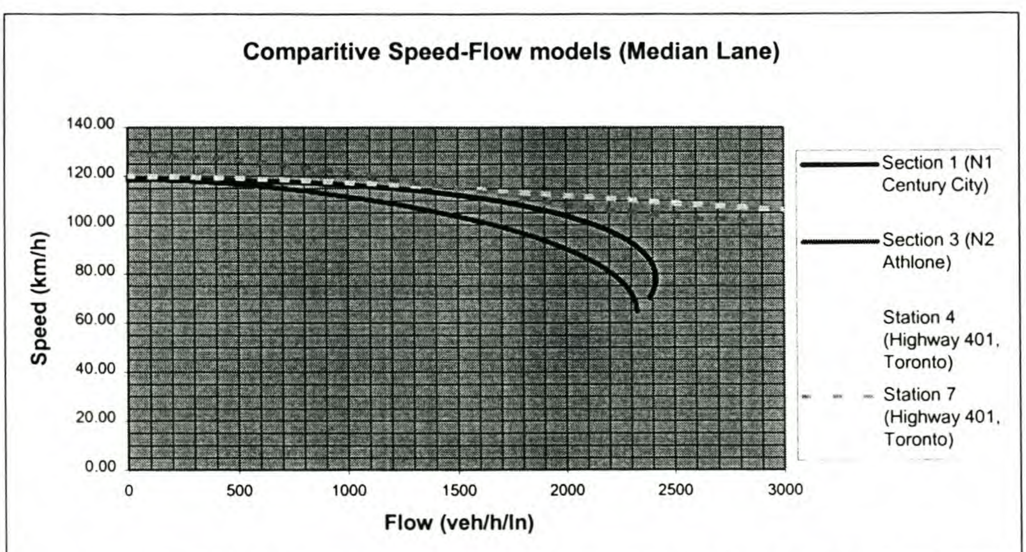

Figure B-69: Comparative Speed-Flow models for Median lanes

Appendix C

Travel-Time and Travel Cost Data

APPENDIX C

Occupancy:
- Passenger cars = 1.831 pass.
- Taxis = 16 pass.
- Buses = 0.9*(85) pass.
- Trucks = 2 pass.

Table C-1.1: Method of acquiring Passenger travel-times for Current situation (Steps 1 through 4)

5min. Intervals	Observed pcu's per 5min. Interval			Step 1: Average Flow Q (pcu's/h)			Step 2: Calculated Density (pcu/km)			Step 3: Calculated Avg. PCU Speed U (km/h)			Step 4: Calculated average Travel Time (sec/km/veh)		
	left	middle	right	left	middle	right	Left	middle	right	left	middle	right	left	middle	right
06:32 - 06:36	64	134	100	768.0	1604.4	1200.0	9.2	17.0	11.0	83.62	94.50	108.80	43	38	33
06:37 - 06:41	79	150	105	945.6	1795.2	1254.0	11.6	19.7	11.6	81.31	90.96	107.96	44	40	33
06:42 - 06:46	95	186	165	1142.4	2227.2	1980.0	14.6	28.7	21.8	78.08	77.61	91.02	46	46	40
06:47 - 06:51	116	189	187	1387.2	2265.6	2240.4	19.1	30.0	28.6	72.64	75.50	78.35	50	48	46
06:52 - 06:56	102	188	183	1221.6	2260.8	2198.4	16.0	29.8	27.1	76.53	75.78	81.16	47	48	44
06:57 - 07:01	112	190	185	1339.2	2281.2	2221.2	18.1	30.6	27.9	73.88	74.51	79.70	49	48	45
07:02 - 07:06	123	186	187	1472.4	2236.8	2238.0	21.0	29.0	28.5	70.18	77.12	78.52	51	47	46
07:07 - 07:11	114	171	179	1366.8	2056.8	2148.0	18.7	24.4	25.6	73.18	84.30	83.96	49	43	43
07:12 - 07:16	109	158	172	1310.4	1892.4	2064.0	17.6	21.3	23.5	74.57	88.79	87.81	48	41	41
07:17 - 07:21	95	144	146	1137.6	1728.0	1756.8	14.6	18.7	18.0	78.17	92.30	97.75	46	39	37
07:22 - 07:26	70	67	84	834.0	808.8	1002.0	96.6	103.4	104.5	8.64	7.82	9.59	417	460	375
07:27 - 07:31	65	67	92	777.6	804.0	1107.6	99.1	103.6	101.0	7.85	7.76	10.97	459	464	328
07:32 - 07:36	73	65	93	880.8	776.4	1110.0	94.4	104.3	100.9	9.33	7.44	11.00	386	484	327
07:37 - 07:41	67	67	73	801.6	805.2	870.0	98.0	103.5	108.7	8.18	7.78	8.00	440	463	450
07:42 - 07:46	77	73	95	926.4	877.2	1134.0	92.2	101.2	100.1	10.05	8.67	11.33	358	415	318
07:47 - 07:51	50	51	58	597.6	606.0	692.4	106.6	108.9	114.0	5.61	5.57	6.07	642	647	593
07:52 - 07:56	57	70	80	684.0	841.2	954.0	103.1	102.5	106.0	6.64	8.21	9.00	543	439	400
07:57 - 08:01	39	70	74	471.6	844.8	888.0	111.5	102.4	108.1	4.23	8.25	8.21	851	436	438

Table C-1.2: Current situation (Step 5)

Step 5											
Passenger cars/lane per interval			Taxi's/lane per interval			Trucks/lane per interval			Buses/lane per interval		
left	middle	right	left	middle	right	left	middle	right	left	middle	right
43	125	80	8	7	17	5	1	0	3	0	2
71	138	74	1	5	20	4	3	0	0	1	7
82	166	121	3	13	26	6	3	0	0	1	12
96	172	137	6	10	27	8	4	1	0	0	14
86	178	124	9	7	44	4	2	1	0	0	9
95	179	127	3	6	38	8	3	3	0	0	10
109	174	129	2	9	41	6	2	0	1	0	11
93	163	129	9	5	41	7	2	0	0	0	6
91	148	117	8	8	46	6	1	0	0	0	6
83	135	86	5	9	45	4	0	2	0	0	8
57	57	51	4	7	28	5	2	0	0	0	3
53	63	56	5	4	22	4	0	4	0	0	5
66	56	60	4	7	28	2	1	0	0	0	3
49	55	35	11	7	30	4	3	0	0	0	5
63	60	60	4	8	27	6	3	0	0	0	5
37	34	24	6	8	23	4	5	1	0	0	6
43	60	56	4	5	19	5	3	0	1	0	3
21	59	57	3	8	17	9	2	0	0	0	0

Table C-1.3: Current situation (Step 6)

Step 6															
Passenger Cars				Taxi's				Trucks				Buses			
Total Pssngr. Car Travel Time (sec/km)				Total Taxi Travel Time (sec/km)				Total Truck Travel Time (sec/km)				Total Bus Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
1851	4762	2647	9260	344	267	563	1174	215	38	0	253	129	0	66	195
3143	5462	2468	11073	44	198	667	909	177	119	0	296	0	40	233	273
3781	7700	4786	16266	138	603	1028	1770	277	139	0	416	0	46	475	521
4758	8202	6295	19254	297	477	1241	2015	396	191	46	633	0	0	643	643
4046	8456	5500	18002	423	333	1952	2708	188	95	44	328	0	0	399	399
4629	8648	5736	19014	146	290	1716	2152	390	145	136	670	0	0	452	452
5591	8123	5914	19629	103	420	1880	2402	308	93	0	401	51	0	504	556
4575	6961	5531	17067	443	214	1758	2414	344	85	0	430	0	0	257	257
4393	6000	4797	15190	386	324	1886	2596	290	41	0	330	0	0	246	246
3822	5265	3167	12255	230	351	1657	2239	184	0	74	258	0	0	295	295
23756	26239	19147	69142	1667	3222	10512	15402	2084	921	0	3005	0	0	1126	1126
24310	29212	18380	71902	2293	1855	7221	11369	1835	0	1313	3148	0	0	1641	1641
25461	27086	19634	72181	1543	3386	9163	14092	772	484	0	1255	0	0	982	982
21569	25456	15741	62765	4842	3240	13492	21574	1761	1389	0	3149	0	0	2249	2249
22573	24926	19062	66561	1433	3323	8578	13335	2150	1246	0	3396	0	0	1589	1589
23764	21987	14228	59978	3854	5173	13635	22662	2569	3233	593	6395	0	0	3557	3557
23329	26325	22409	72064	2170	2194	7603	11967	2713	1316	0	4029	543	0	1201	1743
17878	25751	24986	68614	2554	3492	7452	13497	7662	873	0	8535	0	0	0	0

Table C-1.4: Current situation (Step 7)

Step 7															
Passenger Car passengers				Taxi passengers				Truck passengers				Bus passengers			
Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
3390	8720	4847	16958	5511	4267	9000	18778	431	76	0	507	9881	0	5063	14944
5756	10002	4519	20277	708	3166	10671	14546	354	237	0	592	0	3028	17857	20885
6923	14100	8764	29787	2213	9648	16453	28315	553	278	0	832	0	3549	36308	39857
8712	15019	11528	35259	4758	7629	19850	32237	793	381	92	1266	0	0	49212	49212
7408	15484	10072	32965	6774	5320	31228	43323	376	190	89	655	0	0	30541	30541
8477	15836	10505	34818	2339	4638	27463	34440	780	290	271	1341	0	0	34554	34554
10239	14875	10830	35944	1642	6722	30075	38439	616	187	0	802	3924	0	38579	42504
8378	12747	10129	31254	7084	3416	28128	38629	689	171	0	860	0	0	19681	19681
8045	10988	8784	27817	6179	5190	30174	41543	579	81	0	660	0	0	18818	18818
7000	9642	5800	22442	3684	5616	26517	35818	368	0	147	516	0	0	22540	22540
43502	48049	35063	126613	26673	51557	168196	246427	4168	1841	0	6009	0	0	86163	86163
44517	53492	33658	131667	36694	29675	115532	181902	3669	0	2626	6295	0	0	125543	125543
46624	49600	35955	132178	24689	54172	146604	225465	1543	967	0	2510	0	0	75102	75102
39496	46615	28824	114936	77471	51838	215870	345179	3521	2777	0	6298	0	0	172022	172022
41336	45644	34907	121886	22931	53175	137247	213353	4300	2493	0	6792	0	0	121521	121521
43516	40262	26054	109832	61657	82774	218162	362593	5138	6467	1186	12790	0	0	272110	272110
42721	48207	41036	131964	34723	35100	121651	191474	5425	2633	0	8058	41505	0	91838	133343
32738	47155	45754	125647	40863	55866	119231	215960	15324	1746	0	17069	0	0	0	0
			1,282,243	**sec**			**2,308,417**	**sec**			**73,853**	**sec**			**1,279,338**

Table C-1.5: Average Passenger (and Vehicle) travel-times for Current situation

Step 8								
5 min. Intervals	Average Travel-Time: All lanes (sec/km)							
	Passenger Cars	% of 1½ hour Flow	Taxi's	% of 1½ hour Flow	Trucks	% of 1½ hour Flow	Buses	% of 1½ hour Flow
06:32 - 06:36	37	74%	37	62%	42	58%	39	75%
06:37 - 06:41	39		35		42		34	
06:42 - 06:46	44		42		46		40	
06:47 - 06:51	48		47		49		46	
06:52 - 06:56	46		45		47		44	
06:57 - 07:01	47		46		48		45	
07:02 - 07:06	48		46		50		46	
07:07 - 07:11	44		44		48		43	
07:12 - 07:16	43		42		47		41	
07:17 - 07:21	40		38		43		37	
07:22 - 07:26	419	26%	395	38%	429	42%	375	25%
07:27 - 07:31	418		367		393		328	
07:32 - 07:36	397		361		418		327	
07:37 - 07:41	452		449		450		450	
07:42 - 07:46	364		342		377		318	
07:47 - 07:51	631		612		640		593	
07:52 - 07:56	453		427		504		436	
07:57 - 08:01	501		482		776		0	
Average =	**146**	sec/km	**188**	sec/km	**248**	sec/km	**137**	sec/km
Avg. Speed =	**24.59**	km/h	**19.14**	km/h	**14.53**	km/h	**26.26**	km/h

Total Passenger Travel Time = **4,943,851** sec/km (passengers)

Total Average Travel Time = **161** sec/km/veh (and sec/km/passenger)

Total Average Speed = **22.33** km/h/veh (and km/h/passenger)

Table C-2.1: Method of acquiring Passenger travel-times for Hypothesis 1 (Steps 1 through 3)

5 min. intervals	**Step 1**			**Step 2**							**Step 3**		
	N1 Traffic ratio's (pcu's)			Total pcu's (N2) 5 min. intervals	Average pcu's/lane (to ratio's)			Average flow Q (pcu/h)			Calculated Avg. Speed U (km/h)		
	Left	Middle	Right		Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	0.241	0.339	0.420	297.7	71.80	100.97	124.93	861.61	1211.66	1499.13	86.5	95.5	112.2
06:37 - 06:41	0.292	0.322	0.386	332.9	97.14	107.12	128.64	1165.67	1285.50	1543.63	85.3	94.6	111.7
06:42 - 06:46	0.311	0.338	0.351	445.8	138.74	150.53	156.52	1664.94	1806.39	1878.27	80.7	85.1	106.4
06:47 - 06:51	0.295	0.324	0.381	491.1	144.99	159.00	187.12	1739.86	1907.94	2245.40	79.6	81.9	95.6
06:52 - 06:56	0.314	0.341	0.345	473.4	148.50	161.62	163.28	1781.95	1939.49	1959.35	78.9	80.7	104.7
06:57 - 07:01	0.317	0.323	0.360	486.8	154.32	157.28	175.20	1851.86	1887.30	2102.44	77.5	82.6	100.9
07:02 - 07:06	0.321	0.329	0.349	495.6	159.21	163.22	173.17	1910.53	1958.59	2078.08	76.2	79.9	101.6
07:07 - 07:11	0.328	0.344	0.328	464.3	152.48	159.59	152.23	1829.75	1915.10	1826.75	78.0	81.6	107.4
07:12 - 07:16	0.339	0.299	0.362	438.9	148.86	131.15	158.88	1786.36	1573.85	1906.59	78.8	90.3	105.9
07:17 - 07:21	0.345	0.334	0.322	385.2	132.86	128.50	123.84	1594.30	1541.99	1486.11	81.7	90.9	112.3
07:22 - 07:26	0.309	0.341	0.350	220.4	68.18	75.09	77.13	818.17	901.10	925.53	8.0	9.8	10.8
07:27 - 07:31	0.353	0.321	0.326	224.1	79.10	71.97	73.03	949.21	863.68	876.30	9.7	9.3	10.0
07:32 - 07:36	0.310	0.353	0.337	230.6	71.49	81.35	77.75	857.89	976.25	933.06	8.5	10.9	10.9
07:37 - 07:41	0.342	0.335	0.322	206.4	70.63	69.24	66.52	847.58	830.92	798.30	8.4	8.8	8.9
07:42 - 07:46	0.325	0.327	0.348	244.8	79.44	80.15	85.21	953.32	961.77	1022.51	9.8	10.7	12.3
07:47 - 07:51	0.337	0.335	0.328	158.0	53.19	52.98	51.83	638.29	635.74	621.97	5.9	6.4	6.6
07:52 - 07:56	0.325	0.313	0.362	206.6	67.06	64.75	74.79	804.68	777.02	897.50	7.9	8.1	10.3
07:57 - 08:01	0.300	0.343	0.357	183.7	55.11	63.07	65.52	661.26	756.86	786.28	6.2	7.8	8.8
							Capacities =	2150	2150	2400			

Table C-2.2: Hypothesis 1 (Steps 4 through 6)

Step 4			Step 5				Step 6											
Calculated average Travel Time (sec/km/veh)			Total Cars	Total Taxis	Total Trucks	Total Buses	Passenger cars/lane per interval (ratio)			Taxi's/lane per interval (ratio)			Trucks/lane per interval (ratio)			Buses/lane per interval (ratio)		
left	middle	right					left	middle	right	left	middle	right	left	middle	right	left	middle	right
42	38	32	248	32	6	5	59.8	84.1	104.1	7.7	10.9	13.4	1.4	2.0	2.5	1.2	1.7	2.1
42	38	32	283	26	7	8	82.6	91.1	109.4	7.6	8.4	10.0	2.0	2.3	2.7	2.3	2.6	3.1
45	42	34	369	42	9	13	114.8	124.6	129.6	13.1	14.2	14.7	2.8	3.0	3.2	4.0	4.4	4.6
45	44	38	405	43	13	14	119.6	131.1	154.3	12.7	13.9	16.4	3.8	4.2	5.0	4.1	4.5	5.3
46	45	34	388	60	7	9	121.7	132.5	133.8	18.8	20.5	20.7	2.2	2.4	2.4	2.8	3.1	3.1
46	44	36	401	47	14	10	127.1	129.6	144.3	14.9	15.2	16.9	4.4	4.5	5.0	3.2	3.2	3.6
47	45	35	412	52	8	12	132.4	135.7	144.0	16.7	17.1	18.2	2.6	2.6	2.8	3.9	4.0	4.2
46	44	34	385	55	9	6	126.4	132.3	126.2	18.1	18.9	18.0	3.0	3.1	3.0	2.0	2.1	2.0
46	40	34	356	62	7	6	120.7	106.4	128.9	21.0	18.5	22.4	2.4	2.1	2.5	2.0	1.8	2.2
44	40	32	304	59	6	8	104.9	101.4	97.7	20.3	19.7	19.0	2.1	2.0	1.9	2.8	2.7	2.6
449	368	335	165	39	7	3	51.0	56.2	57.7	12.1	13.3	13.6	2.2	2.4	2.4	0.9	1.0	1.0
370	389	359	172	31	8	5	60.7	55.2	56.0	10.9	10.0	10.1	2.8	2.6	2.6	1.8	1.6	1.6
423	331	331	182	39	3	3	56.4	64.2	61.4	12.1	13.8	13.2	0.9	1.1	1.0	0.9	1.1	1.0
429	409	403	139	48	7	5	47.6	46.6	44.8	16.4	16.1	15.5	2.4	2.3	2.3	1.7	1.7	1.6
368	338	294	183	39	9	5	59.4	59.9	63.7	12.7	12.8	13.6	2.9	2.9	3.1	1.6	1.6	1.7
607	566	542	95	37	10	6	32.0	31.9	31.2	12.5	12.4	12.1	3.4	3.4	3.3	2.0	2.0	2.0
458	444	348	159	28	8	4	51.6	49.8	57.6	9.1	8.8	10.1	2.6	2.5	2.9	1.3	1.3	1.4
582	459	410	137	28	11	0	41.1	47.0	48.9	8.4	9.6	10.0	3.3	3.8	3.9	0.0	0.0	0.0

Table C-2.3: Hypothesis 1 (Step 7)

Step 7															
Passenger Cars				Taxi's				Trucks				Buses			
Total Passenger Car Travel Time (sec/km)				Total Taxi Travel Time (sec/km)				Total Truck Travel Time (sec/km)				Total Bus Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
2489	3172	3339	9000	321	409	431	1161	60	77	81	218	50.2	63.9	67.3	181.4
3487	3465	3525	10477	320	318	324	963	86	86	87	259	98.6	97.9	99.7	296.2
5120	5273	4382	14775	583	600	499	1682	125	129	107	360	180.4	185.8	154.4	520.5
5407	5765	5810	16983	574	612	617	1803	174	185	187	545	186.9	199.3	200.9	587.1
5554	5910	4602	16066	859	914	712	2484	100	107	83	290	128.8	137.1	106.7	372.7
5903	5647	5148	16699	692	662	603	1957	206	197	180	583	147.2	140.8	128.4	416.4
6256	6113	5099	17468	790	771	644	2205	121	119	99	339	182.2	178.0	148.5	508.8
5837	5837	4230	15905	834	834	604	2272	136	136	99	372	91.0	91.0	65.9	247.9
5516	4241	4383	14139	961	739	763	2462	108	83	86	278	93.0	71.5	73.9	238.3
4622	4017	3132	11771	897	780	608	2285	91	79	62	232	121.6	105.7	82.4	309.8
22908	20693	19323	62925	5415	4891	4567	14873	972	878	820	2670	416.5	376.2	351.3	1144.1
22490	21481	20104	64075	4053	3872	3623	11548	1046	999	935	2980	653.8	624.5	584.4	1862.7
23847	21252	20324	65422	5110	4554	4355	14019	393	350	335	1078	393.1	350.3	335.0	1078.4
20416	19050	18039	57505	7050	6579	6229	19858	1028	959	908	2896	734.4	685.3	648.9	2068.5
21874	20233	18714	60821	4662	4312	3988	12962	1076	995	920	2991	597.6	552.8	511.3	1661.8
19407	18035	16878	54320	7558	7024	6574	21156	2043	1898	1777	5718	1225.7	1139.1	1066.0	3430.8
23650	22143	20032	65825	4165	3899	3528	11592	1190	1114	1008	3312	595.0	557.1	504.0	1656.0
23916	21590	20044	65550	4888	4413	4097	13397	1920	1734	1609	5263	0.0	0.0	0.0	0.0

Table C-2.4: Hypothesis 1 (Step 8)

Step 8															
Passenger Car passengers				Taxi passengers				Truck passengers				Bus passengers			
Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
4557	5808	6115	16480	5138	6548	6894	18580	120	153	162	435	3838	4892	5150	13880
6385	6344	6456	19185	5126	5093	5182	15400	172	171	174	518	7540	7492	7624	22656
9377	9655	8025	27057	9325	9602	7981	26908	250	257	214	721	13800	14211	11811	39821
9901	10558	10640	31099	9185	9794	9870	28850	347	370	373	1090	14298	15246	15365	44910
10170	10823	8426	29419	13742	14623	11385	39750	200	213	166	580	9855	10488	8165	28508
10810	10341	9428	30579	11071	10590	9655	31315	412	394	359	1166	11262	10773	9822	31857
11456	11193	9337	31987	12634	12344	10297	35274	243	237	198	678	13940	13620	11361	38921
10689	10689	7747	29125	13342	13342	9669	36353	273	273	198	744	6959	6959	5043	18962
10100	7765	8026	25891	15369	11816	12213	39398	217	167	172	556	7111	5467	5651	18230
8464	7356	5735	21556	14354	12474	9725	36553	182	159	124	465	9305	8087	6305	23697
41950	37894	35384	115228	86636	78259	73075	237969	1944	1756	1640	5339	31864	28783	26876	87522
41184	39337	36814	117335	64855	61946	57974	184775	2092	1998	1870	5960	50014	47771	44708	142493
43668	38916	37218	119801	81760	72862	69682	224304	786	701	670	2157	30070	26798	25628	82497
37385	34885	33034	105304	112801	105256	99671	317727	2056	1919	1817	5792	56180	52423	49641	158243
40055	37051	34269	111375	74586	68992	63811	207389	2152	1990	1841	5982	45720	42291	39115	127125
35538	33026	30908	99471	120934	112387	105179	338501	4086	3797	3553	11436	93765	87138	81549	262452
43308	40548	36683	120539	66636	62390	56443	185469	2380	2228	2016	6624	45515	42614	38553	126682
43795	39536	36705	120036	78206	70602	65545	214353	3840	3467	3219	10526	0	0	0	0
			1,171,467	sec/km			**2,218,870**	sec/km			**60,77**	sec/km			**1,268,457**

Table C-2.5: Average Passenger (and Vehicle) travel-times for Hypothesis 1 (Step 9)

Step 9								
5 min. Intervals	Average Travel-Times: All lanes (sec/km)							
	Pssngr. Cars	% of 11/2 hour flow	Taxi's	% of 11/2 hour flow	Trucks	% of 11/2 hour flow	Buses	% of 11/2 hour flow
06:32 - 06:36	36		36		36		36	
06:37 - 06:41	37		37		37		37	
06:42 - 06:46	40		40		40		40	
06:47 - 06:51	42		42		42		42	
06:52 - 06:56	41	74%	41	62%	41	58%	41	75%
06:57 - 07:01	42		42		42		42	
07:02 - 07:06	42		42		42		42	
07:07 - 07:11	41		41		41		41	
07:12 - 07:16	40		40		40		40	
07:17 - 07:21	39		39		39		39	
07:22 - 07:26	381		381		381		381	
07:27 - 07:31	373		373		373		373	
07:32 - 07:36	359		359		359		359	
07:37 - 07:41	414	26%	414	38%	414	42%	414	25%
07:42 - 07:46	332		332		332		332	
07:47 - 07:51	572		572		572		572	
07:52 - 07:56	414		414		414		414	
07:57 - 08:01	478		478		478			
Average	<u>134</u>	sec/km	<u>181</u>	sec/km	<u>204</u>	sec/km	<u>136</u>	sec/km
Avg. Speed =	<u>26.92</u>	km/h	<u>19.91</u>	km/h	<u>17.65</u>	km/h	<u>26.49</u>	km/h

Total Passenger Travel Time = <u>4,719,564</u> sec/km (passengers)
Total Average Travel Time = <u>154</u> sec/km/veh (and sec/km/passenger)
Total Average Speed = <u>23.39</u> km/h/veh (and km/h/passenger)

Table C-3.1: Method of acquiring Passenger travel-times for Hypothesis 2.A (Steps 1 and 2)

Highest congestion: (5 min. interval) left lane: 471 pcu/h; middle: 606 pcu/h; right: 692 pcu/h

Congested traffic ratios: left lane: 0.484; middle: 0.516

5min. Intervals	Step 1					Step 2														
	Total pcu's (N2 data)	Total Cars	Total Taxi's	Total Trucks	Total Buses	Total pcu's/lane (5min. Interval)			Total Taxi's/lane (Assigned)			Total Buses/lane (Assigned)			Total Trucks/lane (Assigned)			Total Passenger Cars/lane (Assigned)		
						Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	297.7	248	32	6	5	125.0	133.2	39.5	0	0	32	0	0	5	6	0	0	114.8	133.2	0
06:37 - 06:41	332.9	283	26	7	8	142.8	152.1	38.0	0	0	26	0	0	8	7	0	0	130.9	152.1	0
06:42 - 06:46	445.8	369	42	9	13	186.1	198.2	61.5	0	0	42	0	0	13	9	0	0	170.8	198.2	0
06:47 - 06:51	491.1	405	43	13	14	206.8	220.3	64.0	0	0	43	0	0	14	13	0	0	184.7	220.3	0
06:52 - 06:56	473.4	388	60	7	9	193.6	206.3	73.5	0	0	60	0	0	9	7	0	0	181.7	206.3	0
06:57 - 07:01	486.8	401	47	14	10	205.7	219.1	62.0	0	0	47	0	0	10	14	0	0	181.9	219.1	0
07:02 - 07:06	495.6	412	52	8	12	206.1	219.5	70.0	0	0	52	0	0	12	8	0	0	192.5	219.5	0
07:07 - 07:11	464.3	385	55	9	6	193.8	206.5	64.0	0	0	55	0	0	6	9	0	0	178.5	206.5	0
07:12 - 07:16	438.9	356	62	7	6	178.1	189.8	71.0	0	0	62	0	0	6	7	0	0	166.2	189.8	0
07:17 - 07:21	385.2	304	59	6	8	152.1	162.1	71.0	0	0	59	0	0	8	6	0	0	141.9	162.1	0
07:22 - 07:26	220.4	165	39	7	3	85.7	91.2	43.5	0	0	39	0	0	3	7	0	0	73.8	91.2	0
07:27 - 07:31	224.1	172	31	8	5	89.9	95.7	38.5	0	0	31	0	0	5	8	0	0	76.3	95.7	0
07:32 - 07:36	230.6	182	39	3	3	90.6	96.5	43.5	0	0	39	0	0	3	3	0	0	85.5	96.5	0
07:37 - 07:41	206.4	139	48	7	5	73.1	77.8	55.5	0	0	48	0	0	5	7	0	0	61.2	77.8	0
07:42 - 07:46	244.8	183	39	9	5	96.0	102.3	46.5	0	0	39	0	0	5	9	0	0	80.7	102.3	0
07:47 - 07:51	158.0	95	37	10	6	54.2	57.8	46.0	0	0	37	0	0	6	10	0	0	37.2	57.8	0
07:52 - 07:56	206.6	159	28	8	4	83.6	89.0	34.0	0	0	28	0	0	4	8	0	0	70.0	89.0	0
07:57 - 08:01	183.7	137	28	11	0	75.4	80.3	28.0	0	0	28	0	0	0	11	0	0	56.7	80.3	0

Table C-3.2: Hypothesis 2.A (Steps 3 through 6)

Step 3			Step 4			Step 5			Step 6					
			Max. Speed =		100	Travel Time			Actual Situation (Congested)					
Calculated Average Flow Q (pcu/h)			Calculated Avg. Speed U (km/h)			Calculated average Travel Time (sec/km/veh)			Actual Trucks/lane			Actual Passenger Cars/lane		
left	middle	right	Left	Middle	Right	left	middle	right	Left	Middle	Right	Left	Middle	Right
471	606	474.0	4.2225	5.5670	116.753	852.6	646.7	36.0	1.9	0.0	0.0	36.0	50.5	0
471	606	456.0	4.2225	5.5670	116.879	852.6	646.7	36.0	1.9	0.0	0.0	36.0	50.5	0
471	606	738.0	4.2225	5.5670	114.519	852.6	646.7	36.0	1.9	0.0	0.0	36.0	50.5	0
471	606	768.0	4.2225	5.5670	114.219	852.6	646.7	36.0	2.5	0.0	0.0	35.1	50.5	0
471	606	882.0	4.2225	5.5670	112.994	852.6	646.7	36.0	1.4	0.0	0.0	36.8	50.5	0
471	606	744.0	4.2225	5.5670	114.46	852.6	646.7	36.0	2.7	0.0	0.0	34.7	50.5	0
471	606	840.0	4.2225	5.5670	113.462	852.6	646.7	36.0	1.5	0.0	0.0	36.7	50.5	0
471	606	768.0	4.2225	5.5670	114.219	852.6	646.7	36.0	1.8	0.0	0.0	36.2	50.5	0
471	606	852.0	4.2225	5.5670	113.33	852.6	646.7	36.0	1.5	0.0	0.0	36.6	50.5	0
471	606	852.0	4.2225	5.5670	113.33	852.6	646.7	36.0	1.5	0.0	0.0	36.6	50.5	0
471	606	522.0	4.2225	5.5670	116.401	852.6	646.7	36.0	3.2	0.0	0.0	33.8	50.5	0
471	606	462.0	4.2225	5.5670	116.838	852.6	646.7	36.0	3.5	0.0	0.0	33.3	50.5	0
471	606	522.0	4.2225	5.5670	116.401	852.6	646.7	36.0	1.3	0.0	0.0	37.0	50.5	0
471	606	666.0	4.2225	5.5670	115.2	852.6	646.7	36.0	3.8	0.0	0.0	32.9	50.5	0
471	606	558.0	4.2225	5.5670	116.168	852.6	646.7	36.0	3.7	0.0	0.0	33.0	50.5	0
471	606	552.0	4.2225	5.5670	116.168	852.6	646.7	36.0	7.2	0.0	0.0	26.9	50.5	0
471	606	408.0	4.2225	5.5670	117.198	852.6	646.7	36.0	3.8	0.0	0.0	32.9	50.5	0
471	606	336.0	4.2225	5.5670	117.631	852.6	646.7	36.0	5.7	0.0	0.0	29.5	50.5	0

Table C-3.3: Hypothesis 2.A (Step 7)

Step 7															
Passenger Cars				Trucks				Taxi's				Buses			
Total Pssngr. Car Travel Time (sec/km)				Total Truck Travel Time (sec/km)				Total Taxi Travel Time (sec/km)				Total Bus Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
30733	32657	0	63390	1606	0	0	1606	0	0	1152	1152	0	0	180	180
30675	32657	0	63332	1641	0	0	1641	0	0	936	936	0	0	288	288
30712	32657	0	63369	1619	0	0	1619	0	0	1512	1512	0	0	468	468
29887	32657	0	62544	2104	0	0	2104	0	0	1548	1548	0	0	504	504
31407	32657	0	64064	1210	0	0	1210	0	0	2160	2160	0	0	324	324
29591	32657	0	62248	2278	0	0	2278	0	0	1692	1692	0	0	360	360
31255	32657	0	63912	1299	0	0	1299	0	0	1872	1872	0	0	432	432
30822	32657	0	63479	1554	0	0	1554	0	0	1980	1980	0	0	216	216
31228	32657	0	63885	1315	0	0	1315	0	0	2232	2232	0	0	216	216
31220	32657	0	63877	1320	0	0	1320	0	0	2124	2124	0	0	288	288
28814	32657	0	61471	2735	0	0	2735	0	0	1404	1404	0	0	108	108
28399	32657	0	61056	2979	0	0	2979	0	0	1116	1116	0	0	180	180
31580	32657	0	64237	1108	0	0	1108	0	0	1404	1404	0	0	108	108
28013	32657	0	60670	3206	0	0	3206	0	0	1728	1728	0	0	180	180
28131	32657	0	60788	3137	0	0	3137	0	0	1404	1404	0	0	180	180
22973	32657	0	55630	6171	0	0	6171	0	0	1332	1332	0	0	216	216
28018	32657	0	60675	3203	0	0	3203	0	0	1008	1008	0	0	144	144
25163	32657	0	57820	4883	0	0	4883	0	0	1008	1008	0	0	0	0

Table C-3.4: Hypothesis 2.A (Step 8)

Step 8															
Passenger Car passengers				Taxi passengers				Truck passengers				Bus passengers			
Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
56279	59801	0	116080	0	0	18432	18432	3212	0	0	3212	0	0	13770	13770
56172	59801	0	115973	0	0	14976	14976	3281	0	0	3281	0	0	22032	22032
56240	59801	0	116041	0	0	24192	24192	3237	0	0	3237	0	0	35802	35802
54730	59801	0	114531	0	0	24768	24768	4207	0	0	4207	0	0	38556	38556
57513	59801	0	117314	0	0	34560	34560	2420	0	0	2420	0	0	24786	24786
54188	59801	0	113989	0	0	27072	27072	4555	0	0	4555	0	0	27540	27540
57235	59801	0	117036	0	0	29952	29952	2598	0	0	2598	0	0	33048	33048
56441	59801	0	116243	0	0	31680	31680	3108	0	0	3108	0	0	16524	16524
57185	59801	0	116986	0	0	35712	35712	2630	0	0	2630	0	0	16524	16524
57170	59801	0	116971	0	0	33984	33984	2640	0	0	2640	0	0	22032	22032
52765	59801	0	112566	0	0	22464	22464	5470	0	0	5470	0	0	8262	8262
52005	59801	0	111806	0	0	17856	17856	5958	0	0	5958	0	0	13770	13770
57829	59801	0	117630	0	0	22464	22464	2216	0	0	2216	0	0	8262	8262
51298	59801	0	111100	0	0	27648	27648	6412	0	0	6412	0	0	13770	13770
51514	59801	0	111315	0	0	22464	22464	6273	0	0	6273	0	0	13770	13770
42069	59801	0	101870	0	0	21312	21312	12341	0	0	12341	0	0	16524	16524
51307	59801	0	111108	0	0	16128	16128	6407	0	0	6407	0	0	11016	11016
46079	59801	0	105880	0	0	16128	16128	9765	0	0	9765	0	0	0	0

Passenger Car: 2,044,442 sec/km
+ Passengers outside 1,5h = 4,443,473 sec/km
Total = 6,487,915 sec/km

Taxi: 441,792 sec/km

Truck: 86,730 sec/km
+ Passengers outside 1,5h = 167,337 sec/km
Total = 254,067 sec/km

Bus: 335,988

Table C-3.5: Average Passenger (and Vehicle) travel-times for Hypothesis 2.A (Step 9)

5min. Intervals	Average Travel-Times: All lanes (sec/km)							
	Pssngr. Cars	% of 1 1/2 hour flow	Taxi's	% of 1 1/2 hour flow	Trucks	% of 1 1/2 hour flow	Buses	% of 1 1/2 hour flow
06:32 - 06:36	732	32.0%	36.00	100.0%	852.6	34.1%	36.0	1.0
06:37 - 06:41	732		36.00		852.6		36.0	
06:42 - 06:46	732		36.00		852.6		36.0	
06:47 - 06:51	731		36.00		852.6		36.0	
06:52 - 06:56	734		36.00		852.6		36.0	
06:57 - 07:01	731		36.00		852.6		36.0	
07:02 - 07:06	733		36.00		852.6		36.0	
07:07 - 07:11	733		36.00		852.6		36.0	
07:12 - 07:16	733		36.00		852.6		36.0	
07:17 - 07:21	733		36.00		852.6		36.0	
07:22 - 07:26	729		36.00		852.6		36.0	
07:27 - 07:31	729		36.00		852.6		36.0	
07:32 - 07:36	734		36.00		852.6		36.0	
07:37 - 07:41	728		36.00		852.6		36.0	
07:42 - 07:46	728		36.00		852.6		36.0	
07:47 - 07:51	718		36.00		852.6		36.0	
07:52 - 07:56	728		36.00		852.6		36.0	
07:57 - 08:01	723		36.00		852.6		0.0	
Average =	**730.2**	sec/km	**36.00**	sec/km	**852.6**	sec/km	**36**	sec/km
Avg. Speed =	**4.93**	km/h	**100.00**	km/h	**4.22**	km/h	**100.00**	km/h

Total Passenger Travel Time = **7,519,762** sec/km (passengers)
Total Average Travel Time = **239.8** sec/km/veh (and sec/km/passenger)
Total Average Speed = **15.01** km/h/veh (and km/h/passenger)

Table C-4.1: Method of acquiring Passenger travel-times for Hypothesis 2.B (Steps 1 and 2)

50% of Uncongested capacity: left lane: 890 pcu/h
right: 1185 pcu/h

Uncongested traffic ratios: left lane: 0.373
right: 0.627

5min. Intervals	Step 1: Total pcu's (N2 data)	Step 1: Total Cars	Step 1: Total Taxi's	Step 1: Total Trucks	Step 1: Total Buses	Step 2: Total pcu's/lane (5min. Interval)			Total Taxi's/lane (Assigned)			Total Buses/lane (Assigned)			Total Trucks/lane (Assigned)			Total Passenger Cars/lane (Assigned)		
						Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	297.7	248	32	6	5	96.2	162.0	39.5	0	0	32	0	0	5	6	0	0	86.0	162.0	0
06:37 - 06:41	332.9	283	26	7	8	109.9	185.0	38.0	0	0	26	0	0	8	7	0	0	98.0	185.0	0
06:42 - 06:46	445.8	369	42	9	13	143.2	241.1	61.5	0	0	42	0	0	13	9	0	0	127.9	241.1	0
06:47 - 06:51	491.1	405	43	13	14	159.2	267.9	64.0	0	0	43	0	0	14	13	0	0	137.1	267.9	0
06:52 - 06:56	473.4	388	60	7	9	149.1	250.8	73.5	0	0	60	0	0	9	7	0	0	137.2	250.8	0
06:57 - 07:01	486.8	401	47	14	10	158.3	266.5	62.0	0	0	47	0	0	10	14	0	0	134.5	266.5	0
07:02 - 07:06	495.6	412	52	8	12	158.6	267.0	70.0	0	0	52	0	0	12	8	0	0	145.0	267.0	0
07:07 - 07:11	464.3	385	55	9	6	149.2	251.1	64.0	0	0	55	0	0	6	9	0	0	133.9	251.1	0
07:12 - 07:16	438.9	356	62	7	6	137.1	230.8	71.0	0	0	62	0	0	6	7	0	0	125.2	230.8	0
07:17 - 07:21	385.2	304	59	6	8	117.1	197.1	71.0	0	0	59	0	0	8	6	0	0	106.9	197.1	0
07:22 - 07:26	220.4	165	39	7	3	65.9	111.0	43.5	0	0	39	0	0	3	7	0	0	54.0	111.0	0
07:27 - 07:31	224.1	172	31	8	5	69.2	116.4	38.5	0	0	31	0	0	5	8	0	0	55.6	116.4	0
07:32 - 07:36	230.6	182	39	3	3	69.7	117.4	43.5	0	0	39	0	0	3	3	0	0	64.6	117.4	0
07:37 - 07:41	206.4	139	48	7	5	56.2	94.7	55.5	0	0	48	0	0	5	7	0	0	44.3	94.7	0
07:42 - 07:46	244.8	183	39	9	5	73.9	124.4	46.5	0	0	39	0	0	5	9	0	0	58.6	124.4	0
07:47 - 07:51	158.0	95	37	10	6	41.7	70.3	46.0	0	0	37	0	0	6	10	0	0	24.7	70.3	0
07:52 - 07:56	206.6	159	28	8	4	64.3	108.3	34.0	0	0	28	0	0	4	8	0	0	50.7	108.3	0
07:57 - 08:01	183.7	137	28	11	0	58.0	97.7	28.0	0	0	28	0	0	0	11	0	0	39.3	97.7	0

Table C-4.2: Hypothesis 2.B (Steps 3 through 6)

Step 3			Step 4			Step 5			Step 6					
			Max. Speed =		100	Travel Time			Actual Situation					
Calculated Average Flow Q			Calculated Avg. Speed U (km/h)			Calculated average Travel Time (sec/km/veh)			Actual Trucks/lane			Actual Passenger Cars/lane		
left	middle	right	Left	Middle	Right	left	middle	right	Left	Middle	Right	Left	Middle	Right
890	1185	474.0	82.00	100.00	116.75	43.9	36.0	36.0	4.6	0.0	0.0	66.3	98.8	0
890	1185	456.0	82.00	100.00	116.88	43.9	36.0	36.0	4.7	0.0	0.0	66.1	98.8	0
890	1185	738.0	82.00	100.00	114.52	43.9	36.0	36.0	4.7	0.0	0.0	66.2	98.8	0
890	1185	768.0	82.00	100.00	114.22	43.9	36.0	36.0	6.1	0.0	0.0	63.9	98.8	0
890	1185	882.0	82.00	100.00	112.99	43.9	36.0	36.0	3.5	0.0	0.0	68.2	98.8	0
890	1185	744.0	82.00	100.00	114.46	43.9	36.0	36.0	6.6	0.0	0.0	63.0	98.8	0
890	1185	840.0	82.00	100.00	113.46	43.9	36.0	36.0	3.7	0.0	0.0	67.8	98.8	0
890	1185	768.0	82.00	100.00	114.22	43.9	36.0	36.0	4.5	0.0	0.0	66.6	98.8	0
890	1185	852.0	82.00	100.00	113.33	43.9	36.0	36.0	3.8	0.0	0.0	67.7	98.8	0
890	1185	852.0	82.00	100.00	113.33	43.9	36.0	36.0	3.8	0.0	0.0	67.7	98.8	0
890	1185	522.0	82.00	100.00	116.40	43.9	36.0	36.0	7.9	0.0	0.0	60.8	98.8	0
890	1185	462.0	82.00	100.00	116.84	43.9	36.0	36.0	8.6	0.0	0.0	59.6	98.8	0
890	1185	522.0	82.00	100.00	116.40	43.9	36.0	36.0	3.2	0.0	0.0	68.7	98.8	0
890	1185	666.0	82.00	100.00	115.20	43.9	36.0	36.0	9.2	0.0	0.0	58.5	98.8	0
890	1185	558.0	82.00	100.00	116.17	43.9	36.0	36.0	9.0	0.0	0.0	58.8	98.8	0
890	1185	552.0	82.00	100.00	116.17	43.9	36.0	36.0	17.8	0.0	0.0	44.0	98.8	0
890	1185	408.0	82.00	100.00	117.20	43.9	36.0	36.0	9.2	0.0	0.0	58.5	98.8	0
890	1185	336.0	82.00	100.00	117.63	43.9	36.0	36.0	14.1	0.0	0.0	50.3	98.8	0

Table C-4.3: Hypothesis 2.B (Step 7)

Step 7															
Passenger Cars				Trucks				Taxi's				Buses			
Total Pssngr. Car Travel Time (sec/km)				Total Truck Travel Time (sec/km)				Total Taxi Travel Time (sec/km)				Total Bus Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
2911	3555	0	6466	203	0	0	203	0	0	1152	1152	0	0	180	180
2904	3555	0	6459	207	0	0	207	0	0	936	936	0	0	288	288
2908	3555	0	6463	205	0	0	205	0	0	1512	1512	0	0	468	468
2804	3555	0	6359	266	0	0	266	0	0	1548	1548	0	0	504	504
2996	3555	0	6551	153	0	0	153	0	0	2160	2160	0	0	324	324
2767	3555	0	6322	288	0	0	288	0	0	1692	1692	0	0	360	360
2977	3555	0	6532	164	0	0	164	0	0	1872	1872	0	0	432	432
2922	3555	0	6477	196	0	0	196	0	0	1980	1980	0	0	216	216
2974	3555	0	6529	166	0	0	166	0	0	2232	2232	0	0	216	216
2973	3555	0	6528	167	0	0	167	0	0	2124	2124	0	0	288	288
2668	3555	0	6223	346	0	0	346	0	0	1404	1404	0	0	108	108
2616	3555	0	6171	377	0	0	377	0	0	1116	1116	0	0	180	180
3018	3555	0	6573	140	0	0	140	0	0	1404	1404	0	0	108	108
2567	3555	0	6122	405	0	0	405	0	0	1728	1728	0	0	180	180
2582	3555	0	6137	396	0	0	396	0	0	1404	1404	0	0	180	180
1930	3555	0	5485	780	0	0	780	0	0	1332	1332	0	0	216	216
2568	3555	0	6123	405	0	0	405	0	0	1008	1008	0	0	144	144
2207	3555	0	5762	617	0	0	617	0	0	1008	1008	0	0	0	0

Table C-4.4: Hypothesis 2.B (Step 8)

Step 8															
Passenger Car passengers				Taxi passengers				Truck passengers				Bus passengers			
Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
5331	6510	0	11841	0	0	18432	18432	406	0	0	406	0	0	13770	13770
5317	6510	0	11827	0	0	14976	14976	415	0	0	415	0	0	22032	22032
5326	6510	0	11836	0	0	24192	24192	409	0	0	409	0	0	35802	35802
5135	6510	0	11645	0	0	24768	24768	532	0	0	532	0	0	38556	38556
5487	6510	0	11996	0	0	34560	34560	306	0	0	306	0	0	24786	24786
5066	6510	0	11576	0	0	27072	27072	576	0	0	576	0	0	27540	27540
5451	6510	0	11961	0	0	29952	29952	328	0	0	328	0	0	33048	33048
5351	6510	0	11861	0	0	31680	31680	393	0	0	393	0	0	16524	16524
5445	6510	0	11955	0	0	35712	35712	332	0	0	332	0	0	16524	16524
5443	6510	0	11953	0	0	33984	33984	334	0	0	334	0	0	22032	22032
4886	6510	0	11396	0	0	22464	22464	691	0	0	691	0	0	8262	8262
4790	6510	0	11300	0	0	17856	17856	753	0	0	753	0	0	13770	13770
5527	6510	0	12036	0	0	22464	22464	280	0	0	280	0	0	8262	8262
4701	6510	0	11211	0	0	27648	27648	810	0	0	810	0	0	13770	13770
4728	6510	0	11238	0	0	22464	22464	793	0	0	793	0	0	13770	13770
3534	6510	0	10044	0	0	21312	21312	1560	0	0	1560	0	0	16524	16524
4702	6510	0	11212	0	0	16128	16128	810	0	0	810	0	0	11016	11016
4041	6510	0	10551	0	0	16128	16128	1234	0	0	1234	0	0	0	0

Passenger Car passengers: 207,442 sec/km
+ Passengers outside 1,5h 131,369 sec/km
Total = 338,811 sec/km

Taxi passengers: 441,792 sec/km

Truck passengers: 10,963 sec/km
+ Passengers outside 1,5h 2,120 sec/km
Total = 13,083 sec/km

Bus passengers: 335,988

Table C-4.5: Average Passenger (and Vehicle) travel-times for Hypothesis 2.B (Step 9)

Step 9								
5min. Intervals	Average Travel-Times: All lanes (sec/km)							
	Pssnger. Cars	% of 11/2 hour flow	Taxis	% of 11/2 hour flow	Trucks	% of 11/2 hour flow	Buses	% of 11/2 hour flow
06:32 - 06:36	39		36.00		43.9		36.0	
06:37 - 06:41	39		36.00		43.9		36.0	
06:42 - 06:46	39		36.00		43.9		36.0	
06:47 - 06:51	39		36.00		43.9		36.0	
06:52 - 06:56	39		36.00		43.9		36.0	
06:57 - 07:01	39		36.00		43.9		36.0	
07:02 - 07:06	39		36.00		43.9		36.0	
07:07 - 07:11	39		36.00		43.9		36.0	
07:12 - 07:16	39	60.6%	36.00	100%	43.9	83.8%	36.0	100%
07:17 - 07:21	39		36.00		43.9		36.0	
07:22 - 07:26	39		36.00		43.9		36.0	
07:27 - 07:31	39		36.00		43.9		36.0	
07:32 - 07:36	39		36.00		43.9		36.0	
07:37 - 07:41	39		36.00		43.9		36.0	
07:42 - 07:46	39		36.00		43.9		36.0	
07:47 - 07:51	38		36.00		43.9		36.0	
07:52 - 07:56	39		36.00		43.9		36.0	
07:57 - 08:01	39		36.00		43.9		0.0	
Average =	**39.1**	sec/km	**36.00**	sec/km	**43.9**	sec/km	**36**	
Avg. Speed =	**92.17**	km/h	**100.00**	km/h	**82.00**	km/h	**100.00**	

Total Passenger Travel Time = **1,129,674** sec/km (passengers)
Total Average Travel Time = **36.77** sec/km/veh (and sec/km/passenger)
Total Average Speed = **97.90** km/h/veh (and km/h/passenger)

Table C-5.1: Method of acquiring Passenger travel-times for Hypothesis 2.C (Steps 1 and 2)

85% of Uncongested capacity: left lane: 1513 pcu/h; right: 2015 pcu/h

Uncongested traffic ratios: left lane: 0.373; right: 0.627

5min. Intervals	Step 1					Step 2														
	Total pcu's (N2 data)	Total Cars	Total Taxi's	Total Trucks	Total Buses	Total pcu's/lane (5min. Interval)			Total Taxi's/lane (Assigned)			Total Buses/lane (Assigned)			Total Trucks/lane (Assigned)			Total Passenger Cars/lane (Assigned)		
						Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	297.7	248	32	6	5	96.2	162.0	39.5	0	0	32	0	0	5	6	0	0	86.0	162.0	0
06:37 - 06:41	332.9	283	26	7	8	109.9	185.0	38.0	0	0	26	0	0	8	7	0	0	98.0	185.0	0
06:42 - 06:46	445.8	369	42	9	13	143.2	241.1	61.5	0	0	42	0	0	13	9	0	0	127.9	241.1	0
06:47 - 06:51	491.1	405	43	13	14	159.2	267.9	64.0	0	0	43	0	0	14	13	0	0	137.1	267.9	0
06:52 - 06:56	473.4	388	60	7	9	149.1	250.8	73.5	0	0	60	0	0	9	7	0	0	137.2	250.8	0
06:57 - 07:01	486.8	401	47	14	10	158.3	266.5	62.0	0	0	47	0	0	10	14	0	0	134.5	266.5	0
07:02 - 07:06	495.6	412	52	8	12	158.6	267.0	70.0	0	0	52	0	0	12	8	0	0	145.0	267.0	0
07:07 - 07:11	464.3	385	55	9	6	149.2	251.1	64.0	0	0	55	0	0	6	9	0	0	133.9	251.1	0
07:12 - 07:16	438.9	356	62	7	6	137.1	230.8	71.0	0	0	62	0	0	6	7	0	0	125.2	230.8	0
07:17 - 07:21	385.2	304	59	6	8	117.1	197.1	71.0	0	0	59	0	0	8	6	0	0	106.9	197.1	0
07:22 - 07:26	220.4	165	39	7	3	65.9	111.0	43.5	0	0	39	0	0	3	7	0	0	54.0	111.0	0
07:27 - 07:31	224.1	172	31	8	5	69.2	116.4	38.5	0	0	31	0	0	5	8	0	0	55.6	116.4	0
07:32 - 07:36	230.6	182	39	3	3	69.7	117.4	43.5	0	0	39	0	0	3	3	0	0	64.6	117.4	0
07:37 - 07:41	206.4	139	48	7	5	56.2	94.7	55.5	0	0	48	0	0	5	7	0	0	44.3	94.7	0
07:42 - 07:46	244.8	183	39	9	5	73.9	124.4	46.5	0	0	39	0	0	5	9	0	0	58.6	124.4	0
07:47 - 07:51	158.0	95	37	10	6	41.7	70.3	46.0	0	0	37	0	0	6	10	0	0	24.7	70.3	0
07:52 - 07:56	206.6	159	28	8	4	64.3	108.3	34.0	0	0	28	0	0	4	8	0	0	50.7	108.3	0
07:57 - 08:01	183.7	137	28	11	0	58.0	97.7	28.0	0	0	28	0	0	0	11	0	0	39.3	97.7	0

Table C-5.2: Hypothesis 2.C (Step 3 through 6)

Step 3			Step 4			Step 5			Step 6					
			Max. Speed =		100	Travel Time			Actual Situation					
Calculated Average Flow Q			Calculated Avg. Speed U (km/h)			Calculated average Travel Time (sec/km/veh)			Actual Trucks/lane			Actual Passenger Cars/lane		
left	middle	right	Left	Middle	Right	left	middle	right	Left	Middle	Right	Left	Middle	Right
1513.0	2014.5	474.0	69	85	116.7531	52.2	42.4	36.0	7.9	0.0	0.0	112.7	167.9	0
1513.0	2014.5	456.0	69	85	116.8791	52.2	42.4	36.0	8.0	0.0	0.0	112.4	167.9	0
1513.0	2014.5	738.0	69	85	114.519	52.2	42.4	36.0	7.9	0.0	0.0	112.6	167.9	0
1513.0	2014.5	768.0	69	85	114.2194	52.2	42.4	36.0	10.3	0.0	0.0	108.6	167.9	0
1513.0	2014.5	882.0	69	85	112.994	52.2	42.4	36.0	5.9	0.0	0.0	116.0	167.9	0
1513.0	2014.5	744.0	69	85	114.4598	52.2	42.4	36.0	11.1	0.0	0.0	107.1	167.9	0
1513.0	2014.5	840.0	69	85	113.4617	52.2	42.4	36.0	6.4	0.0	0.0	115.3	167.9	0
1513.0	2014.5	768.0	69	85	114.2194	52.2	42.4	36.0	7.6	0.0	0.0	113.2	167.9	0
1513.0	2014.5	852.0	69	85	113.33	52.2	42.4	36.0	6.4	0.0	0.0	115.1	167.9	0
1513.0	2014.5	852.0	69	85	113.33	52.2	42.4	36.0	6.5	0.0	0.0	115.1	167.9	0
1513.0	2014.5	522.0	69	85	116.4005	52.2	42.4	36.0	13.4	0.0	0.0	103.3	167.9	0
1513.0	2014.5	462.0	69	85	116.8375	52.2	42.4	36.0	14.6	0.0	0.0	101.3	167.9	0
1513.0	2014.5	522.0	69	85	116.4005	52.2	42.4	36.0	5.4	0.0	0.0	116.9	167.9	0
1513.0	2014.5	666.0	69	85	115.1997	52.2	42.4	36.0	15.7	0.0	0.0	99.4	167.9	0
1513.0	2014.5	558.0	69	85	116.1679	52.2	42.4	36.0	15.4	0.0	0.0	100.0	167.9	0
1513.0	2014.5	552.0	69	85	116.168	52.2	42.4	36.0	30.2	0.0	0.0	74.7	167.9	0
1513.0	2014.5	408.0	69	85	117.1984	52.2	42.4	36.0	15.7	0.0	0.0	99.4	167.9	0
1513.0	2014.5	336.0	69	85	117.6306	52.2	42.4	36.0	23.9	0.0	0.0	85.5	167.9	0

Table C-5.3: Hypothesis 2.C (Step 7)

Step 7															
Passenger Cars				Trucks				Taxi's				Buses			
Total Pssngr. Car Travel Time (sec/km)				Total Truck Travel Time (sec/km)				Total Taxi Travel Time (sec/km)				Total Bus Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
5881	7110	0	12991	410	0	0	410	0	0	1152	1152	0	0	180	180
5866	7110	0	12976	419	0	0	419	0	0	936	936	0	0	288	288
5876	7110	0	12986	413	0	0	413	0	0	1512	1512	0	0	468	468
5665	7110	0	12775	537	0	0	537	0	0	1548	1548	0	0	504	504
6053	7110	0	13163	309	0	0	309	0	0	2160	2160	0	0	324	324
5589	7110	0	12699	582	0	0	582	0	0	1692	1692	0	0	360	360
6014	7110	0	13124	332	0	0	332	0	0	1872	1872	0	0	432	432
5904	7110	0	13014	397	0	0	397	0	0	1980	1980	0	0	216	216
6007	7110	0	13117	336	0	0	336	0	0	2232	2232	0	0	216	216
6005	7110	0	13115	337	0	0	337	0	0	2124	2124	0	0	288	288
5391	7110	0	12501	698	0	0	698	0	0	1404	1404	0	0	108	108
5285	7110	0	12395	761	0	0	761	0	0	1116	1116	0	0	180	180
6097	7110	0	13207	283	0	0	283	0	0	1404	1404	0	0	108	108
5186	7110	0	12296	819	0	0	819	0	0	1728	1728	0	0	180	180
5217	7110	0	12327	801	0	0	801	0	0	1404	1404	0	0	180	180
3899	7110	0	11009	1576	0	0	1576	0	0	1332	1332	0	0	216	216
5188	7110	0	12298	818	0	0	818	0	0	1008	1008	0	0	144	144
4459	7110	0	11569	1247	0	0	1247	0	0	1008	1008	0	0	0	0

Table C-5.4: Hypothesis 2.C (Step 8)

Step 8															
Passenger Car passengers				**Taxi passengers**				**Truck passengers**				**Bus passengers**			
Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)				Total passenger Travel Time (sec/km)			
left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes	left	middle	right	All lanes
10769	13020	0	23789	0	0	18432	18432	820	0	0	820	0	0	13770	13770
10742	13020	0	23762	0	0	14976	14976	838	0	0	838	0	0	22032	22032
10759	13020	0	23779	0	0	24192	24192	827	0	0	827	0	0	35802	35802
10374	13020	0	23394	0	0	24768	24768	1074	0	0	1074	0	0	38556	38556
11084	13020	0	24104	0	0	34560	34560	618	0	0	618	0	0	24786	24786
10235	13020	0	23255	0	0	27072	27072	1163	0	0	1163	0	0	27540	27540
11013	13020	0	24033	0	0	29952	29952	663	0	0	663	0	0	33048	33048
10811	13020	0	23831	0	0	31680	31680	794	0	0	794	0	0	16524	16524
11001	13020	0	24021	0	0	35712	35712	672	0	0	672	0	0	16524	16524
10997	13020	0	24017	0	0	33984	33984	674	0	0	674	0	0	22032	22032
9872	13020	0	22892	0	0	22464	22464	1397	0	0	1397	0	0	8262	8262
9678	13020	0	22698	0	0	17856	17856	1521	0	0	1521	0	0	13770	13770
11165	13020	0	24185	0	0	22464	22464	566	0	0	566	0	0	8262	8262
9497	13020	0	22517	0	0	27648	27648	1637	0	0	1637	0	0	13770	13770
9553	13020	0	22572	0	0	22464	22464	1602	0	0	1602	0	0	13770	13770
7141	13020	0	20160	0	0	21312	21312	3152	0	0	3152	0	0	16524	16524
9500	13020	0	22519	0	0	16128	16128	1636	0	0	1636	0	0	11016	11016
8165	13020	0	21184	0	0	16128	16128	2494	0	0	2494	0	0	0	0
			416,714	sec/km			**441,792**	sec/km			**22,148**	sec/km			**335,988**
+ Passengers outside 1,5h		=	**-16,555**	sec/km				+ Passengers outside 1,5h		=	**-6,600**	sec/km			
		Total =	**400,159**	sec/km						Total =	**15,548**	sec/km			

Table C-5.5: Average Passenger (and Vehicle) travel-times for Hypothesis 2.C (Step 9)

Step 9								
5min. Intervals	Average Travel-Times: All lanes (sec/km)							
	Passenger Cars	% of $1^1/_2$ hour flow	Taxis	% of $1^1/_2$ hour flow	Trucks	% of $1^1/_2$ hour flow	Buses	% of $1^1/_2$ hour flow
06:32 - 06:36	46		36.00		52.2		36.0	
06:37 - 06:41	46		36.00		52.2		36.0	
06:42 - 06:46	46		36.00		52.2		36.0	
06:47 - 06:51	46		36.00		52.2		36.0	
06:52 - 06:56	46		36.00		52.2		36.0	
06:57 - 07:01	46		36.00		52.2		36.0	
07:02 - 07:06	46		36.00		52.2		36.0	
07:07 - 07:11	46		36.00		52.2		36.0	
07:12 - 07:16	46	103.1%	36.00	100.0%	52.2	142.5%	36.0	100.0%
07:17 - 07:21	46		36.00		52.2		36.0	
07:22 - 07:26	46		36.00		52.2		36.0	
07:27 - 07:31	46		36.00		52.2		36.0	
07:32 - 07:36	46		36.00		52.2		36.0	
07:37 - 07:41	46		36.00		52.2		36.0	
07:42 - 07:46	46		36.00		52.2		36.0	
07:47 - 07:51	45		36.00		52.2		36.0	
07:52 - 07:56	46		36.00		52.2		36.0	
07:57 - 08:01	46		36.00		52.2		0.0	
Average =	**46.2**	sec/km	**36.00**	sec/km	**52.2**	sec/km	**36**	sec/km
Avg. Speed =	**78.00**	km/h	**100.00**	km/h	**69.00**	km/h	**100.00**	km/h

Total Passenger Travel Time	=	**1,139,487**	sec/km (passengers)
Total Average Travel Time	=	**39.14**	sec/km/veh (and sec/km/passenger)
Total Average Speed	=	**91.98**	km/h/veh (and km/h/passenger)

Table C-6.1: Total Vehicle Operating Costs for Current situation

5min. Intervals	Total Operating Costs (R/km)											
	Passenger cars			Taxis			Trucks			Buses		
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	25.32	73.62	47.38	6.18	5.58	14.17	10.70	2.24	0.00	5.24	0.00	3.91
06:37 - 06:41	41.82	81.23	43.81	0.77	3.95	16.63	8.48	6.62	0.00	0.00	1.80	13.63
06:42 - 06:46	48.35	97.90	71.22	2.29	9.89	20.52	12.55	6.26	0.00	0.00	1.70	21.65
06:47 - 06:51	56.78	101.55	80.77	4.51	7.57	20.59	16.39	8.28	2.09	0.00	0.00	23.90
06:52 - 06:56	50.75	105.07	73.04	6.83	5.30	33.79	8.32	4.15	2.12	0.00	0.00	15.55
06:57 - 07:01	56.14	105.74	74.84	2.26	4.53	29.07	16.47	6.19	6.32	0.00	0.00	17.17
07:02 - 07:06	64.60	102.64	76.05	1.50	6.84	31.28	12.19	4.17	0.00	1.65	0.00	18.79
07:07 - 07:11	54.99	95.95	75.94	6.78	3.87	31.72	14.37	4.29	0.00	0.00	0.00	10.49
07:12 - 07:16	53.75	87.10	68.86	6.04	6.27	35.98	12.38	2.19	0.00	0.00	0.00	10.67
07:17 - 07:21	48.94	79.48	50.69	3.81	7.13	36.24	8.37	0.00	4.55	0.00	0.00	14.87
07:22 - 07:26	72.05	76.96	60.31	5.94	11.17	38.69	21.94	9.51	0.00	0.00	0.00	8.84
07:27 - 07:31	71.39	85.48	61.02	7.96	6.42	27.80	18.97	0.00	14.60	0.00	0.00	13.40
07:32 - 07:36	79.39	78.20	65.27	5.63	11.59	35.32	8.26	4.95	0.00	0.00	0.00	8.02
07:37 - 07:41	64.21	74.53	46.52	16.99	11.22	47.07	18.34	14.33	0.00	0.00	0.00	16.88
07:42 - 07:46	72.37	75.69	64.14	5.35	11.86	33.42	23.39	13.13	0.00	0.00	0.00	13.10
07:47 - 07:51	63.30	58.47	38.71	12.36	16.57	44.48	25.24	31.73	5.89	0.00	0.00	25.28
07:52 - 07:56	65.06	78.45	68.95	7.22	7.71	27.43	27.28	13.72	0.00	3.92	0.00	9.27
07:57 - 08:01	44.66	76.87	74.48	7.79	12.28	26.18	72.98	9.11	0.00	0.00	0.00	0.00
	1033.86	1534.94	1142.02	110.23	149.76	550.39	336.61	140.89	35.56	10.81	3.51	245.42
		3710.82			**810.38**			**513.05**			**259.73**	

Table C-6.2: Total Vehicle Operating Costs for Hypothesis 1

5min. Intervals	Total Operating Costs (R/km)											
	Passenger cars			**Taxis**			**Trucks**			**Buses**		
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	35.20	49.55	61.76	6.01	8.68	11.32	3.13	4.58	6.11	2.13	3.12	4.17
06:37 - 06:41	48.61	53.64	64.88	5.89	6.68	8.45	4.40	5.05	6.55	4.10	4.72	6.12
06:42 - 06:46	67.65	73.34	76.64	10.03	11.01	12.20	5.92	6.54	7.47	6.98	7.71	8.83
06:47 - 06:51	70.46	77.22	90.91	9.71	10.71	13.11	8.08	8.94	11.16	7.09	7.85	9.82
06:52 - 06:56	71.74	78.04	79.10	14.37	15.71	17.03	4.61	5.05	5.66	4.83	5.30	5.96
06:57 - 07:01	74.98	76.29	85.17	11.34	11.71	13.76	9.26	9.64	11.62	5.39	5.62	6.79
07:02 - 07:06	78.11	79.95	84.98	12.67	13.11	14.81	5.34	5.55	6.47	6.52	6.79	7.94
07:07 - 07:11	74.56	77.94	74.71	13.76	14.54	14.97	6.18	6.56	7.01	3.36	3.57	3.82
07:12 - 07:16	71.18	62.62	76.22	16.05	14.59	18.54	4.98	4.60	5.97	3.48	3.22	4.19
07:17 - 07:21	61.75	59.69	58.01	15.65	15.53	15.99	4.39	4.42	4.68	4.78	4.81	5.11
07:22 - 07:26	67.75	65.67	63.65	18.90	18.11	17.47	10.09	9.49	9.07	3.13	2.97	2.85
07:27 - 07:31	71.20	66.79	64.43	14.98	14.09	13.53	11.29	10.67	10.17	5.15	4.86	4.65
07:32 - 07:36	71.98	70.31	67.23	18.14	17.48	16.72	4.13	3.89	3.72	2.99	2.85	2.73
07:37 - 07:41	61.30	58.19	55.38	24.92	23.59	22.43	10.76	10.14	9.63	5.57	5.26	5.00
07:42 - 07:46	69.40	66.40	65.11	17.26	16.44	16.00	11.63	10.98	10.55	4.72	4.47	4.33
07:47 - 07:51	52.47	49.69	47.09	24.53	23.14	21.88	20.22	18.97	17.87	8.68	8.16	7.70
07:52 - 07:56	69.47	65.71	64.96	14.46	13.65	13.31	12.30	11.59	11.04	4.45	4.19	4.04
07:57 - 08:01	65.39	63.39	61.13	16.01	15.31	14.67	19.11	17.92	17.00	0.00	0.00	0.00
	1183.19	1194.41	1241.37	264.68	264.09	276.18	155.83	154.59	161.74	83.36	85.49	94.04
		3618.97			**804.95**			**472.15**			**262.88**	

Table C-6.3: Total Vehicle Operating Costs for Hypothesis 2.A

5min. Intervals	Total Operating Costs (R/km)											
	Passenger cars			Taxis			Trucks			Buses		
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	76.74	86.84	0.00	0.00	0.00	25.95	15.30	0.00	0.00	0.00	0.00	9.39
06:37 - 06:41	76.60	86.84	0.00	0.00	0.00	21.09	15.62	0.00	0.00	0.00	0.00	15.03
06:42 - 06:46	76.69	86.84	0.00	0.00	0.00	34.06	15.41	0.00	0.00	0.00	0.00	24.42
06:47 - 06:51	74.63	86.84	0.00	0.00	0.00	34.87	20.03	0.00	0.00	0.00	0.00	26.30
06:52 - 06:56	78.43	86.84	0.00	0.00	0.00	48.66	11.52	0.00	0.00	0.00	0.00	16.91
06:57 - 07:01	73.89	86.84	0.00	0.00	0.00	38.12	21.69	0.00	0.00	0.00	0.00	18.78
07:02 - 07:06	78.05	86.84	0.00	0.00	0.00	42.17	12.37	0.00	0.00	0.00	0.00	22.54
07:07 - 07:11	76.97	86.84	0.00	0.00	0.00	44.60	14.80	0.00	0.00	0.00	0.00	11.27
07:12 - 07:16	77.98	86.84	0.00	0.00	0.00	50.28	12.52	0.00	0.00	0.00	0.00	11.27
07:17 - 07:21	77.96	86.84	0.00	0.00	0.00	47.85	12.57	0.00	0.00	0.00	0.00	15.03
07:22 - 07:26	71.95	86.84	0.00	0.00	0.00	31.63	26.05	0.00	0.00	0.00	0.00	5.64
07:27 - 07:31	70.92	86.84	0.00	0.00	0.00	25.14	28.37	0.00	0.00	0.00	0.00	9.39
07:32 - 07:36	78.86	86.84	0.00	0.00	0.00	31.63	10.55	0.00	0.00	0.00	0.00	5.64
07:37 - 07:41	69.95	86.84	0.00	0.00	0.00	38.93	30.53	0.00	0.00	0.00	0.00	9.39
07:42 - 07:46	70.25	86.84	0.00	0.00	0.00	31.63	29.87	0.00	0.00	0.00	0.00	9.39
07:47 - 07:51	57.37	86.84	0.00	0.00	0.00	30.01	58.77	0.00	0.00	0.00	0.00	11.27
07:52 - 07:56	69.96	86.84	0.00	0.00	0.00	22.71	30.51	0.00	0.00	0.00	0.00	7.51
07:57 - 08:01	62.83	86.84	0.00	0.00	0.00	22.71	46.50	0.00	0.00	0.00	0.00	0.00
	1320.03	1563.15	0.00	0.00	0.00	622.01	413.00	0.00	0.00	0.00	0.00	229.16
Outside 11/2 h	3332.30	2904.05		-			796.84			-		
		9119.52			**622.01**			**1209.83**			**229.16**	

Table C-6.4: Total Vehicle Operating Costs for Hypothesis 2.B

5min. Intervals	Total Operating Costs (R/km)											
	Passenger cars			Taxis			Trucks			Buses		
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	39.05	58.25	0.00	0.00	0.00	25.95	9.83	0.00	0.00	0.00	0.00	9.39
06:37 - 06:41	38.95	58.25	0.00	0.00	0.00	21.09	10.04	0.00	0.00	0.00	0.00	15.03
06:42 - 06:46	39.01	58.25	0.00	0.00	0.00	34.06	9.90	0.00	0.00	0.00	0.00	24.42
06:47 - 06:51	37.61	58.25	0.00	0.00	0.00	34.87	12.87	0.00	0.00	0.00	0.00	26.30
06:52 - 06:56	40.19	58.25	0.00	0.00	0.00	48.66	7.40	0.00	0.00	0.00	0.00	16.91
06:57 - 07:01	37.11	58.25	0.00	0.00	0.00	38.12	13.94	0.00	0.00	0.00	0.00	18.78
07:02 - 07:06	39.93	58.25	0.00	0.00	0.00	42.17	7.95	0.00	0.00	0.00	0.00	22.54
07:07 - 07:11	39.20	58.25	0.00	0.00	0.00	44.60	9.51	0.00	0.00	0.00	0.00	11.27
07:12 - 07:16	39.89	58.25	0.00	0.00	0.00	50.28	8.05	0.00	0.00	0.00	0.00	11.27
07:17 - 07:21	39.87	58.25	0.00	0.00	0.00	47.85	8.07	0.00	0.00	0.00	0.00	15.03
07:22 - 07:26	35.79	58.25	0.00	0.00	0.00	31.63	16.73	0.00	0.00	0.00	0.00	5.64
07:27 - 07:31	35.09	58.25	0.00	0.00	0.00	25.14	18.23	0.00	0.00	0.00	0.00	9.39
07:32 - 07:36	40.48	58.25	0.00	0.00	0.00	31.63	6.78	0.00	0.00	0.00	0.00	5.64
07:37 - 07:41	34.44	58.25	0.00	0.00	0.00	38.93	19.62	0.00	0.00	0.00	0.00	9.39
07:42 - 07:46	34.64	58.25	0.00	0.00	0.00	31.63	19.19	0.00	0.00	0.00	0.00	9.39
07:47 - 07:51	25.89	58.25	0.00	0.00	0.00	30.01	37.75	0.00	0.00	0.00	0.00	11.27
07:52 - 07:56	34.44	58.25	0.00	0.00	0.00	22.71	19.60	0.00	0.00	0.00	0.00	7.51
07:57 - 08:01	29.60	58.25	0.00	0.00	0.00	22.71	29.87	0.00	0.00	0.00	0.00	0.00
	661.19	1048.58	0.00	0.00	0.00	622.01	265.32	0.00	0.00	0.00	0.00	229.16
Outside 11/2 h	295.12	815.04		-			51.31			-		
		2819.94			**622.01**			**316.63**			**229.16**	

Table C-6.5: Total Vehicle Operating Costs for Hypothesis 2.C

5min. Intervals	Total Operating Costs (R/km)											
	Passenger cars			Taxis			Trucks			Buses		
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
06:32 - 06:36	66.88	98.81	0.00	0.00	0.00	25.95	15.90	0.00	0.00	0.00	0.00	9.39
06:37 - 06:41	66.71	98.81	0.00	0.00	0.00	21.09	16.25	0.00	0.00	0.00	0.00	15.03
06:42 - 06:46	66.81	98.81	0.00	0.00	0.00	34.06	16.03	0.00	0.00	0.00	0.00	24.42
06:47 - 06:51	64.42	98.81	0.00	0.00	0.00	34.87	20.83	0.00	0.00	0.00	0.00	26.30
06:52 - 06:56	68.83	98.81	0.00	0.00	0.00	48.66	11.98	0.00	0.00	0.00	0.00	16.91
06:57 - 07:01	63.56	98.81	0.00	0.00	0.00	38.12	22.56	0.00	0.00	0.00	0.00	18.78
07:02 - 07:06	68.39	98.81	0.00	0.00	0.00	42.17	12.87	0.00	0.00	0.00	0.00	22.54
07:07 - 07:11	67.13	98.81	0.00	0.00	0.00	44.60	15.39	0.00	0.00	0.00	0.00	11.27
07:12 - 07:16	68.31	98.81	0.00	0.00	0.00	50.28	13.02	0.00	0.00	0.00	0.00	11.27
07:17 - 07:21	68.29	98.81	0.00	0.00	0.00	47.85	13.07	0.00	0.00	0.00	0.00	15.03
07:22 - 07:26	61.30	98.81	0.00	0.00	0.00	31.63	27.08	0.00	0.00	0.00	0.00	5.64
07:27 - 07:31	60.10	98.81	0.00	0.00	0.00	25.14	29.50	0.00	0.00	0.00	0.00	9.39
07:32 - 07:36	69.33	98.81	0.00	0.00	0.00	31.63	10.97	0.00	0.00	0.00	0.00	5.64
07:37 - 07:41	58.98	98.81	0.00	0.00	0.00	38.93	31.75	0.00	0.00	0.00	0.00	9.39
07:42 - 07:46	59.32	98.81	0.00	0.00	0.00	31.63	31.06	0.00	0.00	0.00	0.00	9.39
07:47 - 07:51	44.34	98.81	0.00	0.00	0.00	30.01	61.11	0.00	0.00	0.00	0.00	11.27
07:52 - 07:56	58.99	98.81	0.00	0.00	0.00	22.71	31.72	0.00	0.00	0.00	0.00	7.51
07:57 - 08:01	50.70	98.81	0.00	0.00	0.00	22.71	48.35	0.00	0.00	0.00	0.00	0.00
	1132.40	1778.64	0.00	0.00	0.00	622.01	429.46	0.00	0.00	0.00	0.00	229.16
Outside 11/2 h	-168.97	80.86		-			-127.98			-		
		2822.93			**622.01**			**301.48**			**229.16**	

Table C-7.1: Total Person Time Costs for Current situation

5min. Intervals	Total Time Costs (R/person hour)			
	Passenger cars	Taxis	Trucks	Buses
06:32 - 06:36	25.67	34.44	3.36	26.14
06:37 - 06:41	30.70	26.68	3.93	36.53
06:42 - 06:46	45.09	51.93	5.52	69.71
06:47 - 06:51	53.38	59.12	8.40	86.07
06:52 - 06:56	49.91	79.46	4.35	53.42
06:57 - 07:01	52.71	63.16	8.90	60.44
07:02 - 07:06	54.42	70.50	5.32	74.34
07:07 - 07:11	47.31	70.85	5.70	34.42
07:12 - 07:16	42.11	76.19	4.38	32.91
07:17 - 07:21	33.97	65.69	3.42	39.42
07:22 - 07:26	191.68	451.95	39.88	150.70
07:27 - 07:31	199.33	333.61	41.78	219.58
07:32 - 07:36	200.10	413.51	16.66	131.36
07:37 - 07:41	174.00	633.07	41.80	300.88
07:42 - 07:46	184.52	391.30	45.07	212.55
07:47 - 07:51	166.27	665.00	84.88	475.94
07:52 - 07:56	199.78	351.17	53.47	233.22
07:57 - 08:01	190.21	396.08	113.27	0.00
	1941.17	**4233.70**	**490.10**	**2237.63**
			Total :	**8902.60**

Table C-7.2: Total Person Time Costs for Hypothesis 1

5min. Intervals	Total Time Costs (R/person hour)			
	Passenger cars	Taxis	Trucks	Buses
06:32 - 06:36	24.95	34.08	2.89	25.90
06:37 - 06:41	29.04	28.24	3.44	38.07
06:42 - 06:46	40.96	49.35	4.78	62.38
06:47 - 06:51	47.08	52.91	7.24	76.74
06:52 - 06:56	44.54	72.90	3.85	45.99
06:57 - 07:01	46.29	57.43	7.74	62.88
07:02 - 07:06	48.42	64.69	4.50	60.53
07:07 - 07:11	44.09	66.67	4.93	38.95
07:12 - 07:16	39.20	72.26	3.69	33.40
07:17 - 07:21	32.63	67.04	3.08	38.09
07:22 - 07:26	174.44	436.44	35.43	216.88
07:27 - 07:31	177.63	338.88	39.55	296.87
07:32 - 07:36	181.37	411.38	14.31	144.29
07:37 - 07:41	159.42	582.72	38.44	311.63
07:42 - 07:46	168.61	380.36	39.70	278.59
07:47 - 07:51	150.59	620.82	75.89	555.61
07:52 - 07:56	182.48	340.15	43.96	292.41
07:57 - 08:01	181.72	393.13	69.85	220.45
	1773.47	**4069.47**	**403.27**	**2799.66**
			Total :	**9045.88**

Table C-7.3: Total Person Time Costs for Hypothesis 2.A

5min. Intervals	Total Time Costs (R/person hour)			
	Passenger cars	Taxis	Trucks	Buses
06:32 - 06:36	175.73	33.80	21.32	24.08
06:37 - 06:41	175.57	27.47	21.77	38.54
06:42 - 06:46	175.67	44.37	21.48	62.62
06:47 - 06:51	173.39	45.43	27.92	67.44
06:52 - 06:56	177.60	63.38	16.06	43.35
06:57 - 07:01	172.57	49.65	30.23	48.17
07:02 - 07:06	177.18	54.93	17.24	57.80
07:07 - 07:11	175.98	58.10	20.62	28.90
07:12 - 07:16	177.10	65.50	17.45	28.90
07:17 - 07:21	177.08	62.33	17.52	38.54
07:22 - 07:26	170.41	41.20	36.30	14.45
07:27 - 07:31	169.26	32.75	39.54	24.08
07:32 - 07:36	178.08	41.20	14.71	14.45
07:37 - 07:41	168.19	50.71	42.55	24.08
07:42 - 07:46	168.52	41.20	41.63	24.08
07:47 - 07:51	154.22	39.09	81.90	28.90
07:52 - 07:56	168.20	29.58	42.52	19.27
07:57 - 08:01	160.29	29.58	64.80	0.00
	3095.06	**810.26**	**575.55**	**587.66**
+ Outside $1^1/_2$ h	**6726.92**	**-**	**1110.47**	**-**
			Total :	**12905.92**

Table C-7.4: Total Person Time Costs for Hypothesis 2.B

5min. Intervals	Total Time Costs (R/person hour)			
	Passenger cars	Taxis	Trucks	Buses
06:32 - 06:36	17.93	33.80	2.69	24.08
06:37 - 06:41	17.90	27.47	2.75	38.54
06:42 - 06:46	17.92	44.37	2.72	62.62
06:47 - 06:51	17.63	45.43	3.53	67.44
06:52 - 06:56	18.16	63.38	2.03	43.35
06:57 - 07:01	17.53	49.65	3.82	48.17
07:02 - 07:06	18.11	54.93	2.18	57.80
07:07 - 07:11	17.96	58.10	2.61	28.90
07:12 - 07:16	18.10	65.50	2.21	28.90
07:17 - 07:21	18.10	62.33	2.21	38.54
07:22 - 07:26	17.25	41.20	4.59	14.45
07:27 - 07:31	17.11	32.75	5.00	24.08
07:32 - 07:36	18.22	41.20	1.86	14.45
07:37 - 07:41	16.97	50.71	5.38	24.08
07:42 - 07:46	17.01	41.20	5.26	24.08
07:47 - 07:51	15.21	39.09	10.35	28.90
07:52 - 07:56	16.97	29.58	5.37	19.27
07:57 - 08:01	15.97	29.58	8.19	0.00
	314.04	**810.26**	**72.75**	**587.66**
+ Outside $1^1/_2$ h	**198.88**	**-**	**14.07**	**-**
			Total :	**1997.66**

Table C-7.5: Total Person Time Costs for Hypothesis 2.C

5min. Intervals	Total Time Costs (R/person hour)			
	Passenger cars	Taxis	Trucks	Buses
06:32 - 06:36	36.01	33.80	5.44	24.08
06:37 - 06:41	35.97	27.47	5.56	38.54
06:42 - 06:46	36.00	44.37	5.49	62.62
06:47 - 06:51	35.42	45.43	7.13	67.44
06:52 - 06:56	36.49	63.38	4.10	43.35
06:57 - 07:01	35.21	49.65	7.72	48.17
07:02 - 07:06	36.38	54.93	4.40	57.80
07:07 - 07:11	36.08	58.10	5.27	28.90
07:12 - 07:16	36.36	65.50	4.46	28.90
07:17 - 07:21	36.36	62.33	4.47	38.54
07:22 - 07:26	34.66	41.20	9.27	14.45
07:27 - 07:31	34.36	32.75	10.10	24.08
07:32 - 07:36	36.61	41.20	3.76	14.45
07:37 - 07:41	34.09	50.71	10.87	24.08
07:42 - 07:46	34.17	41.20	10.63	24.08
07:47 - 07:51	30.52	39.09	20.91	28.90
07:52 - 07:56	34.09	29.58	10.86	19.27
07:57 - 08:01	32.07	29.58	16.55	0.00
	630.86	**810.26**	**146.98**	**587.66**
+ Outside $1^1/_2$ h	**-25.06**	**-**	**-43.80**	**-**
			Total :	**2106.89**