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Free-flow speeds for representative road and terrain types

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TITEL/TITLE FREE-FLOW SPEEDS FOR REPRESENTATIVE ROAD AND TERRAIN TYPES

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SINOPSIS:

Spoed speel 'n belangrike rol in die regverdiging van padinfrastruktuurprojekte. Dit beïnvloed beide voertuigbedryfskoste en reistydkoste. Indien verkeerde waardes vir spoed in die ekonomiese evaluering van vervoerprojekte gebruik word, kan dit tot verkeerde investeringsbesluite lei.

Hierdie studie het beoog om die waardes vir vryvloei-spoed in die betrokke tabelle van program CB-Roads te verifieer deur middel van spoedmetings op geselekteerde padseksies. Hierdie verslag beskryf die spoedeksperiment en gee die resultate. Die resultate kan ook gebruik word om die spoedvoorspellingsformules in die huidige uitgawe van CB-Roads te verifieer.

Inligting van ander studies is aanvullend tot die resultate van hierdie studie gebruik om 'n matriks van vryvloei-spoed, soortgelyk aan die in vorige uitgawes van CB-Roads, te ontwikkel.

SYNOPSIS:

Speed plays an important role in the justification of road infrastructure projects. It affects both vehicle operating cost and travel time cost. If incorrect values for speed are used in the economic analyses of transport projects, incorrect investment decisions can result.

This study was intended to verify the values for free-flow speed given in the look-up tables of program CB-Roads by means of speed measurements on selected road sections. This report explains the speed experiment and gives the results. These results can also be used to verify and/or calibrate the speed prediction formulae contained in the current version of CB-Roads.

Information from other studies was used to supplement the study results in developing a matrix of free-flow speeds similar to that used in previous versions of CB-Roads.

TREFWOORDE:
KEYWORDS: free-flow speed, speed model, road type, terrain type, pavement condition, CB Roads

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DISCLAIMER

The views and opinions expressed in this report are those of the authors and do not represent Department of Transport policy.

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1. INTRODUCTION

1.1 BACKGROUND

Speed is an important input to the economic evaluation of road projects. Projects are often justified on the basis of increased speed and the consequent saving in travel time. Vehicle operating cost is also influenced by speed. It is therefore important that correct values for vehicle speed should be used in project evaluation. If not, the benefits and costs associated with a project cannot be correctly quantified. Incorrect input values, of whatever type, will affect the justification and ranking of candidate projects. This will lead to incorrect decision-making at a strategic level.

At present, program CB-Roads (1) is used to calculate the cost and benefits of providing or improving rural road infrastructure and to perform an economic analysis. Using this standardised approach, projects can be evaluated and ranked in priority order. The program complies with the requirements of the Central Economic Advisory Service for the economic analysis of public sector projects. To ensure comparable results, the program operates on a number of standard data tables. In Version 3.4 of the program, for example, Tables SD8(b) to SD8(h) give values for free-flow operating speed by vehicle class, topography, surface condition and road type. These values are then used in the calculation of actual operating speed for a given road section.

1.2. STUDY OBJECTIVE

The objective of this study is to verify the values for free-flow speed given in Version 3.4 of program CB-Roads by means of speed measurements on selected road sections. Improvements to program CB-Roads in Version 4.1 involved, inter alia, the replacement of the look-up tables by speed formulae. The results of this study can also be used to verify and/or calibrate these functions.

1.3 METHODOLOGY

The values in the speed tables in Version 3.4 of program CB-Roads are based on the Road Needs Study data, the Comprehensive Traffic Observations (CTO) database and personal judgement. The element of personal judgement is a crucial one, as it is nearly impossible to find all the combinations of road types, terrain types, surface condition types and vehicle types to completely sample all the data points presented in the speed tables. Even if this was possible, it would not be cost-effective. Starting from the speed tables, this study was designed to sample some extreme and some intermediate points in the tables to base the revised values on these surveyed points, while interpolating the values that could not be sampled within the restraints of time and budget.

There are various research reports containing data pertinent to speeds. These were analysed to obtain, as far as possible, input from available sources. Although care must be exercised when using data from other sources, as the purpose of the studies and the limitations of the data could be different or unknown, it is essential that optimal use should be made of these results where possible. This also broadens the base of the data geographically and in terms of sample size. Likewise, it was sought to utilise the CTO data were possible. Unfortunately, the format of the CTO data is restricted to light and heavy vehicles, limiting the comparison with cars, light delivery vehicles (LDVs) and minibuses, and buses, medium and heavy goods vehicles respectively to relative terms.

Starting with the existing data, the study was designed to collect speed data at sites representing typical situations where the speeds need to be verified. The verification of speed values in the look-up tables was done by sampling actual free-flow speeds over homogeneous sections of road of known characteristics. The revised tables of free-flow speeds were constructed using the sampled speeds and reported results. Where no data were available, the speeds were derived through deduction or interpolation.

1.4. ORGANISATION OF THE REPORT

The report is divided into seven chapters. The first section provides a short background to the project, noting the importance of speed in the economic analysis of transport projects. The study objectives and the methodology followed in the execution of the study are briefly described. The second section contains a general discussion of the determinants of vehicle speed. The third section is devoted to speed models. It firstly looks at general models, ranging from look-up tables such as used in Version 3.4 of program CB-Roads, to multivariate speed models such as the Highway Design and Maintenance model HDMIII. It then considers specific models pertaining to geometric and pavement variables. This section on speed models is included for three reasons: firstly, to give some background to the phenomenon of speed modelling; secondly, to supplement the results of the speed surveys where necessary; and thirdly, to facilitate the interpretation and application of speed values suggested in Section 5. Speeds, as surveyed for the study, are presented in Section 4. In Section 5 the observed speeds are used, together with information from other sources, to complete a matrix of speed values in a format similar to that used in Version 3.4 of CB-Roads. The conclusions to the study are given in Section 6. The list of references is given in Section 7. Processed data and selected data from the CTO database are contained in the appendices.

1.5 DEFINITIONS

The term "speed" is found in combination with a number of qualifying terms. These concepts are defined below to ensure a clear understanding of the meaning intended where used in the study.

Speed:	The rate of movement of a vehicle in distance per unit time.
Average speed:	The arithmetic mean of the speeds under discussion.
Desired speed:	The speed at which the driver wishes to travel.
Free-flow speed:	The speed at which a driver travels on a road under favourable climatic conditions, unaffected by other traffic. This would reflect level of service A on a well-designed road.
Free-flow operating speed:	The average speed of all vehicles of a given type or types on a road section under free-flow conditions.
Macroscopic speed:	The speed calculated by dividing the sum of distances travelled by individual vehicles by the sum of the individual journey times. This is also known as "space mean speed".
Spot speed:	The instantaneous measure of speed over a short distance or at a spot.
Travel speed:	The average speed of a vehicle on a road section.

2. DETERMINANTS OF VEHICLE SPEED

2.1 INTRODUCTION

Vehicle speed is influenced by a wide range of measurable and non-measurable factors. These factors are often inter-related. In this section, these factors are listed and each is discussed in a short paragraph. Speed is a complex phenomenon, and in a study of speeds, the influence of all variables should be considered. Similarly, in the application of any speed model, its limitations must be borne in mind, by reviewing the factors discussed in Section 2.2 in order to identify if any of them could override the assumptions or limitations of the model.

The overview is followed by a short discussion of the treatment of some of these factors in selected speed models.

2.2 GENERAL OVERVIEW OF THE DETERMINANTS OF VEHICLE SPEED

The discussion that follows is a precis of a discussion by Oppenlander in the Transportation and Traffic Engineering Handbook (2). This serves as a general introduction to the determinants of vehicle speed, as some of these factors do not present as such in the South African driving environment, while other factors, unique to South Africa, could be added. One such factor is the 80 km/h speed limit for heavy vehicles.

2.1.1 Driver aspects

In general, persons travelling long distances have newer cars and drive faster than local travellers, and their speeds increase with trip length. Lone drivers tend to travel at higher speeds than drivers with passengers. Women drivers travel at about the same or at slightly lower average speed than male drivers. More men than woman travel at dangerously high speeds and if the driver is married, he or she will drive slower than his or her unmarried or divorced counterpart. These driver variables influence vehicular speed to different degrees in various parts.

2.2.2 Variations by vehicle type

Vehicle type and vehicle age have an effect on spot speeds. Some of the observations described by Oppenlander are unique to the USA, and are not repeated here. Commercial vehicles exhibit a trend of decreasing speed with increasing gross weight. For a given travel distance, the average speed decreases as the vehicle age increases. Newer cars are generally driven faster than older vehicles because new cars go faster, ride more comfortably, travel more smoothly and quietly, handle better and are generally in better mechanical condition.

2.2.3 Variations by roadway elements

The actual speed adopted by the drivers are greatly affected by various aspects of the roadway. Functional classification of the roadway, curvature, gradient, length of grade, number of lanes and type of surface appear to have the most pronounced effects on speed characteristics. However, geographic location, sight distance, lane position, lateral clearance, and frequency of intersections are also roadway elements that do influence speed patterns.

Highway types

On rural highways and urban expressways, drivers can operate their vehicles at safe speeds determined by the geometric design elements of those roadways, whereas vehicle speeds on major streets are regulated by recurring peak traffic volumes, traffic control devices, intersections, and other physical and psychological retarding forces peculiar to the urban environment. Thus the functional classification of highway facilities with similar characteristics is a variable influencing speed characteristics. In the USA, speeds of all vehicles on rural highways progressively increase from primary feeder, to intercity, to interstate and interregional highway systems. These speed differences by highway type remain consistent throughout the range from low to high traffic volumes.

Horizontal alignment

Vehicular speeds are lower on horizontal curves than on tangent alignments, and the average spot speed approaches the calculated design speed as the degree of curvature increases.

Vertical alignment

The vertical alignment of a roadway has a marked influence on vehicular speeds. However, the various effects are more pronounced on trucks than on passenger cars. Average spot speeds on downgrades, as compared to travel on level tangent sections, increase on down-grades up to 5 percent for trucks and on downgrades up to 3 percent for buses and passenger cars. The speeds are reduced on downgrades steeper than these limits and on upgrades for all vehicle types. In studies of the gradability of heavy commercial vehicles, the speed on a given upgrade was reduced almost linearly with an increase in the length of the grade until the crawl speed was reached. The truck then continued up the grade at this minimum speed.

Number of lanes

Roadways with more than four lanes have operational characteristics similar to four-lane facilities. However, four-lane highways, on which passing is not restricted by opposing traffic, have higher average speeds than two-lane and three-lane highways. This discrepancy is even more pronounced for divided highways. In addition, observed speeds on three-lane facilities are only slightly higher than on similar two-lane roads.

Geographic location

The average speeds on main rural highways in the central and western regions of the United States of America have been consistently from 6 km/h to 11 km/h higher than in the eastern region. These differences are probably explained by the varying topographic conditions and the different state restrictions on maximum speed limits. In a study on the simulation of traffic on two-lane rural roads in South Africa, Joubert remarks that during field observations to validate TRARR under local conditions, performance of passenger cars in a developing region was found to be considerably lower than the performance of the average passenger car (3). This can be considered a geographic factor, and may be attributed to various influences such as the driver and his perception of time, vehicle age and mechanical condition.

Sight distance

On two-lane rural roads, restricted sight distance limits the opportunities for passing manoeuvres. Speed is determined by the combined influence of the traffic volume and the percentage of total roadway length with sight distances insufficient to permit passing.

Lane position

Average speeds of inbound traffic are from 3 km/h to 6 km/h faster than for outbound traffic on roadway approaches to urban areas. On three-lane two-way highways, the average speeds in the two outside lanes show the normal linear decrease with an increase in volume, but the average speed in the centre lane is faster and does not change with variation in traffic volume. The average values of spot speeds on multi-lane freeways are reduced as the lane position progresses from the median, to the middle, to the shoulder lanes. The marked reduction in speeds for the vehicles in the curb lane is largely attributed to the presence of commercial vehicles in the outside lane, to the speed change manoeuvres performed by ingress and egress traffic in the outside lane, and to hazards of merging and diverging traffic anticipated by the through traffic.

Lateral clearance

In general, restricted lateral clearances on two-lane highways cause reductions in average speeds from 2 km/h to 5 km/h. Truck drivers are less influenced by lateral restrictions than drivers of passenger cars. Finally, spot speeds on urban roadways tend to decrease with an increase in the number of friction points passed per unit of distance.

Road surface condition

The road surface condition, as measured by riding quality, influences the speed at which it is safe and comfortable to travel. The extent of the influence depends on the type of pavement as well as the riding quality. Riding quality can be measured in a number of ways, such as the subjective present serviceability index (PSI) or the Quarter Car Index (QI) based in linear displacements. On paved roads, the effect on speed only becomes important as the pavement reaches a critically poor condition. On gravel roads, the effect is more pronounced and speeds are reduced gradually as the road surface deteriorates.

2.2.4 Speed-volume relation

As the volume on a given roadway increases, the average speed decreases approximately linearly until the traffic volume reaches the capacity of the particular facility under the prevailing road and traffic conditions. This observation is not found in South African data.

2.2.5 Speed-density relation

Speed is related to the density of the traffic stream.

2.2.6 Passing opportunities

As vehicular volumes increases, the effect of increasing percentages of commercial vehicles on speed characteristics becomes more pronounced. When the increasing volume limits the opportunities for passing, average speeds decrease linearly with an increase in the percentage of commercial vehicles. Drivers cannot maintain their desired speeds unless the faster moving vehicles can change lanes and pass the slower moving vehicles. Therefore, passing manoeuvres necessitate speed changes and alter speed characteristics.

2.2.7 Access control

The control of access to a roadway is often a prerequisite in the design of modern highways. In rural areas the degree of access control apparently has little influence on spot speeds, but in suburban and urban districts average speeds increase with greater control of access.

2.2.8 Environmental variables

Environmental variables of time and weather present important considerations in the evaluation of speed characteristics. Since 1942 the average speeds on main rural highways in the USA have continued to increase at the rate of 1,6 km/h per year. Other measurements of vehicle speeds during different seasons of the year have indicated that average speeds are highest in the fall and winter, intermediate in the spring, and lowest in the summer. Conflicting statements on daily and hourly fluctuations in vehicular speeds on a given roadway appear in the literature. However, average spot speeds in daytime are about 2 km/h in urban areas and from 3 km/h to 13 km/h higher in rural areas than the corresponding speed values during the nighttime. Unfavourable road surface conditions appear to produce greater speed reductions than does low visibility. Reductions in average spot speeds attributed to weather conditions ranged from 7 percent to 23 percent for poor visibility, 4 percent to 38 percent for unfavourable road surface, and 10 percent to 24 percent for both impaired visibility and road surface.

2.3 TREATMENT OF SELECTED DETERMINANTS IN SPEED MODELLING

In this section, specific aspects influencing vehicle speed are lifted out for a more detailed discussion. These aspects are "vehicle type", "road type" and "terrain type". In particular, it will be considered how these aspects are treated in selected speed models.

2.3.1 Vehicle type

The classification of vehicles into types depends on the purpose of the study, the availability of data, the level of detail required and level of complexity that can be handled. For a simulation program like TRARR, the purposes of using a large number of vehicle types are listed by Joubert (3) as follows:

- to allow for a distribution of behavioural and performance characteristics
- to respond to chances in traffic composition
- to allow the inclusion of special vehicles.

TRARR (4) simulates 18 vehicle types. This level of detail is not normally necessary in the context of the economic evaluation of road infrastructure projects.

Wolhuter (5) only uses passenger cars and three types of heavy vehicles in his analysis of delay on gradients, principally on the basis of the classification abilities of the traffic counter used to gather data. The RODES2 (6) and ECANET (7) programs developed by Bester allow for four vehicle types, namely passenger cars, light delivery vehicles, medium trucks and heavy trucks.

In program CB-Roads (1), six vehicle types are used. These types are passenger car, light delivery vehicle, mini-bus, bus, medium truck and heavy truck. Each of these vehicles types has important implications for the economic analysis of road projects, especially in developing areas. This classification is considered sufficient for the purpose of the economic evaluation of rural road projects.

2.3.2 Road type

Program CB-Roads uses seven road types. These are listed and described below. Speed restrictions for light vehicles on paved roads are assumed to be 120 km/h.

- Freeway: divided multi-lane road with grade separated, full control of access and high design standards
- Expressway: divided multi-lane road with at-grade intersections, high design standards
- Four-lane road: undivided multi-lane road, design standards vary
- Two-lane road: two-lane two-way trafficked road, design standard vary
- Three-lane road: two-way trafficked road, one continuous lane per direction, the third lane alternating between the directions to provide a climbing or auxiliary lane
- Gravel road: unsurfaced but engineered road
- Dirt road: track or informal road with no engineering improvements.

2.3.3 Terrain type

The classification system for terrain types adopted in CB-Roads is the same as that described in the Highway Capacity Manual (8) and other design manuals. These terrain types are flat, rolling and mountainous. In the literature, terrain types are not always uniquely defined. Some definitions utilise the truck equivalency factor and percentage no-passing zone as criteria, others the length of grade subject to stated limits. These definitions are mostly qualitative and therefore subjective. These terrain descriptions often imply a combination of horizontal and vertical alignment, assuming that flat terrain is associated with large curve radii, or mountainous terrain with sharp curves. This is not always true, as illustrated by Pienaar (9). In his study on fuel consumption, he describes five terrain types to accommodate more combinations of horizontal and vertical alignment, namely:

- Flat and tangent
- Flat and winding, as found next to a river or coast
- Rolling and tangent
- Rolling and winding
- Mountainous.

Substitutes for terrain types were investigated by Bester (7). The alignment parameters chosen are extensions of the COBA parameters, and are the following:

<u>Vertical alignment</u>

- H: hilliness, ie total rise plus fall of a uniform section of road (in metres per kilometre)
- N: number of rises plus falls per kilometre

<u>Horizontal alignment</u>

- B: bendiness, ie sum of horizontal deflections in degrees per kilometre
- LC: the length of curvature as a fraction of the total length of road.

In terms of these parameters, terrain types can be defined as follows:

Flat terrain: $H < 30$ m, that is road gradients less than 3%, and the number of rises plus falls does not play a significant role as the speed is not influenced greatly by the flat up or down slopes.

Rolling terrain: $30 \text{ m} < H < 50$ m, that is road gradients between 3% and 5%, and $1 < N < 2$, that is more than one change of gradient from rise to fall or inversely per km.

Mountainous terrain: $H > 50$ m, that is gradients greater than 5%, and $N < 1$, that is single gradients longer than one km.

2.4 CONCLUSIONS

The fact that speed is influenced by a variety of factors can easily be overlooked when working with mathematical models. When working with a particular model, it is important to consider its limitations, given the nature of the problem to which it is applied.

3. OVERVIEW OF SELECTED SPEED MODELS

3.1 INTRODUCTION

In this section speed models are classified as either general or specific models. General models typically consider a broad range of factors influencing vehicle speed. With specific models, speed is related to a single variable, for example vertical alignment, and often for specific conditions, such as climbing lanes.

3.2 GENERAL MODELS

General models differ from one another in the amount and level of detail required. They can range from look-up tables for speed values for different conditions or combinations of conditions, to multi-variable mathematical formulae, to microscopic simulations in small intervals. These models require increasingly more data and are therefore more expensive to use. Three models are discussed, in order to illustrate the difference in levels at which models operate.

3.2.1 CB-Roads (Version 3.4)

The relationship between speed, traffic flow and traffic density is well-known and documented. Speed decreases as traffic flow and density increase, due to the interaction between vehicles. CB-Roads uses sets of curves for different flow regimes experienced in a certain hour during the course of a year. The look-up tables in Version 3.4 of CB-Roads are used to generate values for free-flow speed that serve as input to the module that calculates vehicle speed as restrained by traffic conditions. The procedure used in Version 3.4 of CB-Roads to obtain operating speed for a given road section is set out in Section 4 of the "Description of Methodologies". In essence, this procedure amounts to the following:

- An appropriate free-flow operating speed is obtained from look-up tables

- The free-flow operating speed is adjusted for traffic conditions by:
  - calculating the flow in each of the eight annual flow regimes as defined for CB-Roads
  - distributing by direction the average flows per flow regime
  - calculating the capacity of the road section
  - using the speed-flow information in Tables SD15(a) to SD15(h) to adjust the free-flow operating speed to operating speed per flow regime.

3.2.2 COBA speed model

In the COBA9 Manual of the Assessments Policy and Methods Division, United Kingdom Department of Transport (10), the Cost Benefit Analysis program (COBA9) is prescribed as the standard way of evaluating projects. The speed/flow/geometry relationships are described by the following parameters:

- B: Bendiness, total change in direction per unit distance (deg/km)
- H_r: Hilliness-rises, sum of rises per unit distance (m/km)
- H_f: Hilliness-falls, sum of falls per unit distance (m/km)
- QL: Flow of vehicles per standard 3,65m lane (veh/h/lane)
- $\blacktriangle$QL: Flow QL above the change point (veh/h/lane), zero if QL below change point, with a change point at 1200 veh/h/lane.

The COBA9 manual (Section 5.4) gives speed prediction formulae for vehicles on rural motorways and all-purpose dual-carriageways. The original formulae were calibrated in 1977-1978. These were revised in 1990 to accommodate the increase in speeds which occurred since the previous study. The final models were recommended as being the most representative of the speeds obtained in good weather and daylight conditions. These speed prediction models are given below.

Light vehicles

$$V_L = C - 0{,}10B - 0{,}28H_r - 0{,}006QL - 0{,}027\blacktriangle QL$$

where:

C = 118 km/h for dual carriageway, 3 and 4 lane motorways
= 111 km/h for dual carriageway, 2 lane motorways
= 108 km/h for dual carriageway, 2 lane all-purpose roads.

Heavy vehicles

$$V_H = C - 0{,}10B - 0{,}50H_r - 0{,}012\blacktriangle QL$$

where:

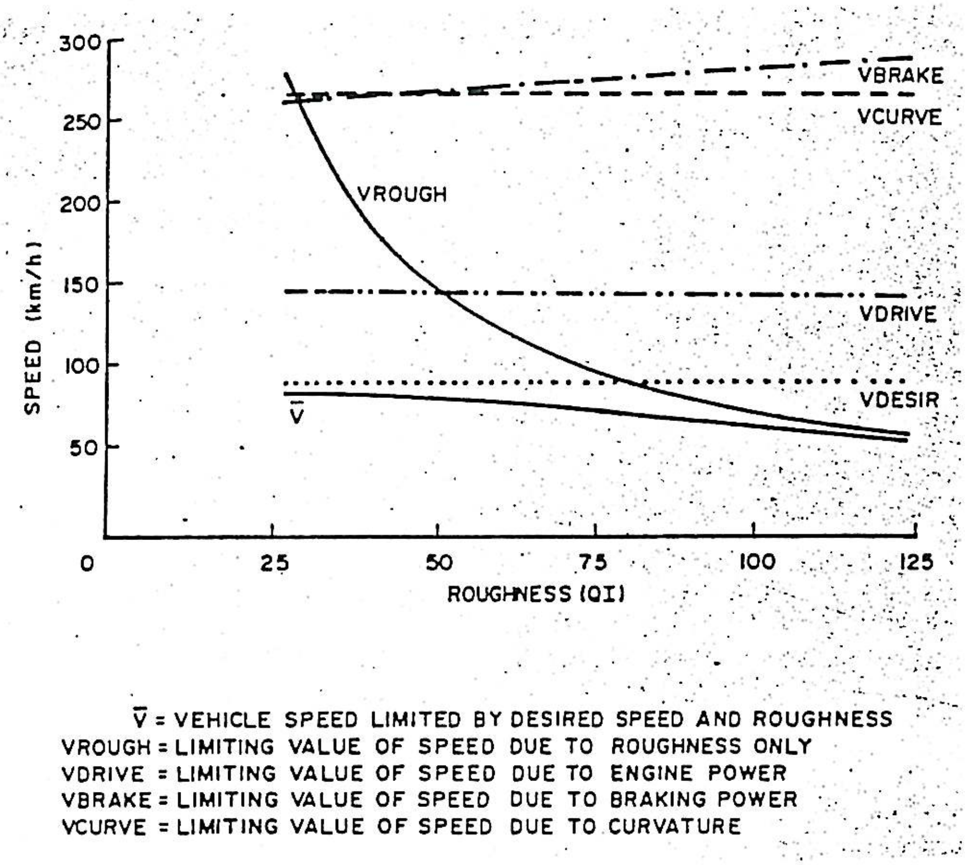
C = 93 km/h dual carriageway motorways
= 86 km/h for dual carriageway all-purpose roads.

These speed prediction models allow a continuous range of speeds to be calculated as functions of the input parameters. Similar formulae exist for rural two-way roads.

3.2.3 HDM3 speed models

The World Bank initiated the Highway Design and Maintenance Standards Study in 1969 as a basis for highway decision-making (15). The study of road user cost in Brazil acknowledged speed as a critical variable in the modelling of total road user cost. Watanatada et al (15) developed a deterministic model for predicting *steady-state speed*. This is defined as the speed that an unimpeded vehicle of known attributes would eventually attain and maintain over a homogeneous road section of known characteristics in a given socio-economic and traffic environment. The final model utilizes several limiting speed functions to determine the *steady state speed V*, namely gradient/vehicle driving power (VDRIVE), gradient/vehicle braking power (VBRAKE), road curvature (VCURVE), road roughness (VROUGH) and a desired speed (VDESIR), which may depend on aspects such as road class, road width and speed limit. A simplified illustration of the HDM3 steady state speed model of speed to road roughness on a straight and level road section, is shown in Figure 3-1.

Figure 3.1: HDMIII steady state speed model for a specific vehicle on a specific road section



3.3 SPECIFIC MODELS

Specific models are discussed under the headings "geometric parameters" and "pavement parameters". Under "geometric parameters", the following aspects are considered:

- vertical alignment
- horizontal alignment
- road width and lateral clearance.

3.3.1. Geometric parameters

Several studies have proposed statistical speed models based on multi-variable analysis in relation to those variables that influence speed. Often these variables are reduced to the minimum required to model with sufficient accuracy the speed under the conditions being investigated. This leads to a variety of speed formulae, each applicable to the conditions for which it was calibrated.

3.3.1.1 Vertical alignment

Free flow speed on level and downhill road sections is primarily influenced by the speed limits and the desired speed pertaining to the road type. The passenger car can achieve the desired speed on roads with 100 km/h and 120 km/h speed limits on grades up to 3 percent. The ability of loaded minibuses and light delivery vehicles to maintain the desired speed on roads with 120 km/h speed limits is limited by the vehicle power available, even on slight grades. Goods vehicles have a speed limit of 80 km/h, which they can attain on level sections, but the effects of grades are evident as soon as the grade starts. The influence of down grades on truck speeds is determined by the steepness and length of grade.

A vehicle travelling on a straight and level road section with no other restrictions will travel at a desired speed, which is a function of the various influences indicated earlier. From a dynamic analysis, the vehicle travelling at a steady velocity is in equilibrium as the resultant force is nil. The forces acting on the vehicle are the driving force, gravitational force, mechanical inertia and friction losses, aerodynamic and rolling resistance and braking forces. As it is difficult to measure each of the forces separately, some being variable with respect to speed, it is customary to solve the equation for speed through a regression analysis. There exist a number of calibrated formulae, each developed for a specific purpose to ensure the simplicity of processing in order to solve the problem in hand. These formulae can be used to calculate the effect of a change in grade while keeping the other values constant.

In RODES2, Bester (6) calibrated the following of V2, the speed at the end of an interval, for a macro simulation program:

$$V2=\frac{-B+\sqrt{B^2-4*A*C}}{2*A}$$

where:

V2	=	speed at the end of the current interval (m/s)
V1	=	entry speed
A	=	1/XX where XX = length of interval (m)
B	=	constant depending on vehicle type (see Table 3.1)
C	=	2*g*G*(0,1 + 0,231*LN(V1)) + B*V1 - 2*D - (V1**2)/XX (for passenger cars and LDVs)
C	=	2*g*G*(1,03 - 1,87/V1) + B*V1 - 2*D - (V1**2)/XX (for trucks)
D	=	constant depending on vehicle type (see Table 3.1)
G	=	gradient of the interval (m/m)
g	=	9,81 m/(s**2)
LN	=	natural logarithm

and (1,03 - 1,87/V1) > or = 0

Table 3.1: Values for B and D for four vehicle types, after Bester (1992)

Vehicle type	B	D
Passenger car	0,050 (0,056)	1,73 (1,85)
Light delivery van	0,050 (0,060)	1,63 (1,72)
8 ton truck	0,037 (0,037)	0,98 (0,93)
25 ton truck	0,030 (0,026)	0,77 (0,57)

These values are based on data suggested by Wolhuter (12) and updated by Bester (7). The update was necessary in the light of higher speed limits on some rural roads and the changes in vehicle outputs since the initial calibrations of RODES2 were done in 1981. The values in brackets are original RODES2 (6) data.

The ECANET program was developed to do economic evaluations on network level. The application of the RODES suite of programmes had two major limitations, namely the extensive data needs and the fact that only one link is handled at a time. In the derivation of the substitute for road alignment, the RODES2 program was used to simulate the speeds on different alignments. A regression analysis was then performed on these speeds and coefficients calibrated for the following variables:

H = hilliness, ie the sum of rises and falls in metres per kilometre

N = number of rises and falls per kilometres

for a uniform section of road, to produce a macroscopic model of speed which could be handled conveniently in ECANET. The values calibrated by Bester are listed in the appendices to the report (7). The ECANET models require little calculation and can estimate the free-flow operating speeds as a continuous function of the variables. When comparing an alternative vertical alignment where a reduction in hilliness occurs, the free-flow operating speed will be reduced even if the two alignments are of the same terrain type.

The formulae for the low flow situations are tabled in Table 3-2. The following conditions apply for low flow, that is when:

<u>On single carriageway roads</u>:

Q = ADT/1000 < 10 for two-lane roads

Q = ADT/3500 < 10 for four-lane roads

<u>On freeways</u>:

Q < 26 for light vehicles

Q < 40 for trucks

where:

Q = ADT/1000 for four-lane freeways

Q = ADT/1500 for six-lane freeways

ADT = two-way average daily traffic.

Table 3.2: ECANET speed formulae

	Speed formulae for different classes of vehicles	
Single carriageway roads	$V_{CH} = 102 - 3,34N - 1,07Q + 0,021N*H + 0,0065H*Q - 0,0018 H*H$ $V_{LHS} = 103 - 2,99N - 0,217H - 0,846Q + 0,045N*H + 0,0054H*Q - 0,00059H*H$ $V_{MHS} = 85,3 - 2,15N - 0,390H + 0,140N*H - 0,0019H*H$ $V_{HHS} = 82,9 - 0,817H + 0,199N*H$	Passenger cars LDVs Medium trucks Heavy trucks
Freeways	$V_{CHF} = 116,9 - 1,336N - 0,298H + 0,758N*H$ $V_{LHF} = 103,5 - 0,949N - 0,121H + 0,0588N*H - 0,0014H*H$ $V_{MHF} = 83,0 - 1,527N - 0,315H + 0,0215N*H - 0,0026H*H$ $V_{HHF} = 79,7 - 0,664H + 0,209N*H - 0,0021H*H$	Passenger cars LDVs Medium trucks Heavy trucks

These formulae must be used within the practical limitations that apply to each road type and bearing in mind that the speeds of passenger cars, light delivery vehicles and minibuses are not influenced by grades less than 3 percent, and therefore hilliness of less than 30 metres per kilometre.

Wolhuter (5) considered warrants for climbing lanes. He reduced the vehicle types to three and fitted a relationship between the desired speeds and gradient. This resulted in the following:

$V_c = 123{,}32 - 6{,}99*G$

$V_t = 76{,}89 - 4{,}79*G$

$V_s = 69{,}13 - 5{,}33*G$

where:

V_c = speed for passenger cars (km/h)

V_t = speed for trucks (km/h)

V_s = speed for semi-trailers (km/h)

G = gradient (%).

He describes the data sets used in his analysis, and gives free-flow speeds on single grades of known lengths. Using data collected with electronic equipment, the speeds of free-flowing vehicles were obtained by screening out vehicles following by less than 10 seconds. The results are summarised in Table 3-3.

Table 3.3: Speed versus gradient for various vehicle classes, after Wolhuter (1990)

Road type, no of lanes (location) sample size gradient distance	Vehicle speed: average speed, standard deviation, speed limit			
	Light	Heavy short	Heavy medium	Heavy long
Rural, 2 (Cornelia) 9 298 vehicles 3,62 % 1600 m	100,6 15,6 120	60,6 15,6 80	51,8 14,3 80	49,8 15,4 80
Rural, 2 (Colenso) 17 384 vehicles 5,21 % 3000 m	89,2 16,0 120	52,3 18,4 80	37,6 13,8 80	34,6 12,9 80
Rural, 2 (Long Tom) 16 200 vehicles 8,38 % 2000 m	64,5 12,9 100	37,7 11,8 80	32,4 15,9 80	19,0 10,2 80
Freeway, 4 (Rigel N) 16 149 vehicles 3,54 % 3100	95,7 14,3 120	60,2 16,1 80	52,1 16,8 80	05,9 16,8 80
Freeway, 4 (Rigel S) 15 985 vehicles 4,45 % 4000 m	92,5 14,4 120	55,1 14,4 80	47,4 16,2 80	48,2 15,9 80
Freeway, 4 (Ben Schoeman) 21 017 vehicles 4,97 % 1400	86,7 15,8 120	52,2 16,7 80	40,4 15,3 80	42,3 16,8 80
Expressway, 4 (Krugersdorp) 21 302 vehicles 6,44 % 1800 m	78,2 15,1 120	44,9 17,3 80	32,7 12,3 80	26,4 9,3 80

The effects of downgrades are determined by their steepness and length, and the drivers' knowledge of the road. On long, flat downgrades, the driver will try to maintain a speed which is near or slightly in excess of the speed limit. On short, medium steep grades, the driver will aim to achieve the maximum speed near the end of the grade to gain momentum for the next upgrade. This technique will be applied on steeper grades if the driver knows the road and if no hazardous locations exist. On long, steep downgrades, the braking ability of the vehicle becomes an important issue. Drivers of heavy vehicles will then gear down to a lower gear and crawl down the grade, using brakes only to augment the retarding force of the engine compression to control speed.

Wolhuter and Kennedy (12) also investigated the flow characteristics on four-lane undivided rural roads. Measurements of free-flow speed were taken on the N2 route at Sir Lowry's Pass and on the N1-24 north of the Kranskop toll plaza. Only three classes of vehicles, as identified by the TEL 4CM traffic counter, are reported. The measurements were not made under free flow conditions and are not directly applicable to this study. The results do, however, indicate the relationship that exists between gradient and average speed. The speeds are summarised in Table 3.4.

Table 3.4: Speed versus gradient on four-lane undivided rural roads, after Wolhuter and Kennedy (1990)

Route: Station number Gradient	Vehicle speed: average speed, standard deviation		
	Light	Medium	Heavy
N2: 1 3,6 %	88,8 16,3	54,7 16,9	50,2 18,6
N2: 2 5,4 %	81,2 13,2	47,0 16,9	40,0 15,3
N2: 3 7,2 %	76,0 13,5	45,5 17,9	35,4 15,6
N2: 4 8,0 %	74,2 14,8	47,1 18,5	34,7 19,6
N1-24 2,6 %	101,7 21,2	91,5 23,6	85,9 23,8
N1-24 0,8 %	107,6 19,3	100,5 18,7	100,1 26,8
N1-24 6,0 %	84,5 25,3	70,5 27,1	67,5 26,8
N1-24 4,7 %	77,8 25,3	64,9 26,0	61,6 25,6

3.3.1.2 Horizontal alignment

Long horizontal curves with superelevation have little influence on the speed that the driver perceives to be safe. Leisch (13) found no effect on speed of curves with radii larger than 600 metres. This is based on the vehicle dynamics as influenced by superelevation and side friction, from the equation:

$$V_R = 3{,}6\sqrt{(e+f)*R}$$

where:

V_R = speed in kilometres per hour

R = radius in metre

e = 0,06 maximum rate of superelevation

f = 0,14 coefficient of side friction.

Watanatada et al (14) analysed data from the Brazil-UNDP-World Bank highway research project. A hyperbolic relationship between speed and curvature was established and showed that the curvature (degrees/kilometre) only start to influence the steady-state speed if the curvature is more than 300 degrees per kilometre for a drive speed of 23 metres per second. This translates to a radius of 200 metres at a speed of 83 km/h. The model permits higher speeds on curves than the dynamic analysis. This can be explained by accepting that the side friction coefficient in the analysis was too conservative and that drivers are prepared to take more discomfort from centrifugal forces on the unpaved roads on which the Brazil study was performed, than on paved roads.

The term **bendiness** (B) was used by the Transport and Road Research Laboratory (10) as a substitute for horizontal alignment. It is defined as the sum of horizontal deflections in degrees per kilometre. Bester (7) added a second factor called the **length of curvature** (LC), which is the fraction of curve length to total length of the road section. Ignoring the curves with radii greater than 600 metres, he calibrated the equation for speed on a road section as a function of bendiness and length of curve to yield:

V_{CV} = 97,4 - 0,130B - 0,028B/LC for passenger cars

V_{LV} = 96,8 - 0,121B - 0,032B/LC for light delivery vehicles

V_{MV} = 86,7 - 0,072B - 0,030B/LC for medium vehicles

V_{HV} = 86,1 - 0,060B - 0,036B/LC for heavy vehicles.

This approach provides a continuous relationship between speed and the independent variables, so that alternatives can be compared on a continuous scale.

3.3.1.3 Road width and lateral clearance

The effects of road width and lateral clearance on the capacity of a road are well known and acknowledged. The Highway Capacity Manual (8) provides factors to reduce the service flows where these effects are encountered. These factors do not apply to a reduction in free-flow operating speed. The Transport and Road Research Laboratory (10) assumes that carriageway width only influences the speed of light vehicles when travelling faster than 80 km/h. This reference increases the speed of light vehicles by 1,1 km/h for each 1 metre increase in carriageway width (CW). Bester (7) uses this relationship to adjust the speed on narrow two-lane roads by subtracting a value (11,4 - CW) x 1,1 km/h from the calculated vehicle speed, as his speed formulae were calibrated for widths of 11,4 metres.

Carriageway width does not play a role in the free-flow operating speeds on freeways, expressways and multilane highways, unless the design standard are substantially lower than normal. The design standards of two-lane roads vary with respect to width and the provision of shoulders. Free-flow operating speeds on two-lane roads with 3,7 metre wide lanes and wide shoulders will be comparable to those on expressways and four-lane roads. The free-flow operating speeds on normal rural roads without shoulders were measured as such and include the width effects. On gravel and dirt roads, the carriageway width is a variable value, depending not only on the constructed width, but also on the traffic and maintenance. The measured free-flow speeds on these roads will include these effects and it is not necessary to adjust separately. Watanatada et al (15) did not consider road or carriage width as a constraining parameter in the HDM3 steady state speed model.

3.3.2 Pavement parameters

The effect of the road pavement condition on speed is manifested through riding quality: if riding quality is high, speeds will be high. Inversely, speeds are low on poor riding quality roads. The relationship is complex and influenced by all the factors mentioned previously. On a given road, speed will further change over time as pavements deteriorate over time and with use. The rate of deterioration is further influenced by environmental conditions.

Riding quality is measured by the Present Serviceability Index (PSI) or the Quarter Car Index (QI). The relationship between PSI and QI is given by the following equations (1):

$$QI=92,63-56,39*\ln(PSI)$$

$$PSI=e^{(1,643-0,0177QI)}$$

For the evaluation of rehabilitation projects, CB-Roads uses the relationships between riding quality and time, and vehicle operating cost (VOC) and riding quality, to calculate total VOC over the economic life of the road.

The classification system used for road surface condition is described in Table 5.8 of the CB-Roads manual. These values are given in Table 3.5 below.

Table 3.5: Values of QI and PSI related to descriptive terms

Term	Road type			
	Surfaced road		Unsurfaced road	
	QI	PSI	QI	PSI
Good	40	2,54	55	1,95
Fair	55	1,95	80	1,25
Poor	80	1,25	100	0,88

Note that in the "Description of methodologies": Chapter 12 of the CB-Roads Manual, the emphasis is on the deterioration of riding surfaces and that a different classification system is adopted there. The following definitions of the levels of riding quality are given:

- Warning level of riding quality: where the pavement would require rehabilitation in order to prevent dramatic increase in future rehabilitation and operating cost
- Severe level of riding quality: the terminal level of riding quality for the class of pavement.

The road pavement parameters in Chapter 12 are given in Table 3.6 below.

Table 3.6: Road pavement parameters

Pavement classification	Situation	Riding quality (PSI)		
		New	Warning	Severe
A	Multi-lane	4,0	3,0	2,5
B	2-Lane AADT > 600	3,5	2,5	2,0
C	2-Lane AADT < 600	3,0	2,0	1,5
Unpaved		2,0	1,5	1,0

Comparing Tables 3-5 and 3-6, it is clear that, from a maintenance point of view, the pavement riding quality of paved roads will probably not be allowed to drop to a poor condition, which is lower than the severe level.

The validity of the HDMIII steady-state speed model, as developed by Watanatada et al (15) for the World Bank in Brazil, was investigated for local road conditions and vehicles by Du Plessis et al (16, 20). They documented the effects of road roughness on vehicle speeds as observed on rural roads in the Pretoria area. To isolate the effect of road roughness, they controlled the other variables as far as possible by choosing sections with characteristics that would not affect vehicle speeds. Thus the sections were reasonably straight, level and away from obstacles. They considered two-lane and dual carriageway roads with paved and unpaved surfaces. The data were collected from 22 road sections and 4400 vehicles were observed. Average speeds observed per vehicle class for each of the test section are listed in Table 3.7. These speeds were measured under free flow conditions and the sections were unaffected by other geometric restrictions. The speeds for heavy trucks were measured for three different vehicle combinations. The most representative speed was selected as the average heavy vehicle speed if a large number of observations were made, otherwise the weighted average was calculated.

Table 3.7: Average speed per vehicle class, after du Plessis et al (1989)

Test section: Road number: Position	Roughness (QI)	Average speed				
		Cars	LDVs and Mini-buses	Buses	Medium trucks	Heavy trucks
F1 S: N1-22 North: km 22,0-23,0	21,4	118,2	110,3	87,8	86,9	83,9
F1 F: N1-22 North: km 22,0-23,0	14,6	124,6	123,1			96,5
F2 S: N1-23 North: km 1,4-2,4	25,0	114,1	114,3	101,3	81,0	80,9
F2 F: N1-23 North: km 1,4-2,4	19,1	109,4	112,2			
F3 S: N12-1 West: km 111,6-112,6	26,5	118,1	104,2	81,0	82,7	82,6
F3 F: N12-1 West: km 111,6-112,6	23,3	125,1	119,2			80,0
F4 S: N12-1 West: km 81,8-80,8	49,5	116,8	110,7	100,0	82,5	78,6
F4 F: N12-1 West: km 81,8-80,8	35,5	121,4	117,7			
F5 S: N12-1 West: km 62,8-61,8	8,2	116,6	110,82	75,0	76,8	70,3
F5 F: N12-1 West: km 62,8-61,8	7,3	121,2	119,4			
1A: Road P36-1: km 12,8-13,8 S	9,2	103,6	96,7	80,4	72,8	78,7
1B: Road P36-1: km 14,4-13,4 N	11,0	104,2	97,6	64,0	74,5	64,4
2A: Road P6-1: km 25,0-26,0 E	21,9	95,7	95,1	79,0	81,6	81,7
2B: Road P6-1: km 27,0-26,0 W	27,4	104,7	97,4	81,5	79,5	72,1
3A: Road 483: km 6,8-7,8 N	16,0	105,6	100,4		78,5	90,0
3B: Road 483: km 8,3-7,3 S	17,9	108,7	101,5		82,5	90,4
4A: Road P154-1: km 38,4-39,4 E	52,1	93,3	96,4			76,8
4B: Road P154-1: km 40,1-39,1 W	66,2	94,0	92,4	79,0		73,7
G1A: Road 1342: km 2-3 N	65,9	75,8	81,8	79,3		
G1B: Road 1342: km 2-3 S	119,9	73,1	70,7	64,3		
G2A: Road 771: km 1-2 N	109,8	62,9	64,1			
G2B: Road 771: km 1-2 S	81,9	55,2	62,3	41,0		

Regression analyses were done of speed against QI for each of the vehicle types (passenger cars, light delivery vehicles and combis, buses, and three classes of trucks). Auto-correlation was detected in the case of cars, light delivery vehicles and combis and single rear-axle trucks. These vehicles had the largest sample sizes. The authors concluded that:

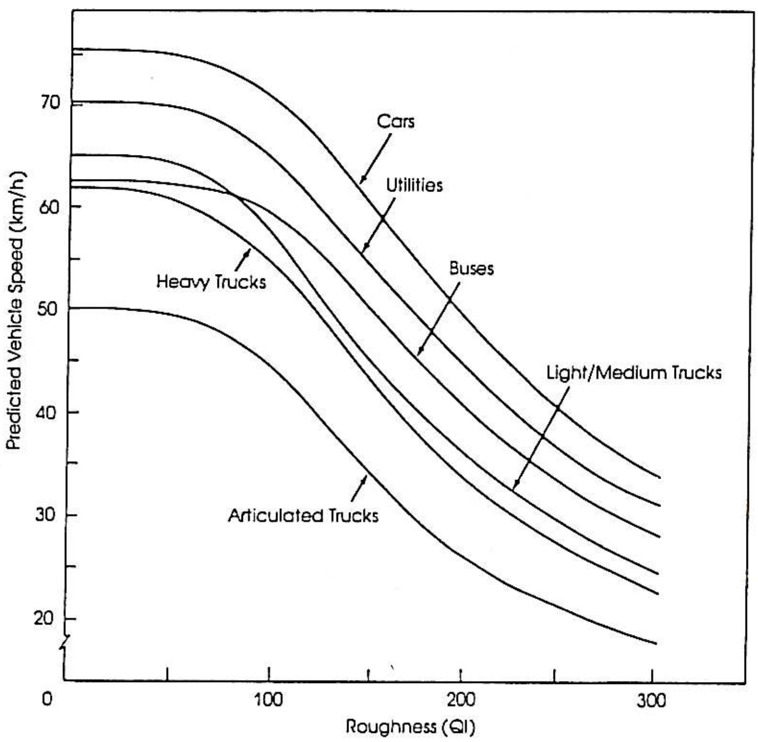
- For cars, light delivery vehicle and combis, and single rear axle trucks, the type of road has a greater impact than road roughness on the speed of the vehicles.
- The obvious relation that exists between road type (as defined in this study) and road roughness, complicates the interpretation of the results.
- The presence of auto-correlation in three of the five simple regression equations where the coefficient of QI appears to be significantly different from zero, is a clear indication of the need to include other relevant variables. It is not only road roughness which would cause a driver to maintain a lower speed on a gravel road, but also factors such as dust, road width and the presence of loose sand.
- The data obtained in this survey were insufficient to identify a roughness-speed relationship for all vehicle classes.

A comparison of the speeds measured by Du Plessis et al (16) (see Table 3.7 above) with the values measured in this study, indicates that for paved roads, the speeds are similar. It can be deduced that for road roughness on paved roads up to QI= 66, no effect on speed can be measured. On gravel roads, the effect of road roughness is correlated with other aspects such as dust and loose sand, and this relationship will be difficult to model.

The effect of road roughness on speed on paved roads is not evident in the ranges of road roughness and desired speeds normally found on the South African paved road network. A survey of all the national roads done by Van Niekerk (17) reports the lowest average value of PSI as 2,34 for the section X0101N, Elandsrivier- Paarl/Matroosberg, over nearly six kilometres. This translates to a QI of 43.

Paterson and Watanatada (11) studied six vehicle classes and plotted the curves of predicted speeds on a level tangent unpaved road against road roughness. These plots are shown in Figure 3-2. They note that it is apparent that at low roughness levels, in the range up to 80 QI, safety and speed limit considerations tend to dominate. This makes the predicted speeds insensitive to roughness. In the middle range, 80 to 200 QI, the attenuating effect on the predicted speed becomes more pronounced. In the high range above 200 QI, the predicted speeds are dominated by the driver response to roughness.

Figure 3.2: Predicted vehicle speed versus roughness on level tangent unpaved roads, after Paterson and Watanatada



Important work on the relationship between speed and riding quality on gravel roads were done at the Division for Roads and Transport Technology. Seydack et al (18) reworked the data collected by Haddow on the speeds travelled on gravel roads in South West Africa (Namibia), to produce a relationship between QI and vehicle speed for passenger cars and light delivery vehicles. The data were collected in August 1989 and a sample of 913 observations on eighteen roads was considered. The objective of Haddow's work was to establish a relationship between the objective QI road roughness measure of gravel roads in South West Africa, and the subjective evaluation of the same road by the road user (19). Data on speed over defined sections of one kilometre each were collected. The average speeds for ranges of QI values are given in Table 3-8. For the purposes of the maintenance and design model that they were investigating, the speeds for buses, medium and heavy goods vehicles were taken as 70 km/h, as it was observed that these vehicles, particularly buses, were not affected by roughness.

Table 3.8: Relationship between QI and vehicle speed, after Seydack et al, (1991)

QI	Average speed (km/h)
< 40	98
40 - 59	92
60 - 79	90
80 - 99	87
>= 100	84

The relatively high speeds indicated in this study can, in part, be explained from the observations by Haddow (19) that:

"Over eighty percent of the road users were local residents of South West Africa. Most road users, with the obvious exception of the tourists, were also familiar with the gravel roads of South West Africa, and several frequently travelled long distances.

Bakkies and 4x4 bakkies made up sixty percent of the vehicles using the gravel roads of the study. Only thirteen percent of the vehicles were trucks of some description. Most of the vehicles, fifty eight percent, were owned by the driver, which could be a reason why the drivers considered vehicle damage, especially due to stoniness and corrugation of the road, a problem.

The average speed was calculated, categorized according to the evaluation given by the road user, and from the result it may be seen that the better the evaluation, the greater the average speed. Note, however, that the differences in average speeds for the five categories are not very large."

Paterson and Watanatada (11) give as the desired speeds on unpaved roads the following:

- 78,8 km/h for cars
- 72,7 km/h for utilities
- 66,1 km/h for buses
- 68,4 for light and medium trucks
- 67,3 km/h for heavy trucks and
- 50,2 km/h for articulated trucks.

These values refer to speeds on roads of poorer quality than gravel roads, and were accepted as typical speeds on dirt roads.

4. RESULTS OF SPEED SURVEYS

4.1 INTRODUCTION

In the following sections, the term "speed" refers to macroscopic speed under free-flow conditions. Speed data were collected at selected survey sites in order to be used, together with information from other sources, to complete a matrix of values for speed in a format similar to that in Version 3.4 of CB-Roads. In this section, survey sites are described, data items collected are listed, the method of data collection is explained and required minimum and actual sample size are given. Finally, survey results are presented.

4.2 DESCRIPTION OF SURVEY SITES

Several aspects were considered in selecting sites for speed observations. These aspects are discussed below.

Road type

- No dirt roads were included in the analysis. Dirt roads, or tracks, are un-engineered roads built from natural material with no specific design standards to relate to. As such, this type of road covers a very broad range of descriptions. Vehicle operations on these roads are influenced by many factors, such as the area, weather, soil condition and drainage. Dirt roads normally occur in rural and remote areas, and considering the low traffic volumes associated with these roads, the cost of staging surveys on them was too high to justify the effort.

- Three road types not included in the look-up tables of previous versions of CB-Roads were considered in the analysis, in order to observe the effect of a lower speed limit on speeds. These "new" road types are:

    - expressway with a speed restriction of 100 km/h
    - three-lane paved road with a speed restriction of 100 km/h
    - two-lane paved road with a speed restriction of 100 km/h.

Road surface condition

The report "Results of riding quality measurements - 1991" (17) was used to identify road sections with a "good", "fair" or "poor" surface condition. However, it became evident that paved road sections with a poor riding quality are not typical. Further, for the reasons given in Section 3, no distinction was made between "good" and "fair" road surface conditions. The speed experiment described in this section therefore involves roads with a "non-critical" surface condition only.

General

The survey method, described in Section 4.3, dictated the exact location of survey sites, in the sense that communication between the two observers, using two-way radio equipment, had to be possible. This caused the two observation points to be on crest curves on either side of a section. With careful site selection, this proved not to affect the reliability of the observations. The distance over which speed measurements were taken usually was in the order of two kilometres. This is a compromise between the need for stabilised speeds which implies relatively long survey sections, and the limiting factor of the range of radio equipment. Further, sites were selected in such a manner as to ensure realistic entrance speeds for a prevailing road and terrain type. Finally, speed samples were taken under free-flow conditions only. This was accomplished by sampling free-moving vehicles only, that is vehicles separated by more than ten seconds from the next vehicle, or leading vehicles in the case of platoons.

A total of 27 survey sites were selected. These are listed in Table 4.1. In Table 4.2 they are classified according to road type and terrain type.

Table 4.1: Description of survey sites

Route number	Position/ remarks	Road type	Terrain type	File name
N1-23(S)	4,0S to 6,372S	Freeway	Flat	H1
N1-23(N)	4,0S to 6,354S	Freeway	Flat	H2
N12-2(W)	02,0E to 98,8E	Freeway	Flat	H7
N12-2(E)	79,0E to 84,0E	Freeway	Flat	H8
N12-2(W)	79,0W to 84,0W	Freeway	Flat	H9
N4-1(E)	20,6E to 22,0E	Freeway	Rolling	H4
N1-22(S)	25,59S to 28,55S	Freeway	Mount	H3
N4-2(W)	6,6E to 7,8E	Freeway	Mount	H5
N4-2(E)	6,8W to 8,36W	Freeway	Mount	H6
N17-2(W)	Measured over 2,486 km	Expressway	Flat	H14
N17-2(E)	Measured over 2,486 km	Expressway	Flat	H15
P29(W)	Measured over 2,0 km	Expressway	Flat	H10
P29(E)	Measured over 2,0 km	Expressway	Flat	H11
P91(W)	Km 6,6; measured over 1,25 km	Expressway	Rolling	H12
P91(E)	Km 6,6; measured over 1,25 km	Expressway	Rolling	H13
P35(N)	Km 12,56 to Km 14,05	Three-lane	Mount	H16
P35(S)	Km 12,56 to Km 14,05	Three-lane	Mount	H17
P30(N)	Km 4,0 to Km 5,0	Three-lane	Mount	H18
P30(S)	Km 4,0 to Km 5,0	Three-lane	Mount	H19
P122-1	Km 9,0 to Km 12,014	Two-lane	Rolling	H20
P2-5(E)	Km 20,0 to Km 22,0	Two-lane	Rolling	H21
P2-5(W)	Km 20,0 to Km 22,0	Two-lane	Rolling	H22
P1386	Km 13,0 to Km 15,0	Two-lane	Rolling	H25
P2-5(E)	Km 16,0 to Km 18,0	Two-lane	Mount	H23
P2-5(W)	Km 16,0 to Km 18,0	Two-lane	Mount	H24
P1814	Km 8,0 to Km 10,0	Two-lane	Flat	H26
P734	Measured over 2,92 km	Gravel	Rolling	H27

Table 4.2: Classification of survey sites

Road type	Terrain type		
	Flat	Rolling	Mountainous
Freeway	H1, H2, H7, H8, H9	H4	H3, H5, H6
Four-lane			
Expressway	H14, H15		
Three-lane			
Two-lane			
Expressway 100 km/h	H10, H11	H12, H13	
Three-lane 100 km/h			H16, H17, H18, H19
Two-lane 100 km/h		H20, H21, H22, H25	H23, H24
Gravel	H26	H27	
Dirt			

4.3 DATA ITEMS COLLECTED AND METHOD OF DATA COLLECTION

Speed measurements were done by two sets of observers, using two-way radio equipment and synchronised watches. The first observer identified the vehicle by type and number plate, and the moment of arrival at a preset entrance mark was called over the radio. Simultaneously, the watch was frozen and the time of arrival noted down. The vehicle description and registration number was also radioed to the second observer. He also noted the arrival time as indicated over the radio, but from his watch. He then waited for the vehicle to pass the preset exit mark, froze the watch and noted the time. The speed was calculated by dividing the known distance between the entrance and exit marks by the travel time. The macroscopic speed per vehicle class was calculated by dividing the product of the distance and the number of vehicles by the total time spent by vehicles on the section of road.

4.4 SAMPLE SIZE

Sample sizes were based on speed variations per vehicle type. Where possible, sufficient numbers of vehicles were observed to obtain an average speed with a permitted error of +- 3,5 km/h with a confidence level of 95 percent. Table 4.3 gives the approximate minimum sample size requirements for a confidence level of 95 percent and a specified permitted error as a function of average range in speeds. This table is based on formulae suggested by Box (21); they were used to determine the required minimum number of observations at each survey site and for each vehicle type. These values are given in Appendix D.

Table 4.3: Approximate minimum sample size requirements for travel time studies with a confidence level of 95 percent

Average range in travel speeds	Minimum number of runs for specified permitted error				
	± 2 km/h	± 3,5 km/h	± 5 km/h	± 6,5 km/h	± 8 km/h
10 km/h	8	4	3	3	2
15 km/h	14	7	5	3	3
20 km/h	21	9	6	5	4
25 km/h	28	13	8	6	5
30 km/h	38	16	10	7	6

4.5 RESULTS OBTAINED

4.5.1 Actual sample size

A total of 2 378 vehicles were surveyed. In Table 4.4 these vehicles are classified by type. Table 4.5 gives a breakdown of the total sample by road type, terrain type and vehicle type.

Table 4.4: Classification of vehicles in survey

Vehicle class	Number	Percentage of total
Cars	830	35
LDVs	572	
Mini-buses	345	24
Buses	57	15
MGVs	254	2
HGVs	320	11
		13
Total	2 378	
		100

Table 4.5: Vehicles observed by road type, terrain type and vehicle type

Road type, terrain type and site description		Vehicle type						
		Cars	LDVs	Mini-buses	Buses	MGVs	HGVs	Total
Freeway								
Flat:	N1-23(S)	35	22	18	2	9	16	102
	N1-23(N)	24	22	21	5	6	19	97
	N12-2(W)	54	40	15	3	12	25	149
	N12-2(E)	29	23	16	0	7	16	91
	N12-2(W)	33	18	20	3	6	15	95
	TOTAL	175	125	90	13	40	91	534
Rolling:	N4-1(E)	39	32	12	0	8	9	100
	TOTAL	39	32	12	0	8	9	100
Mount:	N1-22(S)	12	0	0	0	3	12	27
	N4-2(W)	14	19	10	0	4	12	59
	N4-2(E)	34	16	23	1	8	15	97
	TOTAL	60	35	33	1	15	39	183
Expressway								
Flat:	N17-2(W)	62	25	11	1	4	14	117
	N17-2(E)	27	6	3	0	1	1	38
	TOTAL	89	31	14	1	5	15	155
Expressway 100 km/h								
Flat:	P29(W)	31	34	24	7	7	24	127
	P29(E)	23	17	16	3	25	23	107
	TOTAL	54	51	40	10	32	47	234
Rolling:	P91(W)	45	28	21	0	26	11	131
	P91(E)	46	27	22	0	22	17	134
	TOTAL	91	55	43	0	48	28	265
Three-lane 100 km/h								
Mount:	P35(N)	25	24	7	0	7	14	77
	P35(S)	46	28	12	0	20	25	131
	P30(N)	21	21	13	5	8	3	71
	P30(S)	17	7	1	0	4	4	33
	TOTAL	109	80	33	5	39	46	312
Two-lane 100 km/h								
Rolling:	P122-1	39	20	2	0	14	5	80
	P2-5(E)	14	7	10	1	14	5	51
	P2-5(W)	38	35	18	1	9	10	111
	P1386	25	22	9	15	7	3	81
	TOTAL	116	84	39	17	44	23	323
Mount:	P2-5(E)	33	27	22	8	8	13	111
	P2-5(W)	43	31	19	2	7	9	111
	TOTAL	76	58	41	10	15	22	222
Gravel								
Flat:	P1814	9	11	0	0	4	0	24
	TOTAL	9	11	0	0	4	0	24
Rolling:	P734	12	10	0	0	4	0	26
	TOTAL	12	10	0	0	4	0	26
Total		830	572	345	57	254	320	2 378

4.5.2 Observed speeds

Appendix A contains a printout of the "raw data" collected per survey site. In Appendix B the processed data are presented as speed histograms per survey site and vehicle type. Statistical details of the processed data are given in Appendix D.

In Figures 4.1 to 4.11 observed values for speed are given per survey site. In these figures, survey sites of a similar road type and terrain type have been grouped together. This serves to highlight differences between sites falling in the same category. In each case, corresponding values from Version 3.4 of CB-Roads for road surface condition "good" and "fair" (indicated as CBR-Good and CBR-Fair respectively) are presented for comparative purposes. "Mountainous" refers to road sections where the grades are at or near the maximum value for freeways (5%) over long distances.

Figure 4.1: Observed speeds per survey site compared to values from CB-Roads for road type: Freeway (120 km/h) and terrain type: Flat

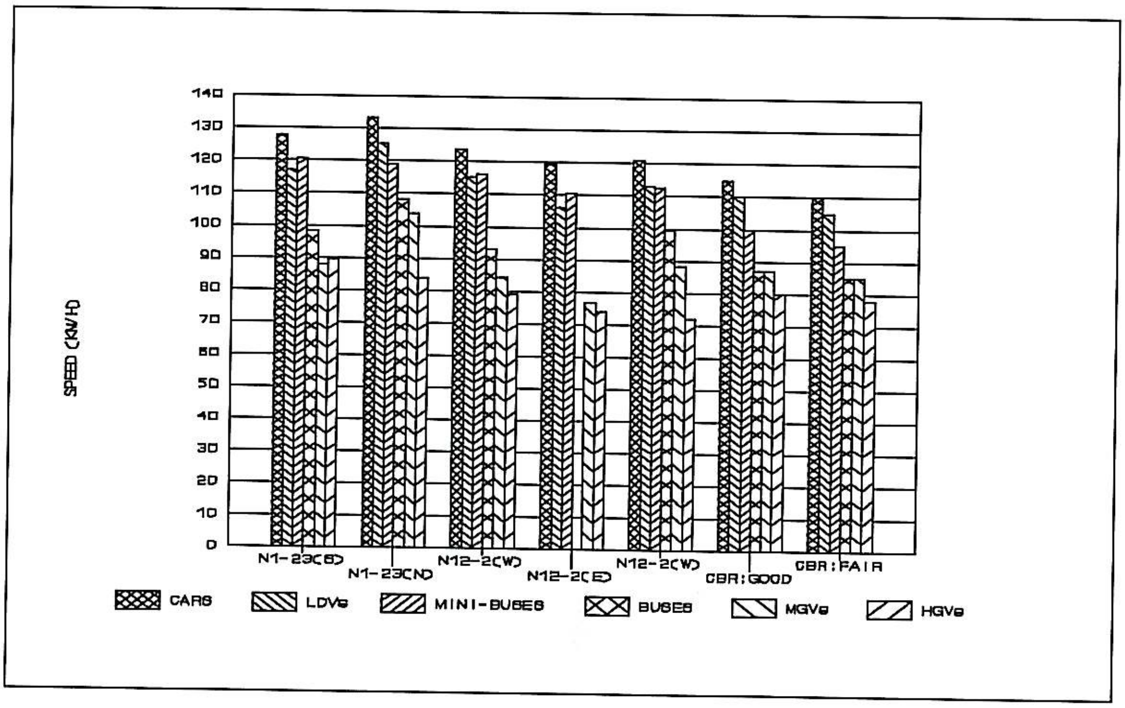


Figure 4.2: Observed speeds per survey site compared to values from CB-Roads for road type: Freeway (120 km/h) and terrain type: Rolling

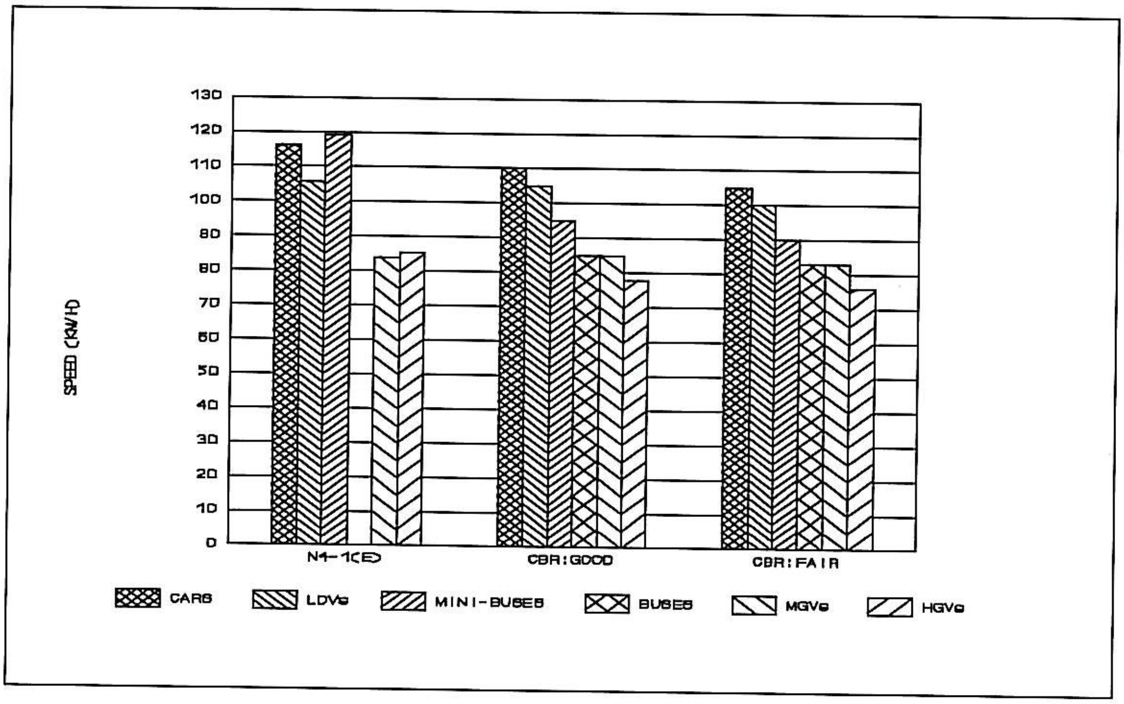


Figure 4.3: Observed speeds per survey site compared to values from CB-Roads for road type: Freeway (120 km/h) and terrain type: Mountainous

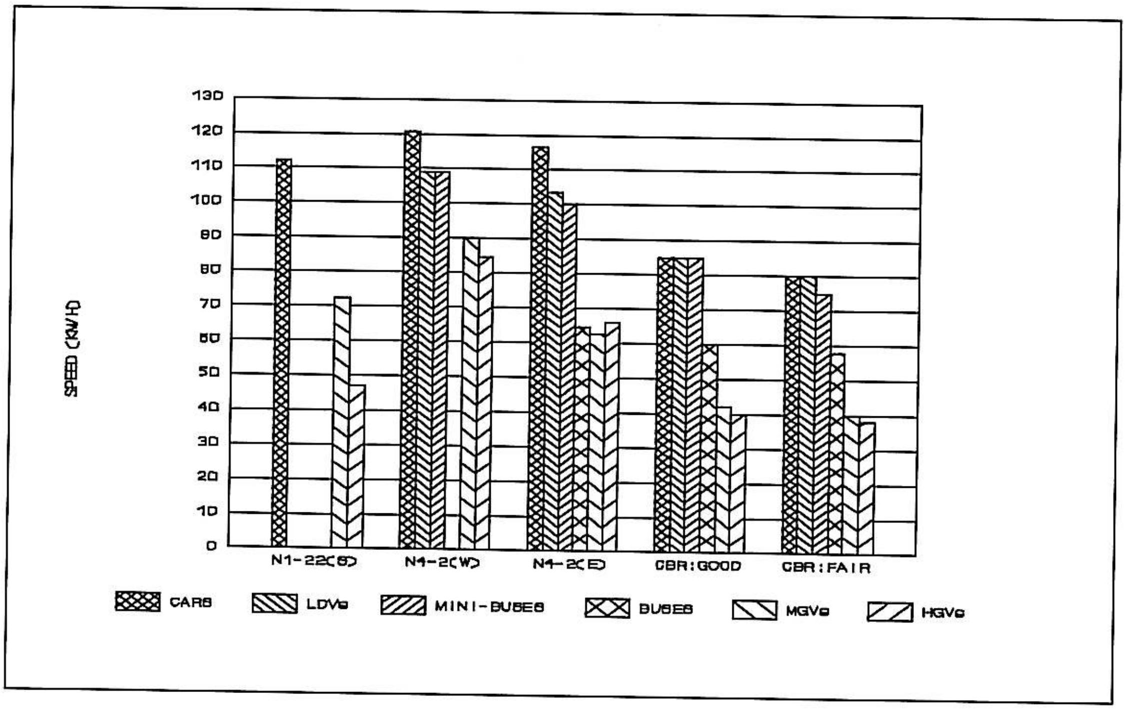


Figure 4.4: Observed speeds per survey site compared to values from CB-Roads for road type: Expressway (120 km/h) and terrain type: Flat

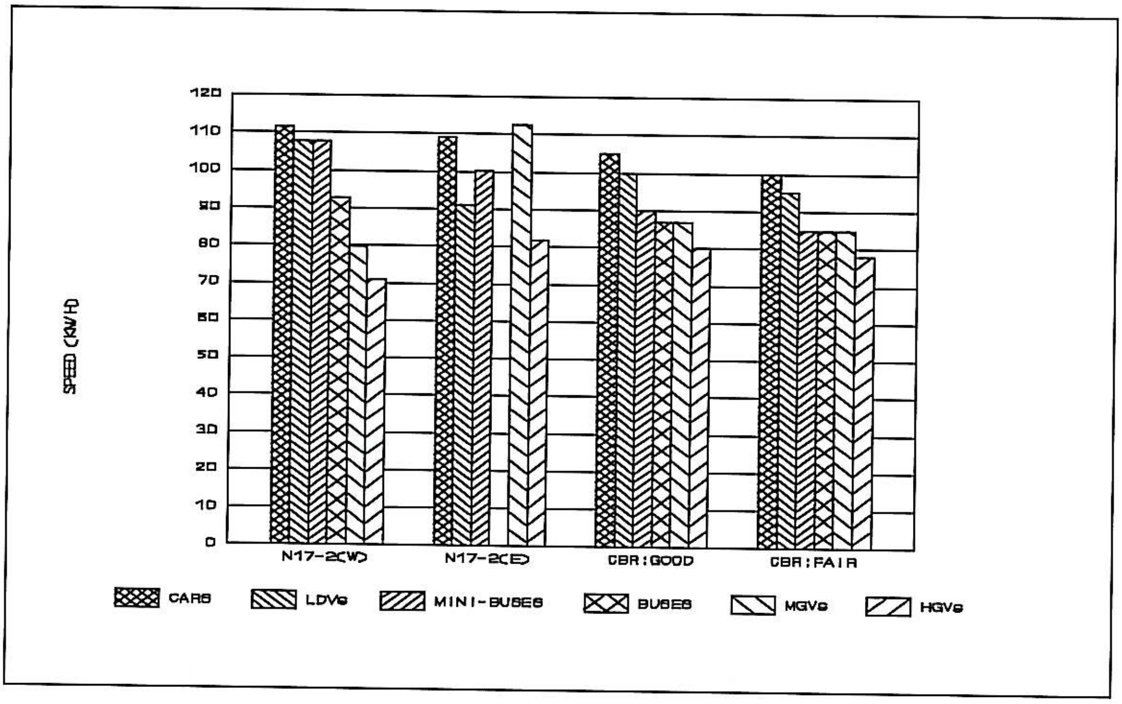


Figure 4.5: Observed speeds per survey site compared to values from CB-Roads for road type: Expressway (100 km/h) and terrain type: Flat

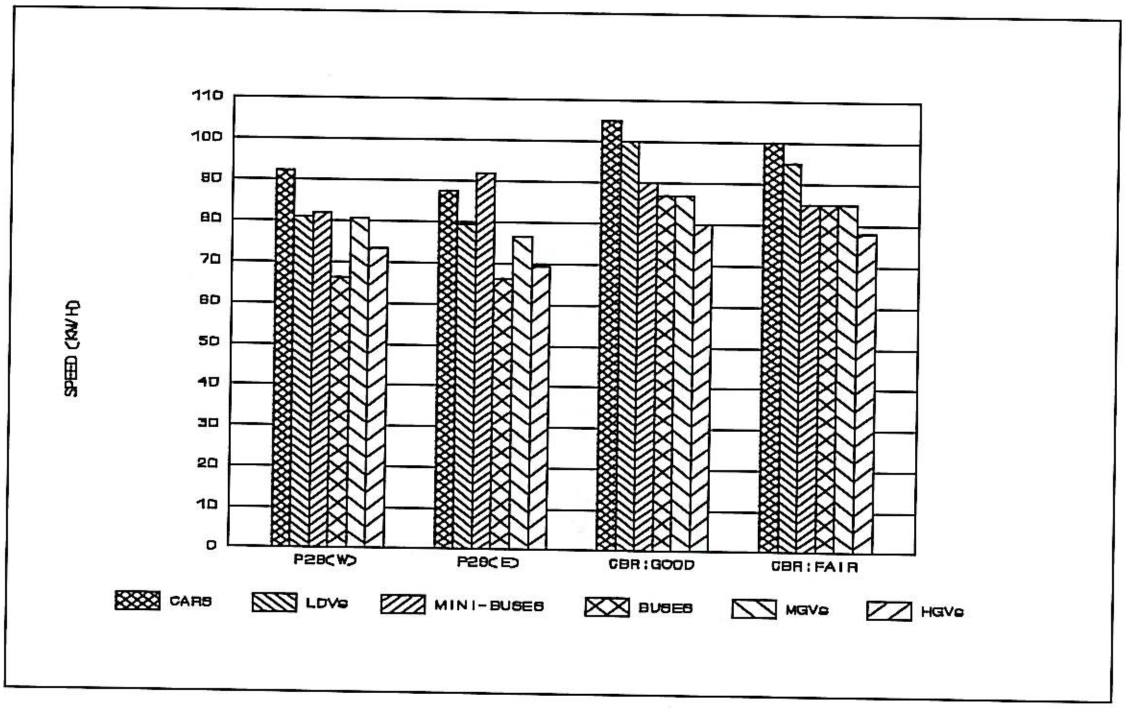


Figure 4.6: Observed speeds per survey site compared to values from CB-Roads for road type: Expressway (100 km/h) and terrain type: Rolling

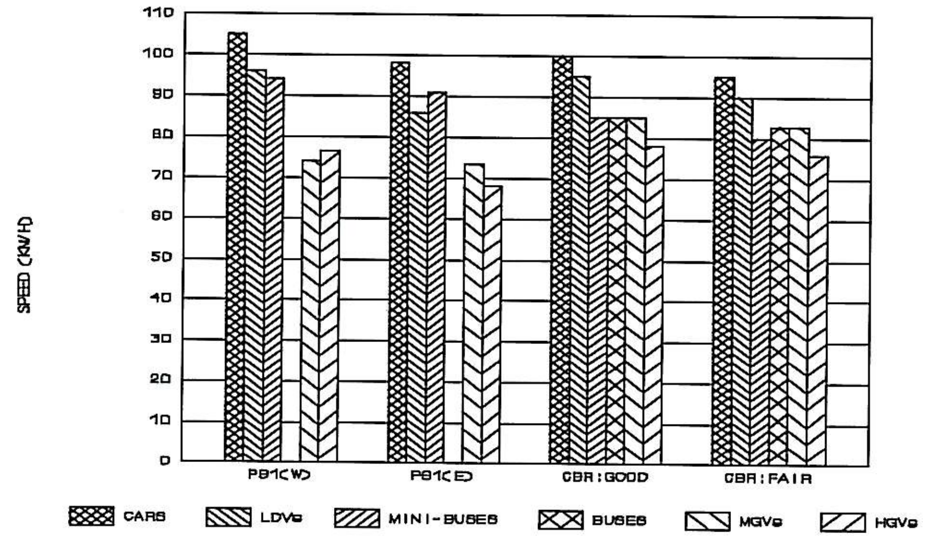


Figure 4.7: Observed speeds per survey site compared to values from CB-Roads for road type: Three-lane (100 km/h) and terrain type: Mountainous

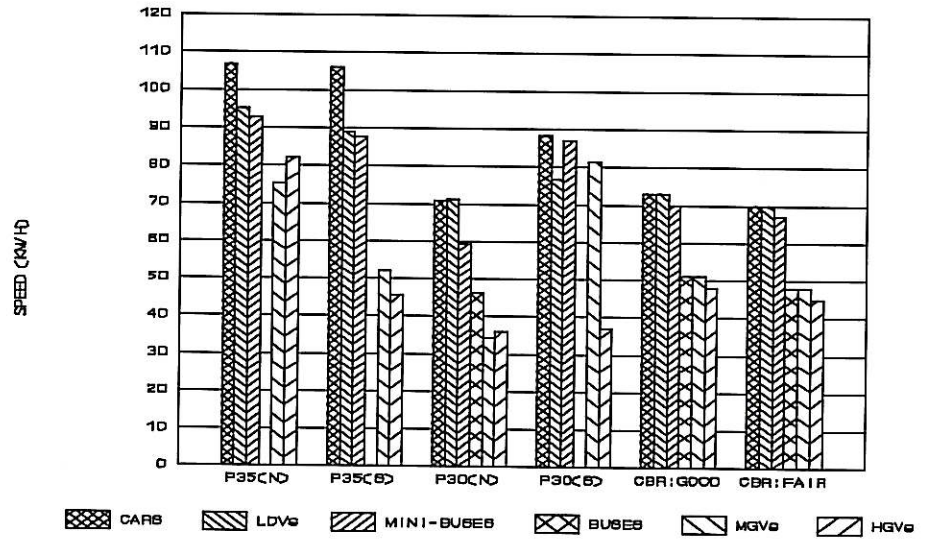


Figure 4.8: Observed speeds per survey site compared to values from CB-Roads for road type: Two-lane (100 km/h) and terrain type: Rolling

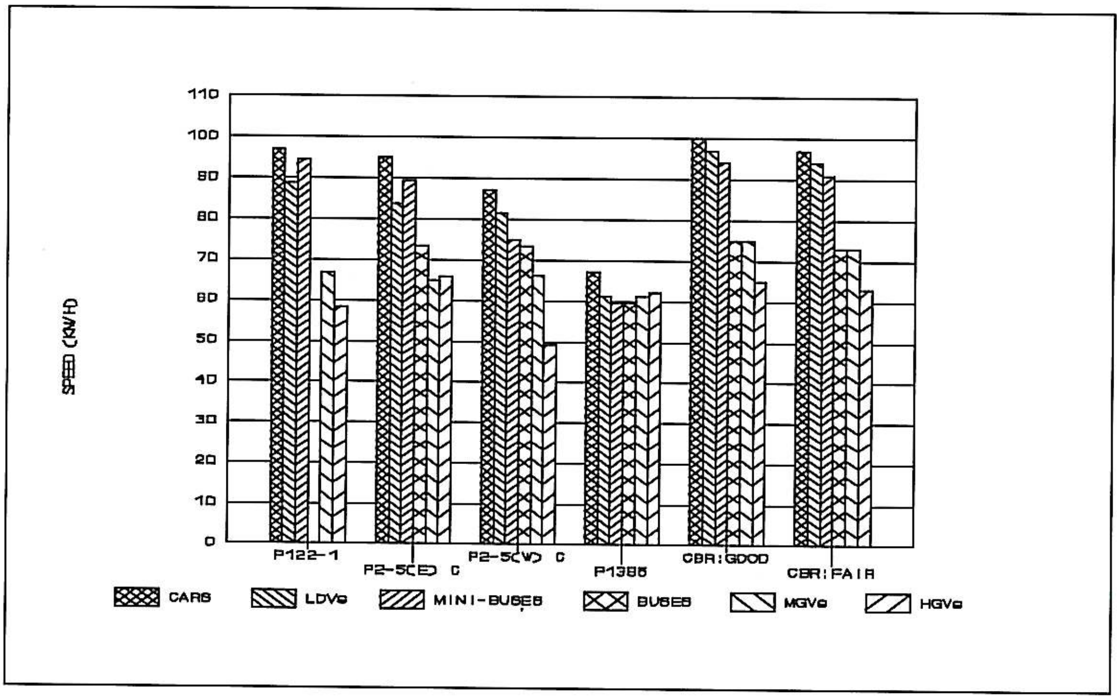


Figure 4.9: Observed speeds per survey site compared to values from CB-Roads for road type: Two-lane (100 km/h) and terrain type: Mountainous

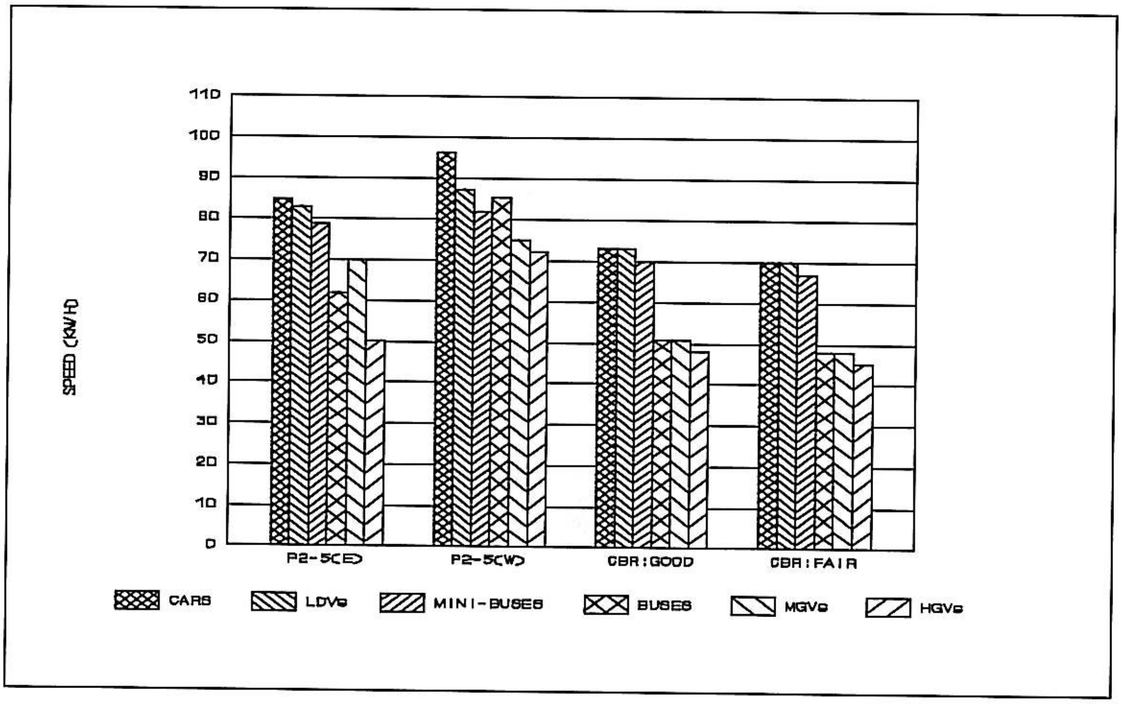


Figure 4.10: Observed speeds per survey site compared to values from CB-Roads for road type: Gravel and terrain type: Flat

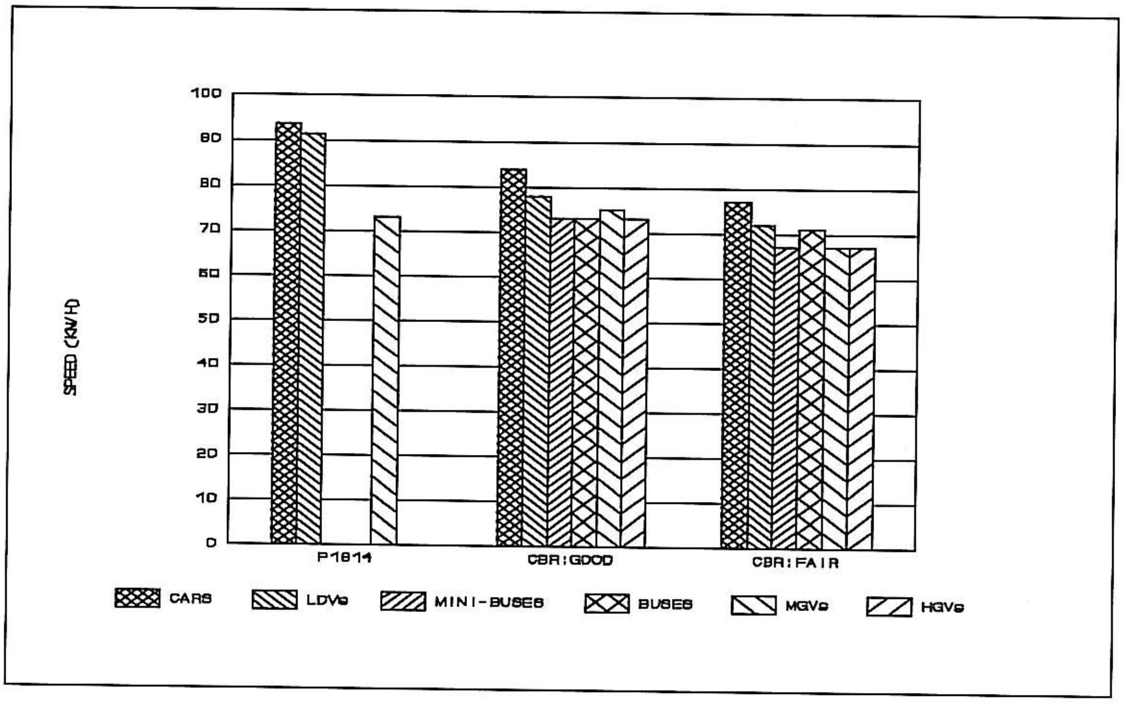
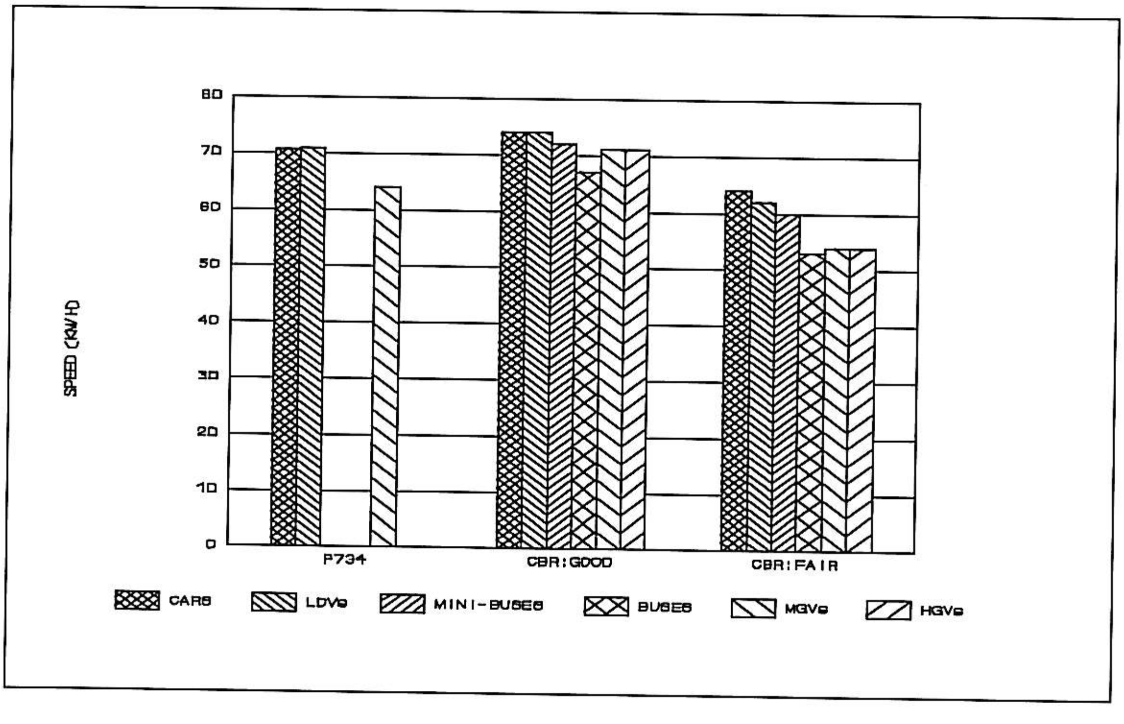


Figure 4.11: Observed speeds per survey site compared to values from CB-Roads for road type: Gravel and terrain type: Rolling



In Table 4.6 the information presented in Figures 4.1 to 4.11 is aggregated and given per road and terrain type. These values are presented graphically in Figures 4.12 to 4.22. In these figures, corresponding values from Version 3.4 of CB-Roads for road surface condition "good" and "fair" (indicated as CBR-Good and CBR-Fair respectively) are also given for comparative purposes.

Table 4.6: Free-flow speed per road and terrain type

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	123	114	115	99	85	78
Rolling	116	106	119	NA	84	85
Mountainous	116	107	103	64	72	58
Expressway						
Flat	111	104	106	93	85	72
Expressway 100 km/h						
Flat	90	80	86	66	77	71
Rolling	102	91	92	NA	74	71
Three-lane 100 km/h						
Mountainous	97	86	79	46	53	52
Two-lane 100 km/h						
Rolling	88	79	76	61	65	56
Mountainous	91	85	80	65	72	57
Gravel						
Flat	94	91	NA	NA	73	NA
Rolling	71	71	NA	NA	64	NA

Figure 4.12: Speed values from CB-Roads and observed values for road type: Freeway (120 km/h) and terrain type: Flat

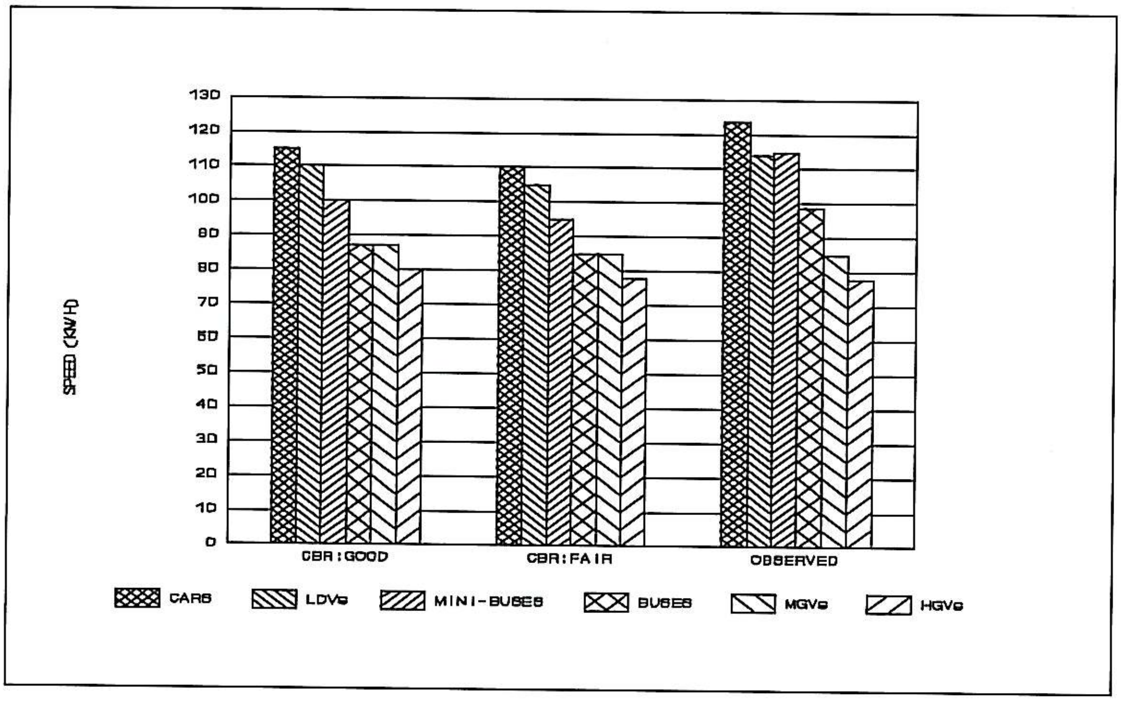


Figure 4.13: Speed values from CB-Roads and observed values for road type: Freeway (120 km/h) and terrain type: Rolling

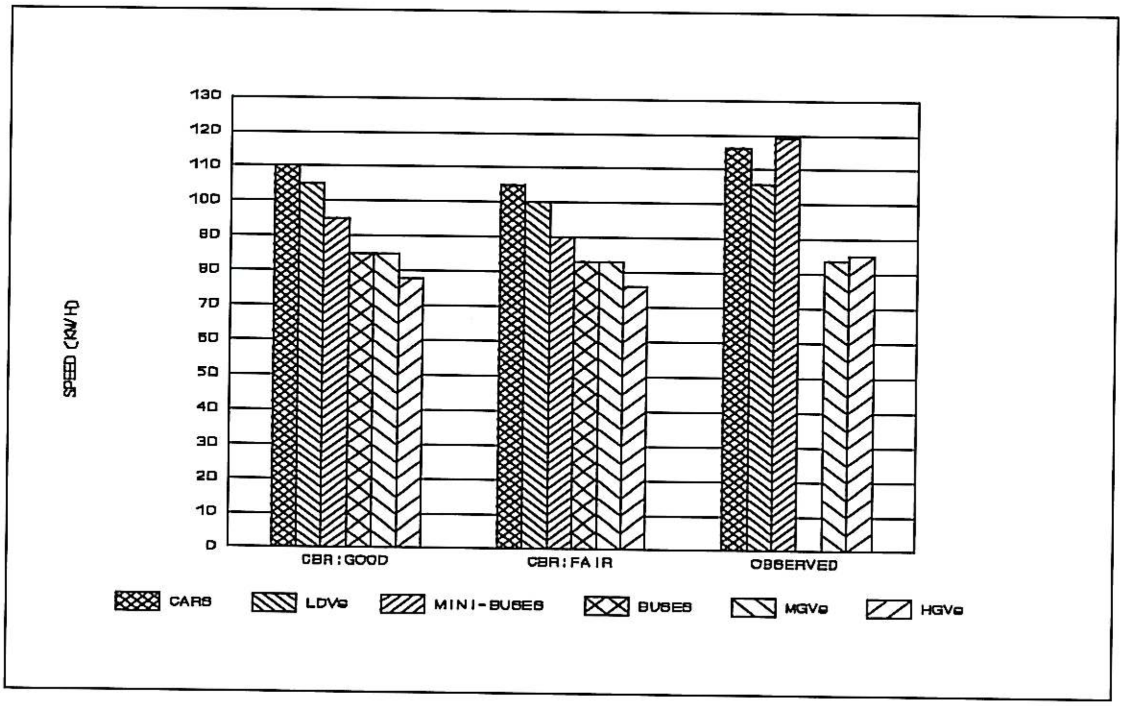


Figure 4.14: Speed values from CB-Roads and observed values for road type: Freeway (120 km/h) and terrain type: Mountainous

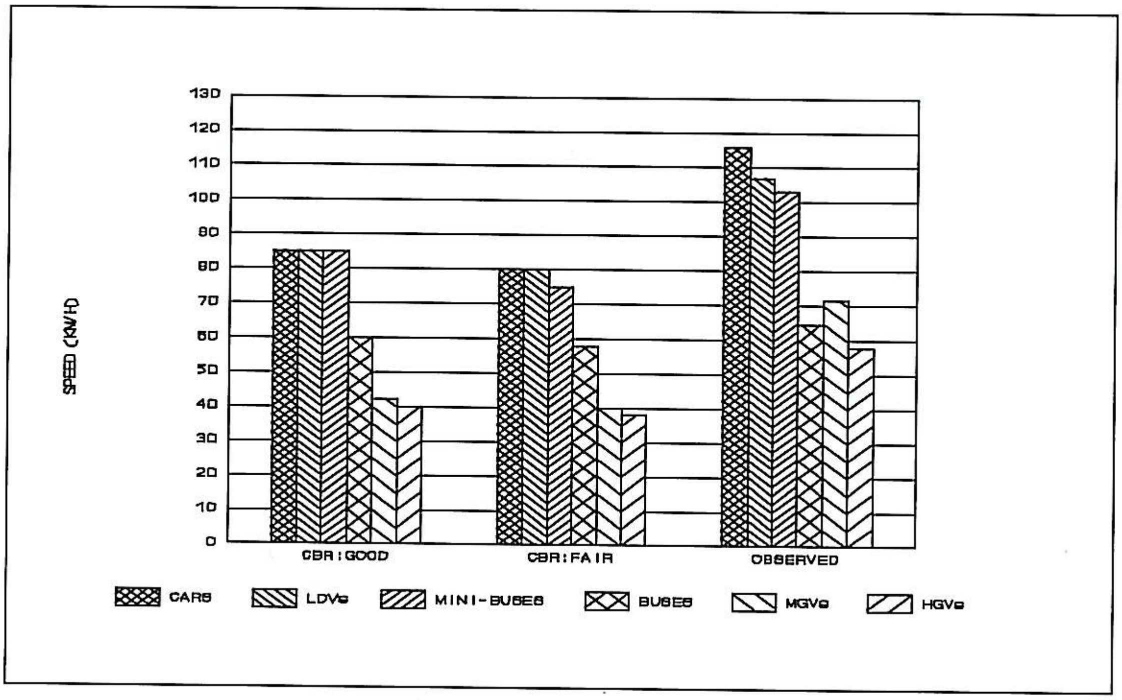


Figure 4.15: Speed values from CB-Roads and observed values for road type: Expressway (120 km/h) and terrain type: Flat

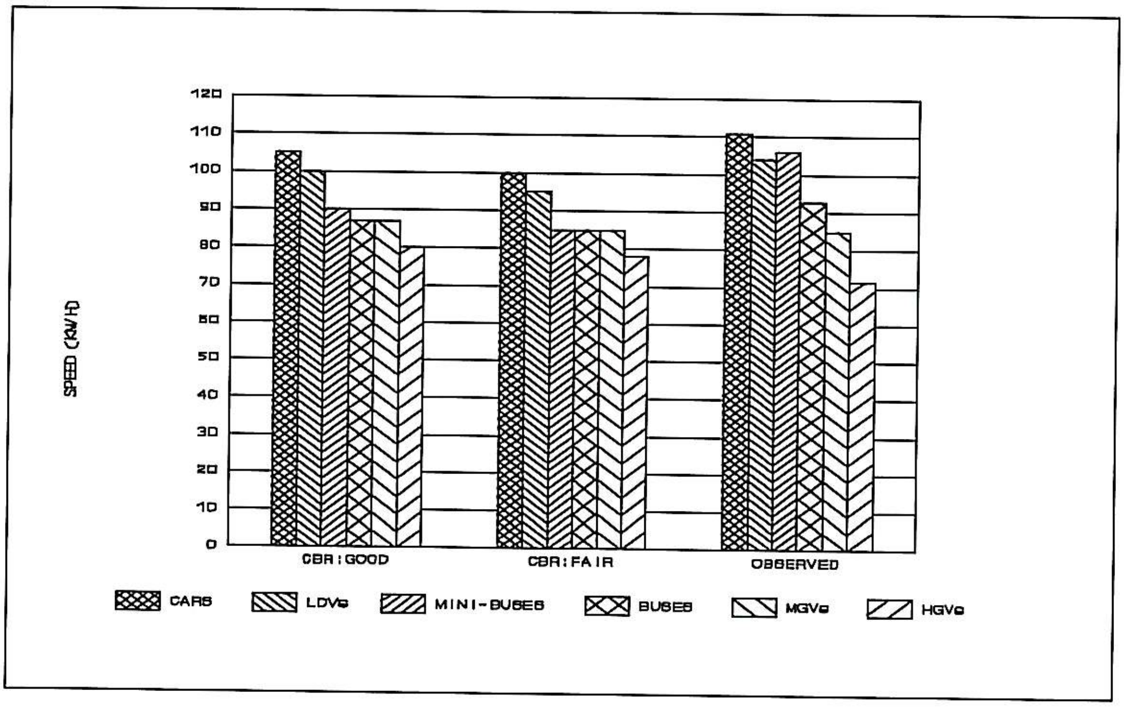


Figure 4.16: Speed values from CB-Roads and observed values for road type: Expressway (100 km/h) and terrain type: Flat

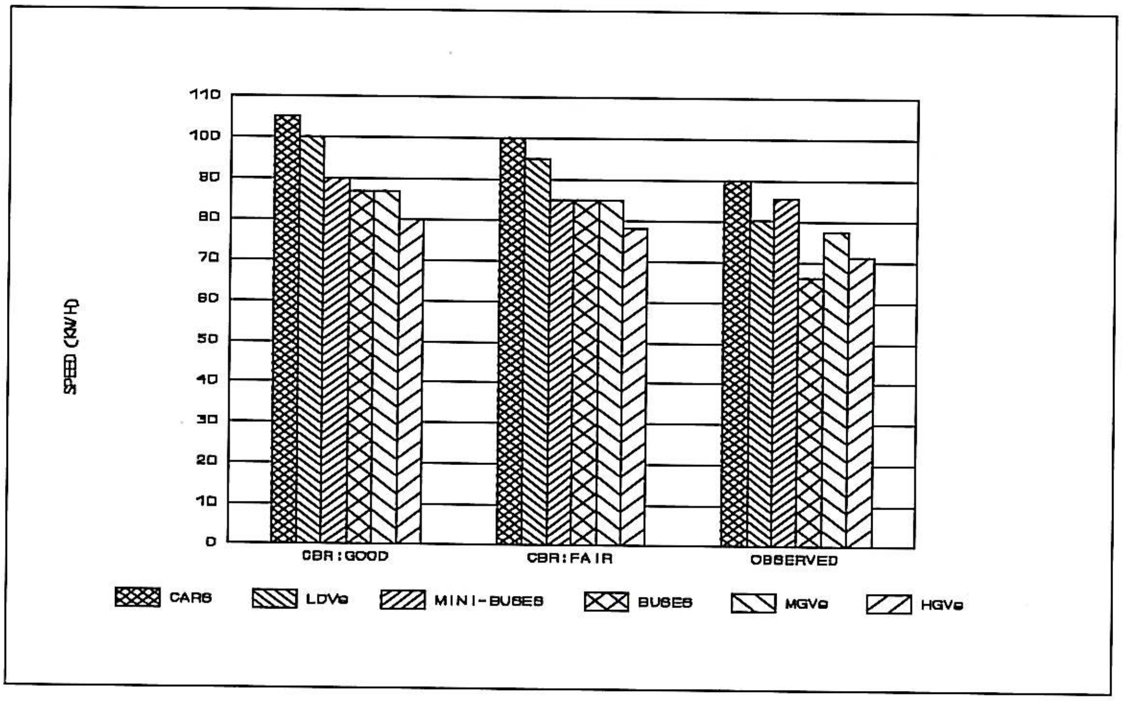


Figure 4.17: Speed values from CB-Roads and observed values for road type: Expressway (100 km/h) and terrain type: Rolling

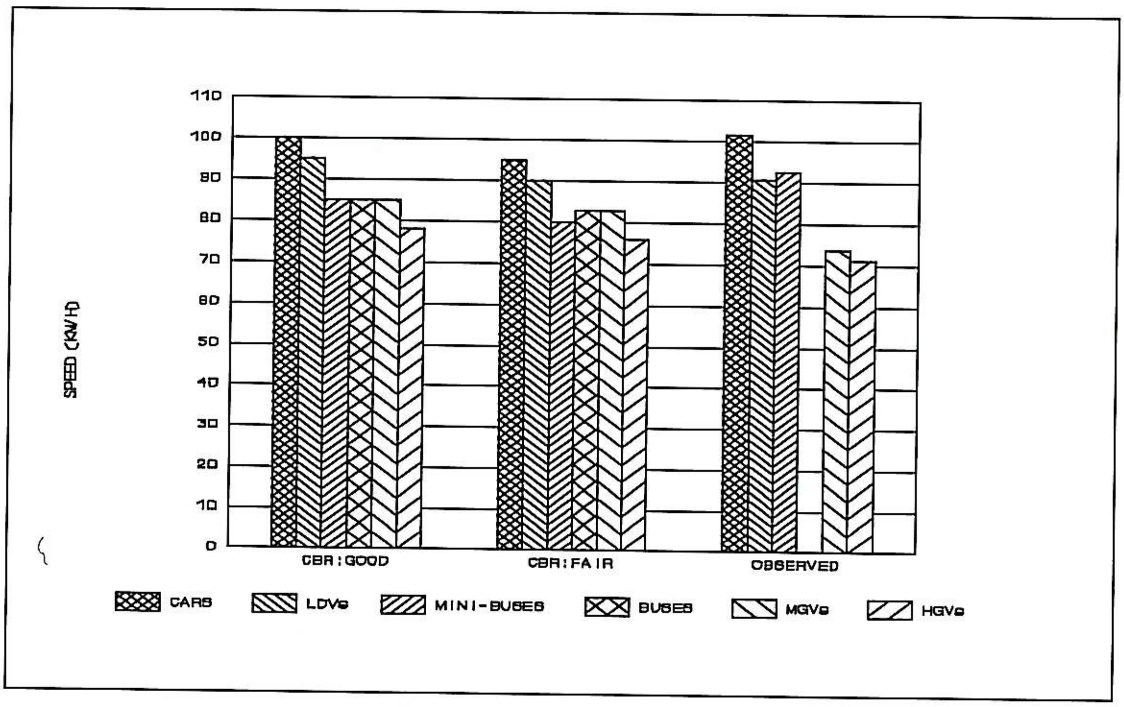


Figure 4.18: Speed values from CB-Roads and observed values for road type: Three-lane (100 km/h) and terrain type: Mountainous CB-Roads

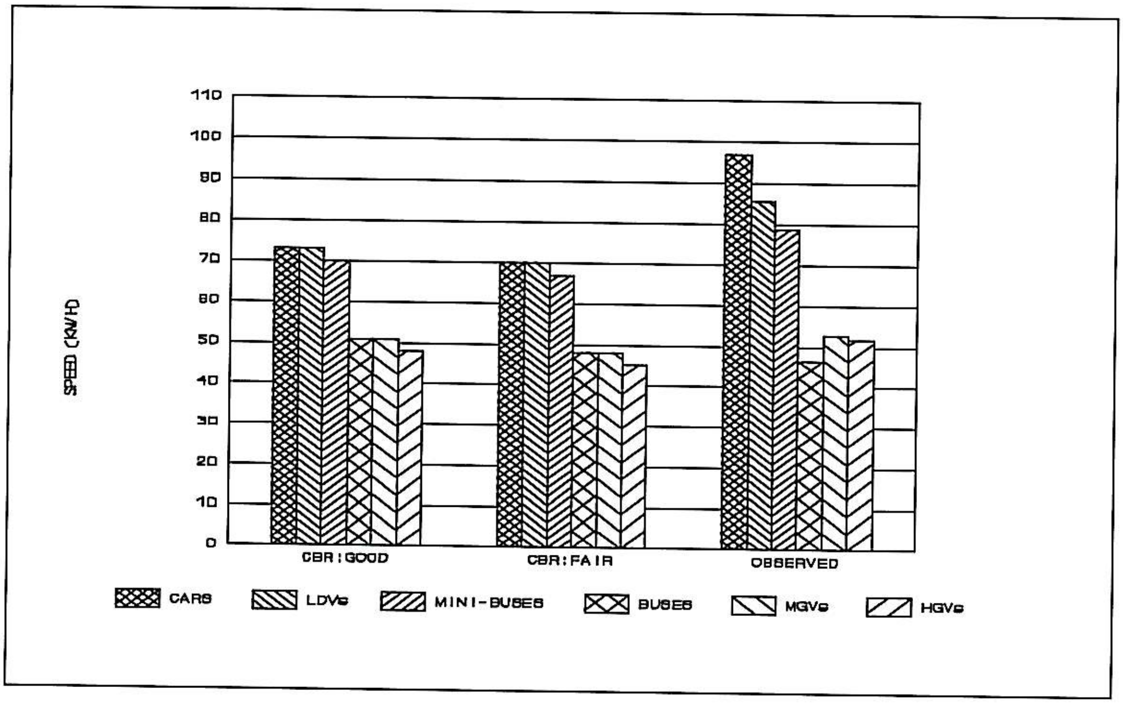


Figure 4.19: Speed values from CB-Roads and observed values for road type: Two-lane (100 km/h) and terrain type: Rolling

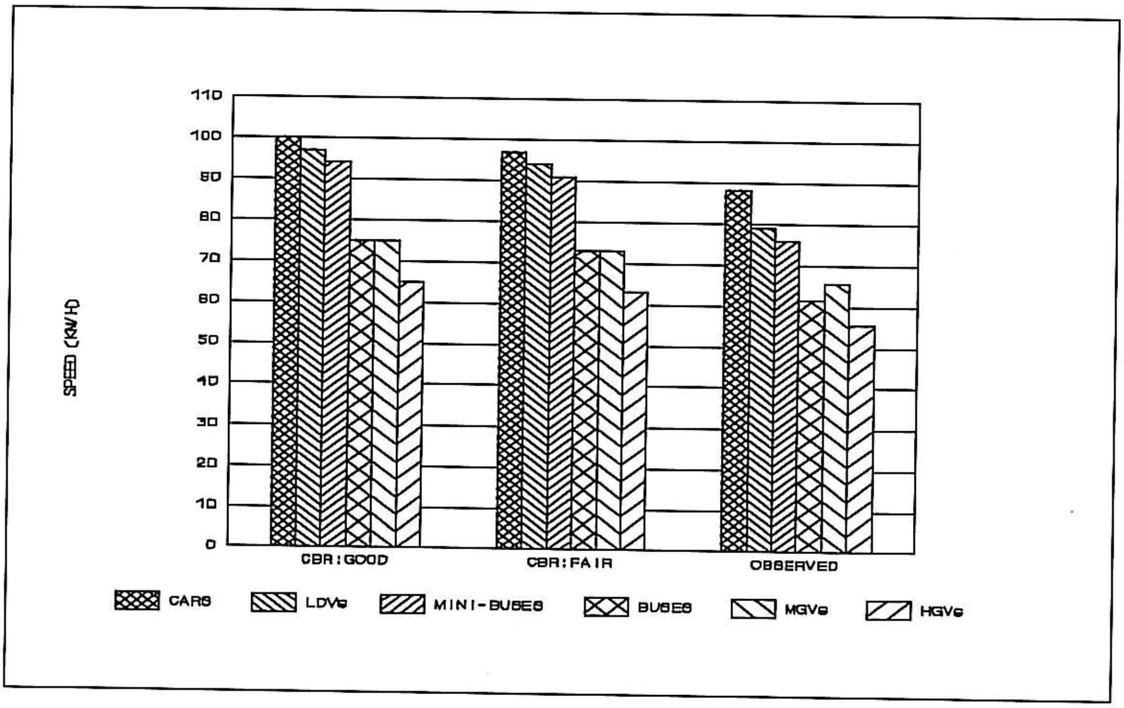


Figure 4.20: Speed values from CB-Roads and observed values for road type: Two-lane (100 km/h) and terrain type: Mountainous

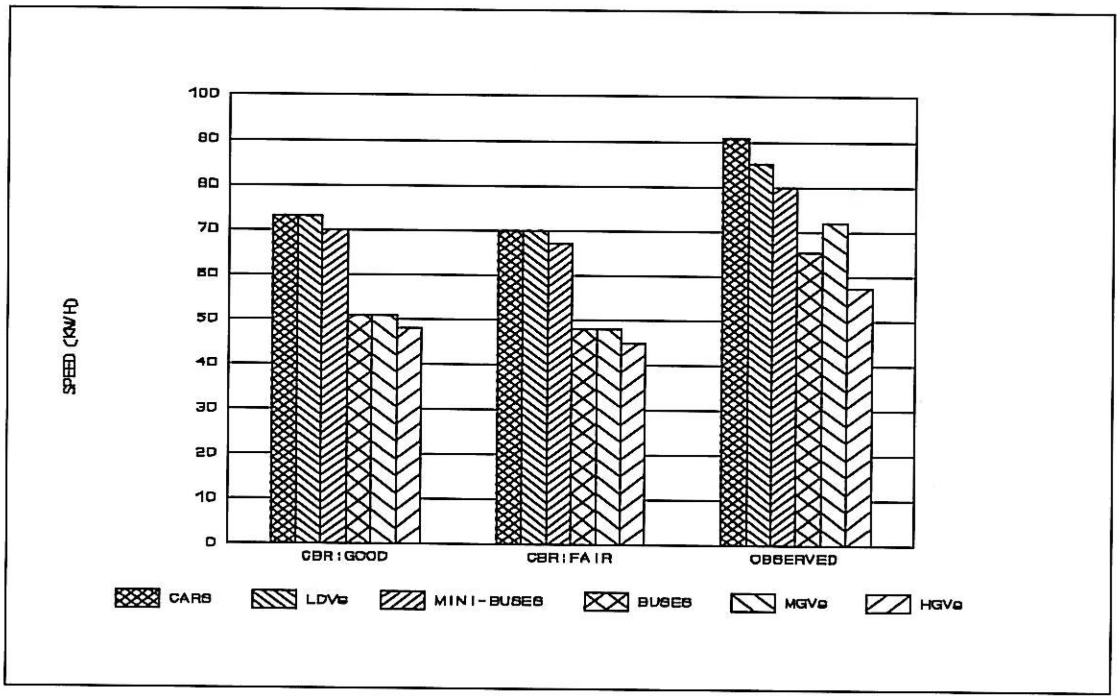


Figure 4.21: Speed values from CB-Roads and observed values for road type: Gravel and terrain type: Flat

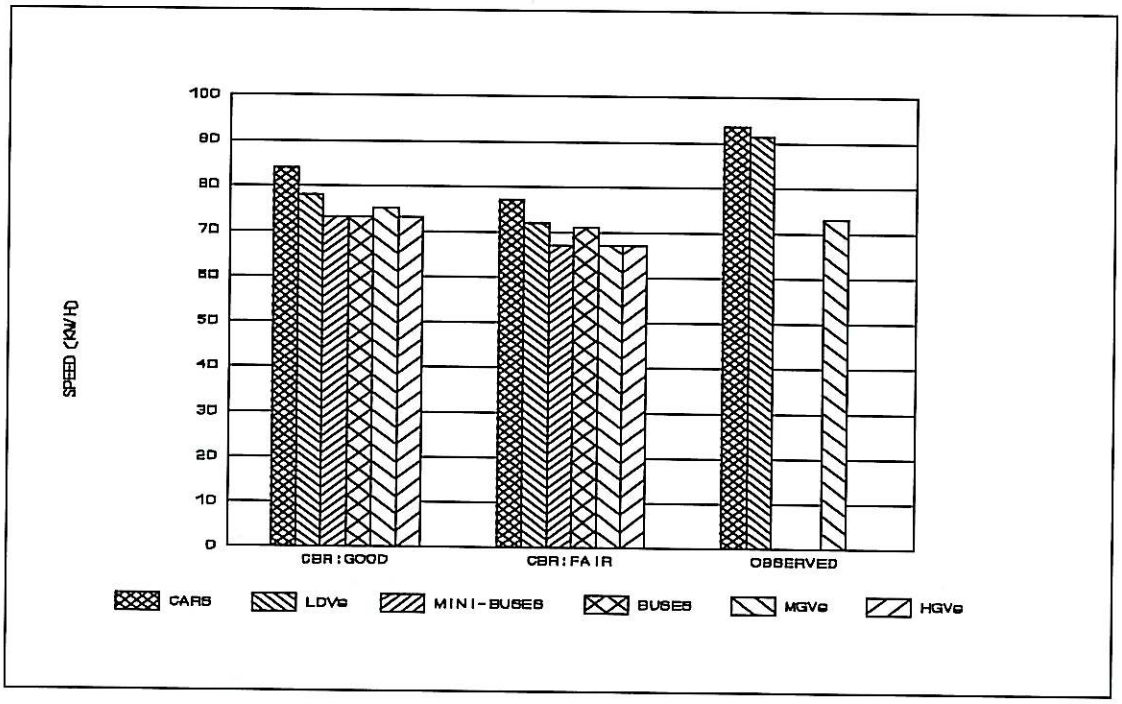
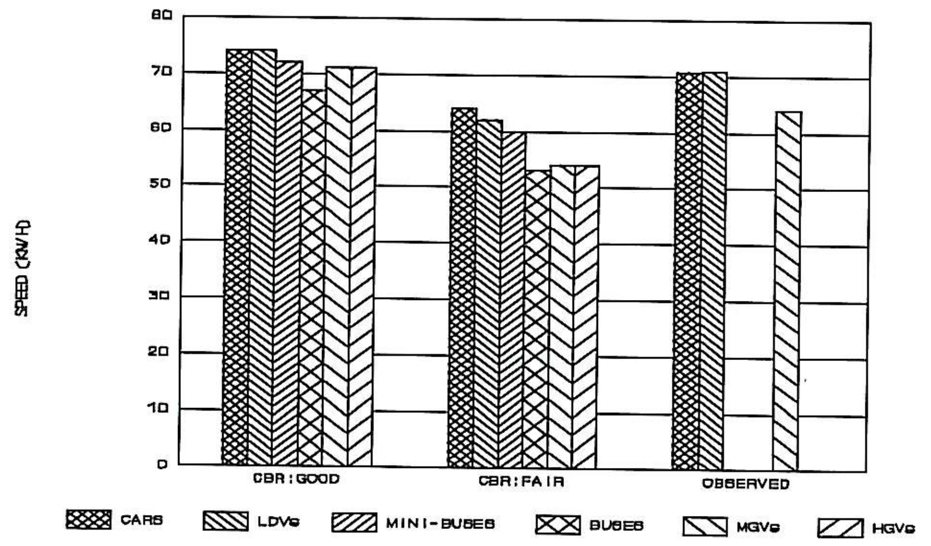


Figure 4.22: Speed values from CB-Roads and observed values for road type: Gravel and terrain type: Rolling



5 APPLICATION OF SURVEY RESULTS

5.1 INTRODUCTION

In this section a matrix of free-flow speed values is developed in a format similar to that used in Version 3.4 of CB-Roads (1). To this end, the results from other sources were used to supplement the results of the speed surveys presented in Section 4. The procedure adopted to complete the matrix involves the following steps:

- the determination of relative speed distributions:
  - between vehicle types
  - between terrain types
  - between road types

- the "distribution" of absolute values between vehicle types, terrain types and road types, considering the pattern that emerged from the first step.

The other sources that were consulted are Version 3.4 of program CB-Roads and the CTO database (22). The CTO project collects data from some 100 permanent and some 300 secondary traffic counting stations on the national route system. The data are processed and reported in the CTO yearbooks. The traffic counting stations are located on sections representing routes between activity centres or major intersections. Spot speeds are measured by means of electronic equipment. The CTO project is the most comprehensive traffic database on the national road system. As such, it was sought to utilise this information as much as possible. Unfortunately, the format of the data is dictated by the electronic equipment used and the purpose for which the database was constructed, namely to provide traffic information on a network level. The vehicle classes are limited to light and heavy vehicles only, and the sites at which the speeds are measured are selected, as far as this is possible, on flat, tangent sections. Although the CTO values do not necessarily represent free-flow speeds, this does not distract from their use for the purpose of this section.

5.2 RELATIVE SPEEDS: VEHICLE TYPES

Although the CTO database provides some insight into the relative speeds between light and heavy vehicles, the fact that only two vehicle classes are distinguished proved to prohibit its use as a possible source of information in this context. As the light vehicle class incorporates cars, light delivery vehicles and minibuses, the speeds recorded are lower than for cars alone. Likewise, the reported speeds for heavy vehicles are higher than for heavy trucks (such as articulated trucks) alone, as "heavy vehicles" also include medium trucks and buses.

The results of the speed surveys proved most useful for determining the relative speed distribution between vehicle types. In Table 5.1, the information presented in Table 4.6 is used to calculate speeds of different vehicle types relative to that of cars, where the speed of cars is set to 100. In other words, values for travel were normalised and expressed as relative indices. This was done for each unique combination of road and terrain type. In this table, road types are ranked from "fastest" to "slowest", where these terms refer to the highest and lowest likely values for speed associated with a given road type respectively. The gaps in the table represent instances where data were not available. The values given for each unique combination of road and terrain type indicate a pattern of speed distributions that are relatively consistent.

The values in the bottom row of Table 5.1 represent the relative macroscopic speed for all vehicles of a given type. It is maintained that these values are sufficiently representative of the relative speed between vehicle types, and these values were therefore used for completing the matrix.

5.3 RELATIVE SPEEDS: TERRAIN TYPES

A similar approach was adopted to obtain the relative speed distribution between terrain types. In this case, terrain type "rolling" was used as the base (=100), and speeds for the other terrain types were calculated relative to speed for rolling terrain types. The indices in Table 5.2.1 are based on the results of the speed surveys, and those in Table 5.2.2 on the values provided in the look-up tables in CB-Roads for road surface condition: fair.

Table 5.1: Relative speed distribution between vehicle types, using results of speed surveys

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	100	93	93	80	69	63
Rolling	100	91	103		72	73
Mountainous	100	92	89	55	62	50
Four-lane						
Flat						
Rolling						
Mountainous						
Expressway						
Flat	100	94	95	84	77	65
Rolling						
Mountainous						
Three-lane						
Flat						
Rolling						
Mountainous						
Two-lane						
Flat						
Rolling						
Mountainous						
Expressway: 100 km/h						
Flat	100	89	96	73	86	79
Rolling	100	89	90		73	70
Mountainous						
Three-lane: 100 km/h						
Flat						
Rolling						
Mountainous	100	89	81	47	55	54
Two-lane: 100 km/h						
Flat						
Rolling	100	90	86	69	74	64
Mountainous	100	93	88	71	79	63
Gravel roads						
Flat	100	97			78	
Rolling	100	100			90	
Mountainous						
Dirt roads						
Flat						
Rolling						
Mountainous						
All vehicles	100	91	92	70	69	65

Table 5.2.1: Relative speed distribution between terrain types, using survey results

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	106	108	97		101	92
Rolling	100	100	100		100	100
Mountainous	100	101	87		86	68
Four-lane						
Flat						
Rolling						
Mountainous						
Expressway						
Flat						
Rolling						
Mountainous						
Three-lane						
Flat						
Rolling						
Mountainous						
Two-lane						
Flat						
Rolling						
Mountainous						
Expressway: 100 km/h						
Flat	88	88	93		104	100
Rolling	100	100	100		100	100
Mountainous						
Three-lane: 100 km/h						
Flat						
Rolling						
Mountainous						
Two-lane: 100 km/h						
Flat						
Rolling	100	100	100	100	100	100
Mountainous	103	108	105	107	111	102
Gravel roads						
Flat	132	128			114	
Rolling	100	100			100	
Mountainous						
Dirt roads						
Flat						
Rolling						
Mountainous						

Table 5.2.2: Relative speed distribution between terrain types, based on values in CB-Roads

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	105	105	106	102	102	103
Rolling	100	100	100	100	100	100
Mountainous	76	80	83	70	48	50
Four-lane						
Flat	105	105	106	102	102	103
Rolling	100	100	100	100	100	100
Mountainous	76	80	83	70	48	50
Expressway						
Flat	105	106	106	102	102	103
Rolling	100	100	100	100	100	100
Mountainous	74	78	81	70	48	50
Three-lane						
Flat	103	101	99	114	114	119
Rolling	100	100	100	100	100	100
Mountainous	72	74	74	66	66	71
Two-lane						
Flat	103	101	99	114	114	119
Rolling	100	100	100	100	100	100
Mountainous	72	74	74	66	66	71
Expressway: 100 km/h						
Flat						
Rolling						
Mountainous						
Three-lane: 100 km/h						
Flat						
Rolling						
Mountainous						
Two-lane: 100 km/h						
Flat						
Rolling						
Mountainous						
Gravel roads						
Flat	120	116	112	134	124	124
Rolling	100	100	100	100	100	100
Mountainous	53	55	53	57	52	52
Dirt roads						
Flat	125	125	125	129	129	129
Rolling	100	100	100	100	100	100
Mountainous	60	60	55	57	57	57

No definitive pattern regarding the relative speed distribution between terrain types could be detected from the information presented in Table 5.2.1. It is, nevertheless, maintained that the data are sufficiently consistent to suggest that the speed differential between rolling and mountainous terrain in Table 5.2.2 is perhaps overstated. For this reason, and after careful consideration of the information presented in both Tables 5.2.1 and 5.2.2, it was concluded that the values given in Table 5.2.3 should be used instead for the purpose of completing the speed matrix in Table 5.4.

5.4 RELATIVE SPEEDS: ROAD TYPES

In Table 5.3.1 the results of the speed surveys are utilised to investigate patterns regarding the relative speed distribution between road types. Freeways are used as the base for calculating relative speeds on other road types. This is done for all three terrain types.

Table 5.3.2 contains similar information, with results from program CB-Roads. Finally, Table 5.3.3 presents information obtained from the CTO database. For each of four road types, ten counting stations were selected at random from the list in the CTO yearbook. Detailed information on speeds for light and heavy vehicles at these stations are given in Appendix C.

The CTO database provides information over a broad range of road types from which a consistent pattern emerges. As this information is further based on large samples, it constituted the main source of information for determining the relative speed distribution between road types. The results from the speed surveys and the values given in Version 3.4 of CB-Roads were used to supplement information from the CTO database.

Table 5.3.4 contains suggested values for the relative speed distribution between road types, based on the information in Tables 5.3.1, 5.3.2 and 5.3.3.

Table 5.2.3: Relative speed distribution between terrain types: Suggested values

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Four-lane						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Expressway						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Three-lane						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Two-lane						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Expressway: 100 km/h						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Three-lane: 100 km/h						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Two-lane: 100 km/h						
Flat	105	105	105	105	105	105
Rolling	100	100	100	100	100	100
Mountainous	95	95	95	90	90	85
Gravel roads						
Flat	115	115	115	115	115	115
Rolling	100	100	100	100	100	100
Mountainous	65	65	65	65	65	55
Dirt roads						
Flat	120	120	120	120	120	120
Rolling	100	100	100	100	100	100
Mountainous	55	55	55	55	55	45

Table 5.3.1: Relative speed distribution between road types, using the results of the speed surveys

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	100	100	100	100	100	100
Rolling	100	100	100	100	100	100
Mountainous	100	100	100	100	100	100
Four-lane						
Flat						
Rolling						
Mountainous						
Expressway						
Flat	90	91	92	94	100	92
Rolling						
Mountainous						
Three-lane						
Flat						
Rolling						
Mountainous						
Two-lane						
Flat						
Rolling						
Mountainous						
Expressway: 100 km/h						
Flat	73	70	75	67	91	91
Rolling	88	86	77		88	84
Mountainous						
Three-lane: 100 km/h						
Flat						
Rolling						
Mountainous	84	80	77	72	74	90
Two-lane: 100 km/h						
Flat						
Rolling	76	75	64		77	66
Mountainous	78	79	78	102	100	98
Gravel roads						
Flat	76	80			86	
Rolling	61	67			76	
Mountainous						
Dirt roads						
Flat						
Rolling						
Mountainous						

Table 5.3.2: Relative speed distribution between road types, using the results from CB-Roads

Road type	Conditions for which indices were calculated	
	Cars, good surface condition, flat terrain	Cars, fair surface condition, rolling terrain
Freeway	100	100
Four-lane	100	100
Expressway	91	90
Three-lane	91	92
Two-lane	91	92
Expressway: 100 km/h		
Three-lane: 100 km/h		
Two-lane: 100 km/h		
Gravel road	73	61
Dirt road	52	38

Table 5.3.3: Relative speed distribution between road types, using information obtained from the CTO database

Road type	Vehicle types for which indices were calculated	
	Light vehicles	Heavy vehicles
Freeway	100	100
Four-lane	98	99
Expressway		
Three-lane		
Two-lane	99	98
Expressway: 100 km/h		
Three-lane: 100 km/h		
Two-lane: 100 km/h	86	86
Gravel road		
Dirt road		

Table 5.3.4: Relative speed distribution between road types: suggested values

Road type	Relative speed distribution
Freeway	100
Four-lane	100
Expressway	95
Three-lane	95
Two-lane	95
Expressway: 100 km/h	85
Three-lane: 100 km/h	85
Two-lane: 100 km/h	85
Gravel road	70
Dirt road	50

5.5 SUGGESTED VALUES FOR FREE-FLOW SPEED FOR DIFFERENT ROAD AND TERRAIN TYPES

The values suggested in Table 5.1, Table 5.2.3 and Table 5.3.4 for the relative speed distribution between vehicle types, terrain types and road types respectively were used to calculate the values given in Table 5.4. In this table, the value for speed for cars (123 km/h, rounded to the nearest 5 km/h), obtained from the sample "freeway:flat", was used as the anchor point in completing the matrix.

Table 5.4: Suggested values for free-flow speed for different road and terrain types

Road and terrain type	Vehicle type					
	Cars	LDVs	Mini-buses	Buses	MGVs	HGVs
Freeway						
Flat	125	113	114	87	86	81
Rolling	119	108	109	83	82	77
Mountainous	113	103	104	75	74	65
Four-lane						
Flat	125	113	114	87	86	81
Rolling	119	108	109	83	82	77
Mountainous	113	103	104	75	74	65
Expressway						
Flat	119	108	109	83	82	78
Rolling	113	103	104	79	78	73
Mountainous	107	98	99	71	70	62
Three-lane						
Flat	119	108	109	83	82	77
Rolling	113	103	104	79	78	73
Mountainous	107	98	99	71	70	62
Two-lane						
Flat	119	108	109	83	82	77
Rolling	113	103	104	79	78	73
Mountainous	107	98	99	71	70	62
Expressway: 100 km/h						
Flat	106	97	98	75	74	69
Rolling	101	92	93	71	70	66
Mountainous	96	87	88	64	63	56
Three-lane: 100 km/h						
Flat	106	97	98	75	74	69
Rolling	101	92	93	71	70	66
Mountainous	96	87	88	64	63	56
Two-lane: 100 km/h						
Flat	106	97	98	75	74	69
Rolling	101	92	93	71	70	66
Mountainous	96	87	88	64	63	56
Gravel roads						
Flat	95	87	87	67	66	62
Rolling	83	76	76	58	57	54
Mountainous	54	49	49	38	37	30
Dirt roads						
Flat	72	66	66	50	49	47
Rolling	60	55	55	42	41	39
Mountainous	33	30	30	23	23	18

6 CONCLUSIONS

6.1 SAMPLE SIZE

The sample used in this study and described in Section 4.5.1 in fact is the aggregate of a large number of sub-samples, as the number of vehicles of a particular type surveyed at a given site constitutes a sample in its own right. Considering the guidelines for the determination of minimum sample size given by Box (21), as explained in Section 4.4, and the values for "required minimum number of observations" presented in Appendix D, it is maintained that sub-samples in almost all cases were large enough to draw meaningful conclusions. It is nevertheless pointed out that buses comprise only 2 percent of the total sample. Also, at certain sites not all vehicle types could be observed. However, this did not prove to be a problem, considering the manner in which survey results were used to complete the speed matrix in Table 5.4.

6.2 EVALUATION OF SURVEY RESULTS

The results from the survey proved most useful for determining the relative speed distribution between vehicle types, as these distributions for the different cases can be regarded as relatively consistent. This enabled the completion of the first step of the procedure adopted for completing the speed matrix in Table 5.4. The CTO results, for example, could not be used for this purpose as the CTO database identifies only two vehicle classes, namely light and heavy vehicles, and do not necessarily represent free-flow conditions. Further, the relatively large sample in the case of freeways served to provide reliable information on vehicle speeds on this type of road. The value obtained for vehicle speed for cars on freeways was therefore used as an anchor point in distributing absolute vehicle speeds between vehicle types, terrain types and road types.

6.3 EFFECT OF ROAD SURFACE CONDITION

From Section 3.2.2 it would appear that, as far as paved roads are concerned, road roughness for QI values below 66 does not have a pronounced effect on vehicle speed (17). Also, Watanatada et al (11) noted that at low roughness levels, in the range up to QI=80, safety and speed limit considerations tend to dominate. Further, as the study by Van Niekerk (17) found no section on the national road network with a QI value in excess of 43, no good/fair/poor classification of road surface condition was adopted in this study. This means that, as far as paved roads are concerned, road surface condition in all cases could be regarded as non-critical in terms of vehicle speed.

6.4 NEED FOR ADDITIONAL ROAD TYPES

In the look-up tables of Version 3.4 of CB-Roads (1) seven road types are distinguished. In this study, three additional road types were considered, namely:

- expressway with a speed limit of 100 km/h
- three-lane road with a speed limit of 100 km/h
- two-lane road with a speed limit of 100 km/h.

6.5 COMPARISON OF STUDY RESULTS WITH CORRESPONDING RESULTS IN VERSION 3.4 OF CB-ROADS

The speed surveys indicated values for vehicle speed that generally are higher than corresponding values in Version 3.4 of CB-Roads. This is particularly relevant in the case of vehicles on the "lighter" side of the vehicle spectrum. This means that the study revealed a relative speed distribution between vehicle types that differs from that suggested in Version 3.4 of CB-Roads.

6.6 APPLICATION OF RESULTS

This study was originally intended to verify the values for free-flow speed given in previous versions of program CB-Roads, by means of speed measurements. Although the look-up tables in CB-Roads have now been replaced by speed equations, the study results are still applicable in the context of CB-Roads, namely to verify and/or calibrate these equations by relating observed values for free-flow speed to the geometric characteristics of the road sections surveyed.

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APPENDIX A

EXAMPLE OF INFORMATION COLLECTED: N1-23(S)

N1-23(S)							
VEHICLE CLASS: CARS							
M1	S1	M2	S2	Dif.T	Speed	Bin	Freq
49	8	50	54	106	81	80	0
17	34	19	9	95	90	85	1
0	46	2	8	82	104	90	1
22	54	24	16	82	104	95	0
37	37	38	57	80	107	100	0
39	50	41	4	74	115	105	2
2	21	3	34	73	117	110	1
52	16	53	28	72	119	115	0
8	28	9	39	71	120	120	3
9	8	10	17	69	124	125	5
2	44	3	53	69	124	130	5
54	19	55	28	69	124	135	4
40	27	41	36	69	124	140	5
16	42	17	49	67	127	145	1
14	36	15	42	66	129	150	1
46	26	47	32	66	129	155	0
5	43	6	49	66	129	160	3
39	17	40	23	66	129	165	1
58	55	0	0	65	131	170	0
10	13	11	18	65	131	175	2
23	59	25	4	65	131	180	0
38	8	39	12	64	133		0
55	1	56	3	62	138		
53	3	54	5	62	138		
9	46	10	47	61	140		
41	7	42	8	61	140		
49	35	50	36	61	140		
52	48	53	48	60	142		
41	37	42	35	58	147		
1	22	2	17	55	155		
0	0	0	54	54	158		
47	53	48	47	54	158		
21	50	22	58	52	164		
14	59	15	49	50	171		
45	55	46	44	49	174		

VEHICLE CLASS: LDVs							
48	30	50	12	102	84	80	0
8	49	10	21	92	93	85	1
39	52	41	22	90	95	90	0
56	23	57	43	80	107	95	2
51	23	52	40	77	111	100	0
25	55	27	10	75	114	105	0
35	15	36	30	75	114	110	1
40	25	41	38	73	117	115	3
31	53	33	5	72	119	120	2
5	21	6	32	71	120	125	7
16	32	17	41	69	124	130	2
34	29	35	38	69	124	135	1
24	36	25	45	69	124	140	2
55	19	56	28	69	124	145	1
6	54	8	3	69	124	150	0
10	39	11	48	69	124		0
32	50	33	58	68	126		
12	52	13	58	66	129		
37	13	38	18	65	131		
53	16	54	19	63	136		
35	31	36	34	63	136		
6	26	7	25	59	145		

VEHICLE CLASS: MINIBUSES							
48	47	50	17	90	95	90	0
36	55	38	13	78	109	95	1
2	30	3	46	76	112	100	0
29	22	30	36	74	115	105	0
33	19	34	32	73	117	110	1
37	31	38	44	73	117	115	1
24	56	26	8	72	119	120	6
1	42	2	54	72	119	125	3
46	57	48	9	72	119	130	3
14	18	15	29	71	120	135	2
4	16	5	25	69	124	140	1
9	32	10	41	69	124	145	0
31	25	32	32	67	127		0
20	33	21	39	66	129		
53	28	54	34	66	129		
29	9	30	13	64	133		
34	51	35	55	64	133		
13	10	14	11	61	140		

VEHICLE CLASS: BUSES							
58	26	59	59	93	92	90	0
50	54	52	13	79	108	95	1
						100	0
						105	0
						110	1
						115	0
							0
VEHICLE CLASS: MGVs							
27	49	29	41	112	76	75	0
28	18	30	3	105	81	80	1
39	15	40	56	101	85	85	2
3	14	4	53	99	86	90	1
33	53	35	27	94	91	95	4
27	20	28	51	91	94	100	1
18	20	19	51	91	94	105	0
19	42	21	13	91	94		0
19	50	21	19	89	96		
VEHICLE CLASS: HGVs							
46	7	47	47	176	49	45	0
31	4	32	48	104	82	50	1
53	58	55	38	100	85	55	0
11	6	12	43	97	88	60	0
55	54	57	30	96	89	65	0
30	33	32	7	94	91	70	0
17	49	19	23	94	91	75	0
23	17	24	51	94	91	80	0
13	29	15	0	91	94	85	1
32	25	33	56	91	94	90	3
18	3	19	31	88	97	95	5
55	42	57	7	85	100	100	1
56	54	58	19	85	100	105	2
21	4	22	24	80	107	110	1
57	14	58	30	76	112	115	2
59	8	0	34	76	112	120	0

APPENDIX B

SPEED HISTOGRAMS FOR THE DIFFERENT SURVEY SITES

APPENDIX B.1: N1-23(S)

FIGURE B.1.1: CARS

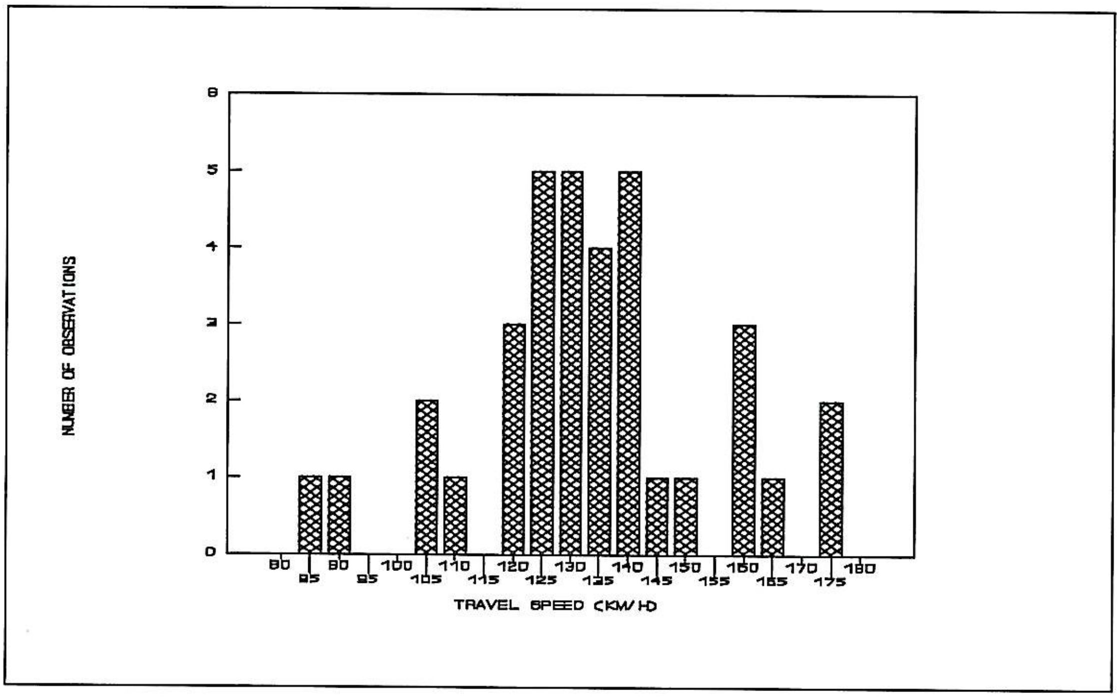


FIGURE B.1.2: LDVs

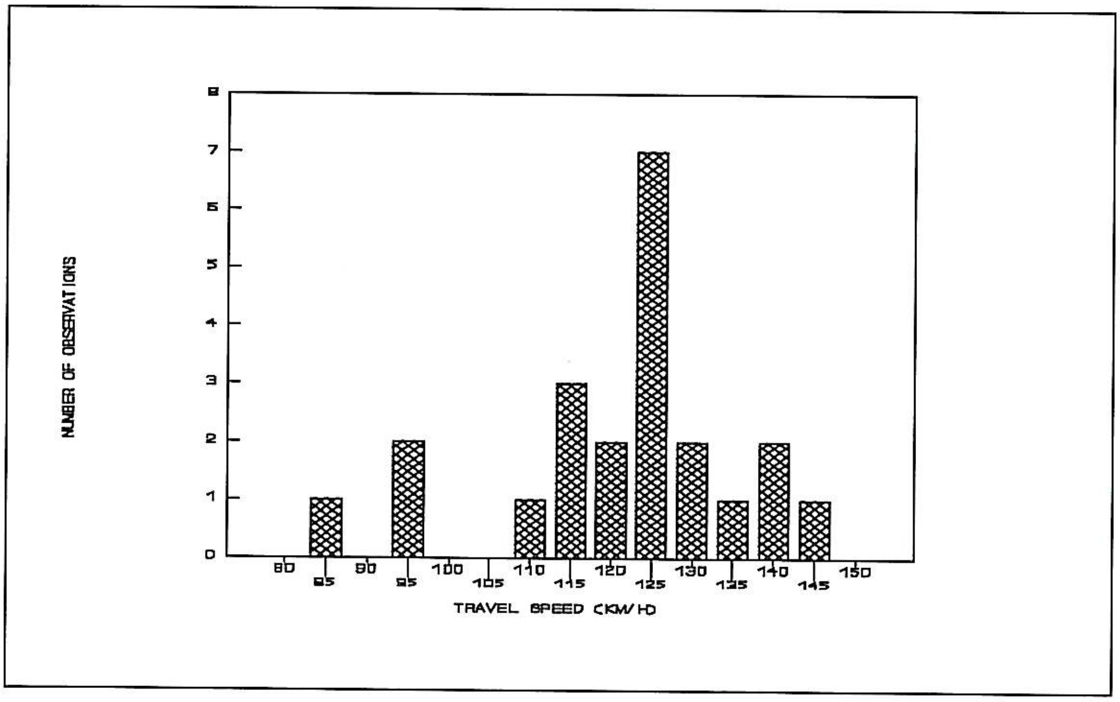


FIGURE B.1.3: MINI-BUSES

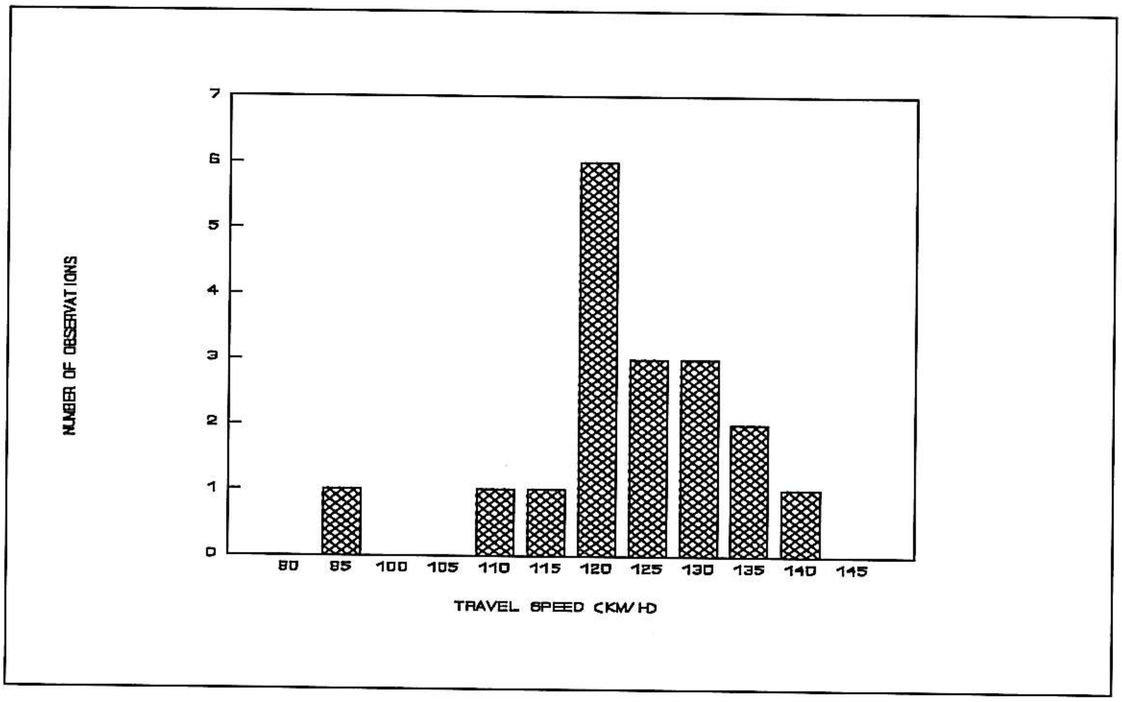


FIGURE B.1.4: BUSES

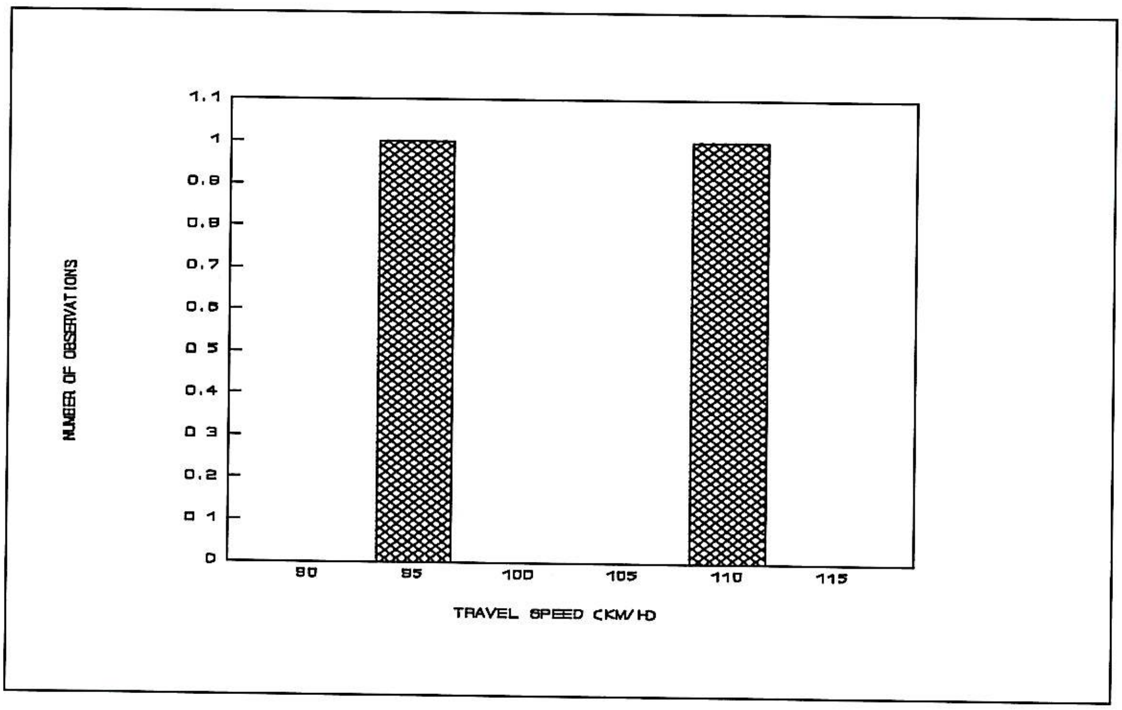


FIGURE B.1.5: MGVs

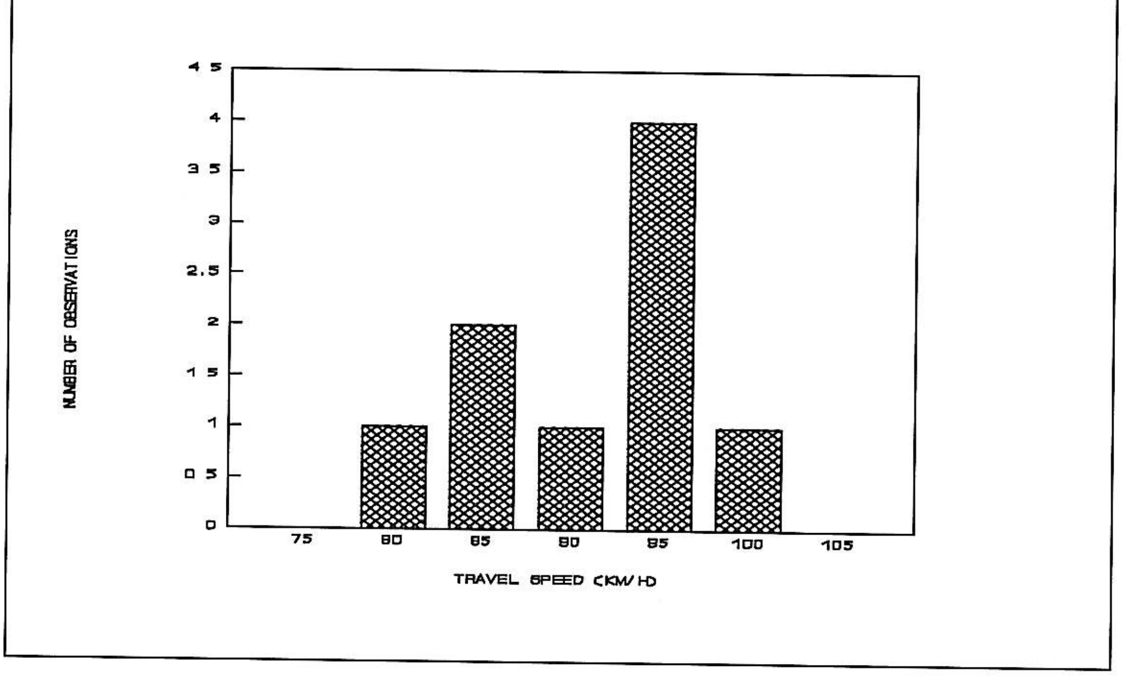
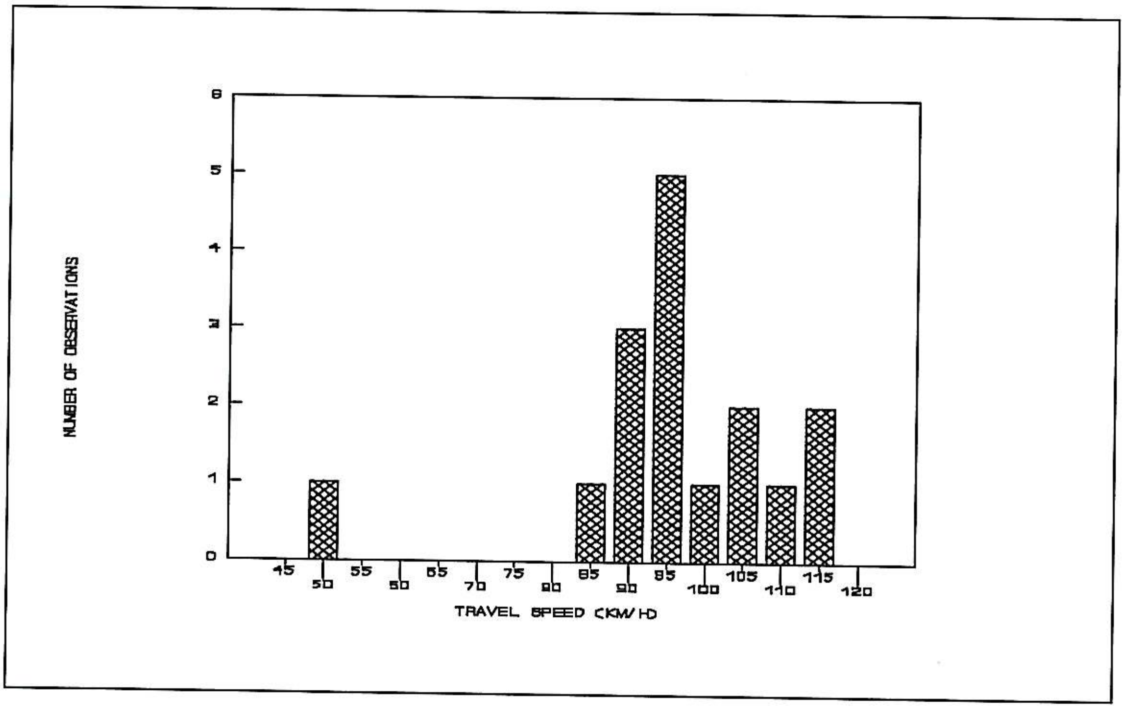


FIGURE B.1.6: HGVs



APPENDIX B.2: N1-23(N)

FIGURE B.2.1: CARS

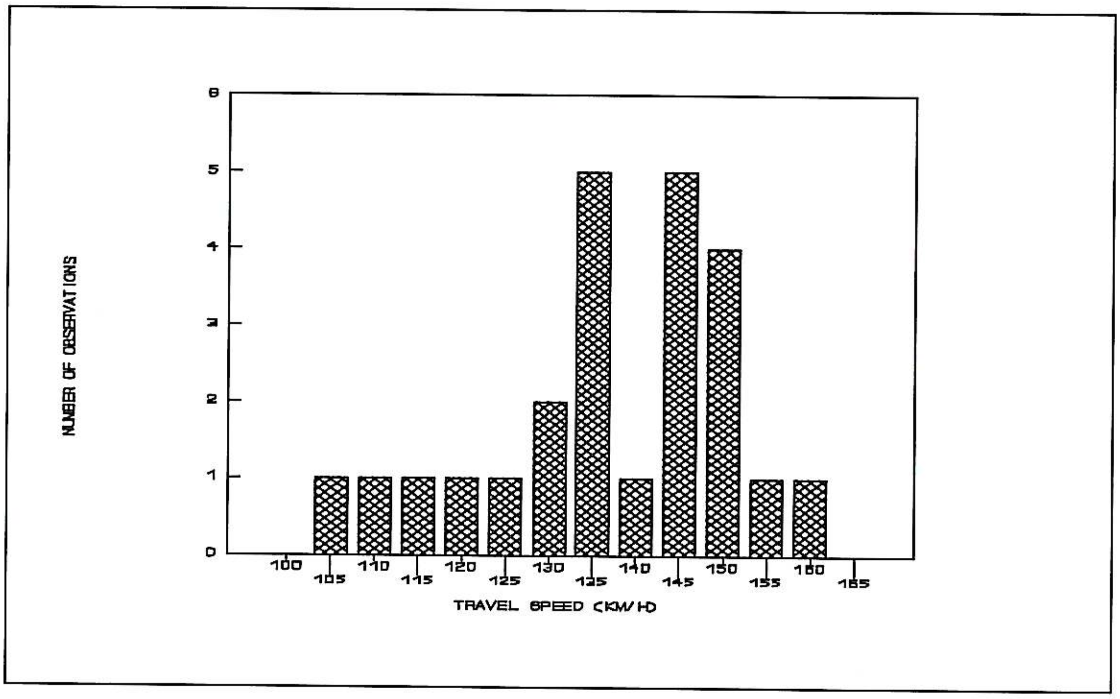


FIGURE B.2.2: LDVs

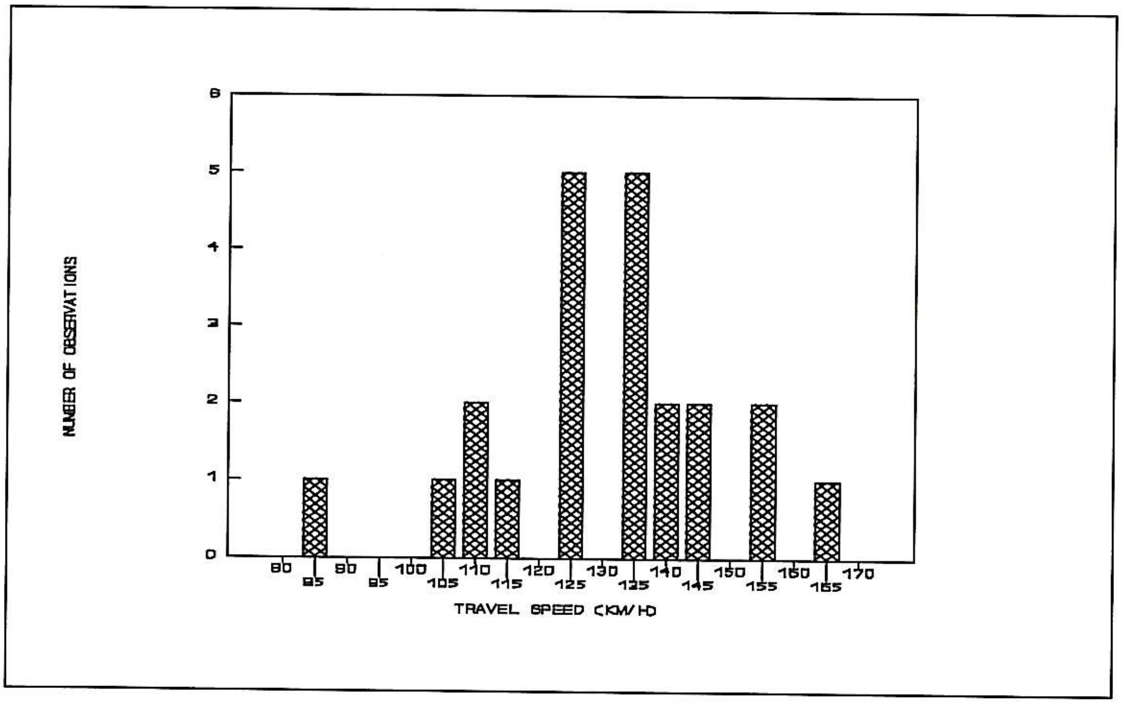


FIGURE B.2.3: MINI-BUSES

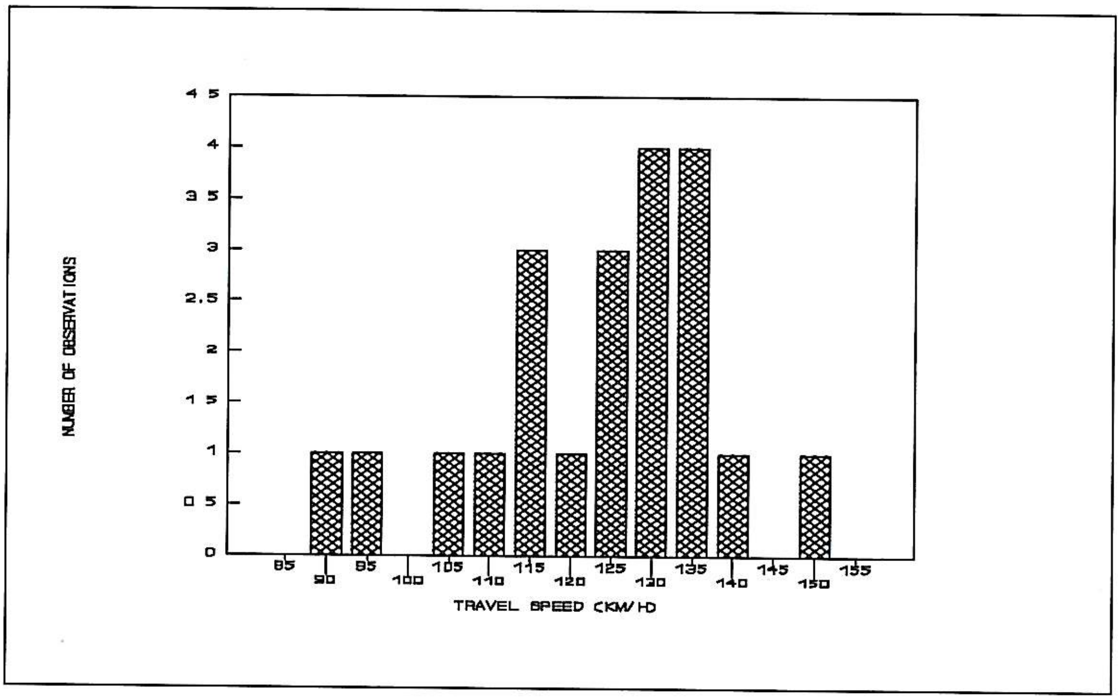


FIGURE B.2.4: BUSES

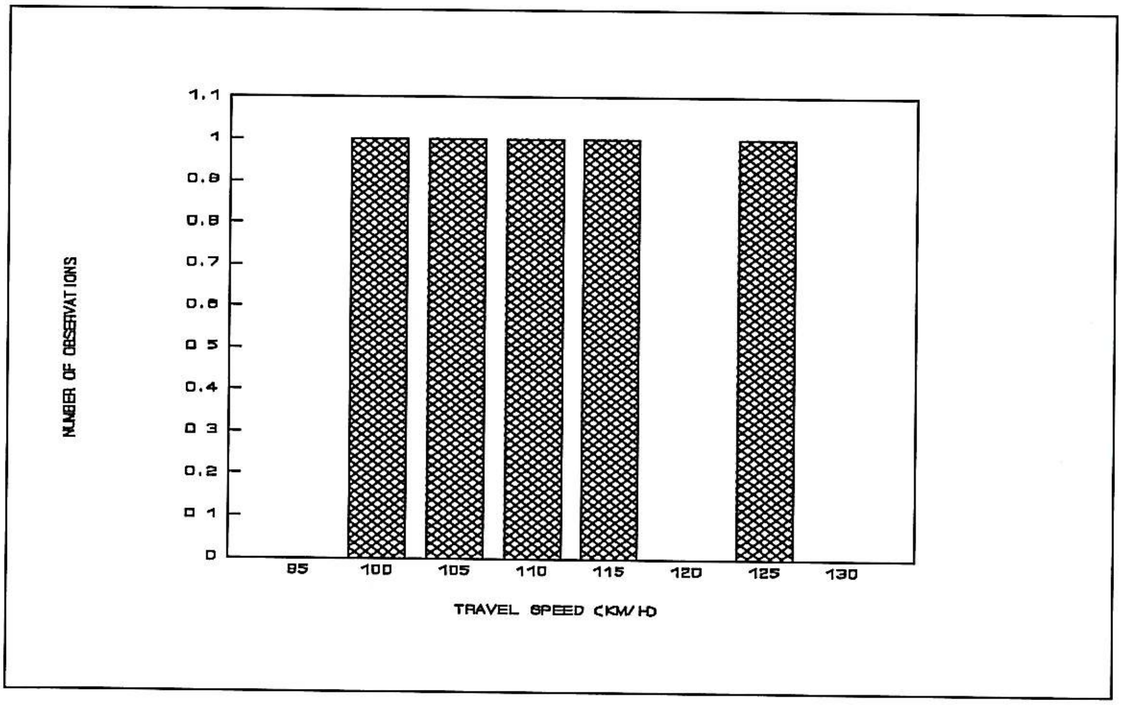


FIGURE B.2.5: MGVs

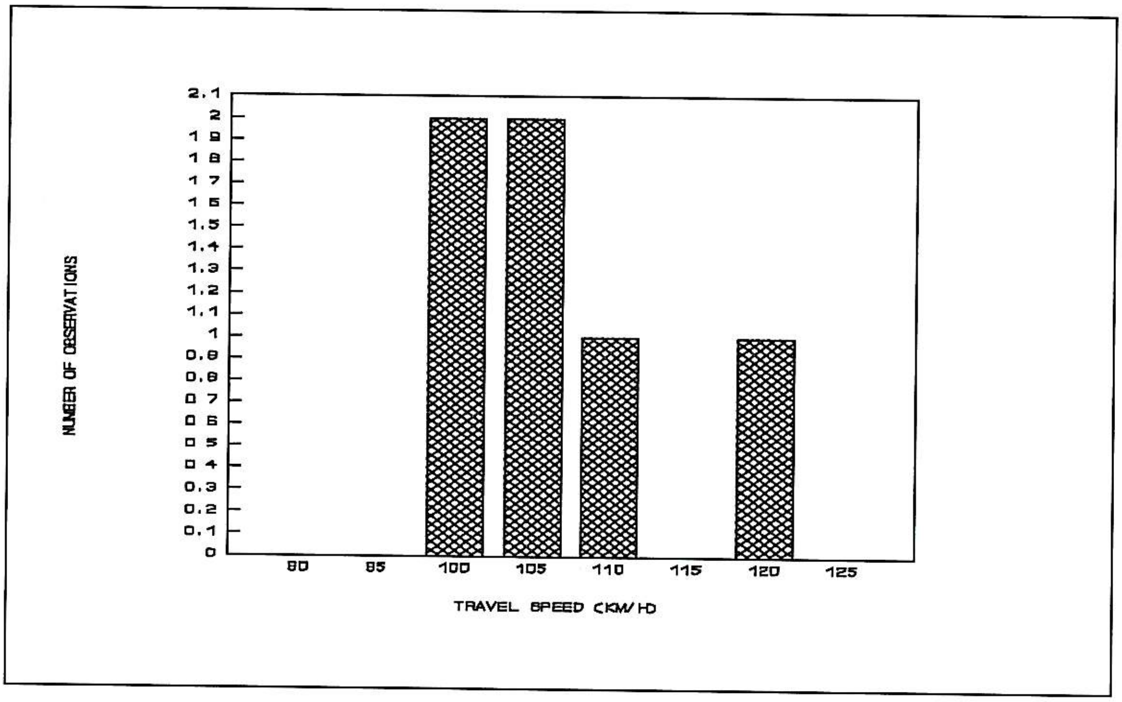
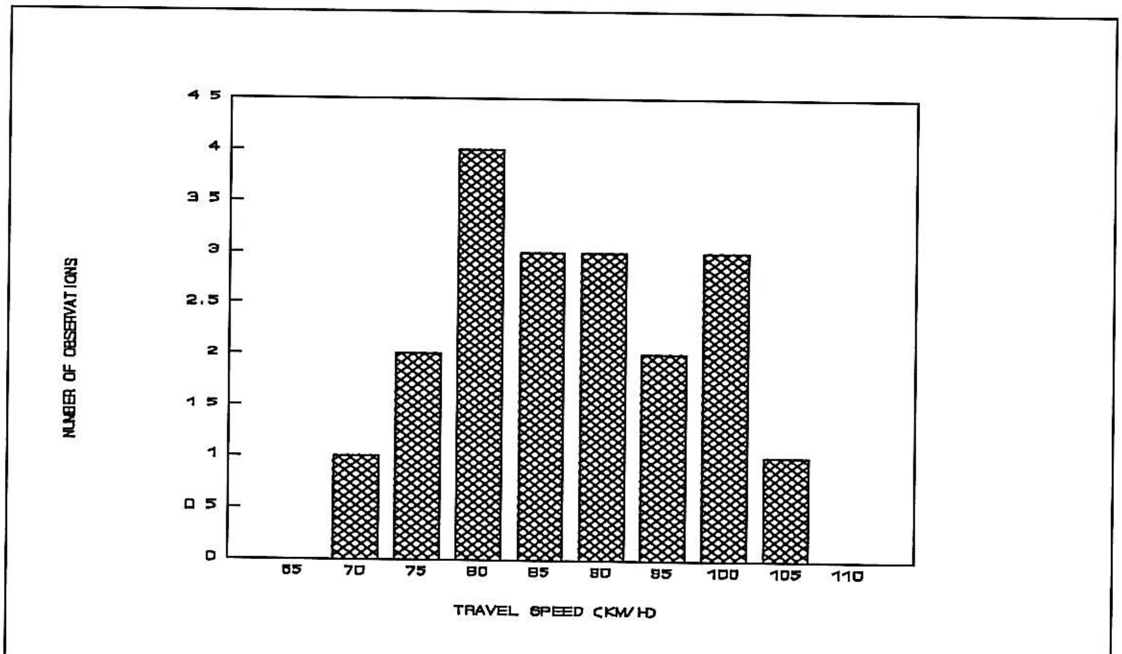


FIGURE B.2.6: HGVs



APPENDIX B.3: N1-22(S)

FIGURE B.3.1: CARS

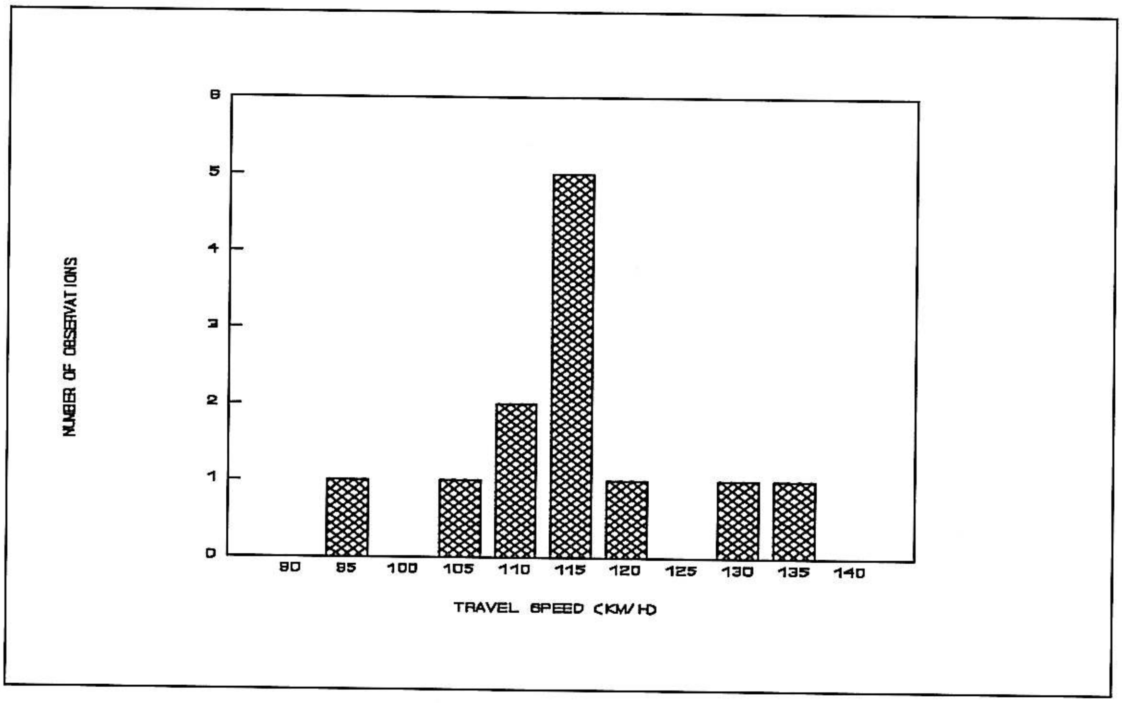


FIGURE B.3.2: MGVs

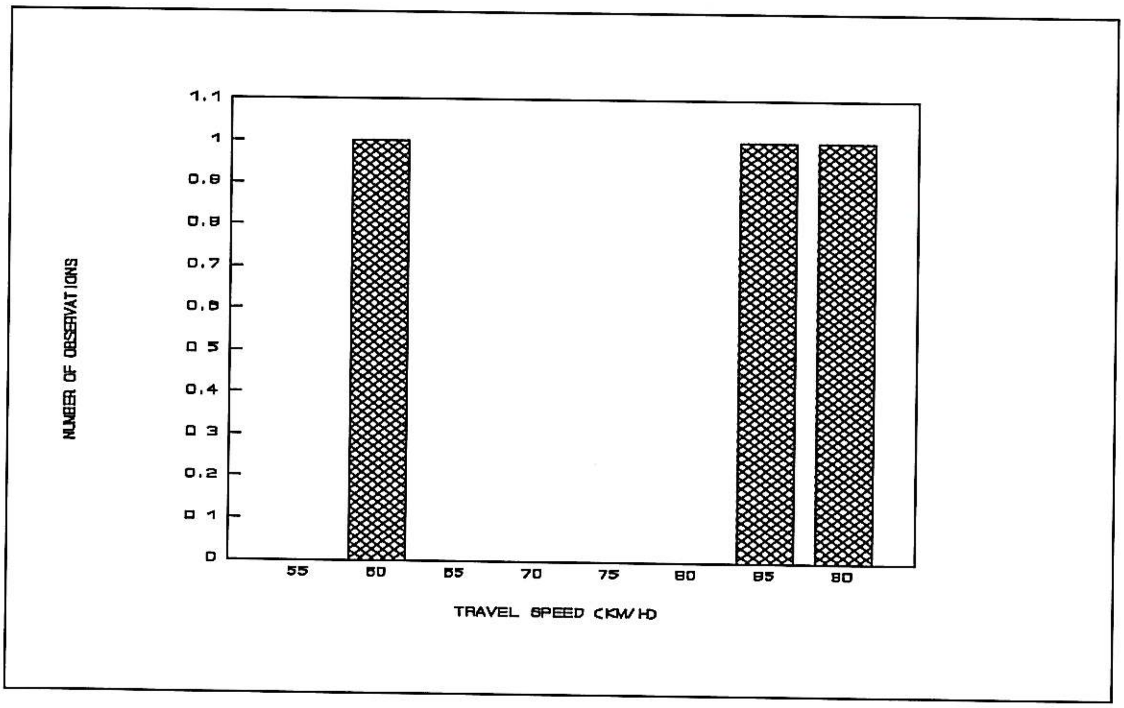
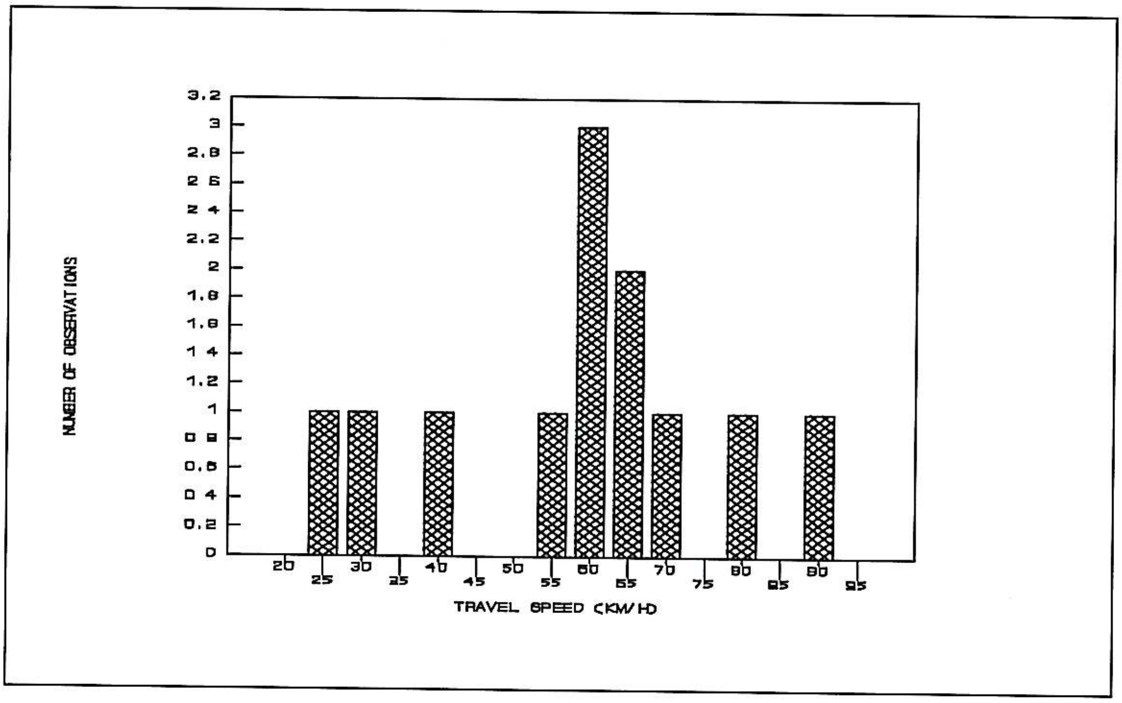


FIGURE B.3.3: HGVs



APPENDIX B.4: N4-1(E)

FIGURE B.4.1: CARS

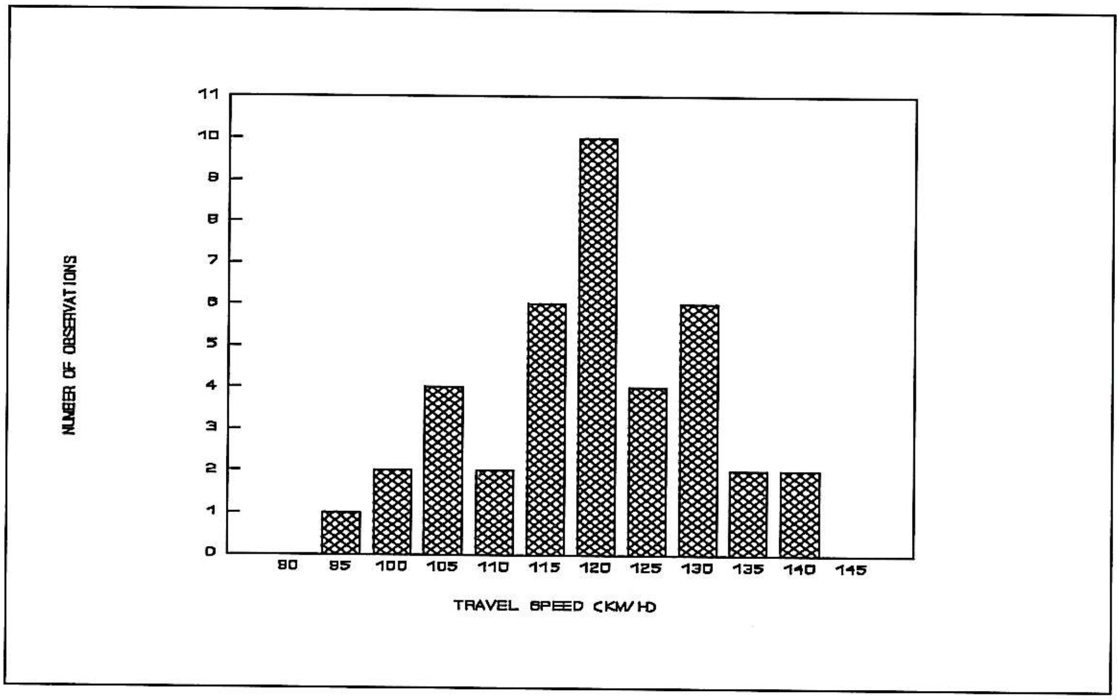


FIGURE B.4.2: LDVs

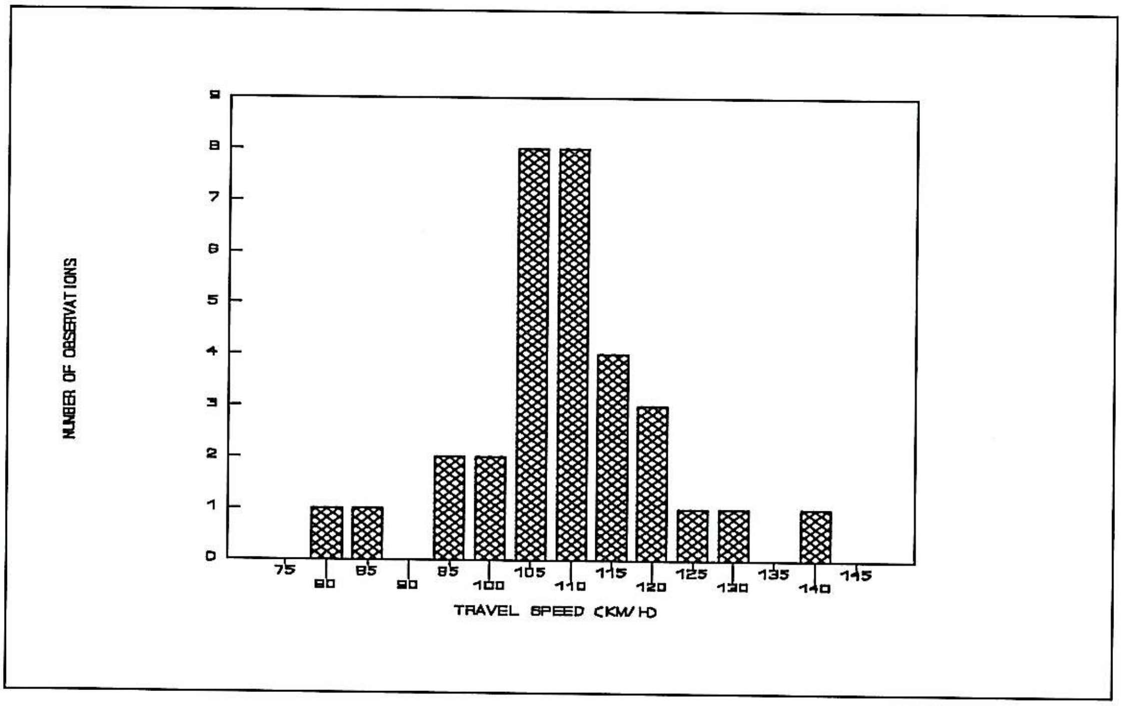


FIGURE B.4.3: MINI-BUSES

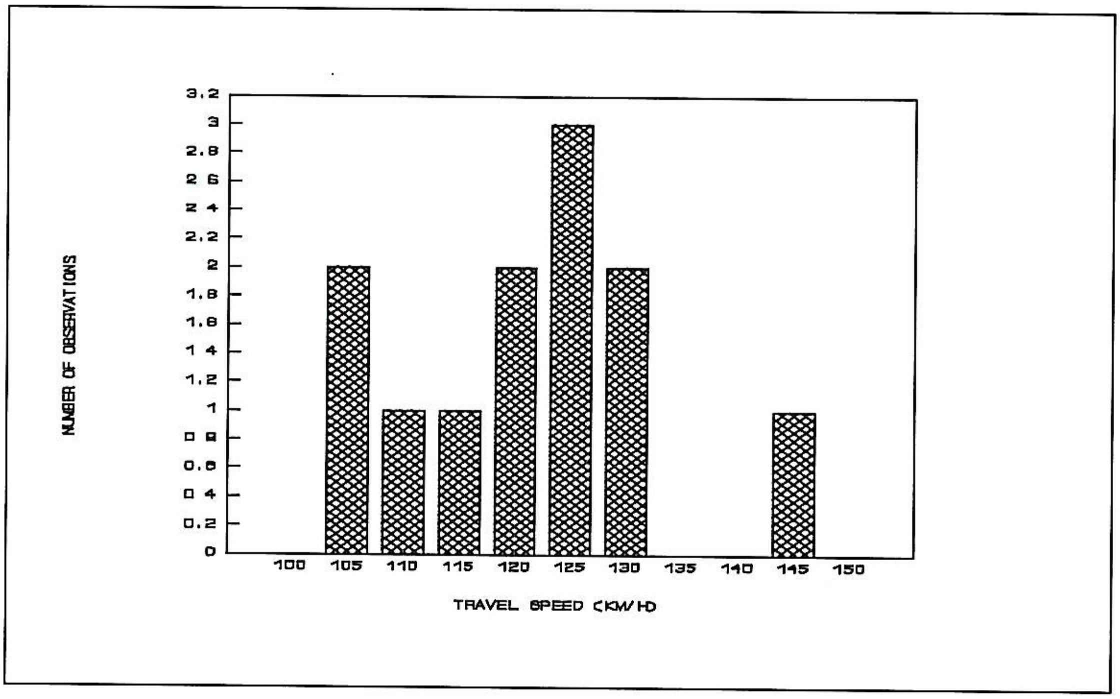


FIGURE B.4.4: MGVs

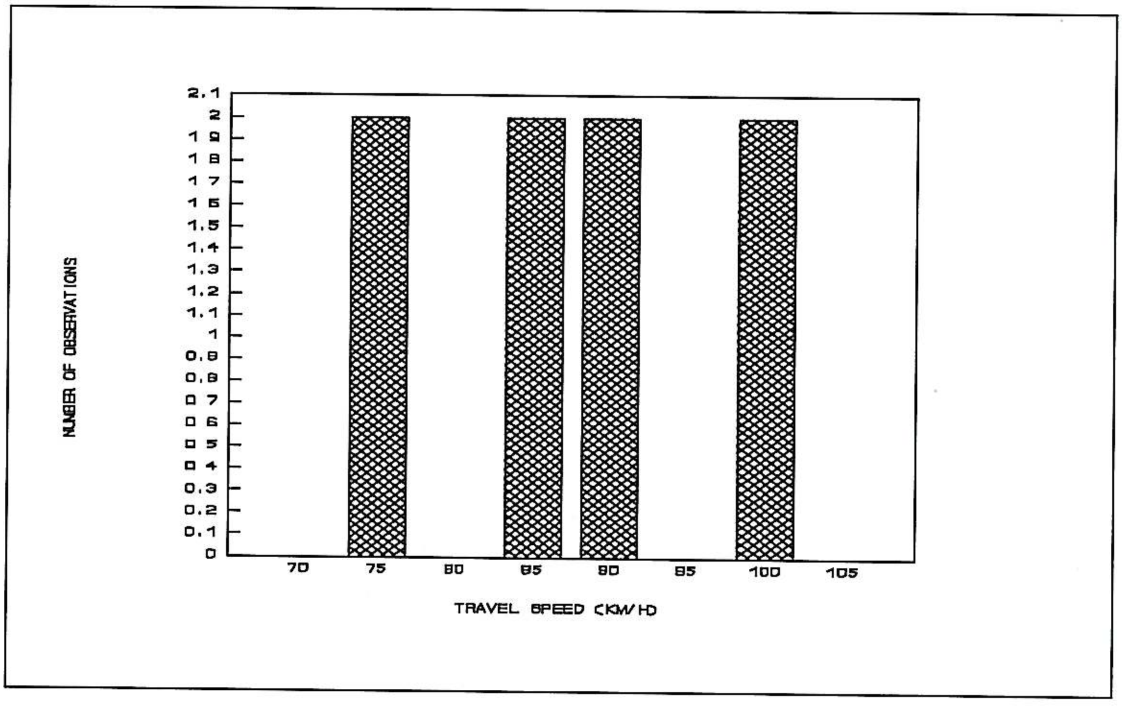
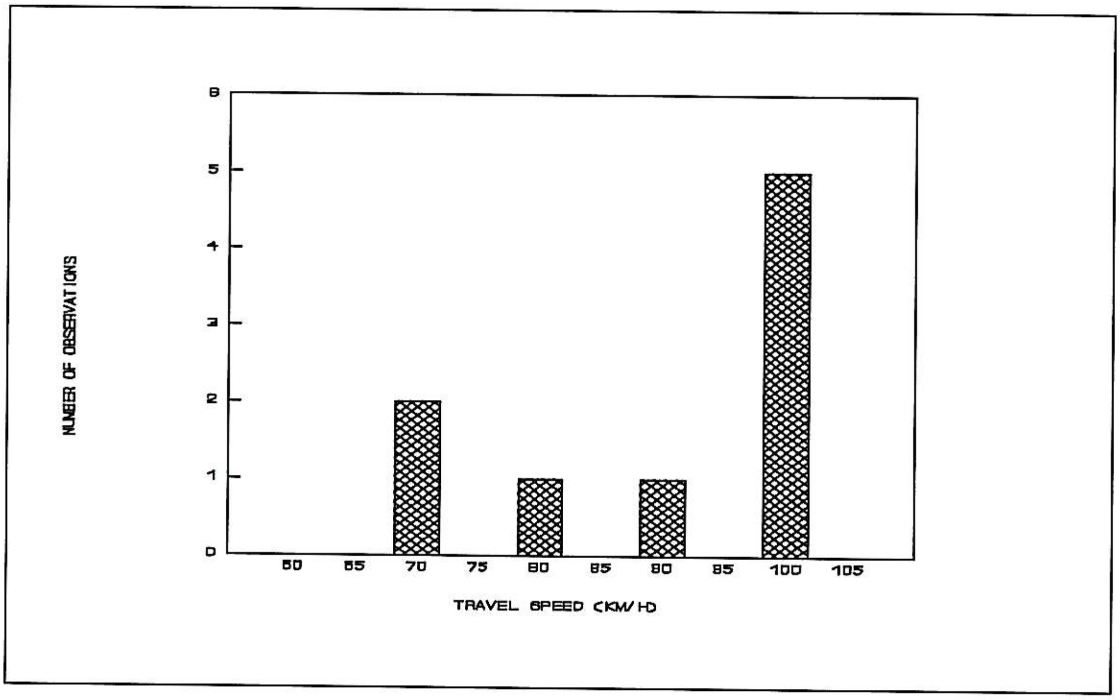


FIGURE B.4.5: HGVs



APPENDIX B.5: N4-2(W)

FIGURE B.5.1: CARS

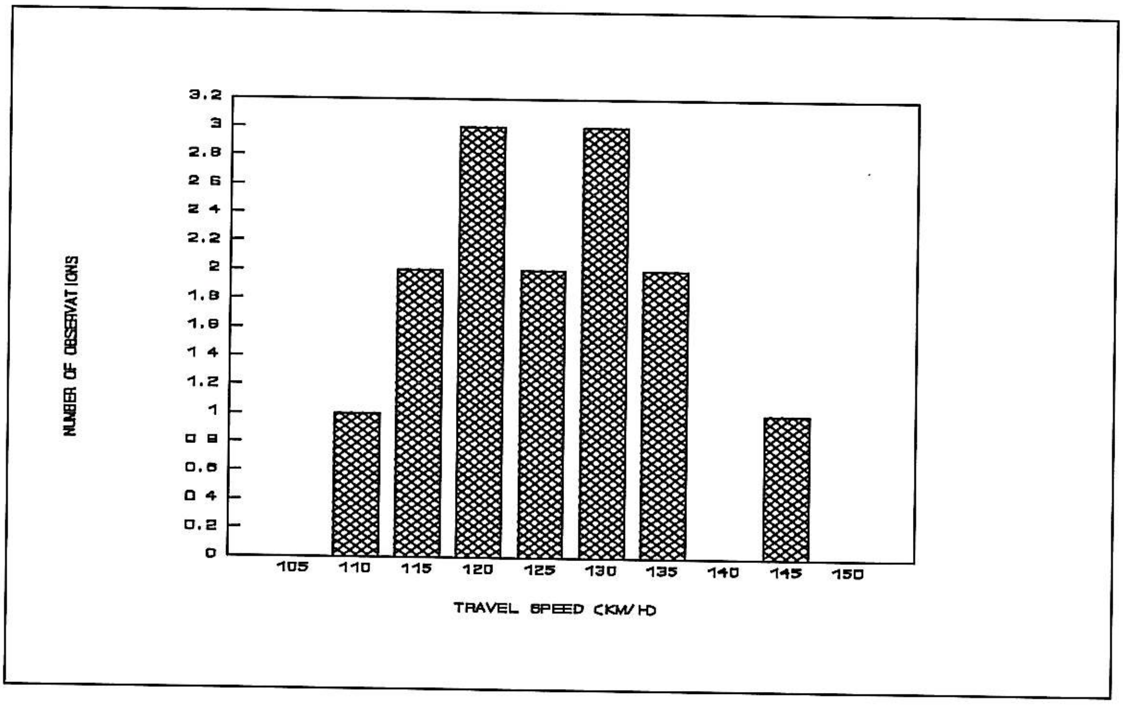


FIGURE B.5.2: LDVs

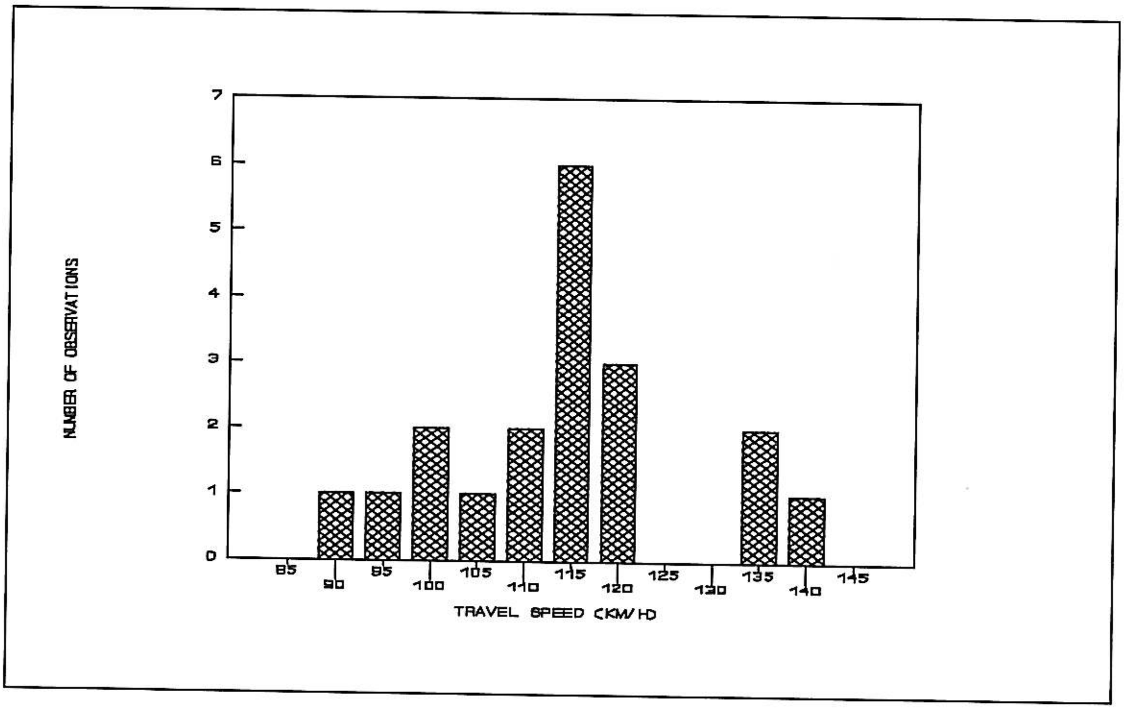


FIGURE B.5.3: MINI-BUSES

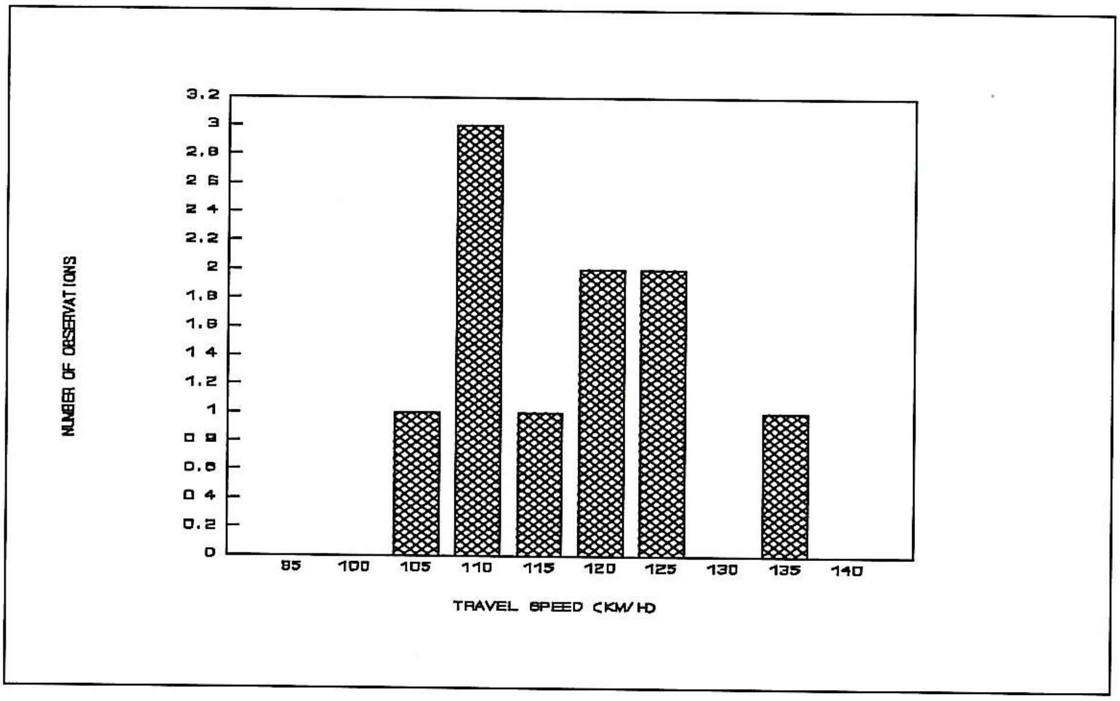


FIGURE B.5.4: MGVs

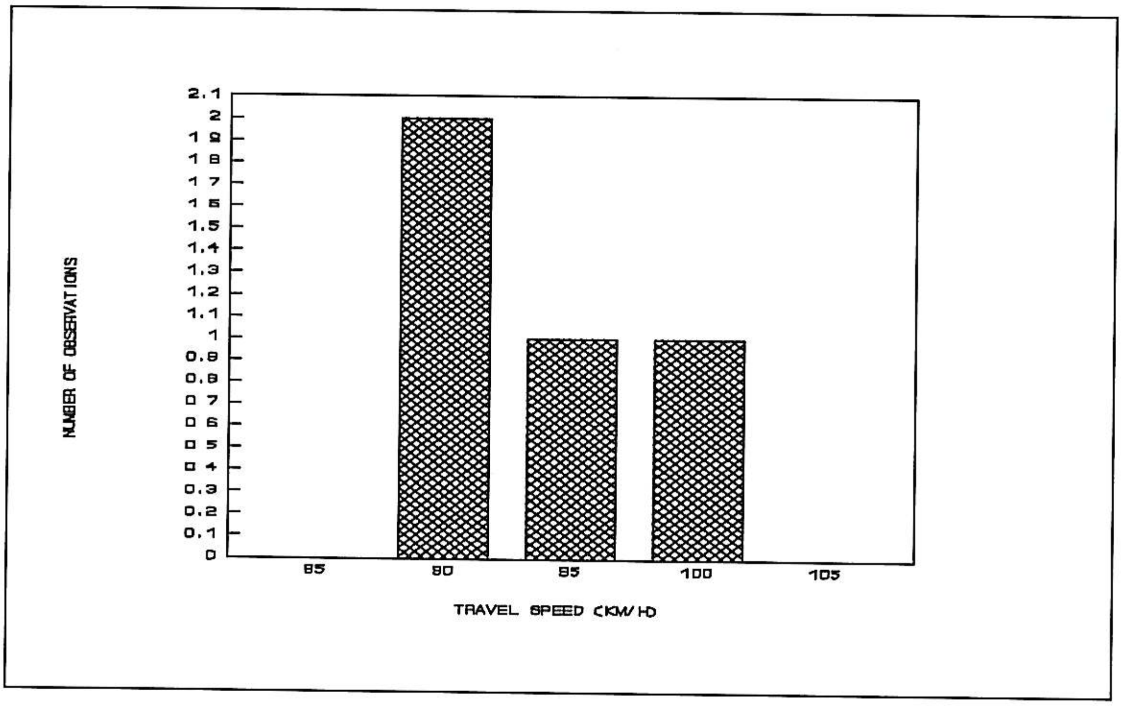
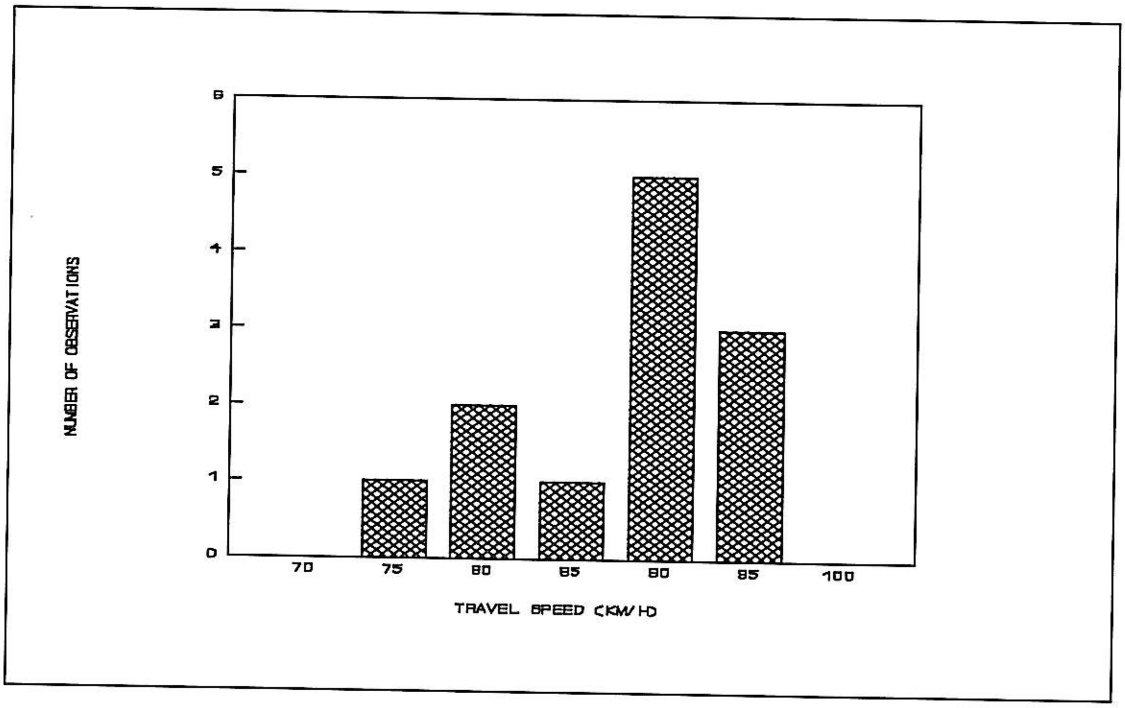


FIGURE B.5.5: HGVs



APPENDIX B.6: N4-2(E)

FIGURE B.6.1: CARS

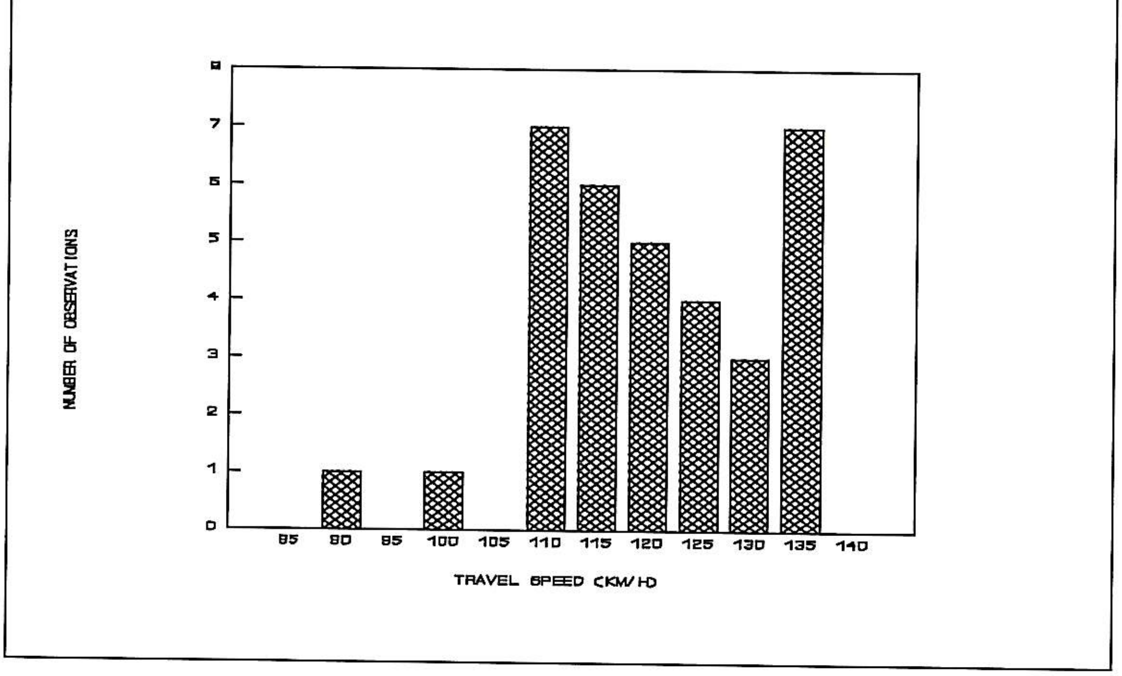


FIGURE B.6.2: LDVs

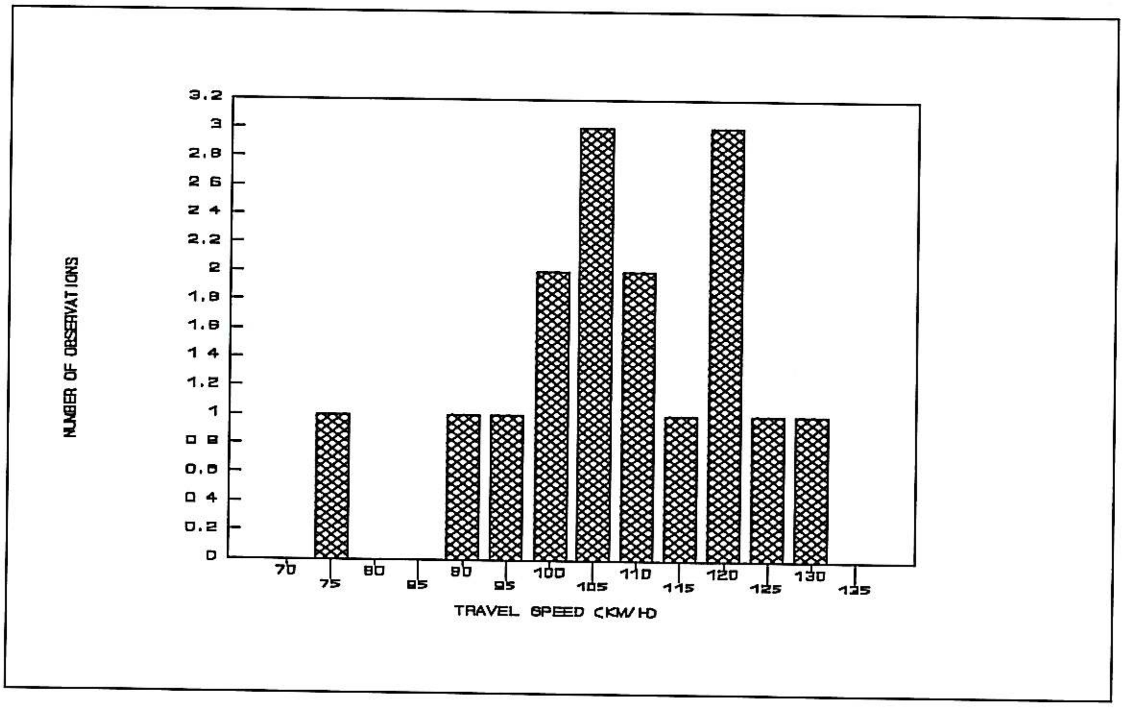


FIGURE B.6.3: MINI-BUSES

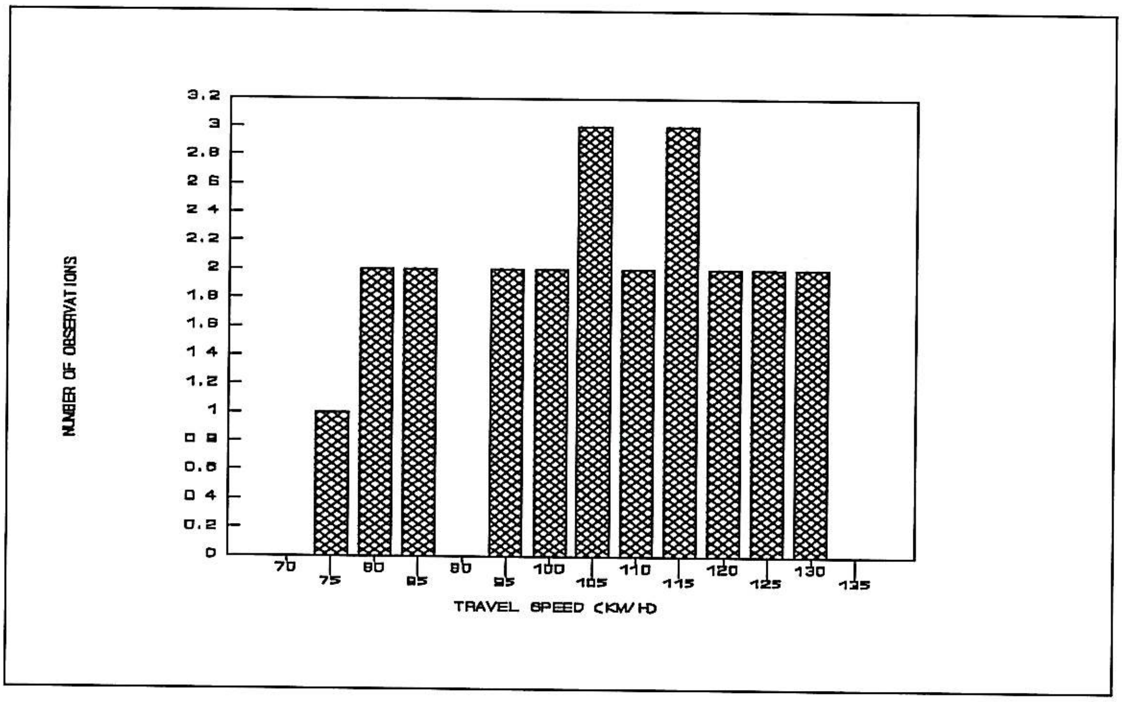


FIGURE B.6.4: BUSES

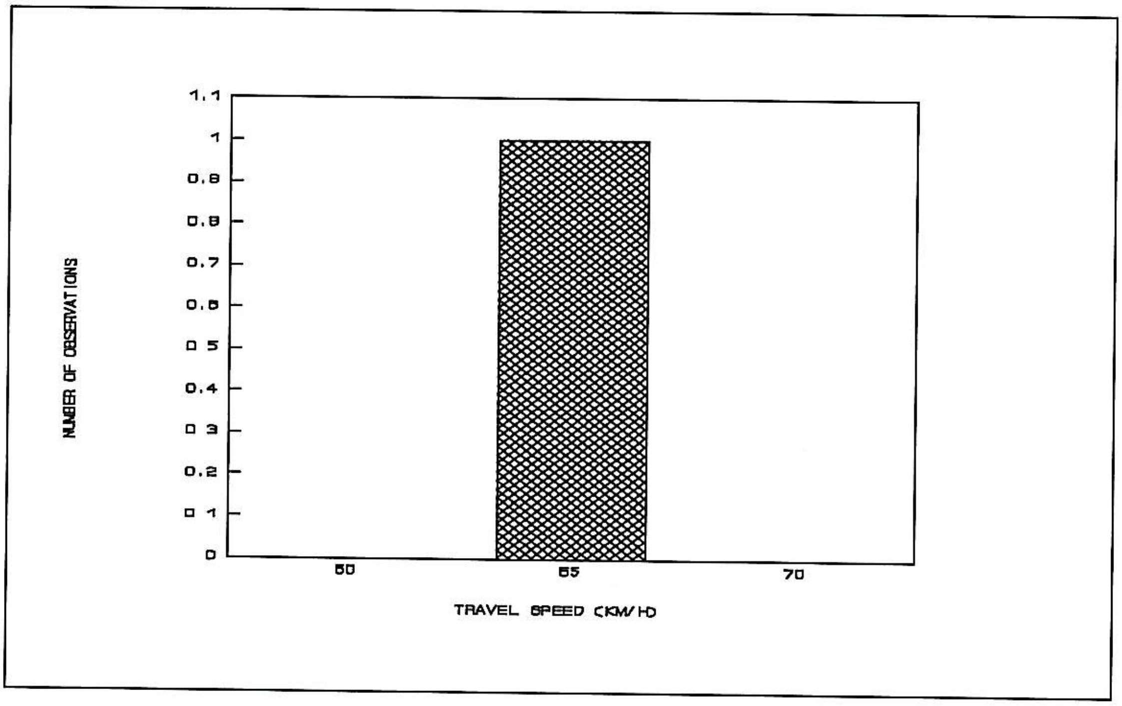


FIGURE B.6.5: MGVs

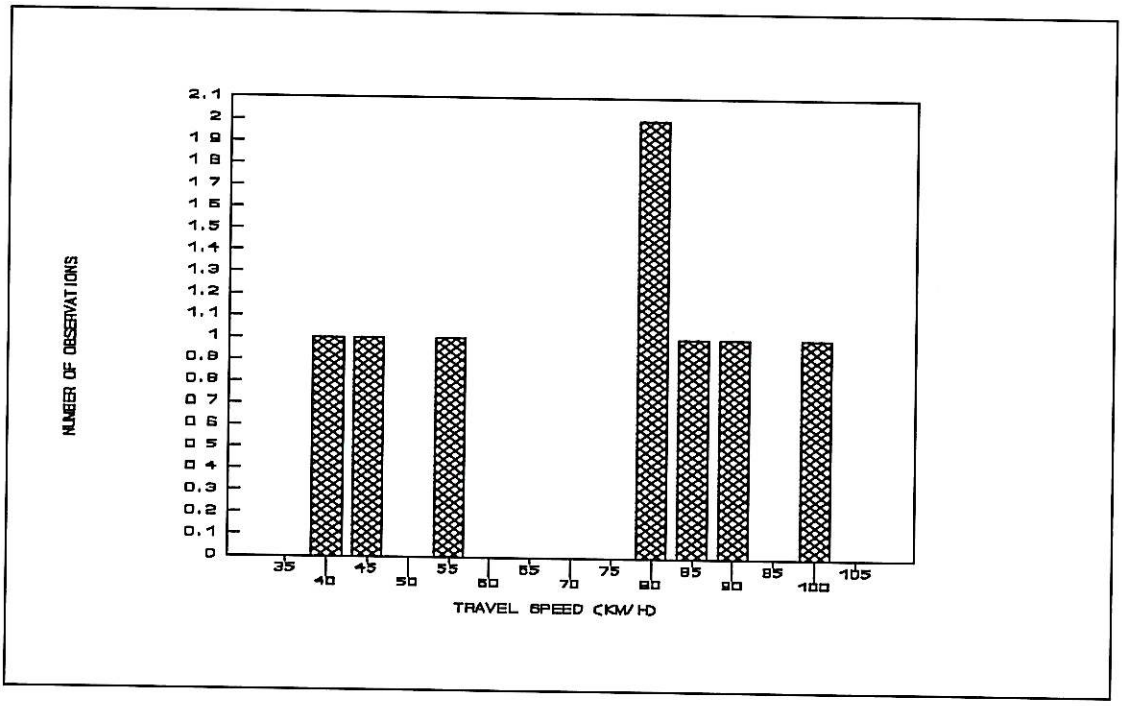
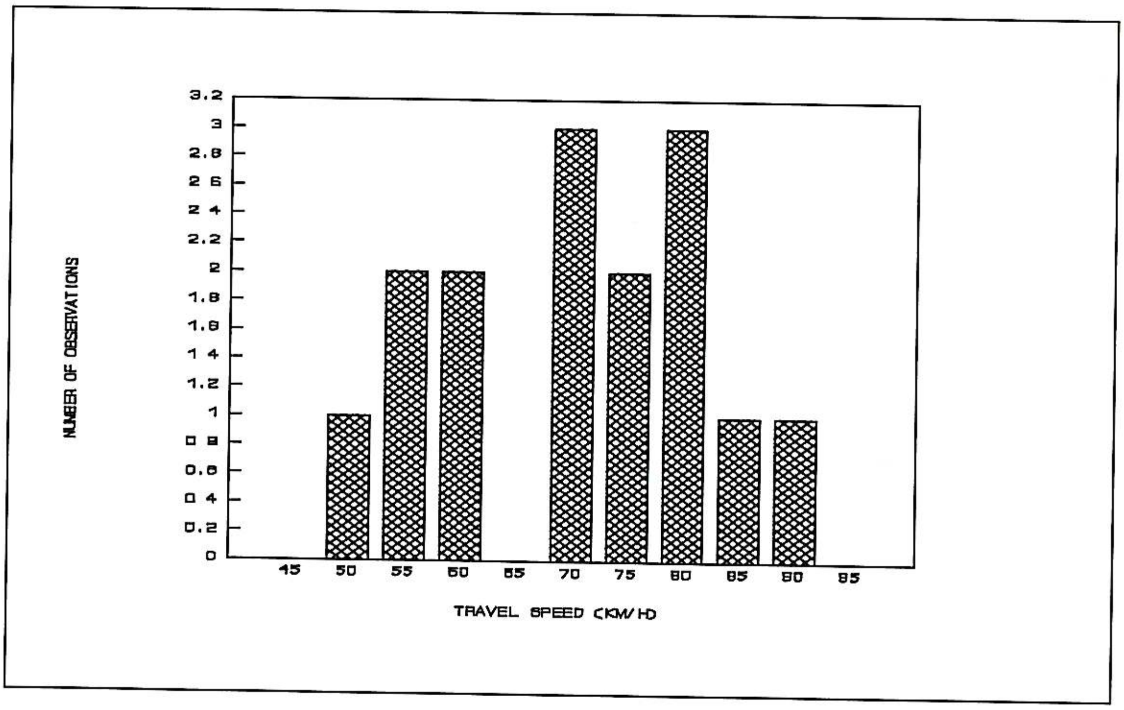


FIGURE B.6.6: HGVs



APPENDIX B.7: N12-2(W)

FIGURE B.7.1: CARS

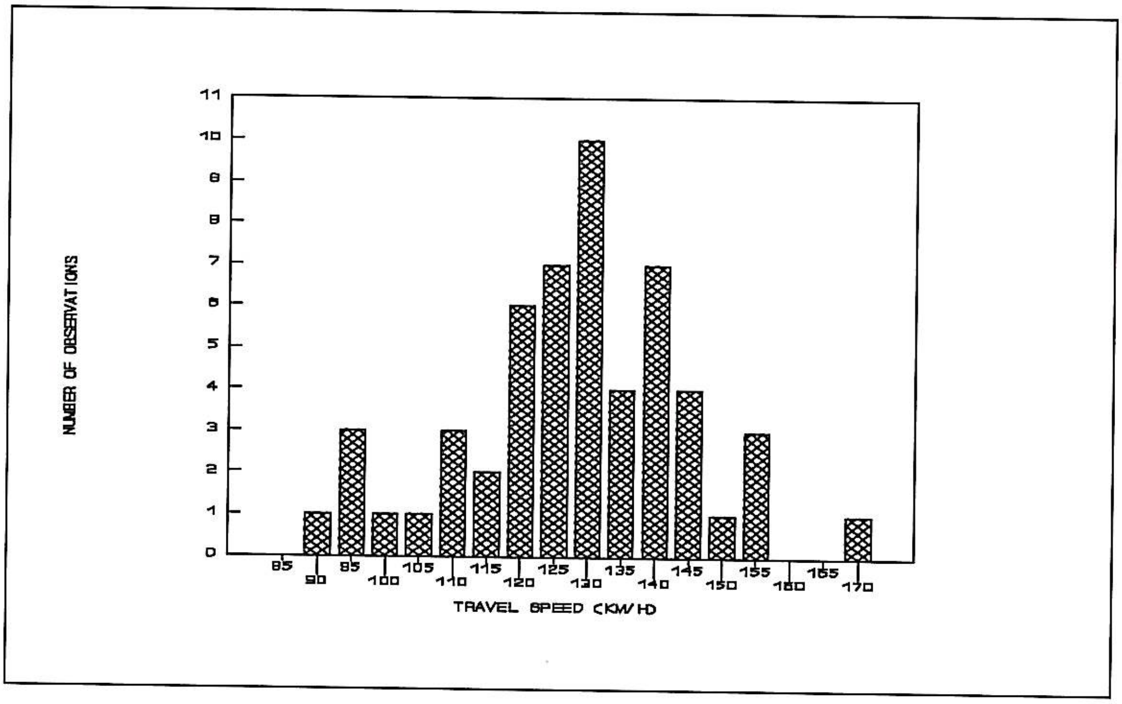


FIGURE B.7.2: LDVs

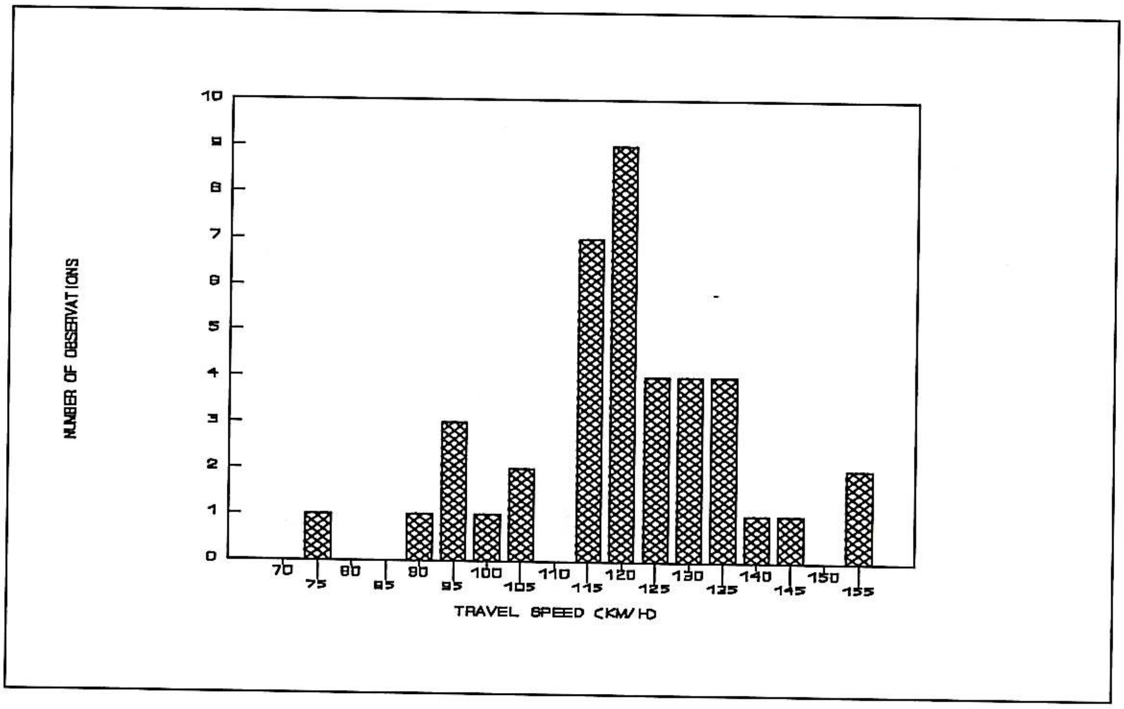


FIGURE B.7.3: MINI-BUSES

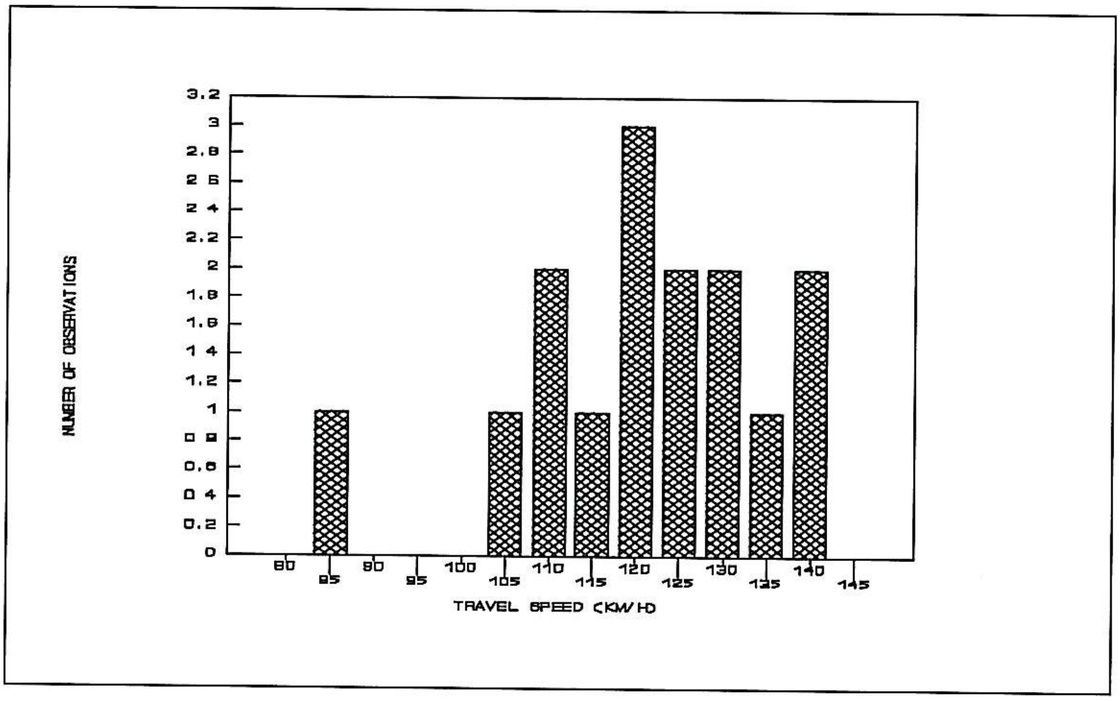


FIGURE B.7.4: BUSES

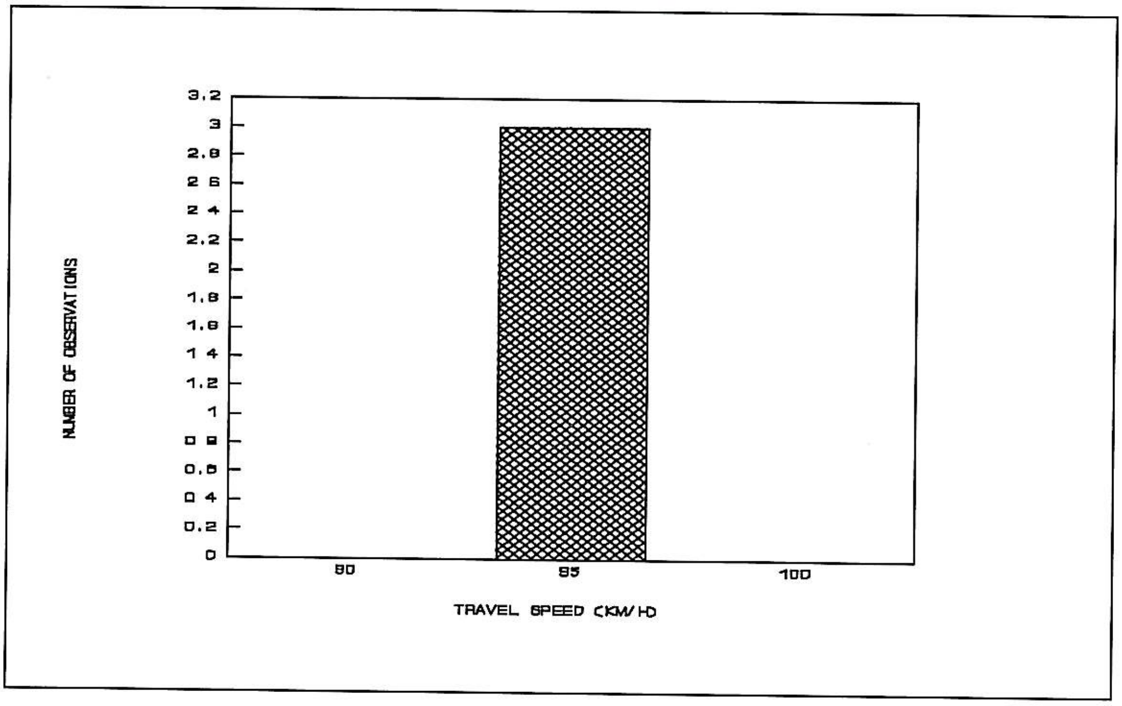


FIGURE B.7.5: MGVs

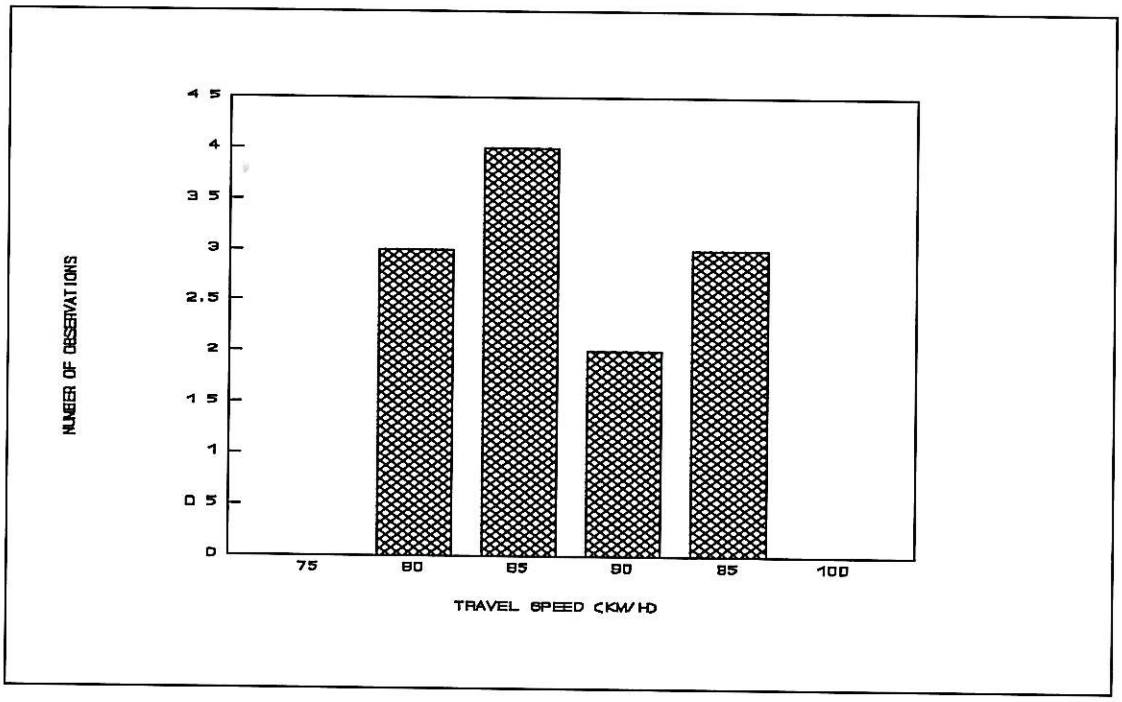
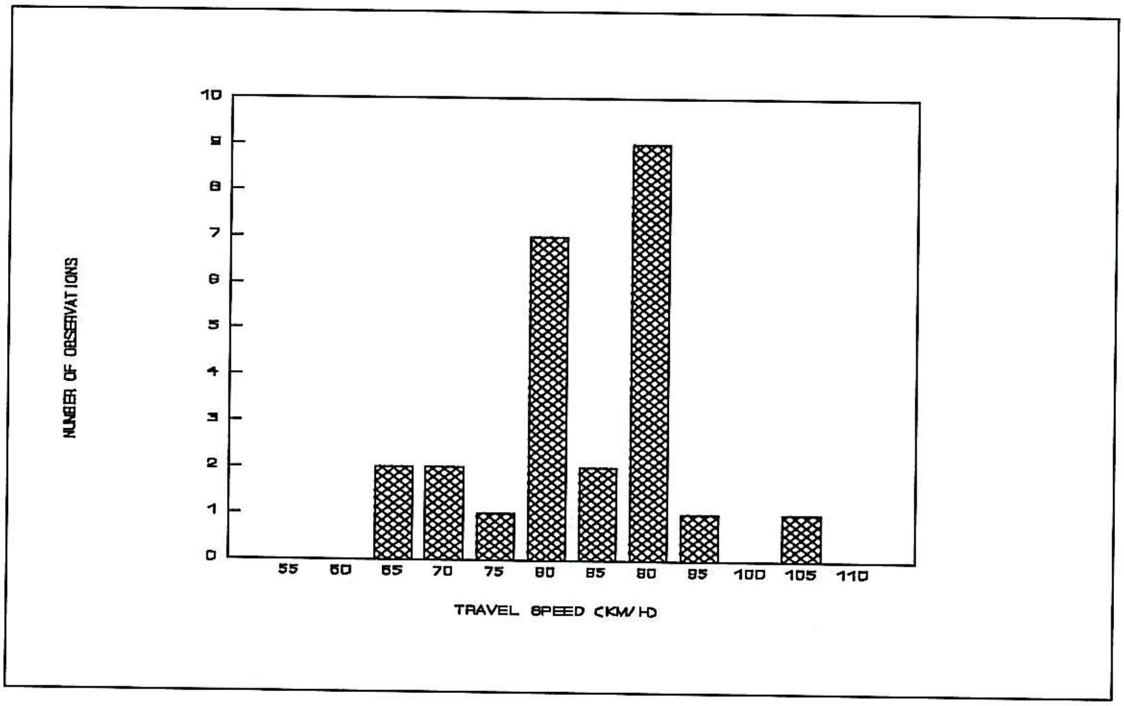


FIGURE B.7.6: HGVs



APPENDIX B.8: N12-2(E)

FIGURE B.8.1: CARS

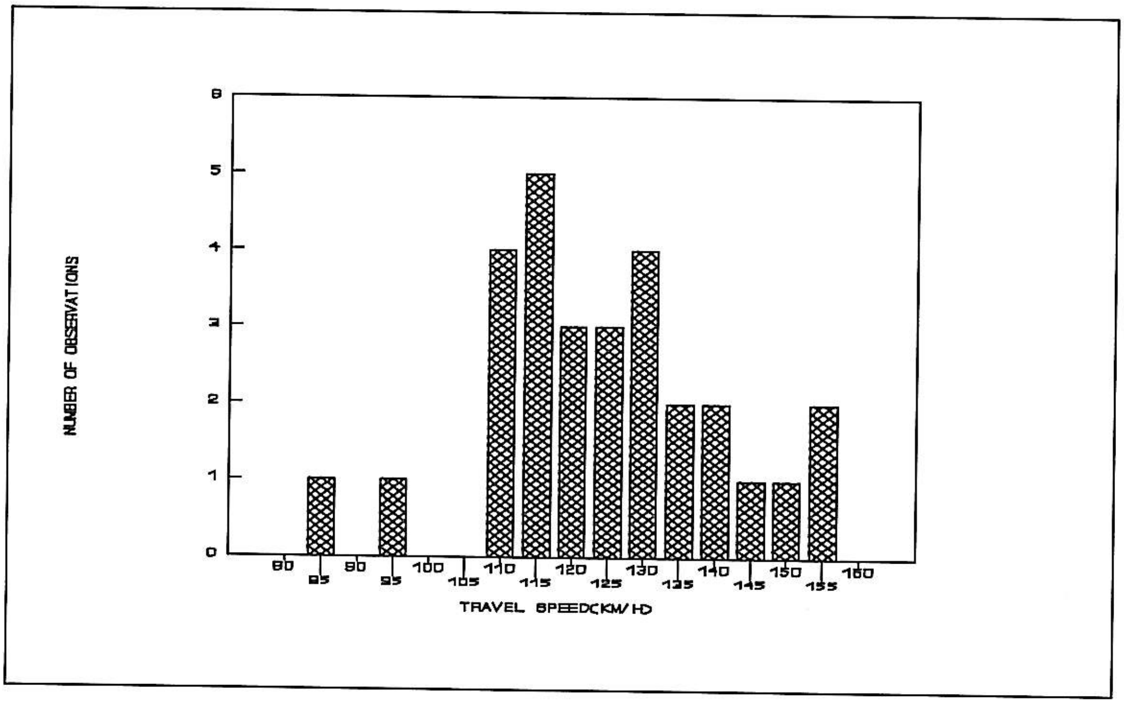


FIGURE B.8.2: LDVs

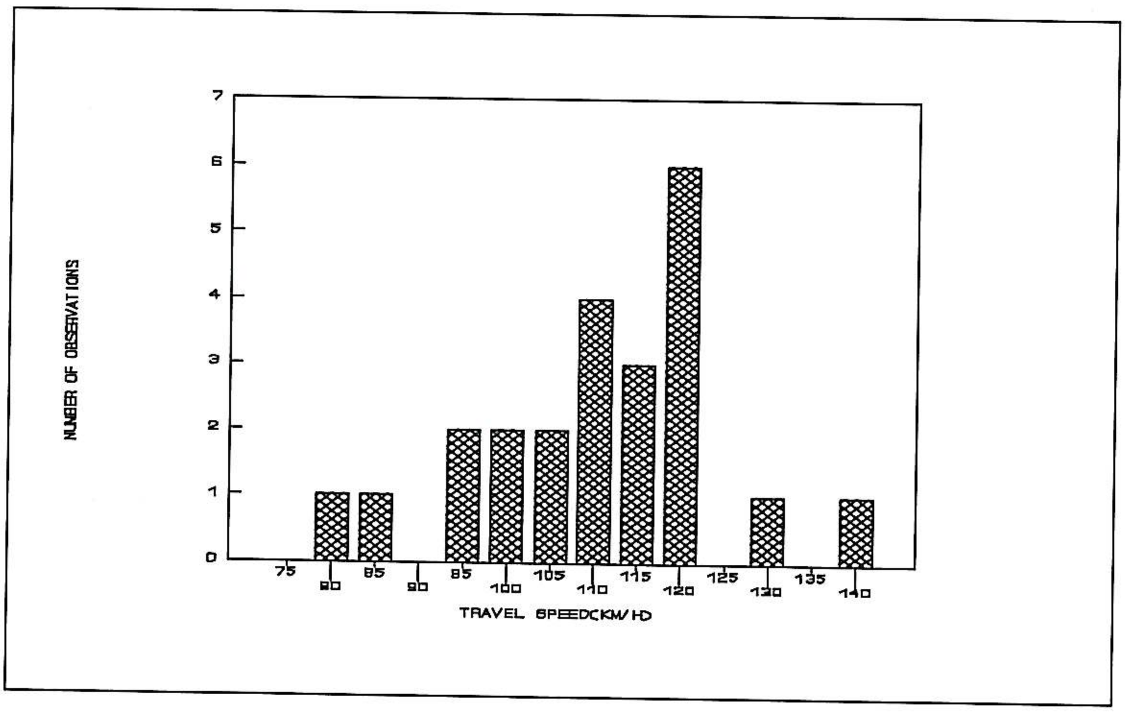


FIGURE B.8.3: MINI-BUSES

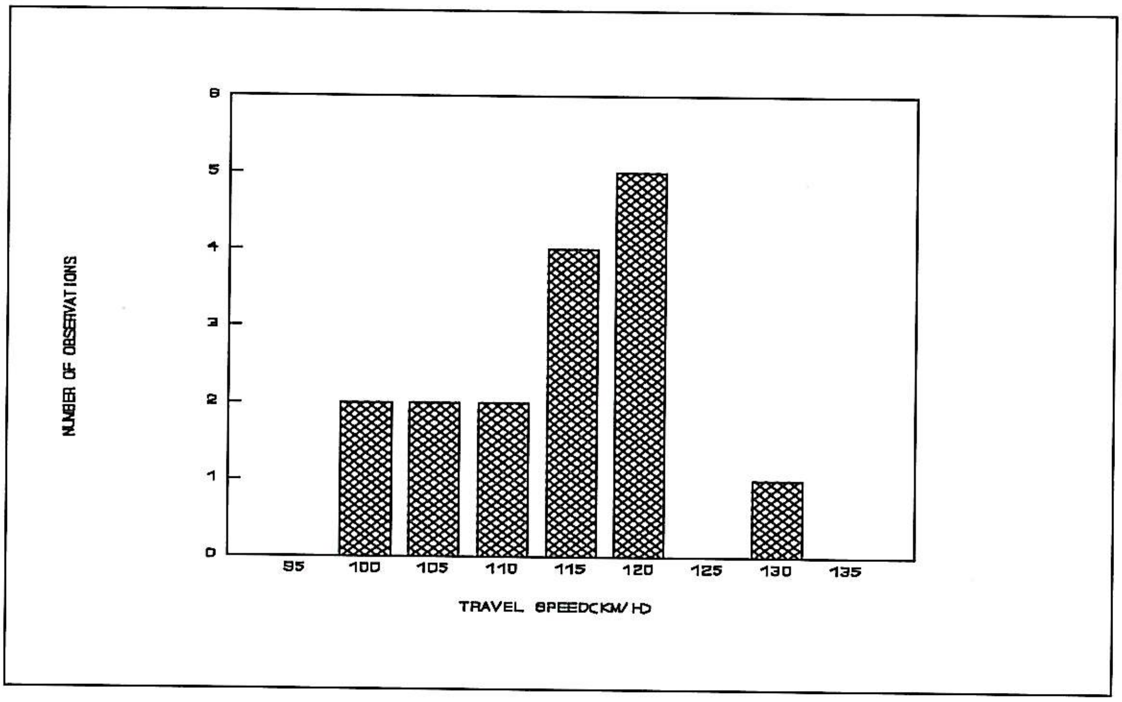


FIGURE B.8.4: MGVs

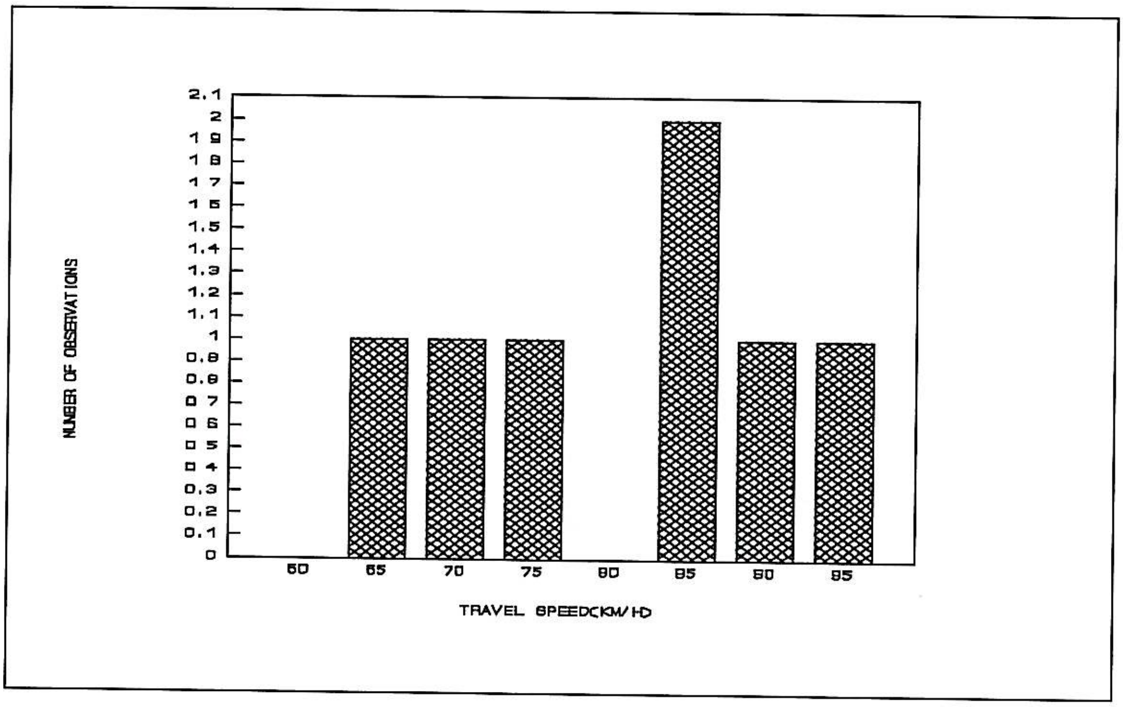
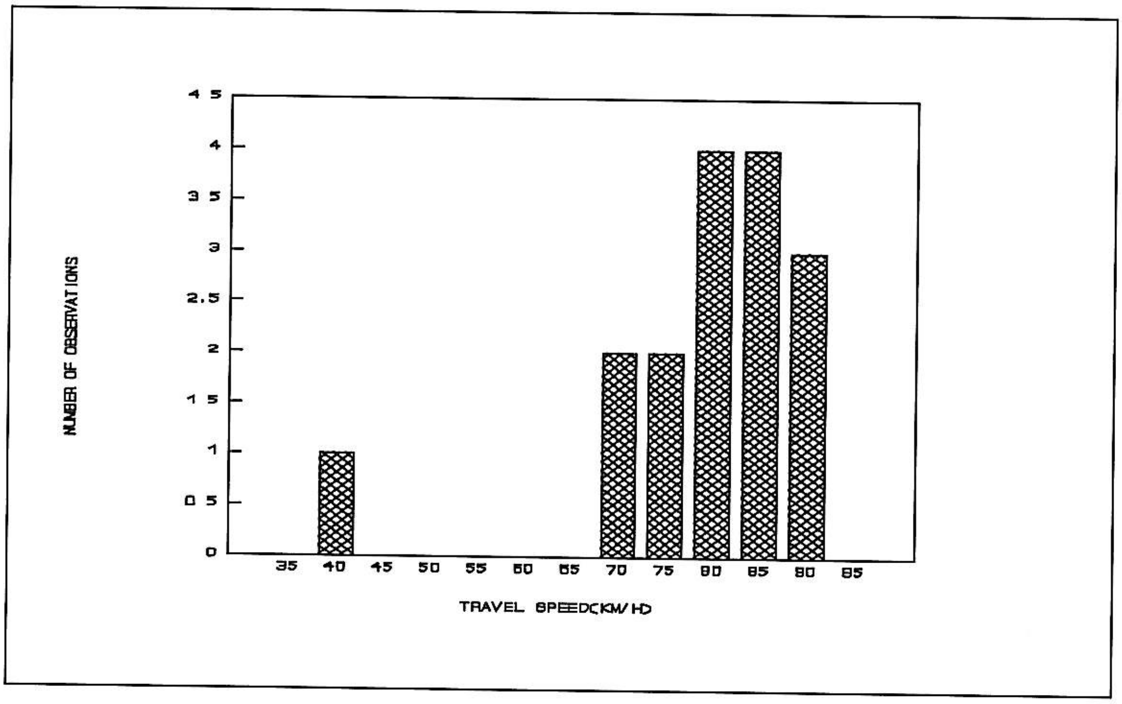


FIGURE B.8.5: HGVs



APPENDIX B.9: N12-2(W)

FIGURE B.9.1: CARS

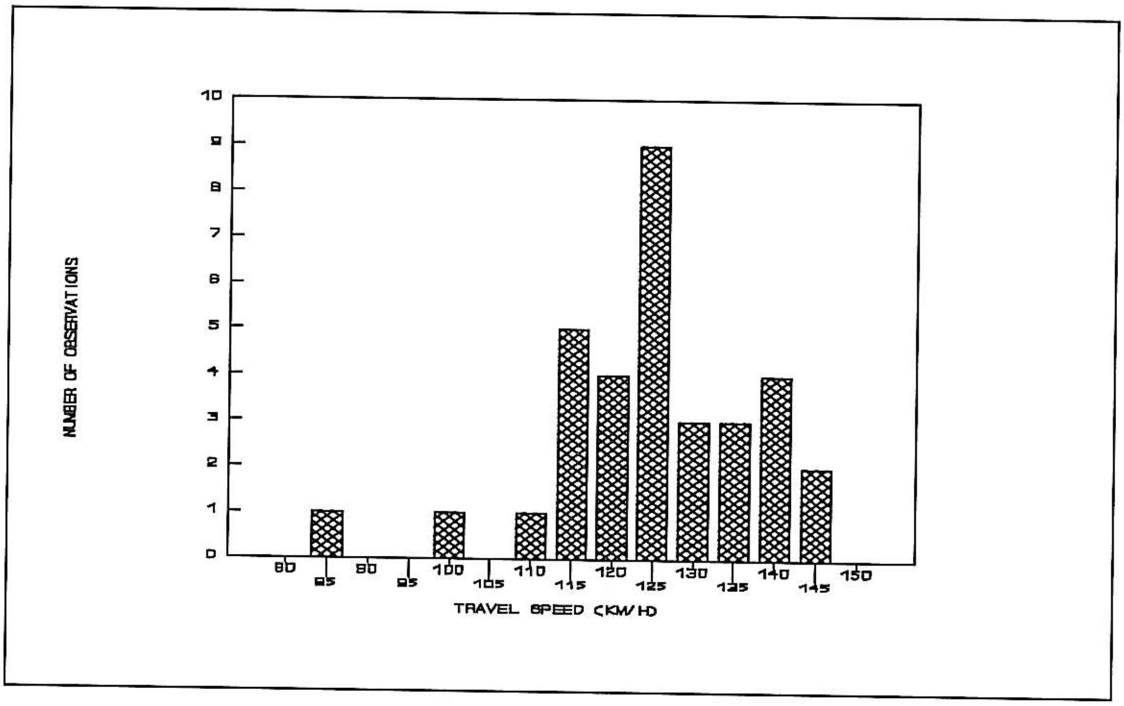


FIGURE B.9.2: LDVs

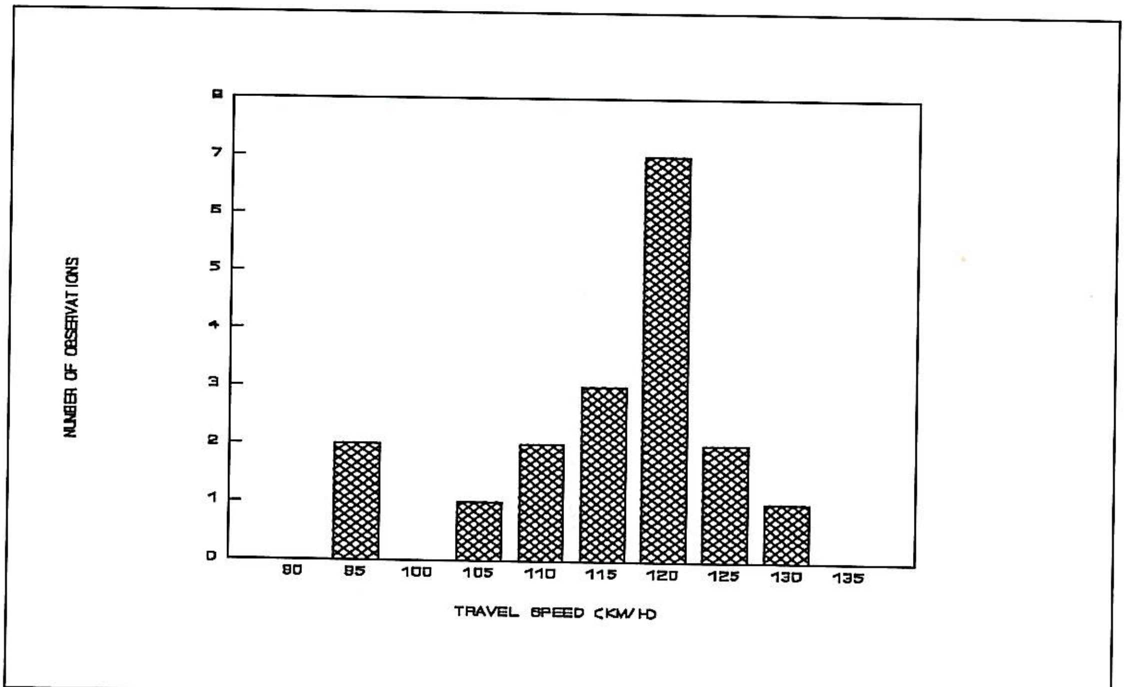


FIGURE B.9.3: MINI-BUSES

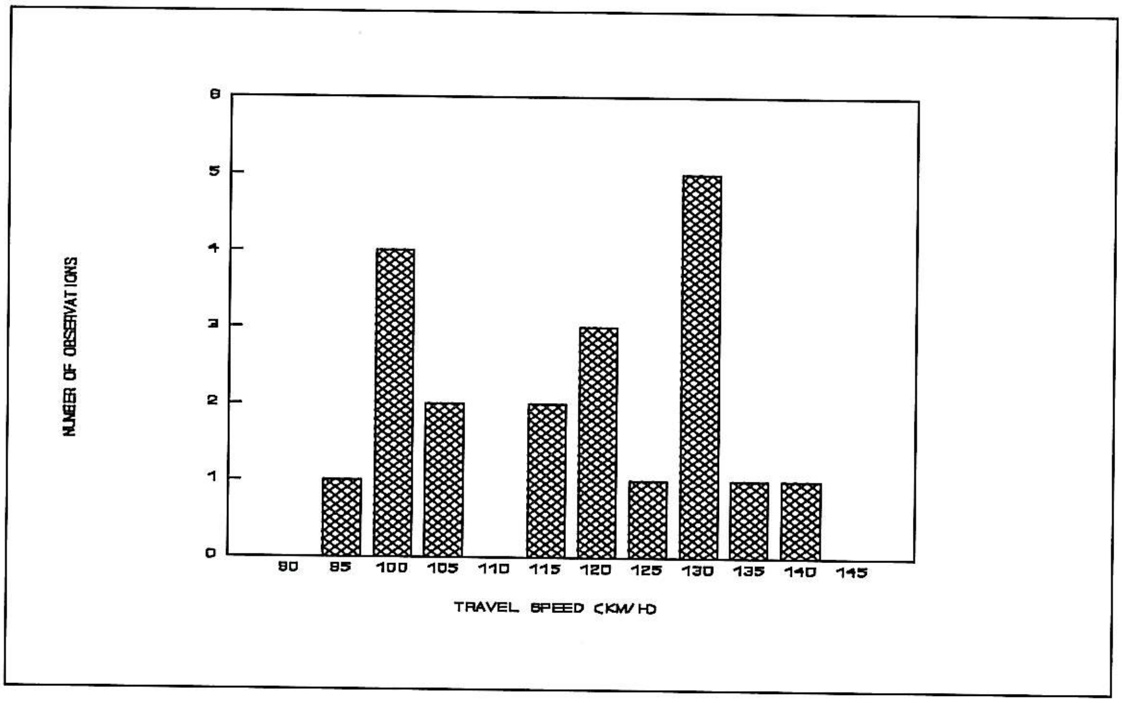


FIGURE B.9.4: BUSES

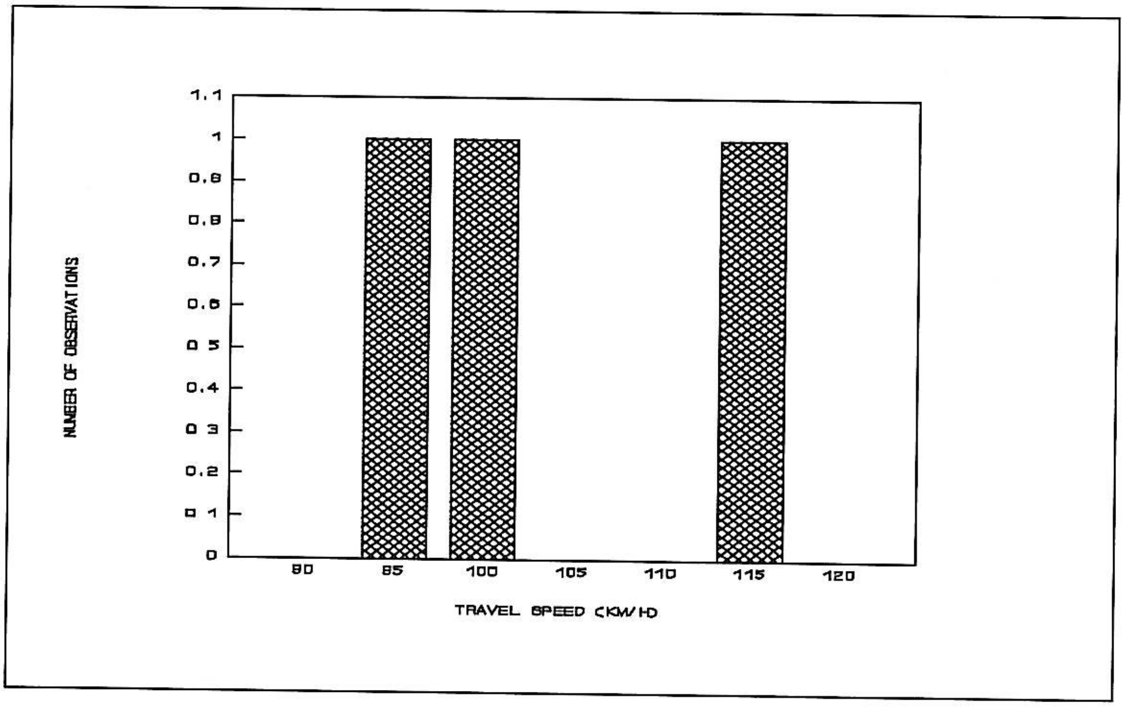


FIGURE B.9.5: MGVs

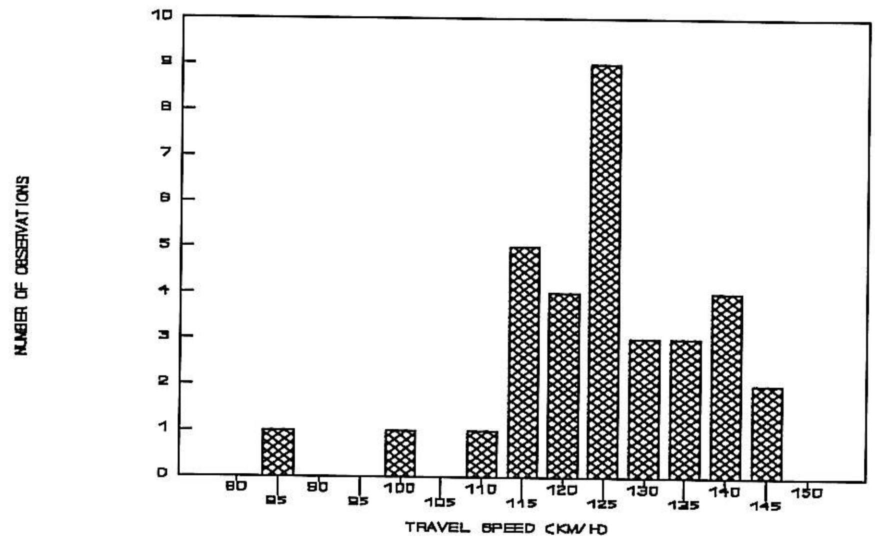
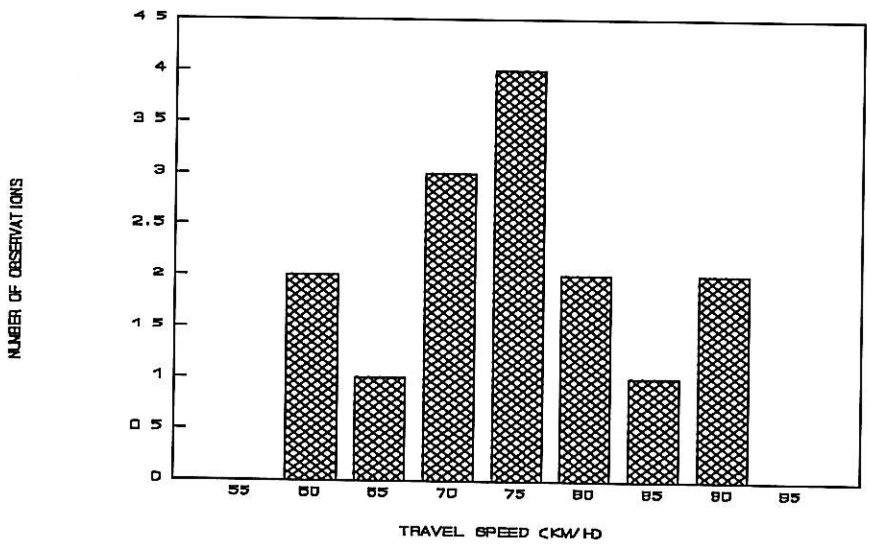


FIGURE B.9.6: HGVs



APPENDIX B.10: P29(W)

FIGURE B.10.1: CARS

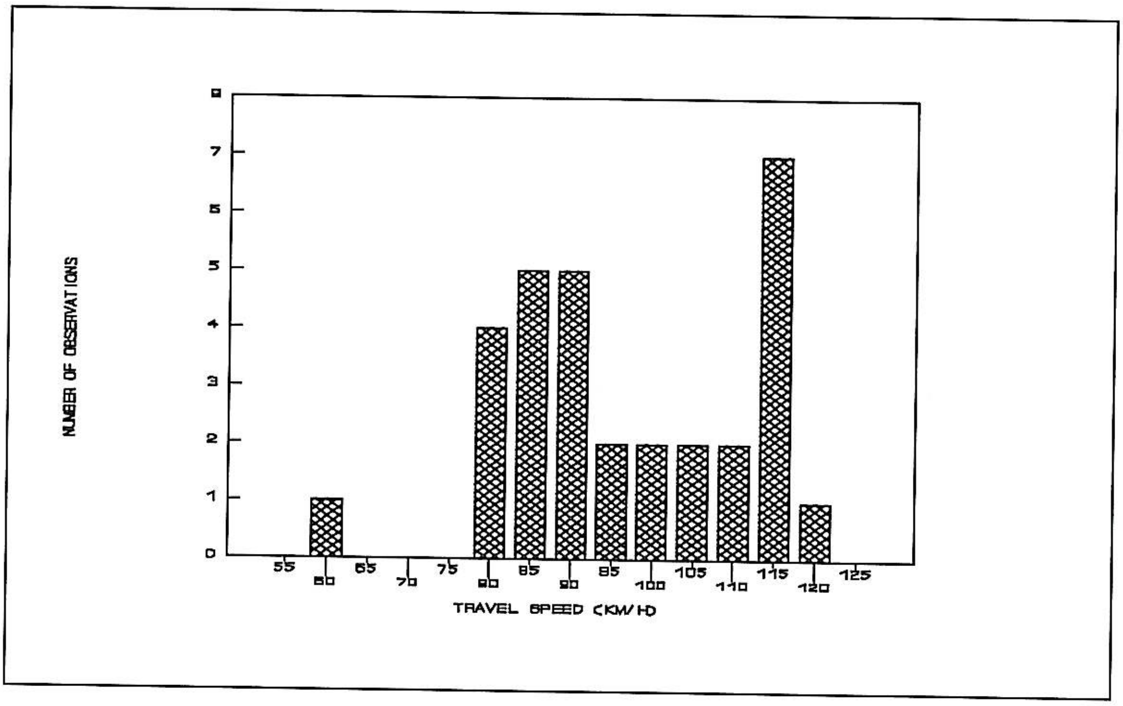


FIGURE B.10.2: LDVs

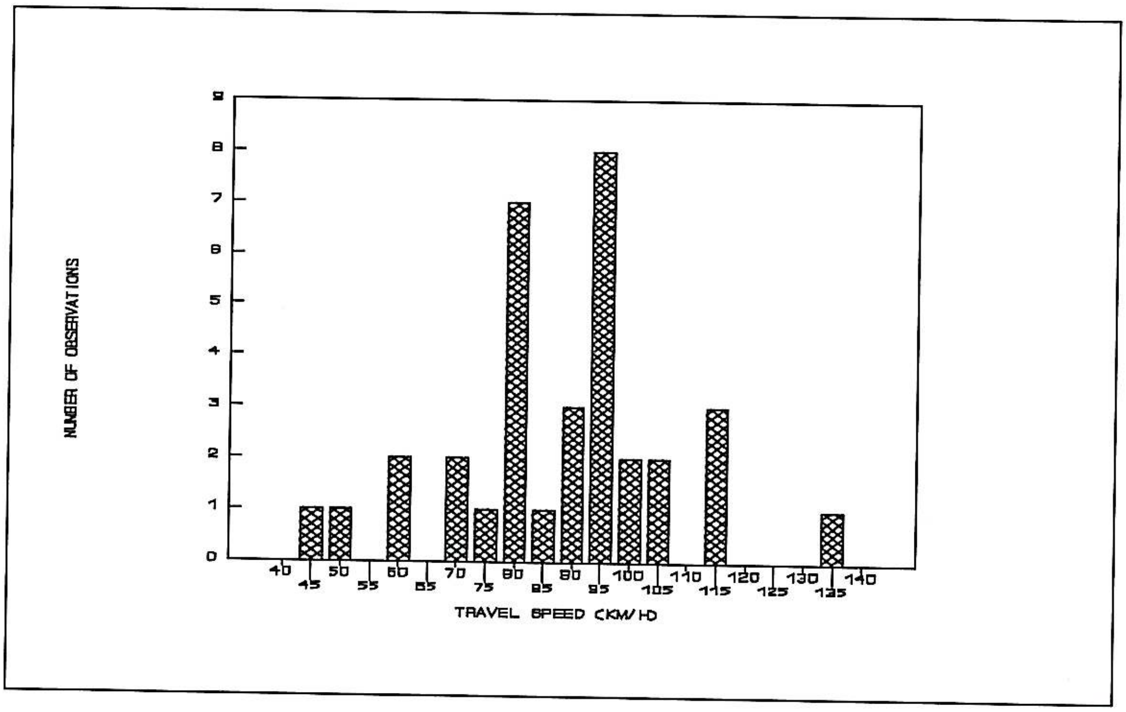


FIGURE B.10.3: MINI-BUSES

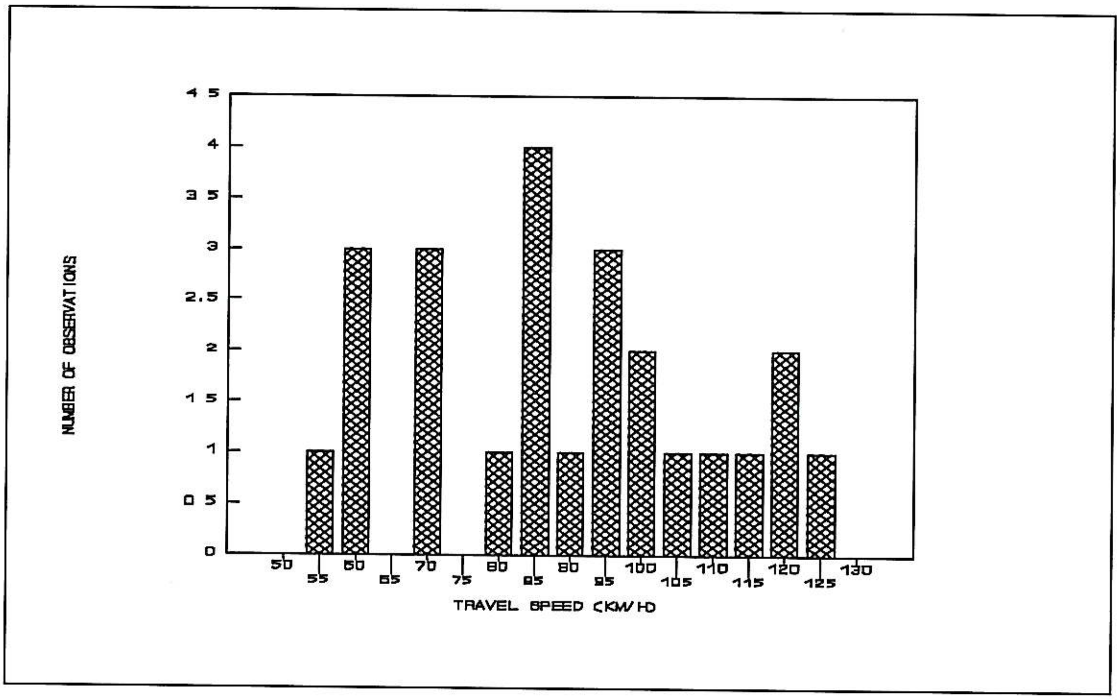


FIGURE B.10.4: BUSES

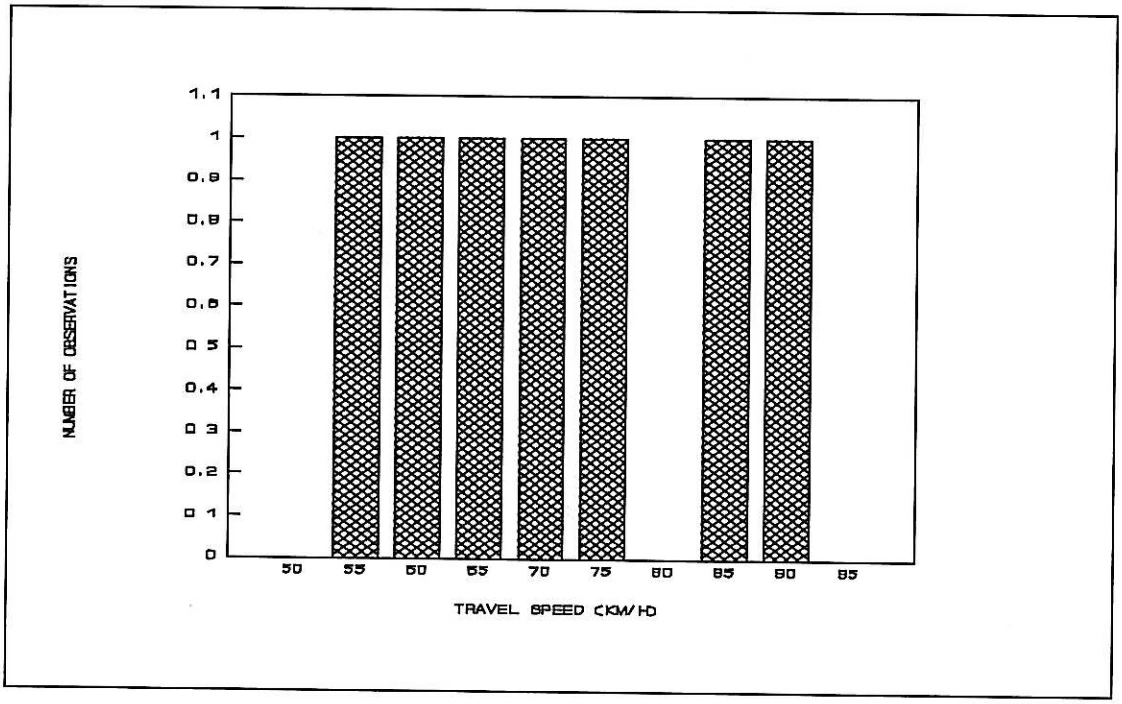


FIGURE B.10.5: MGVs

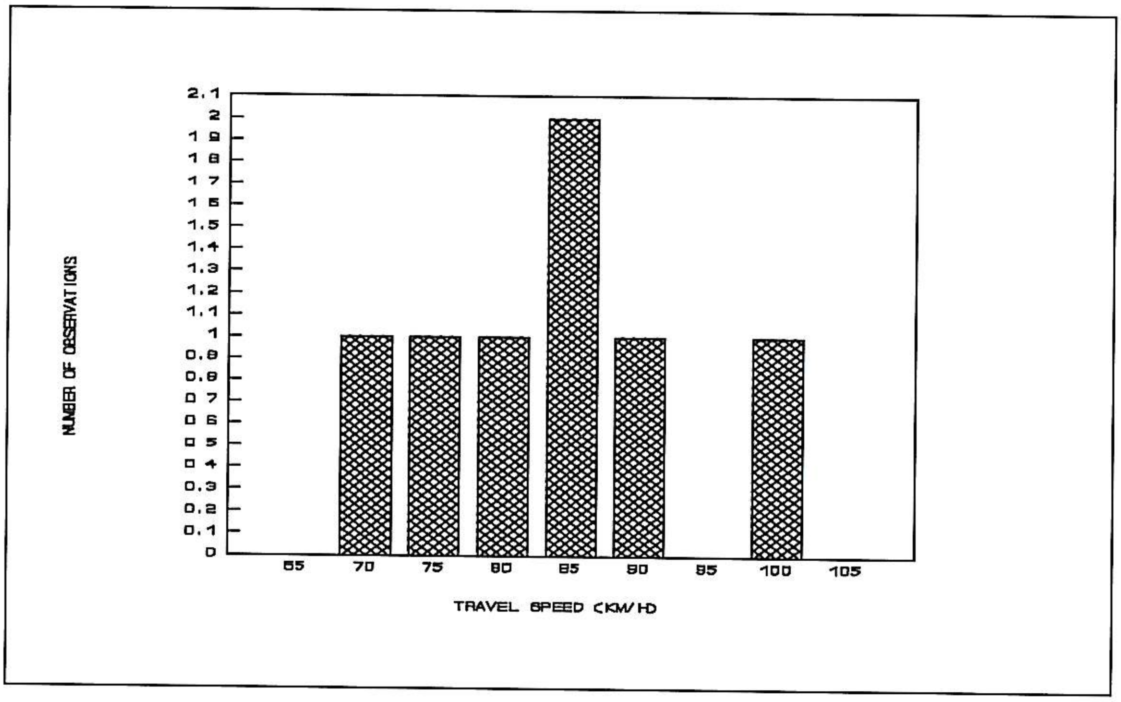
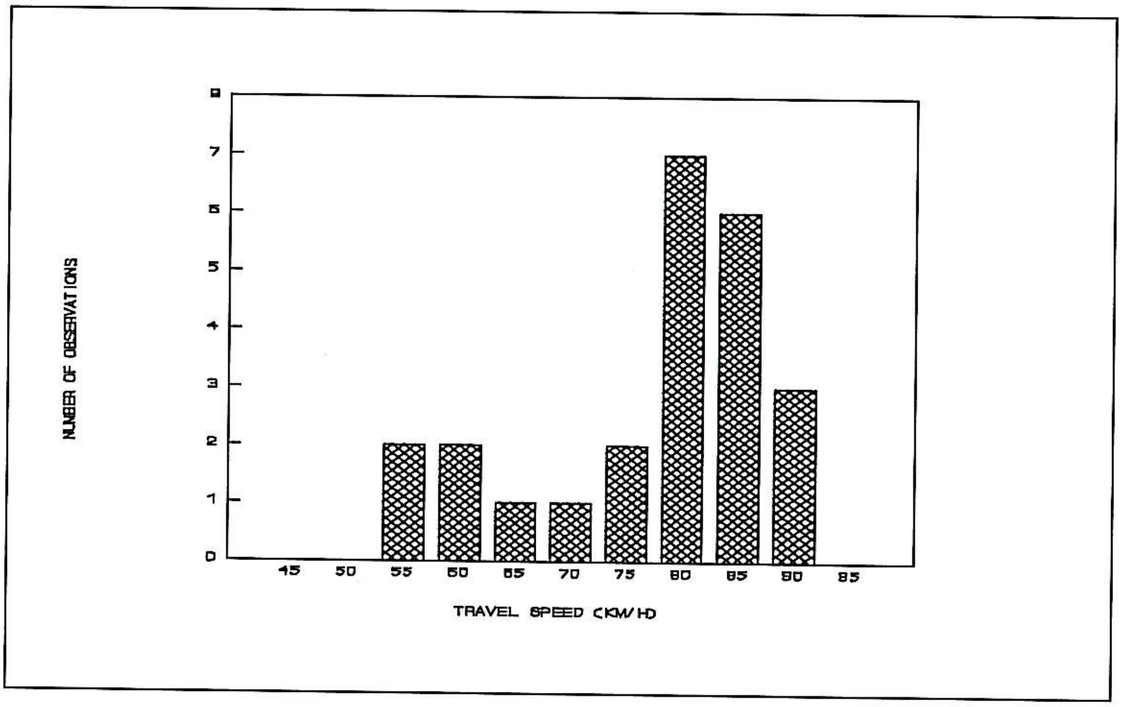


FIGURE B.10.6: HGVs



APPENDIX B.11: P29(E)

FIGURE B.11.1: CARS

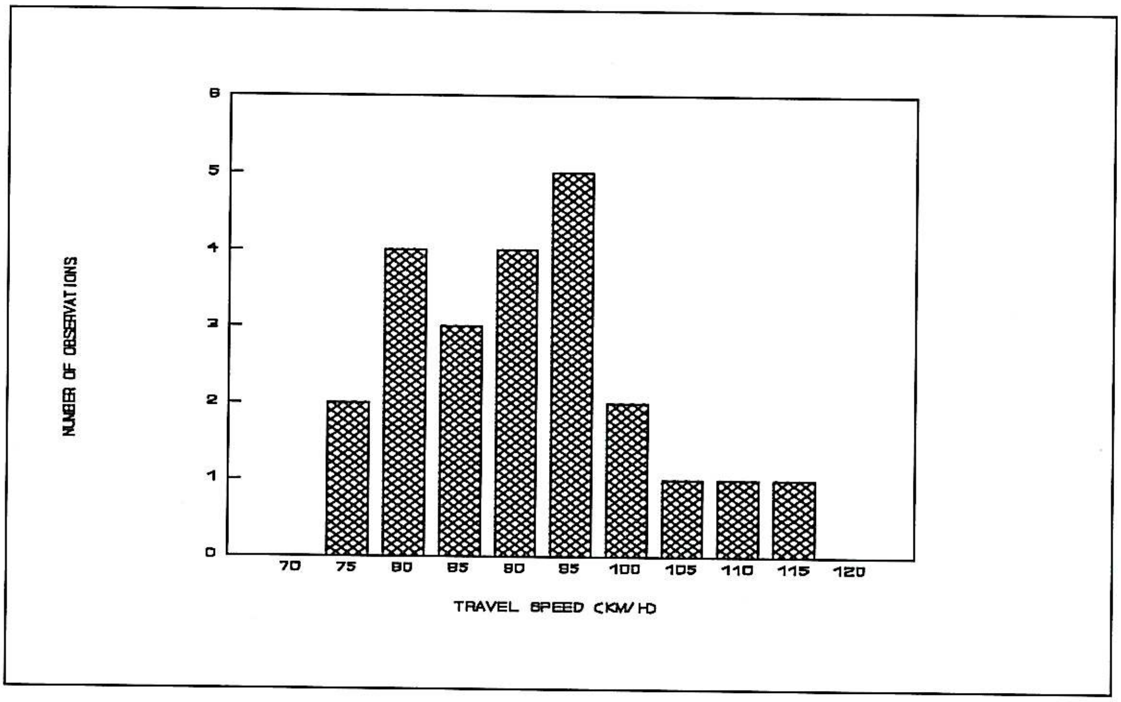


FIGURE B.11.2: LDVs

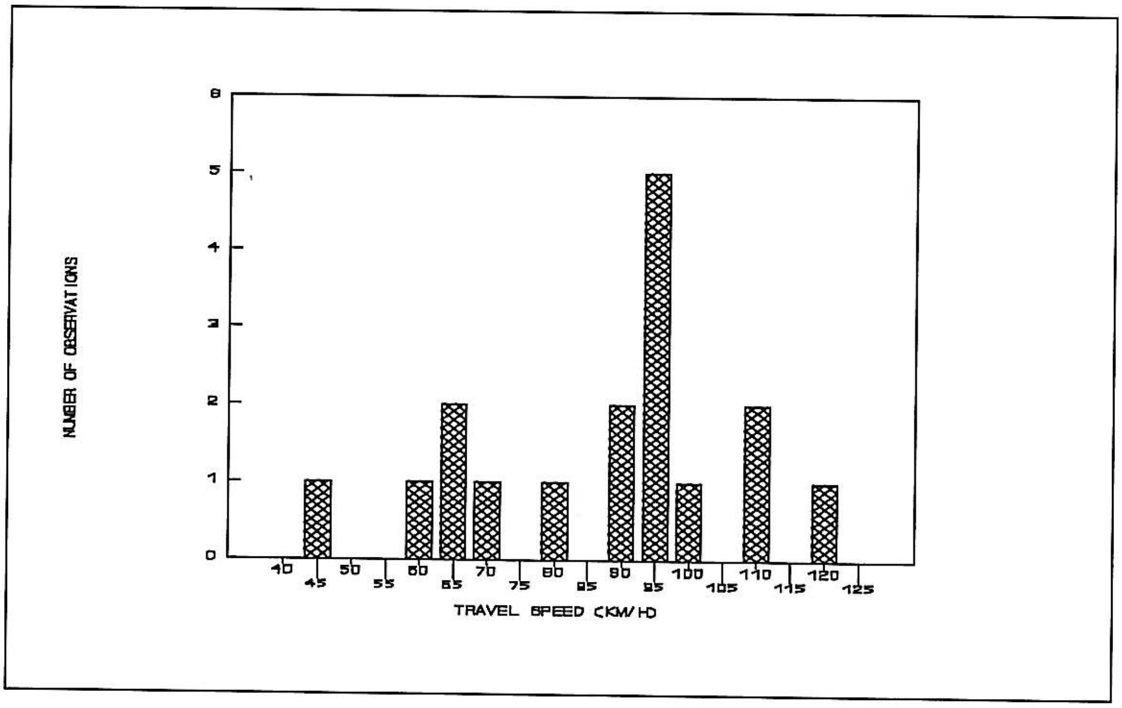


FIGURE B.11.3: MINI-BUSES

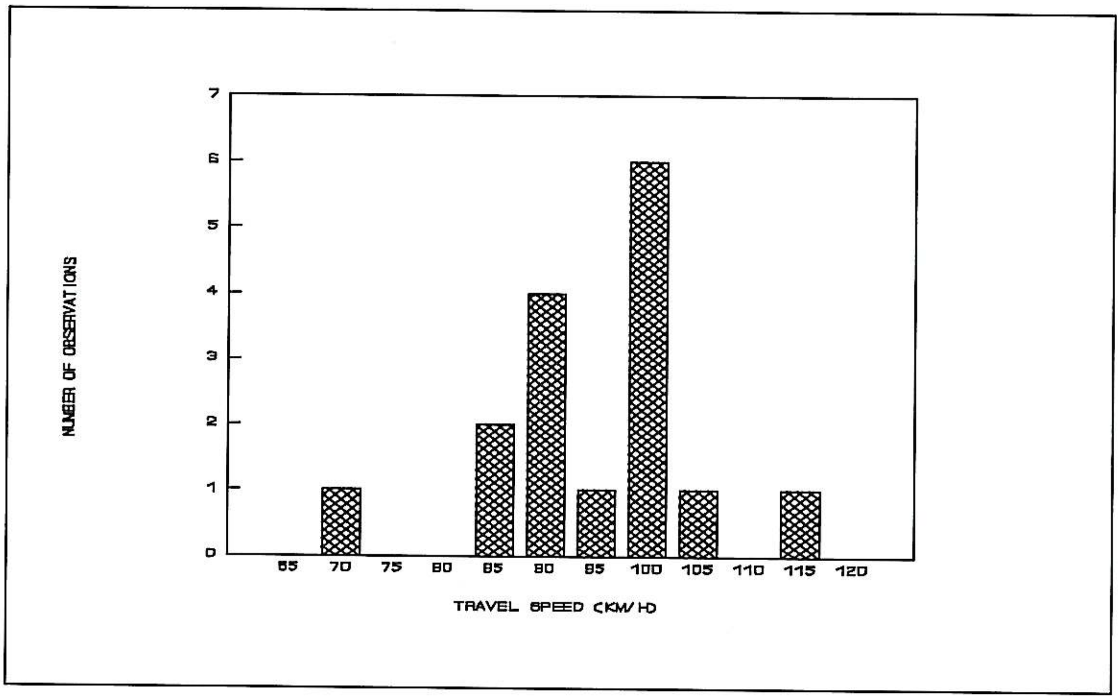


FIGURE B.11.4: BUSES

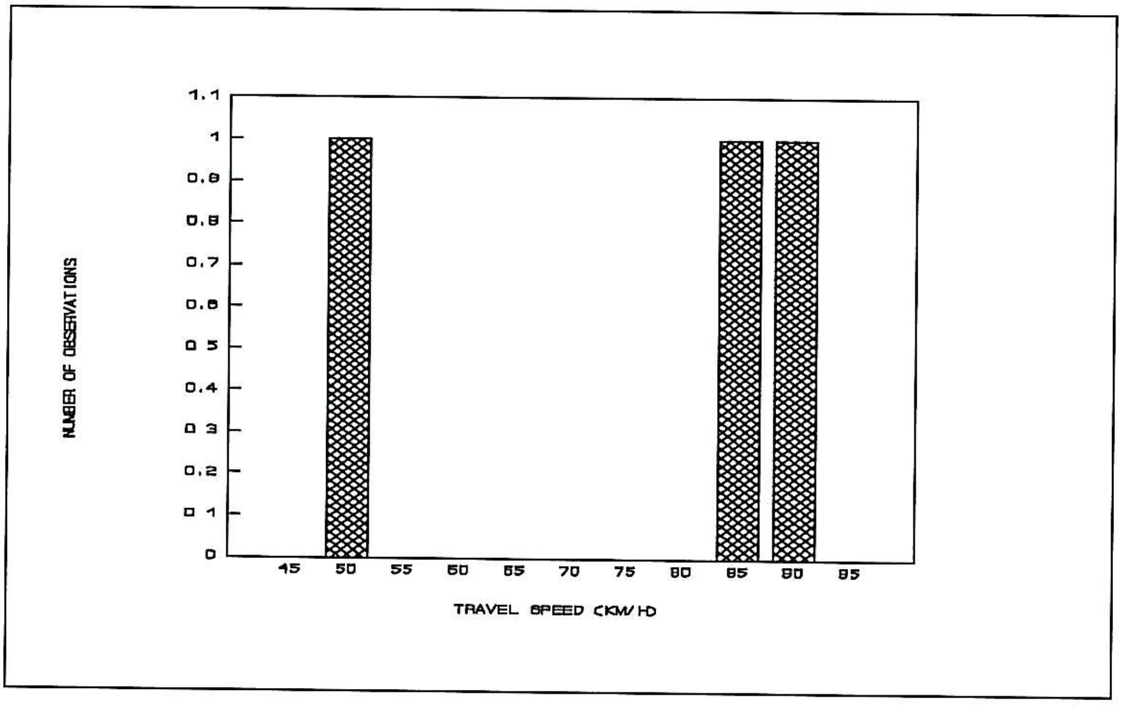


FIGURE B.11.5: MGVs

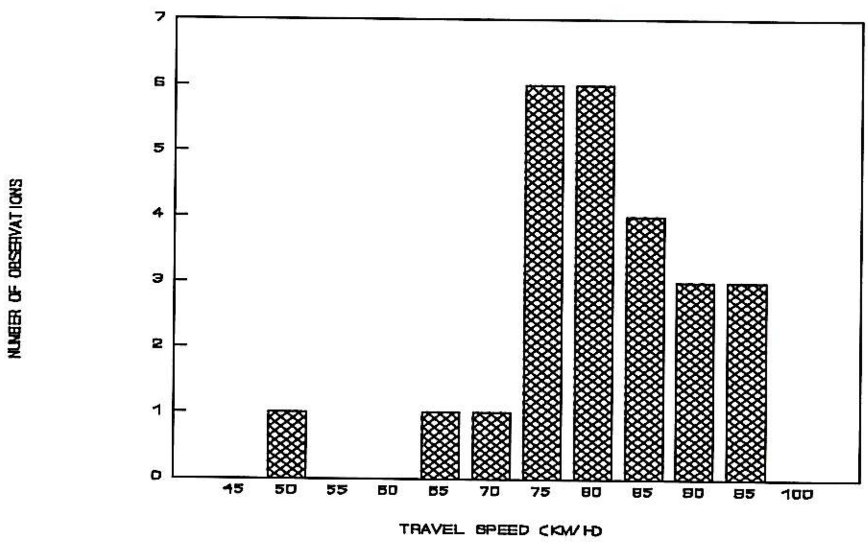
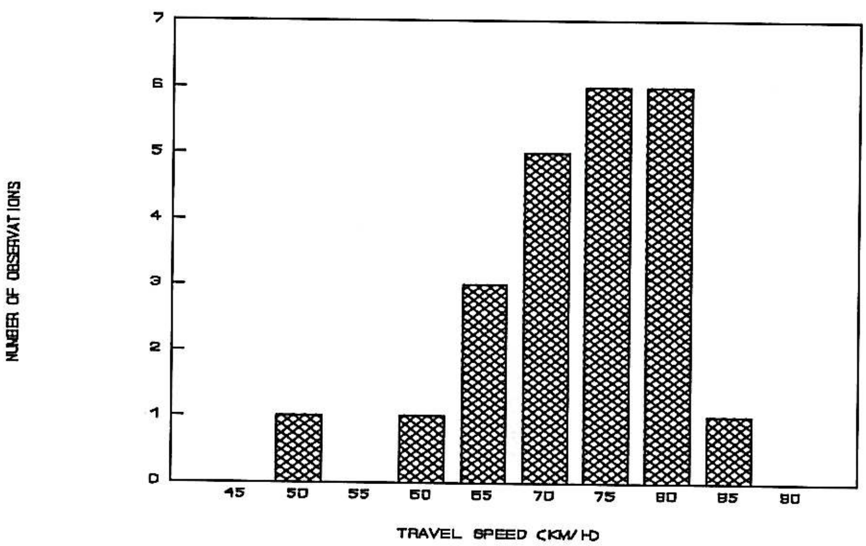


FIGURE B.11.6: HGVs



APPENDIX B.12: P91(W)

FIGURE B.12.1: CARS

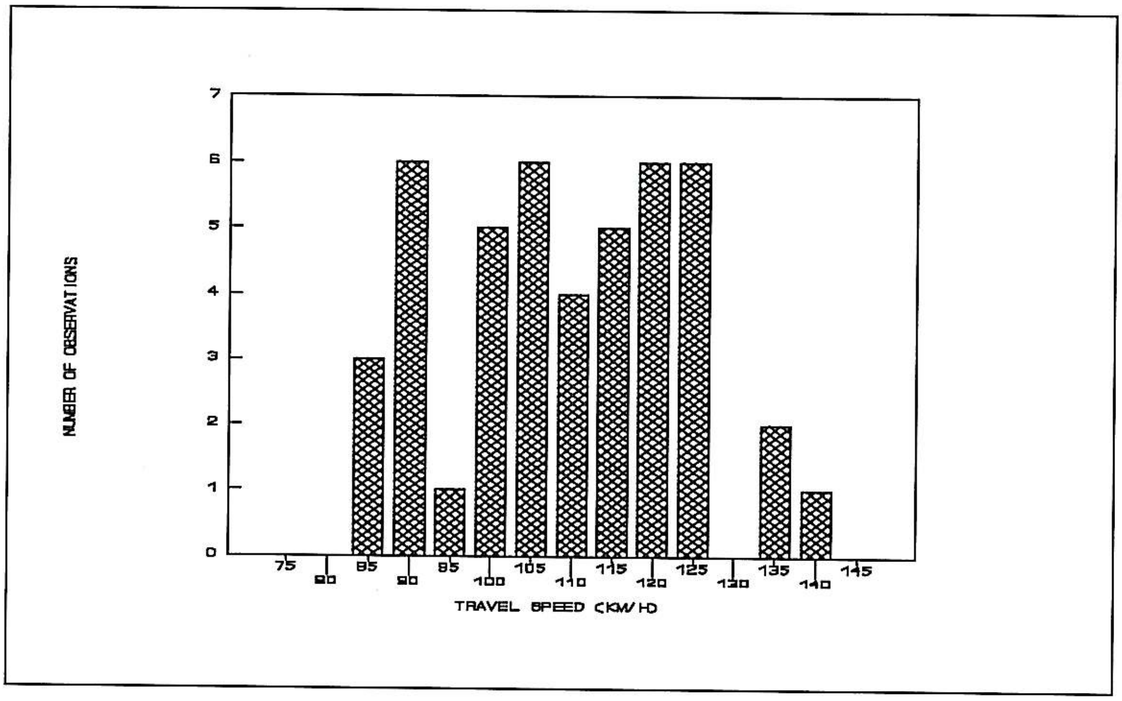


FIGURE B.12.2: LDVs

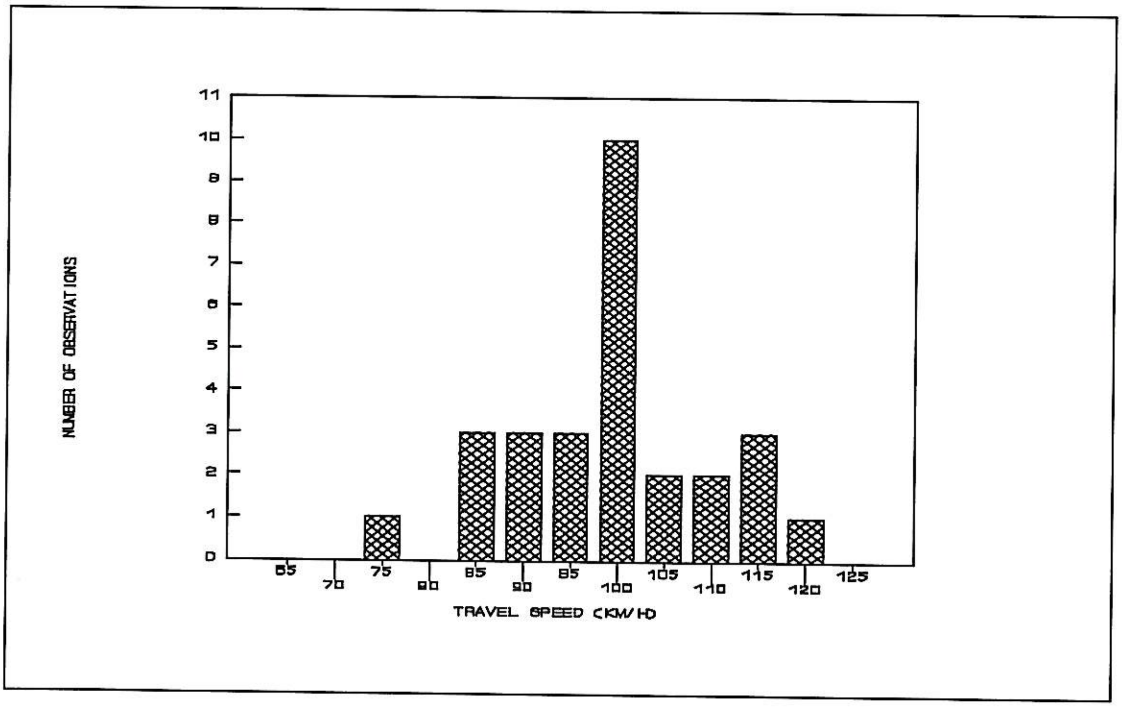


FIGURE B.12.3: MINI-BUSES

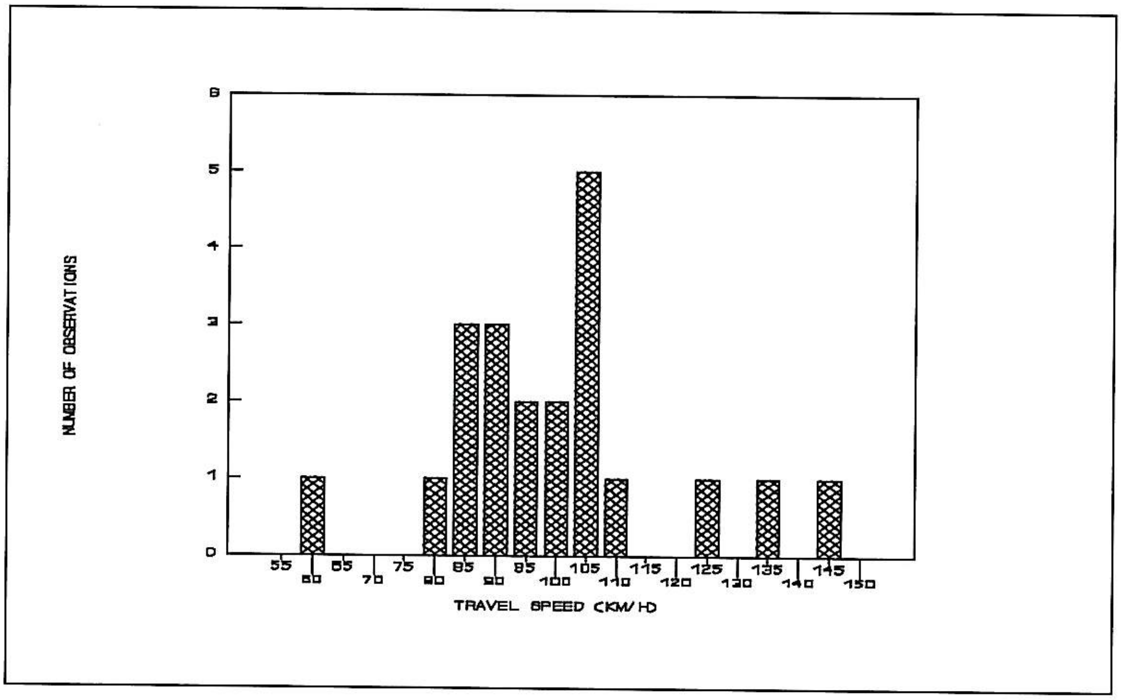


FIGURE B.12.4: MGVs

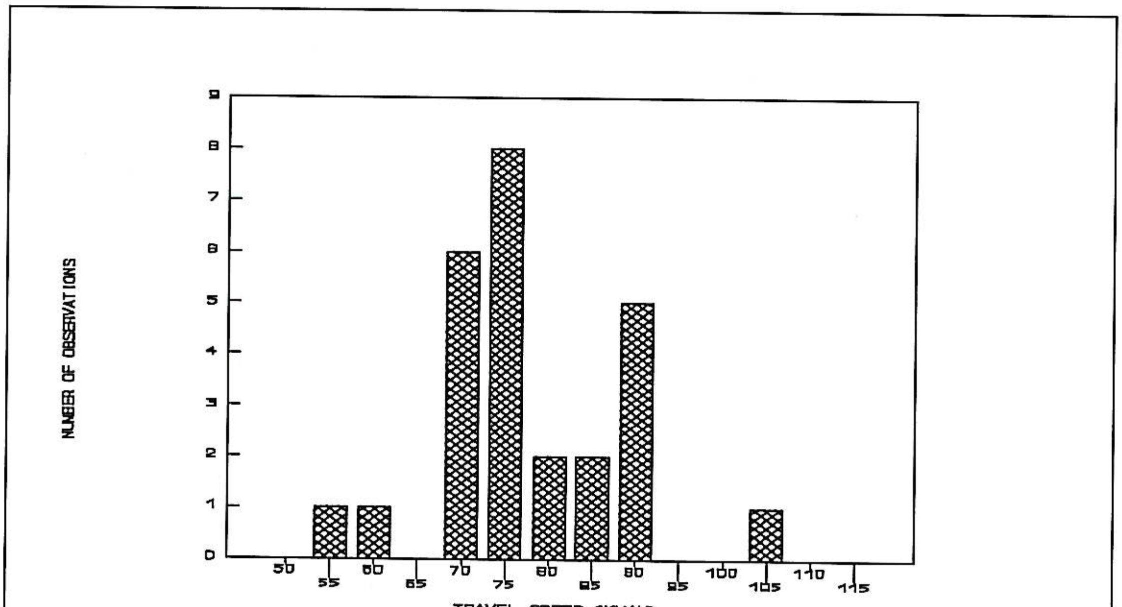
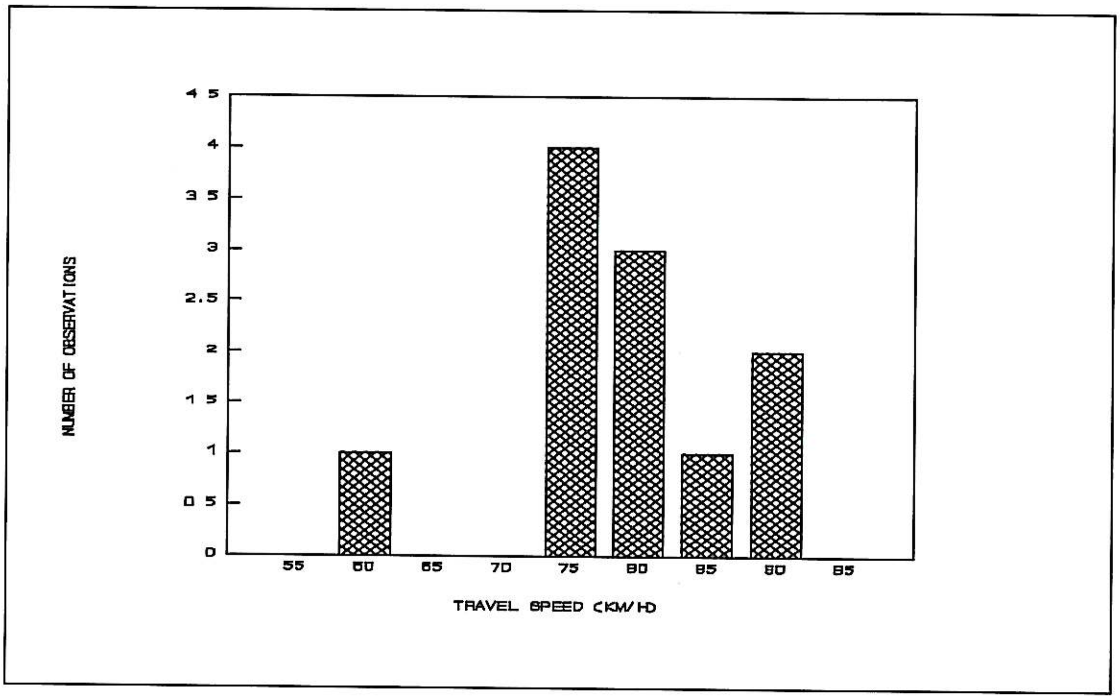


FIGURE B.12.5: HGVs



APPENDIX B.13: P91(E)

FIGURE B.13.1: CARS

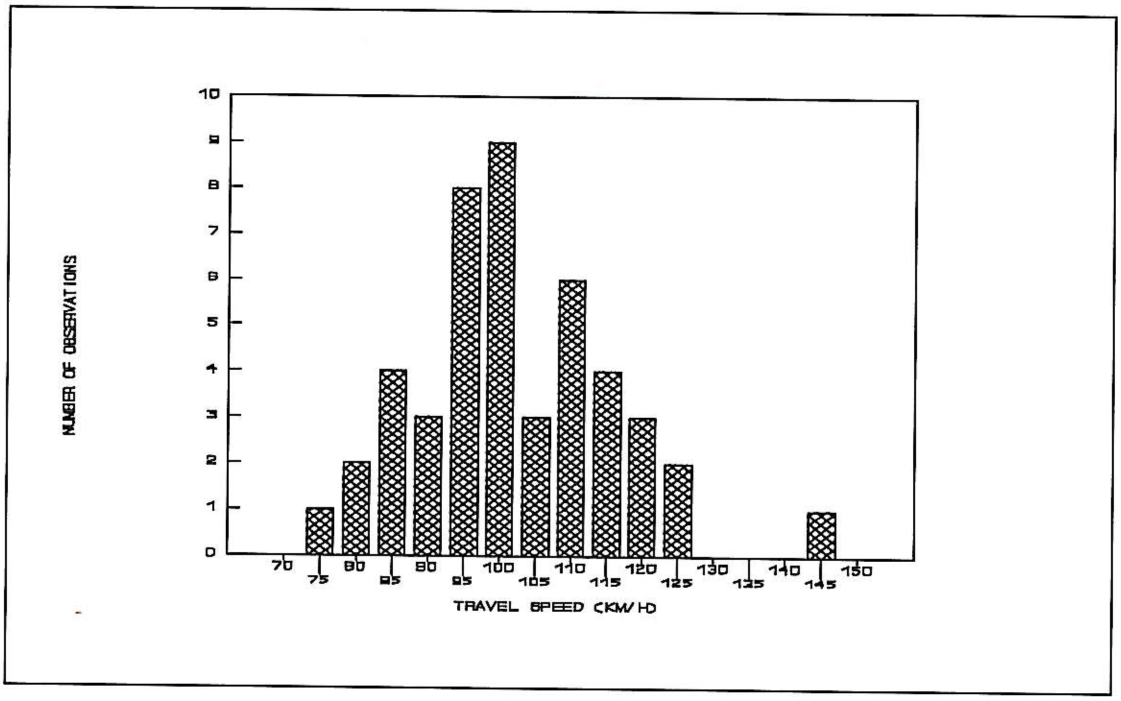


FIGURE B.13.2: LDVs

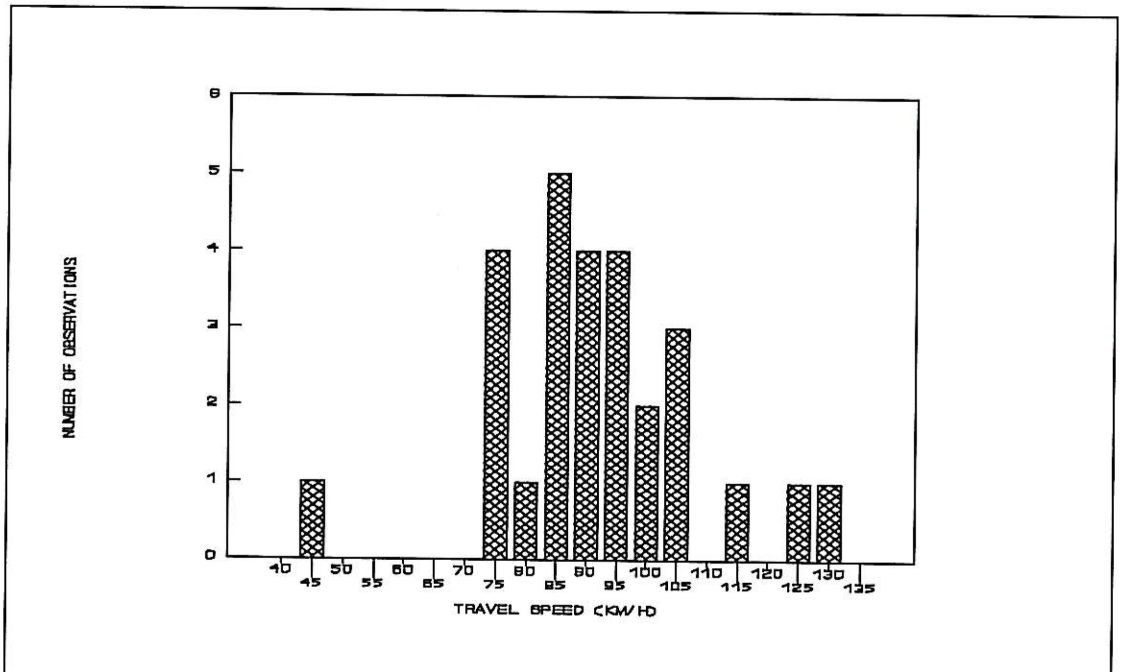


FIGURE B.13.3: MINI-BUSES

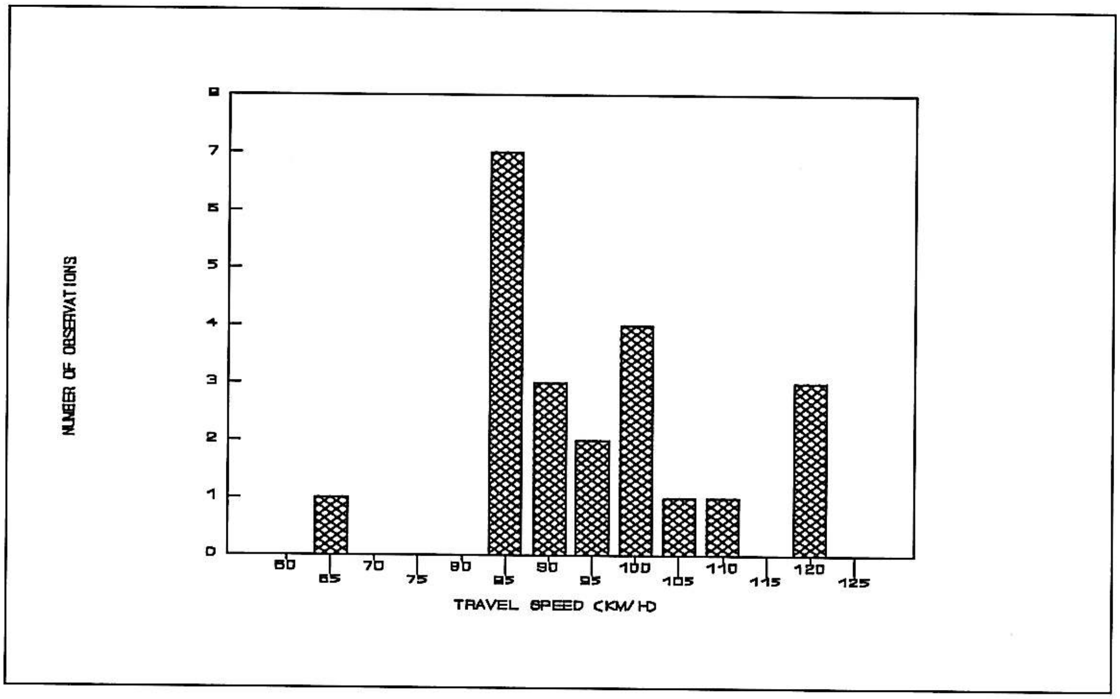


FIGURE B.13.4: MGVs

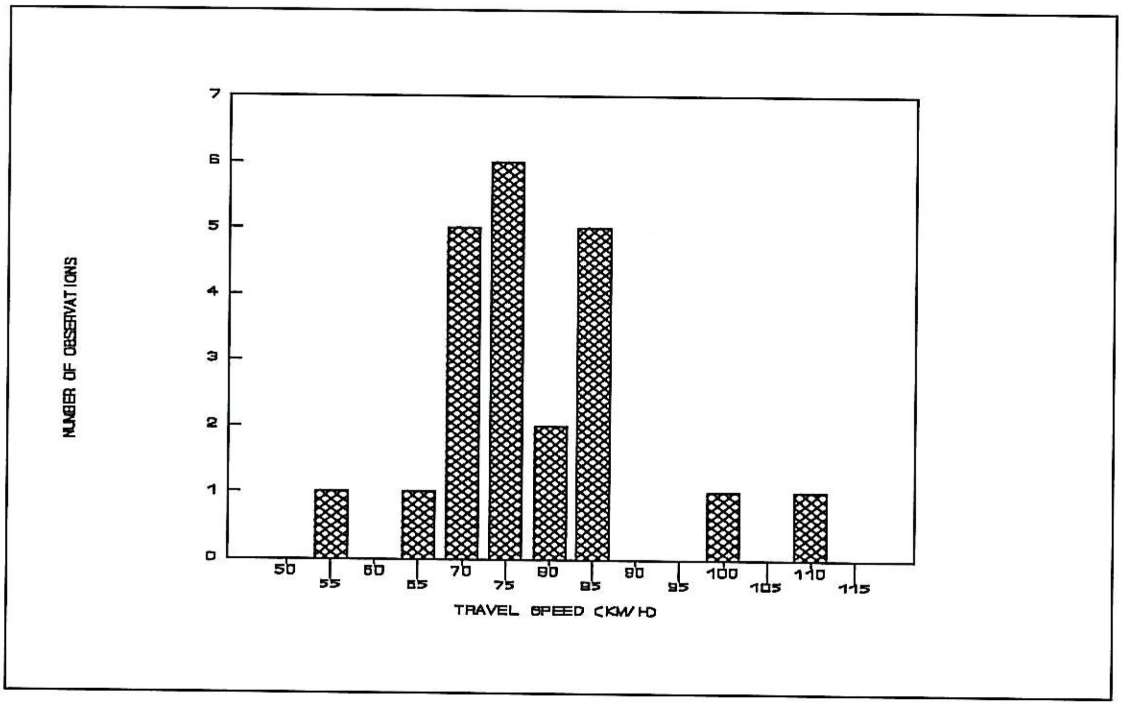
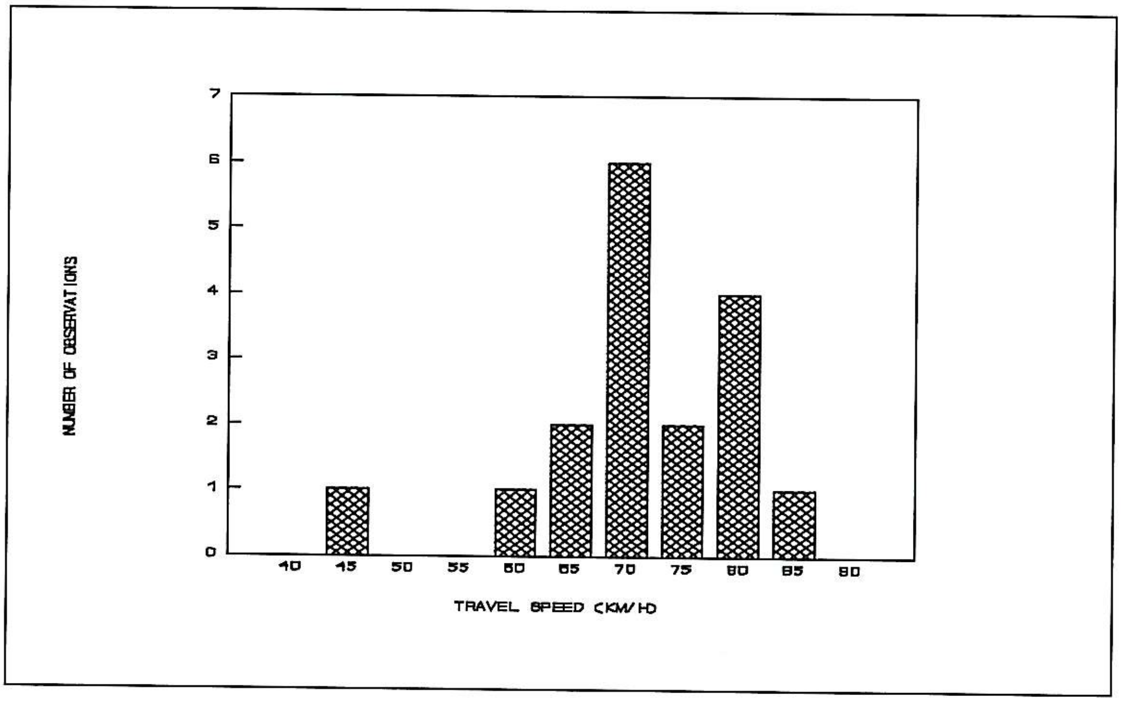


FIGURE B.13.5: HGVs



APPENDIX B.14: N17-2(W)

FIGURE B.14.1: CARS

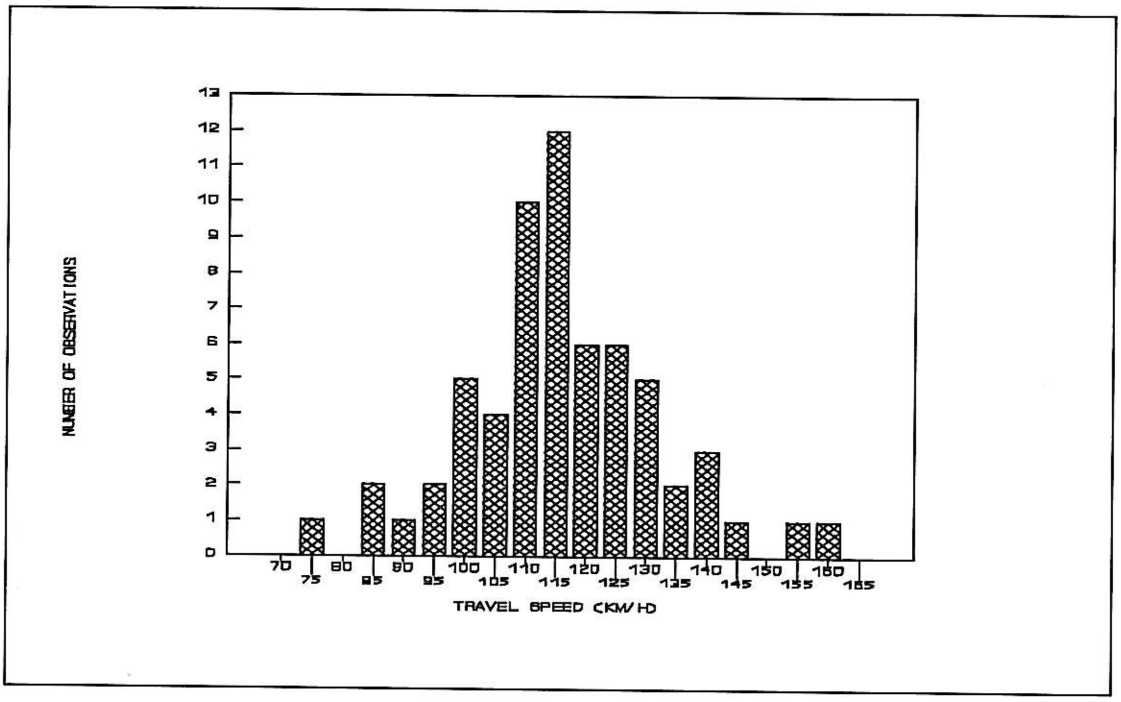


FIGURE B.14.2: LDVs

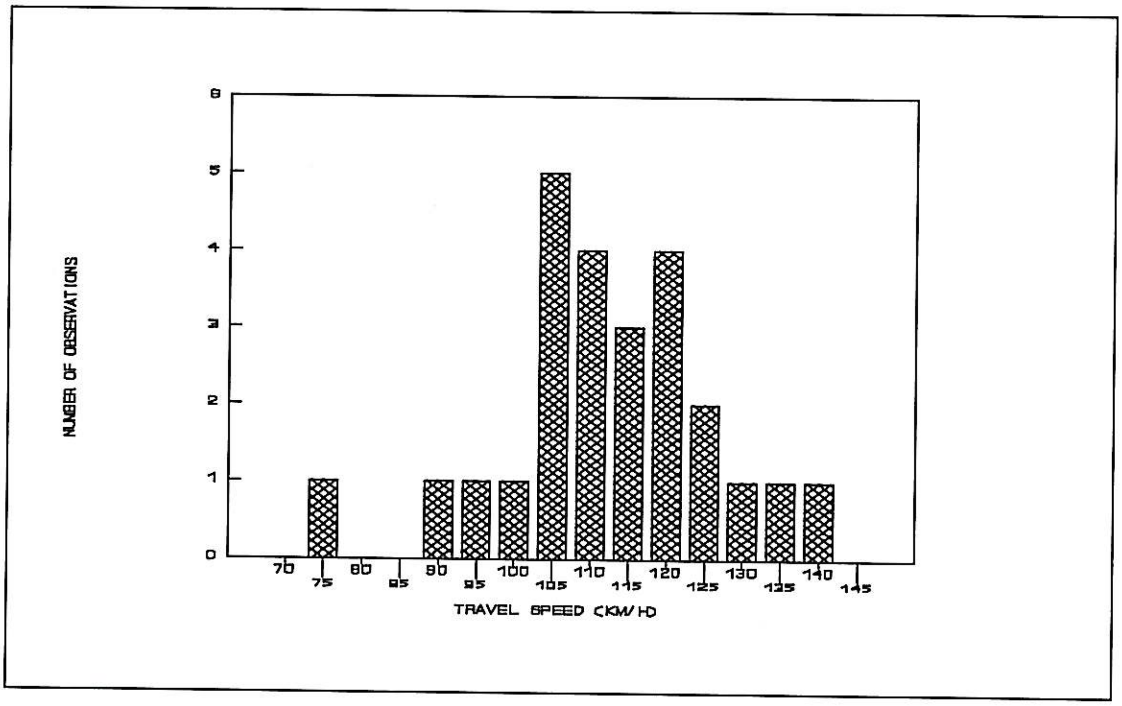


FIGURE B.14.3: MINI-BUSES

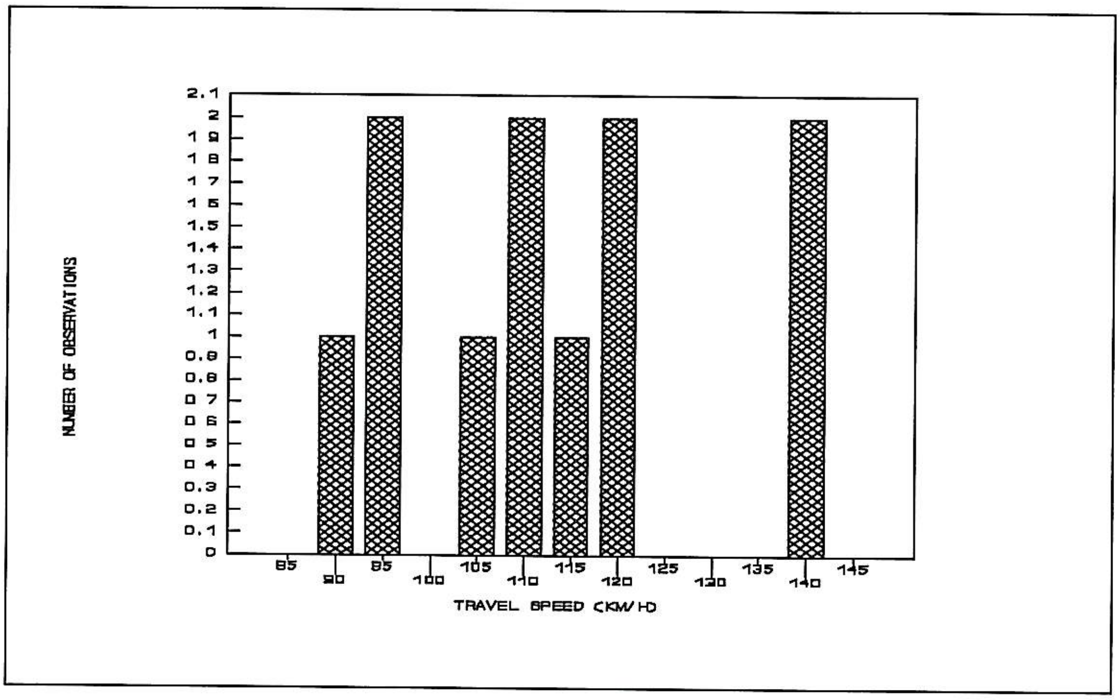


FIGURE B.14.4: BUSES

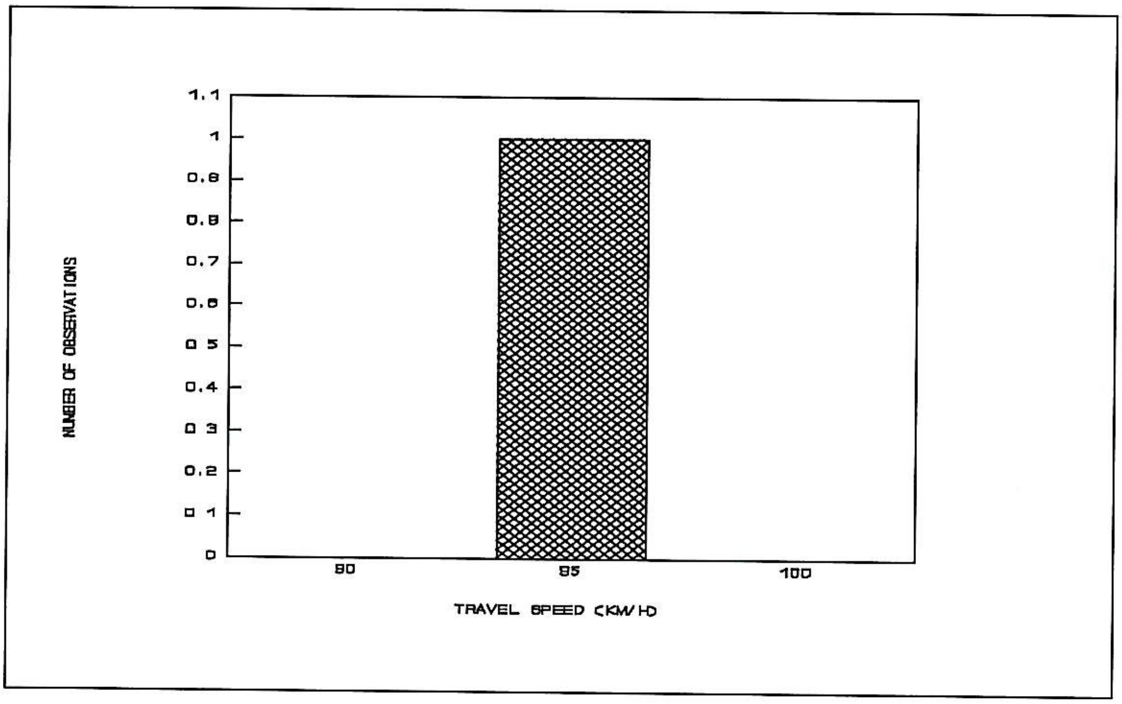


FIGURE B.14.5: MGVs

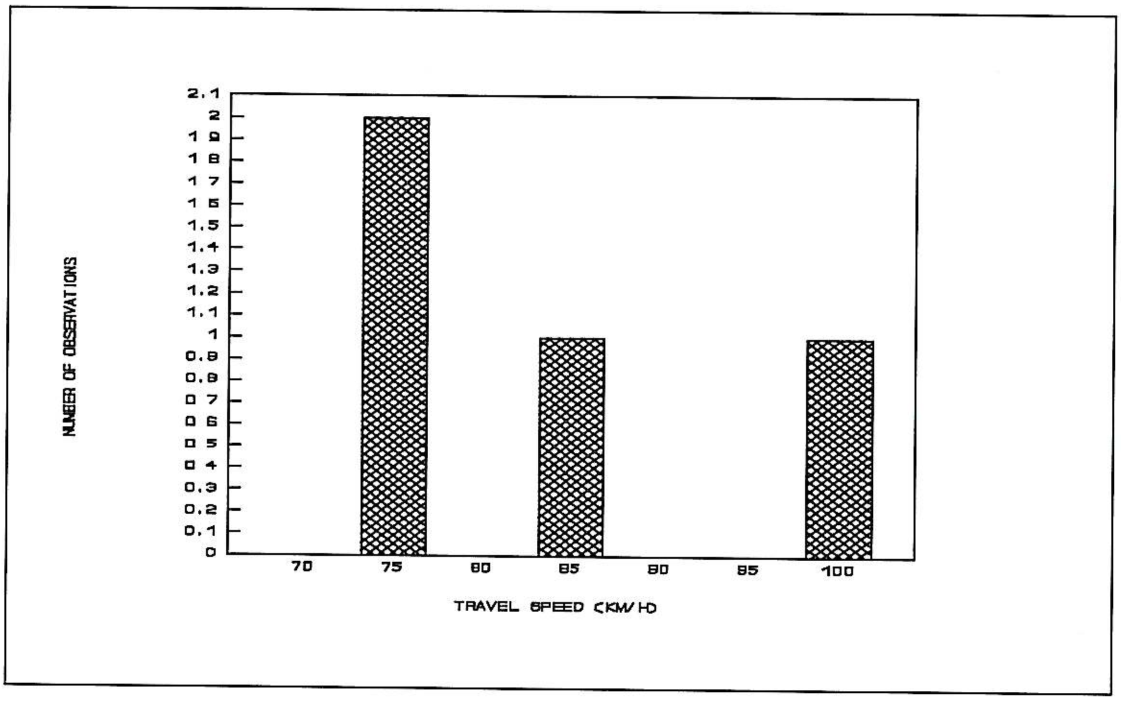
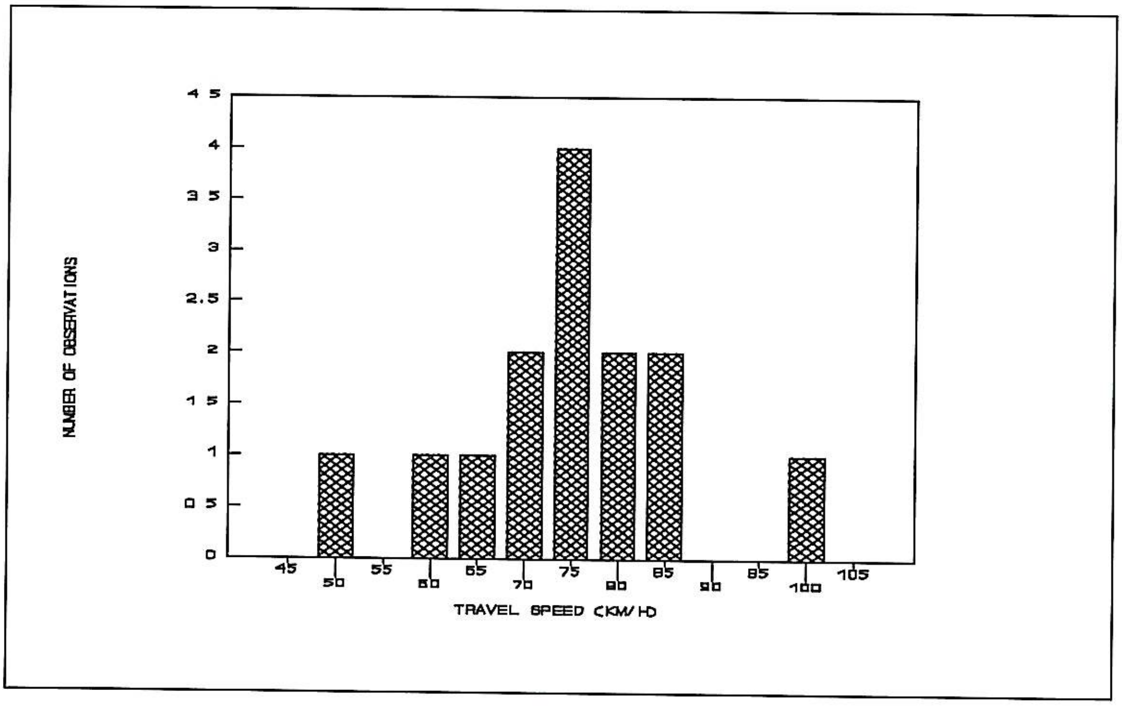


FIGURE B.14.6: HGVs



APPENDIX B.15: N17-2(E)

FIGURE B.15.1: CARS

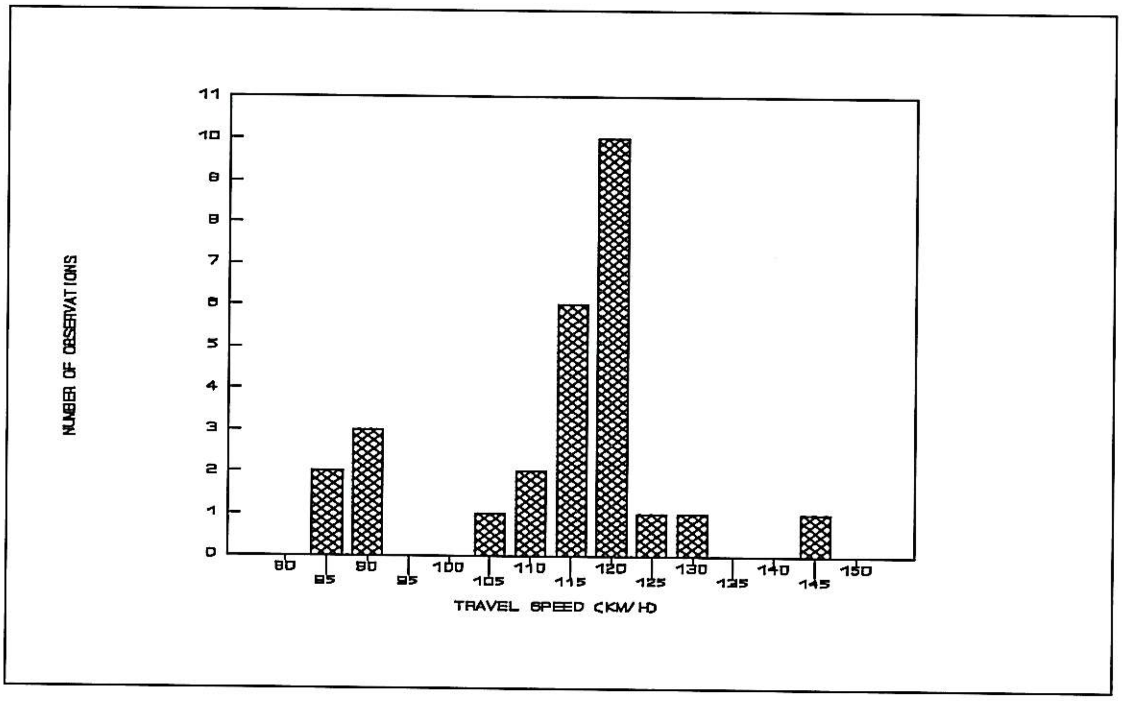


FIGURE B.15.2: LDVs

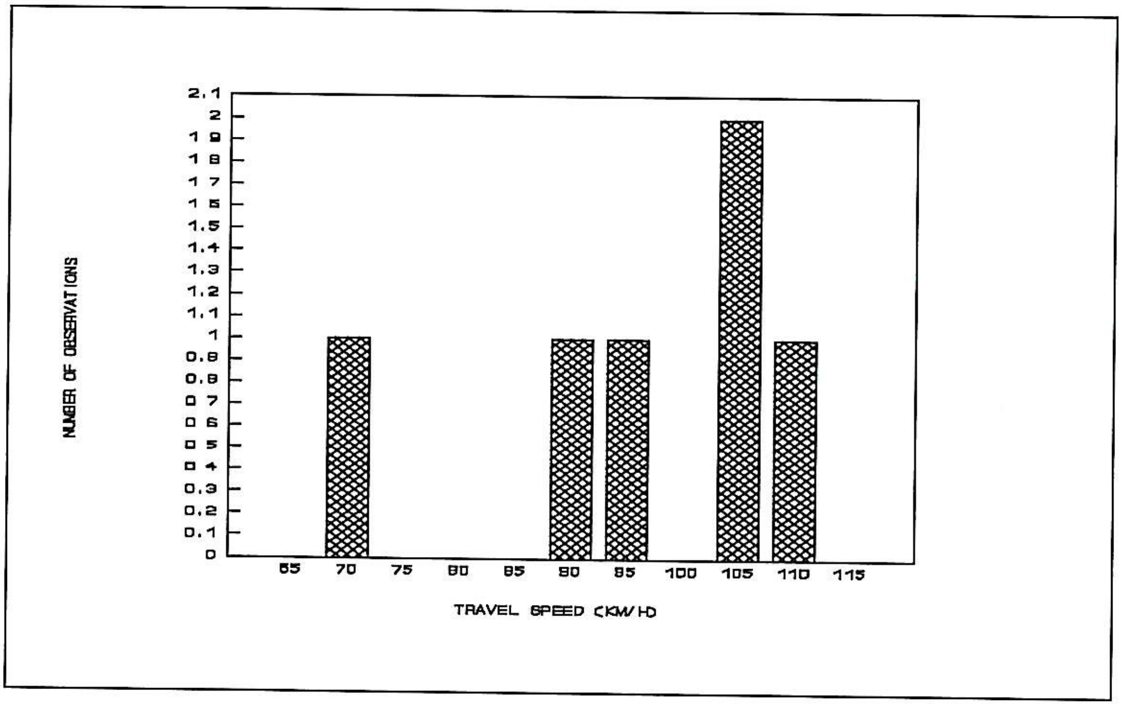


FIGURE B.15.3: MINI-BUSES

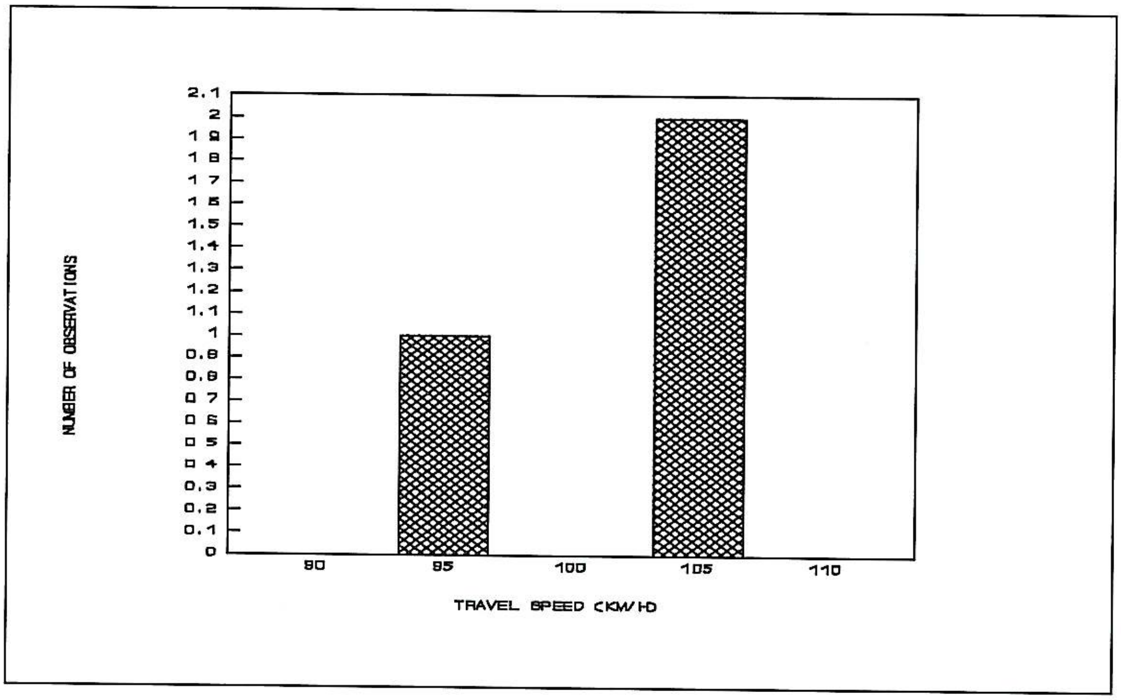


FIGURE B.15.4: MGVs

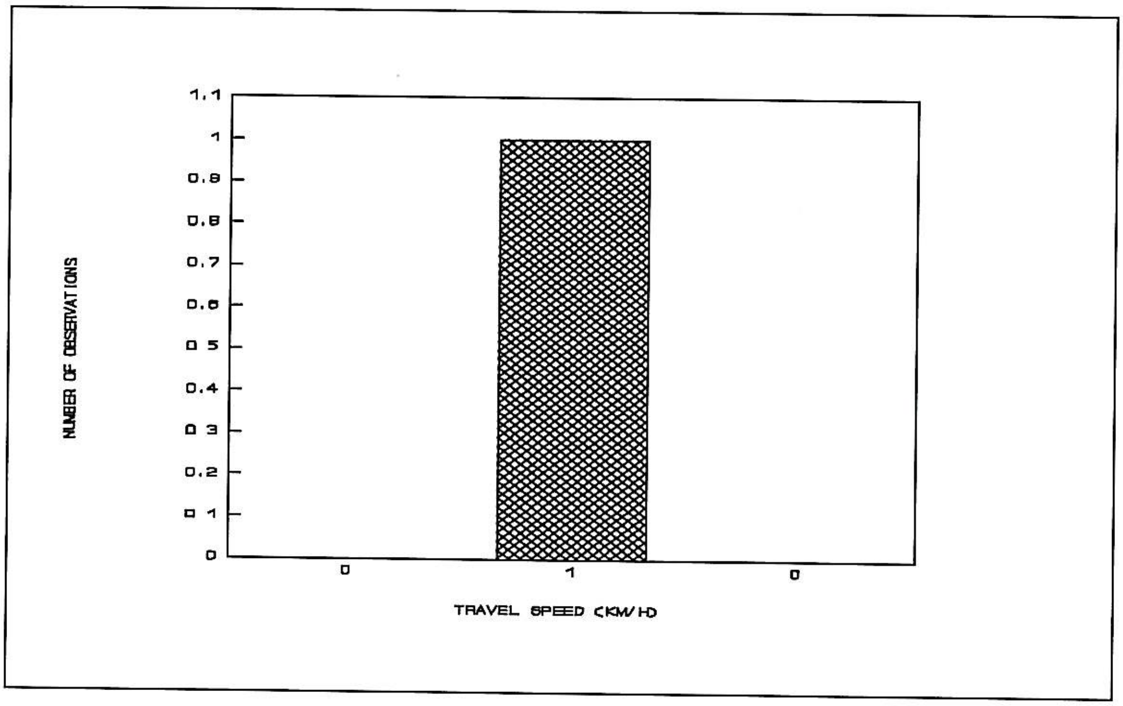
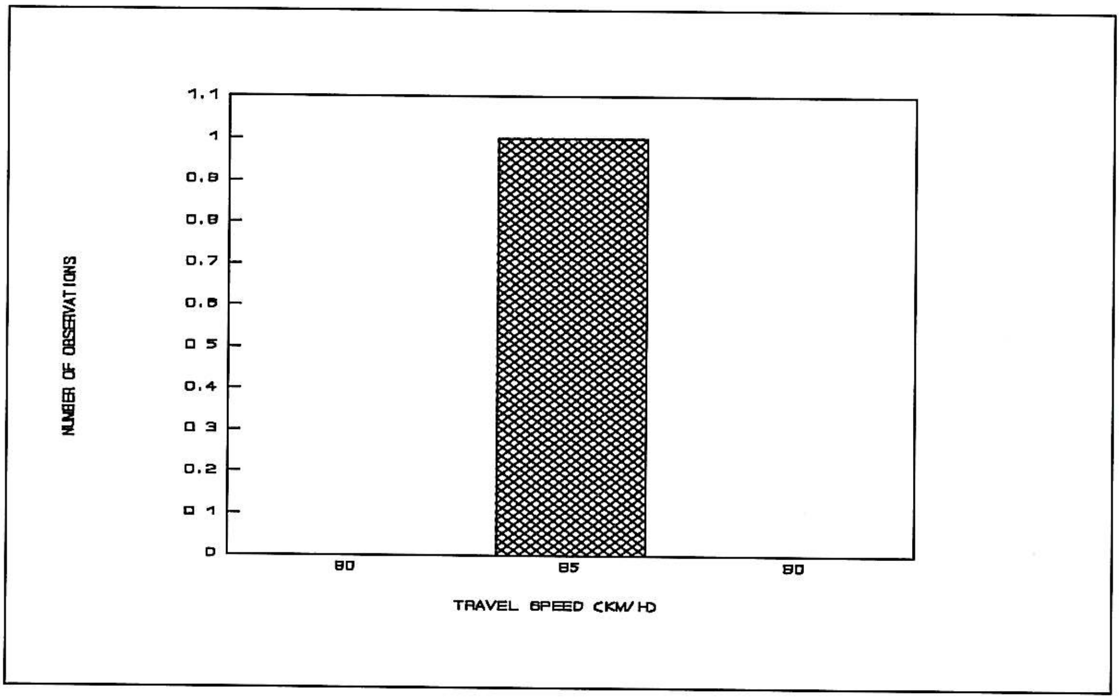


FIGURE B.15.5: HGVs



APPENDIX B.16: P35(N)

FIGURE B.16.1: CARS

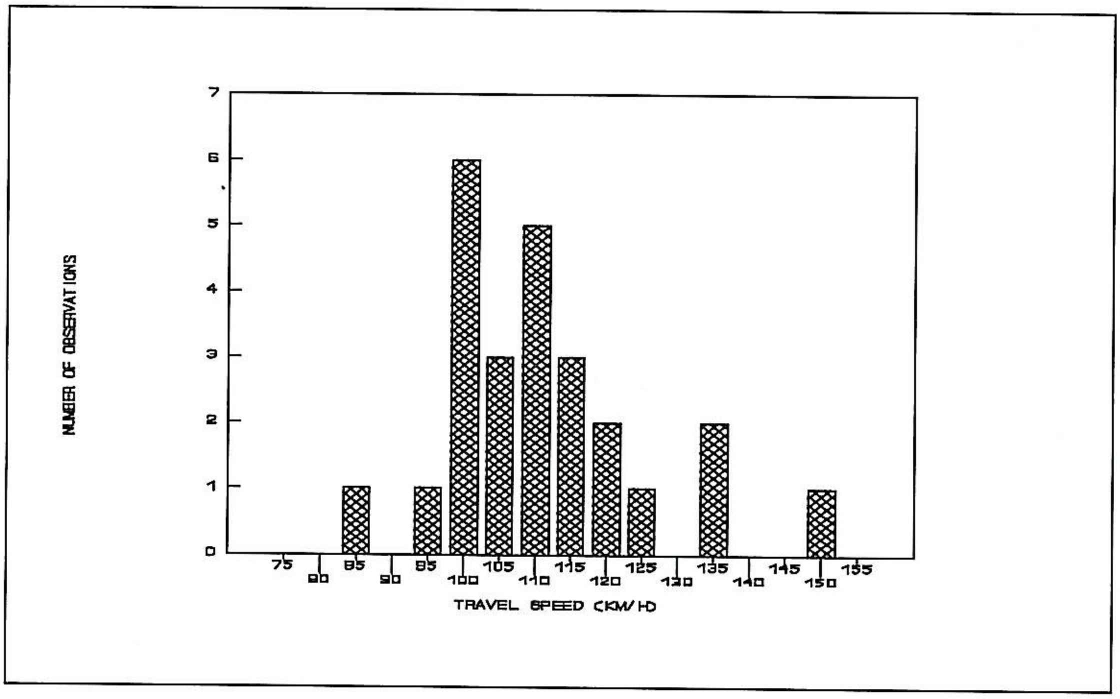


FIGURE B.16.2: LDVs

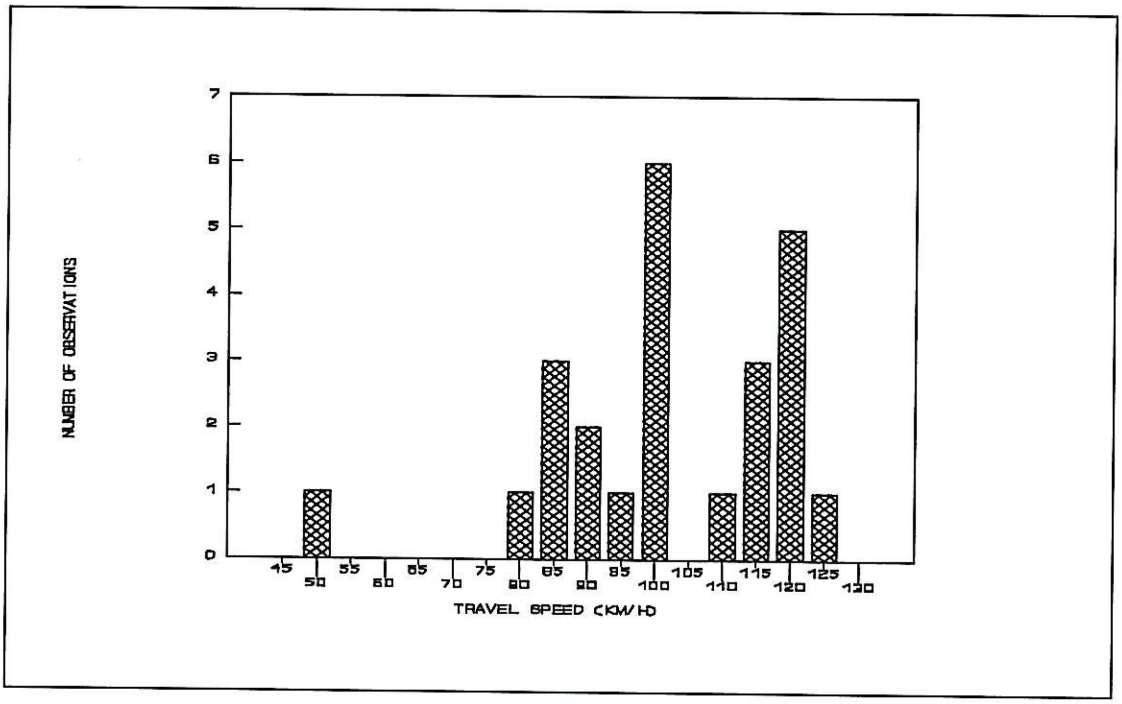


FIGURE B.16.3: MINI-BUSES

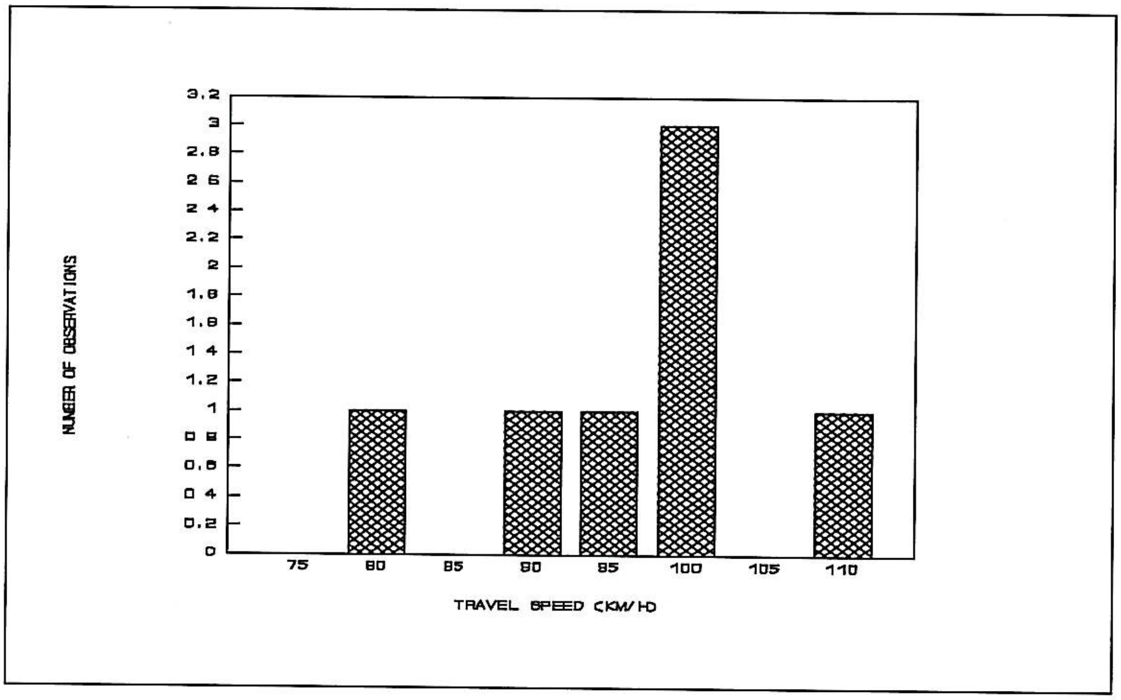


FIGURE B.16.4: MGVs

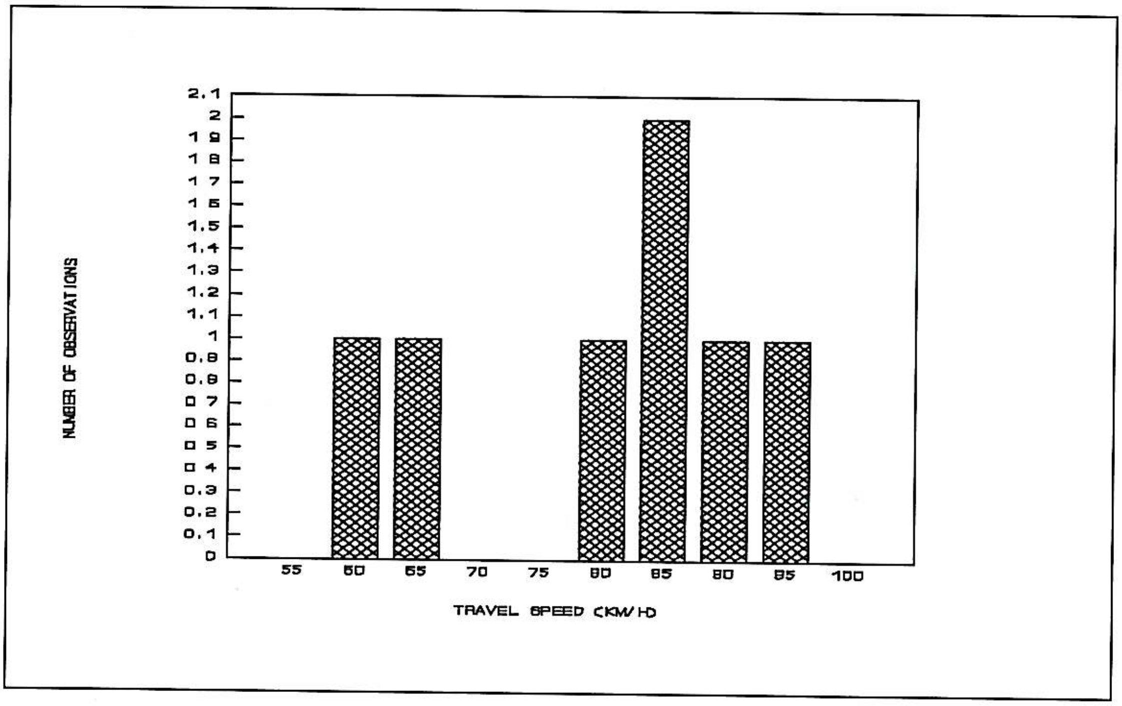
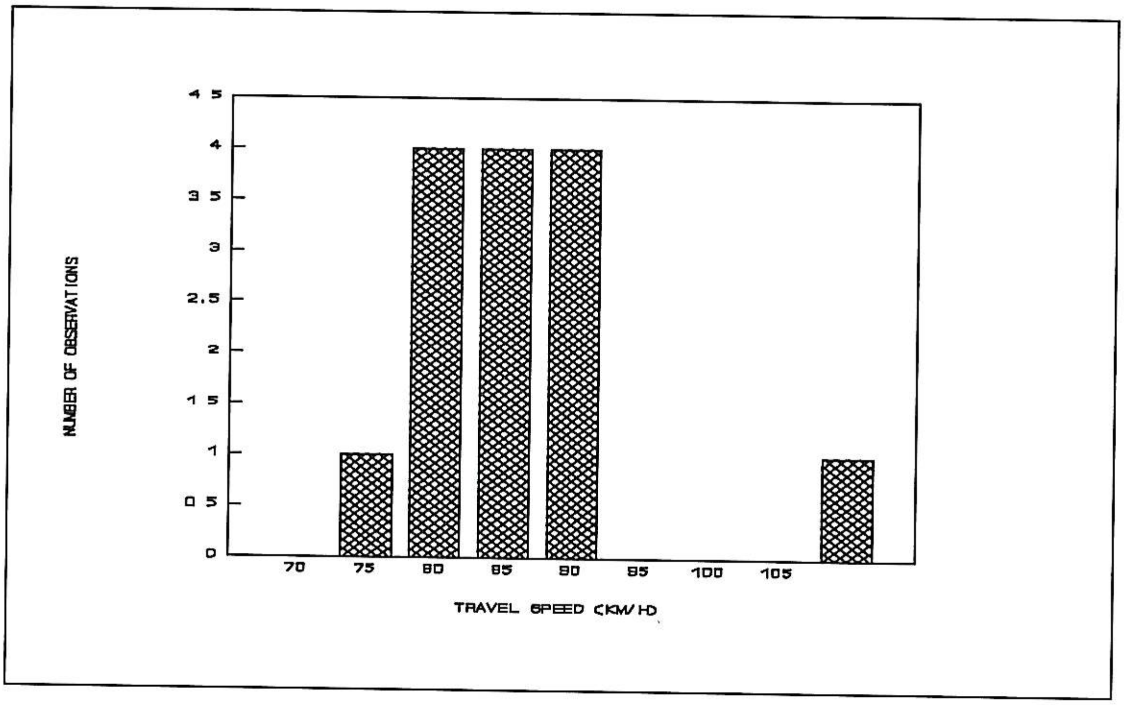


FIGURE B.16.5: HGVs



APPENDIX B.17: P35(S)

FIGURE B.17.1: CARS

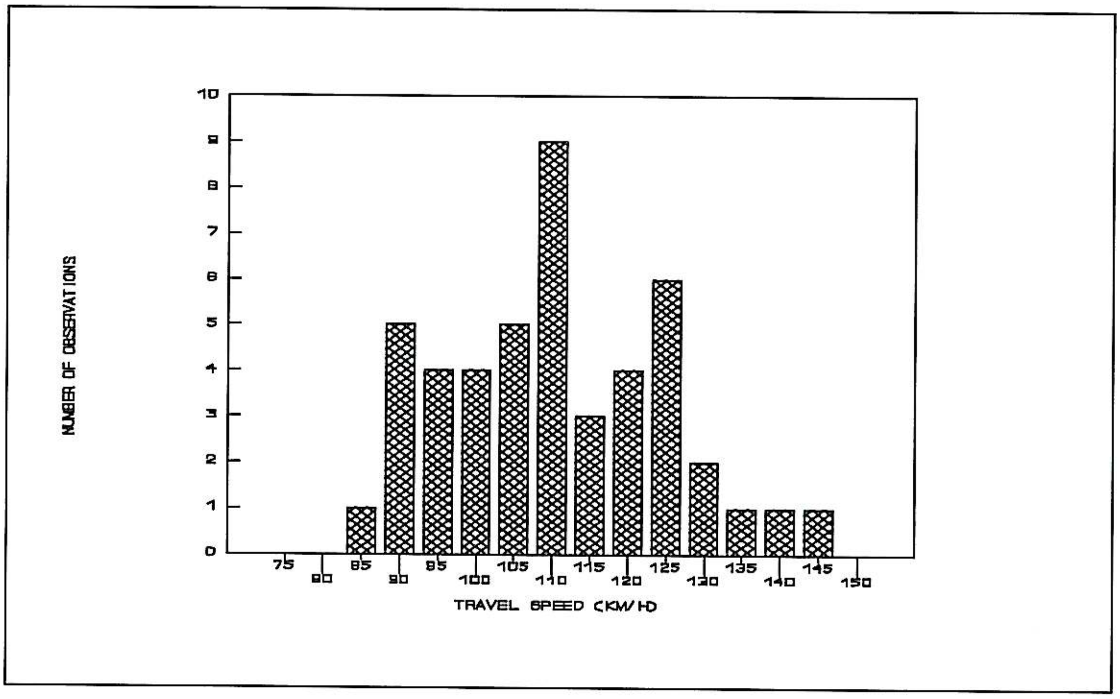


FIGURE B.17.2: LDVs

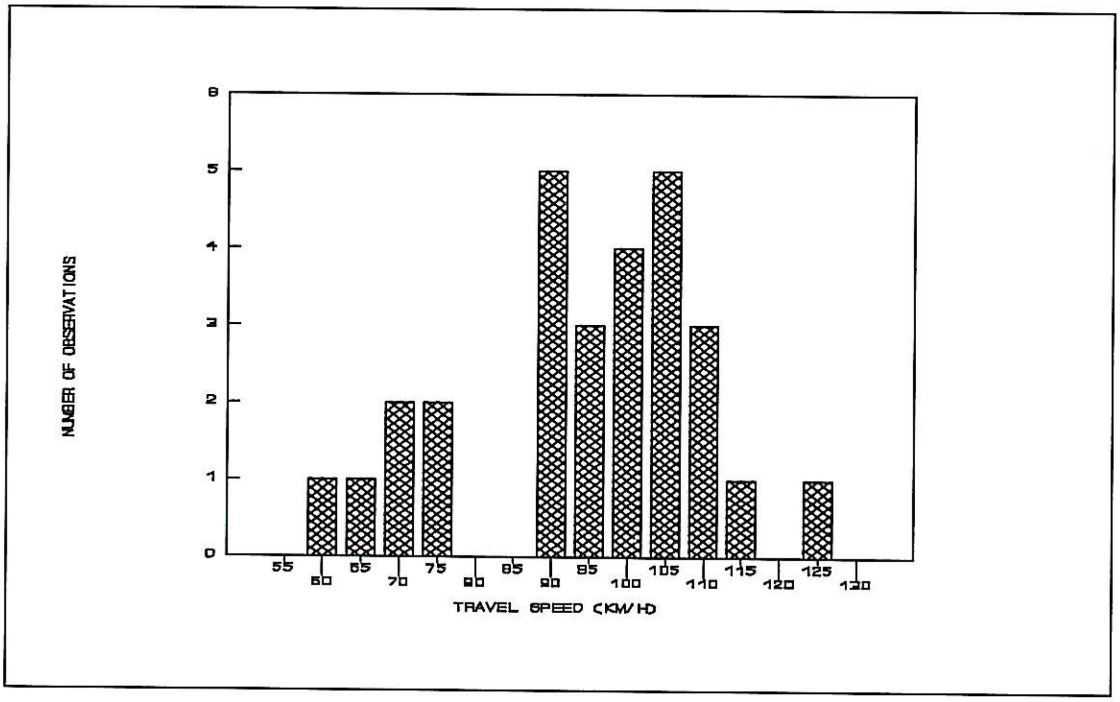


FIGURE B.17.3: MINI-BUSES

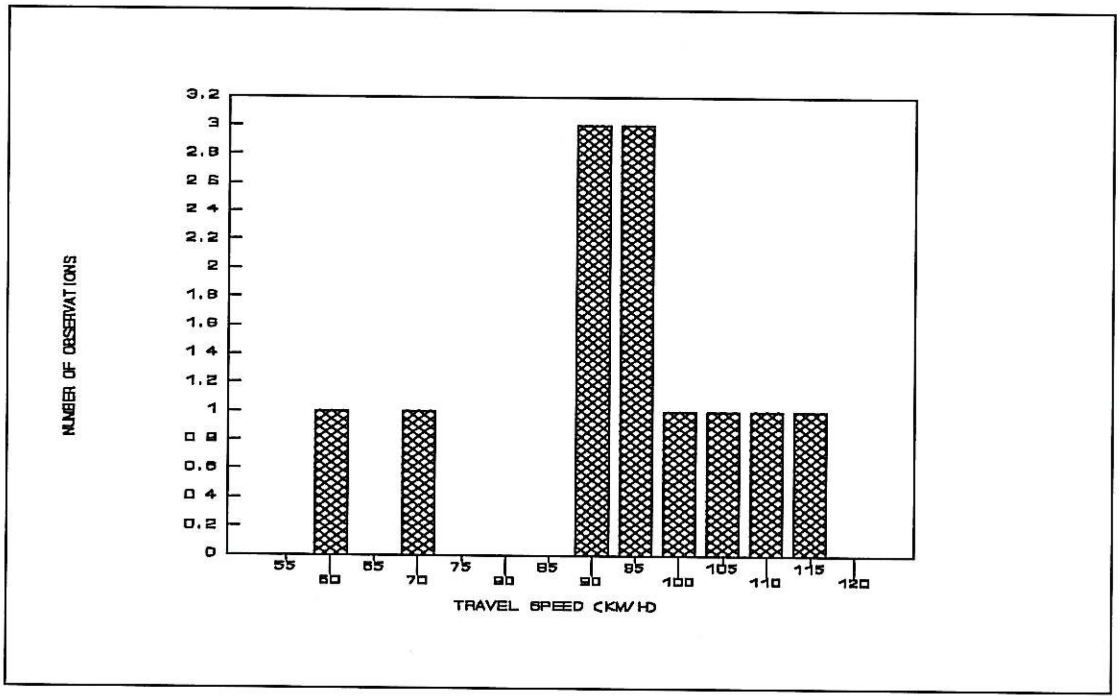


FIGURE B.17.4: MGVs

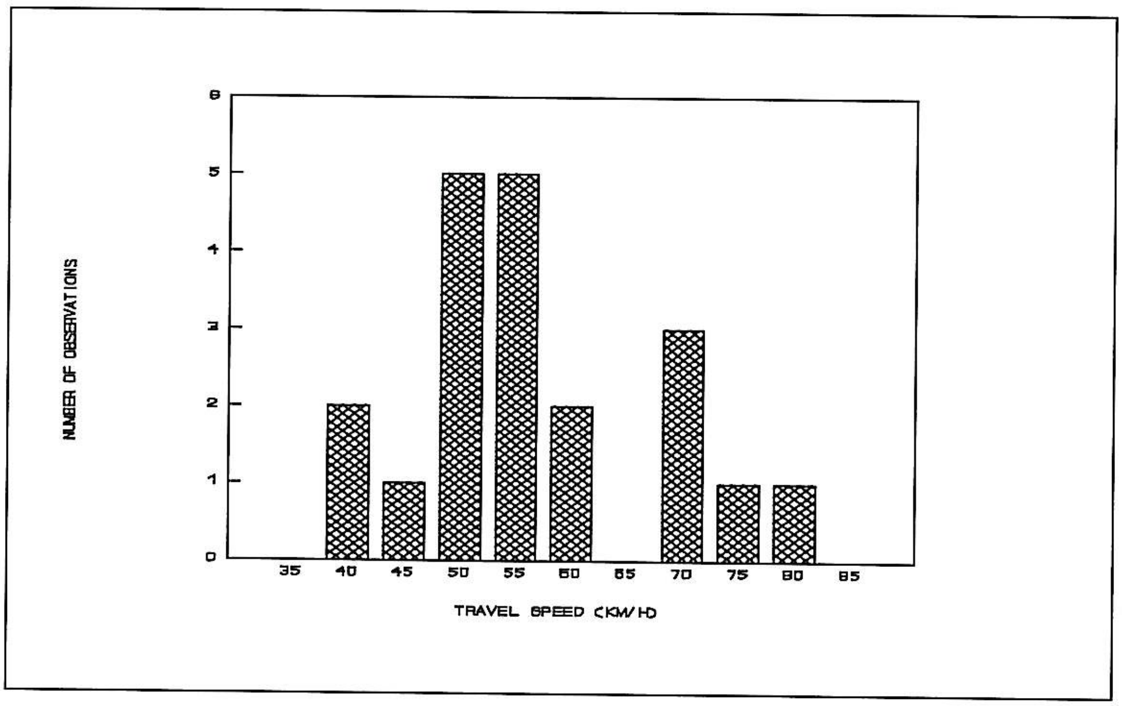
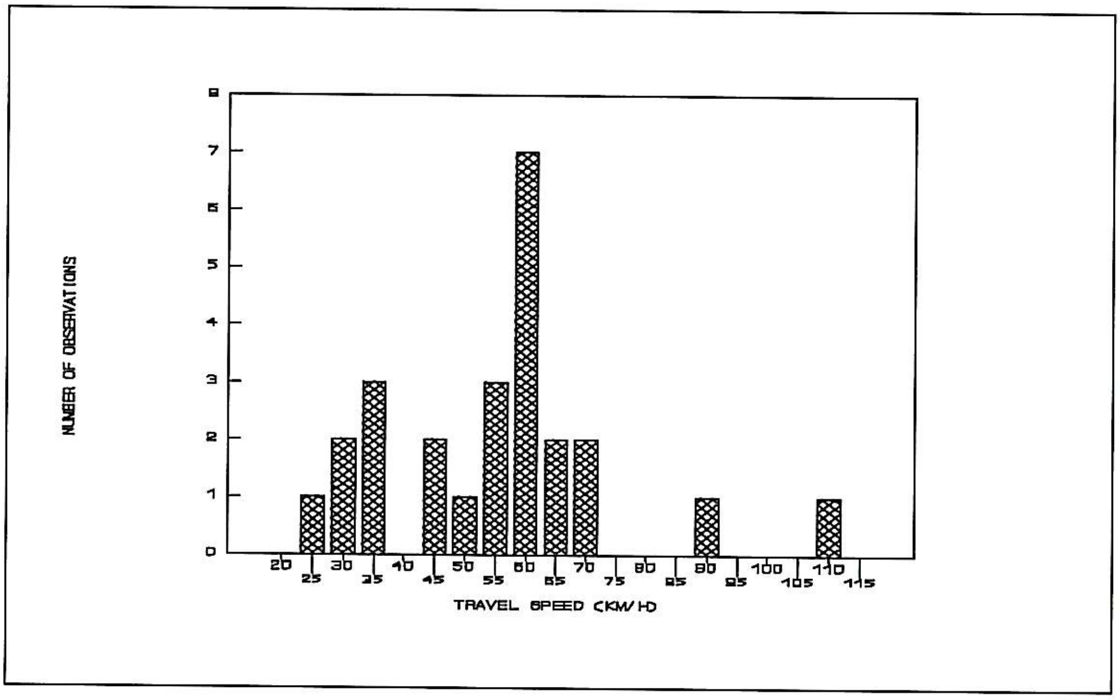


FIGURE B.17.5: HGVs



APPENDIX B.18: P30(N)

FIGURE B.18.1: CARS

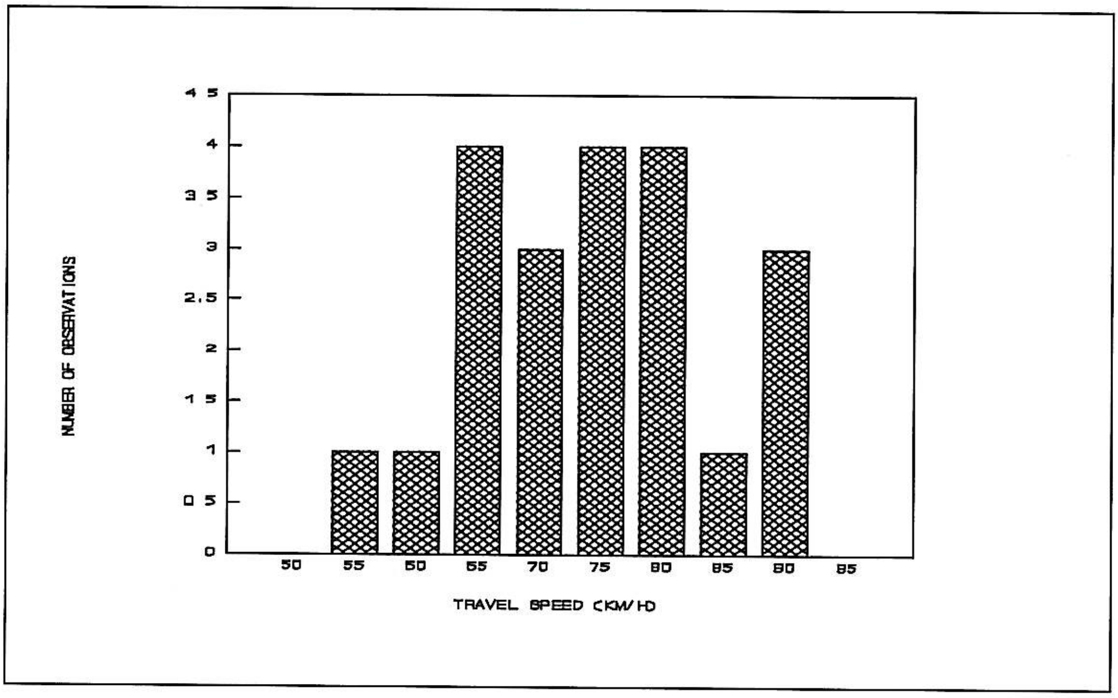


FIGURE B.18.2: LDVs

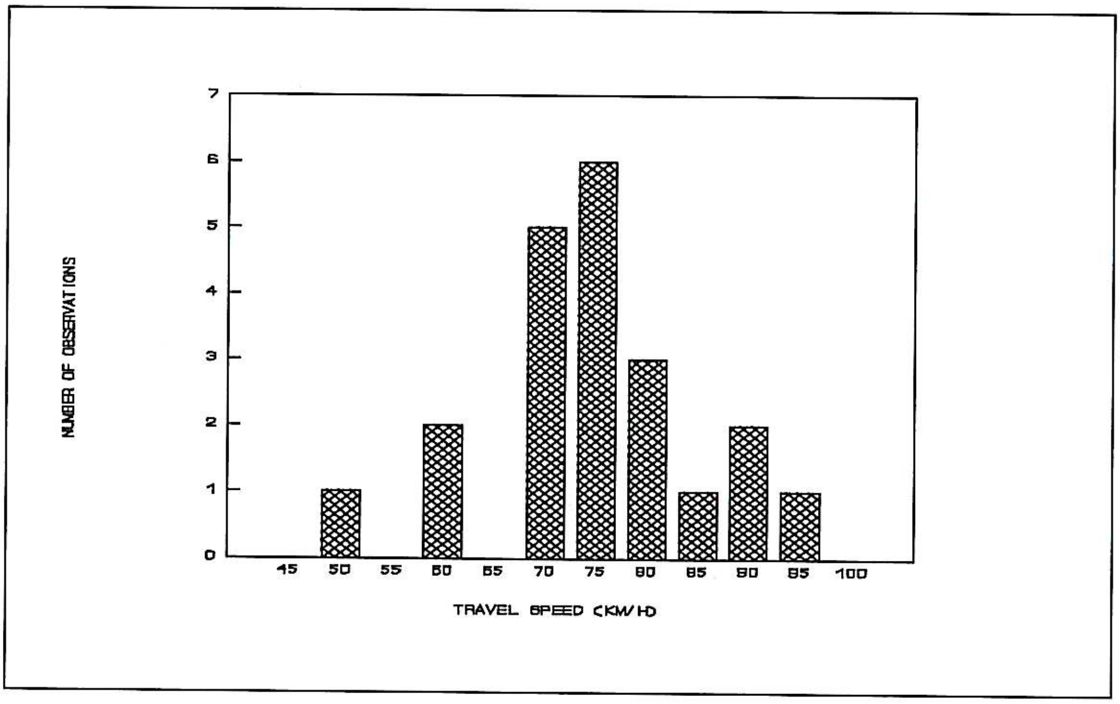


FIGURE B.18.3: MINI-BUSES

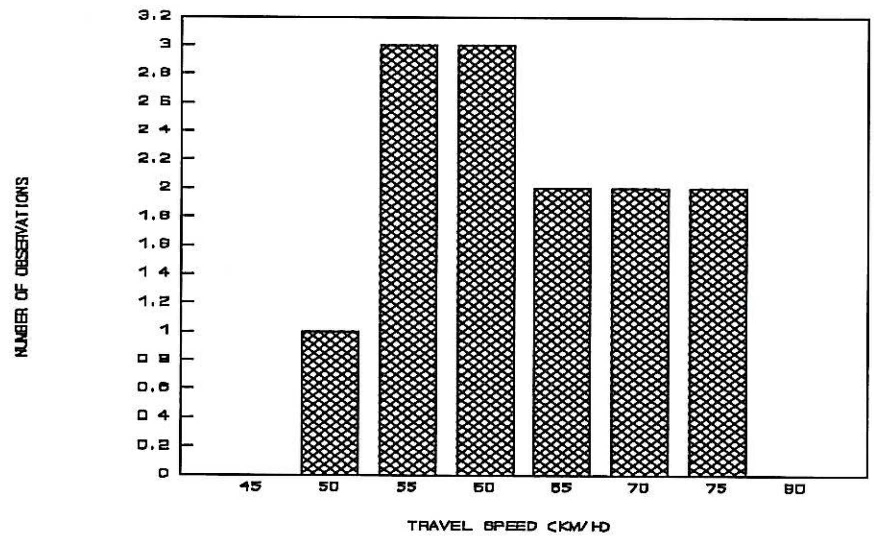


FIGURE B.18.4: BUSES

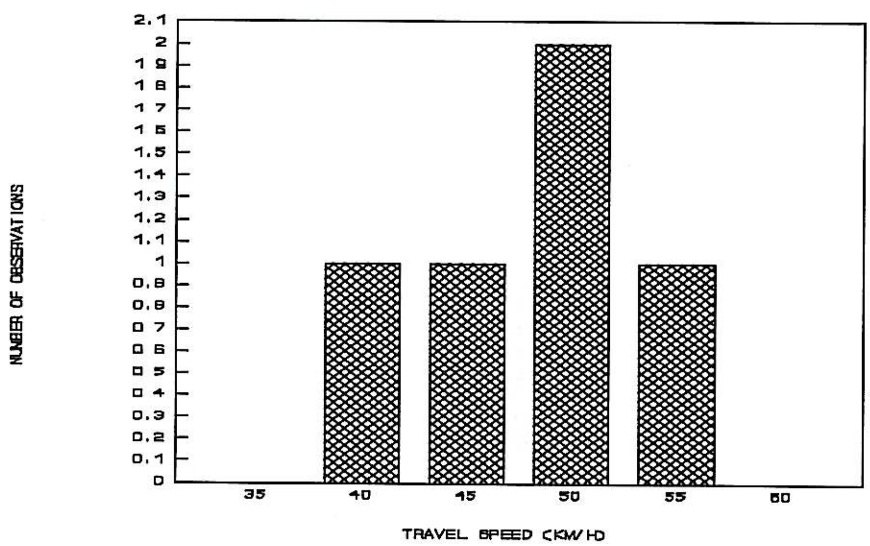


FIGURE B.18.5: MGVs

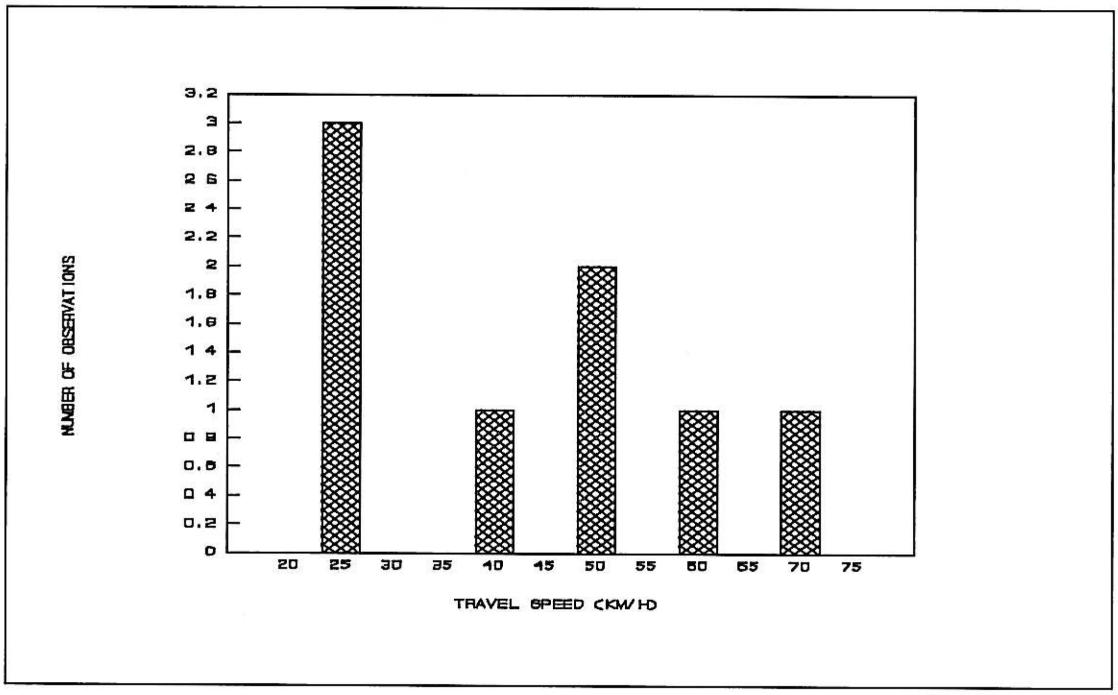
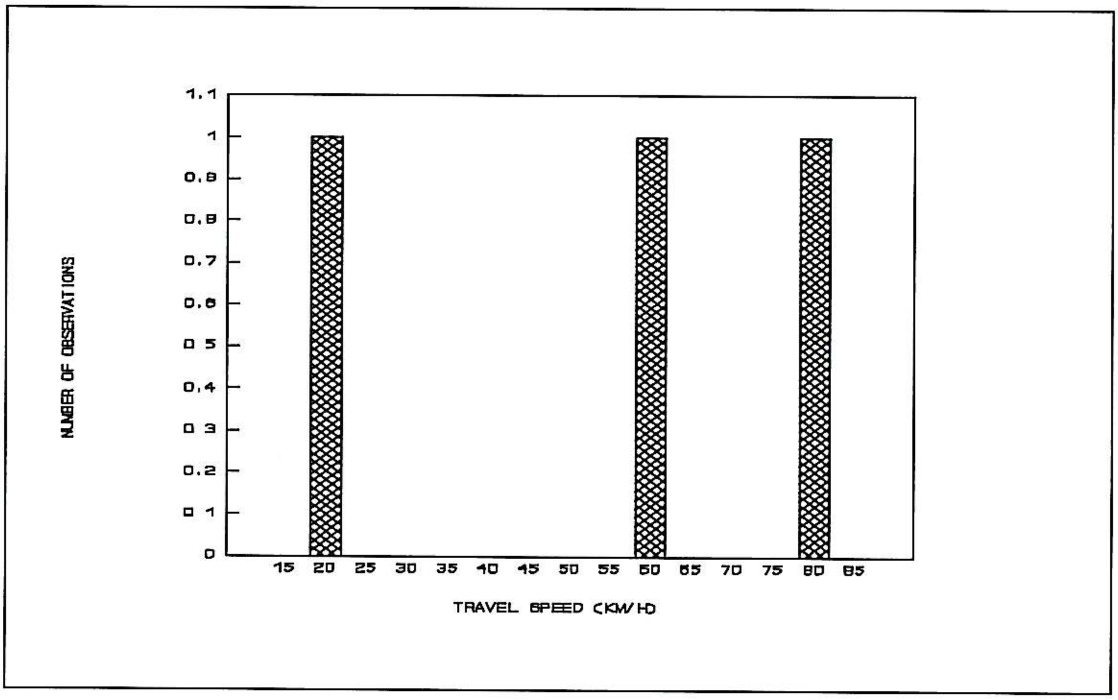


FIGURE B.18.6: HGVs



APPENDIX B.19: P30(S)

FIGURE B.19.1: CARS

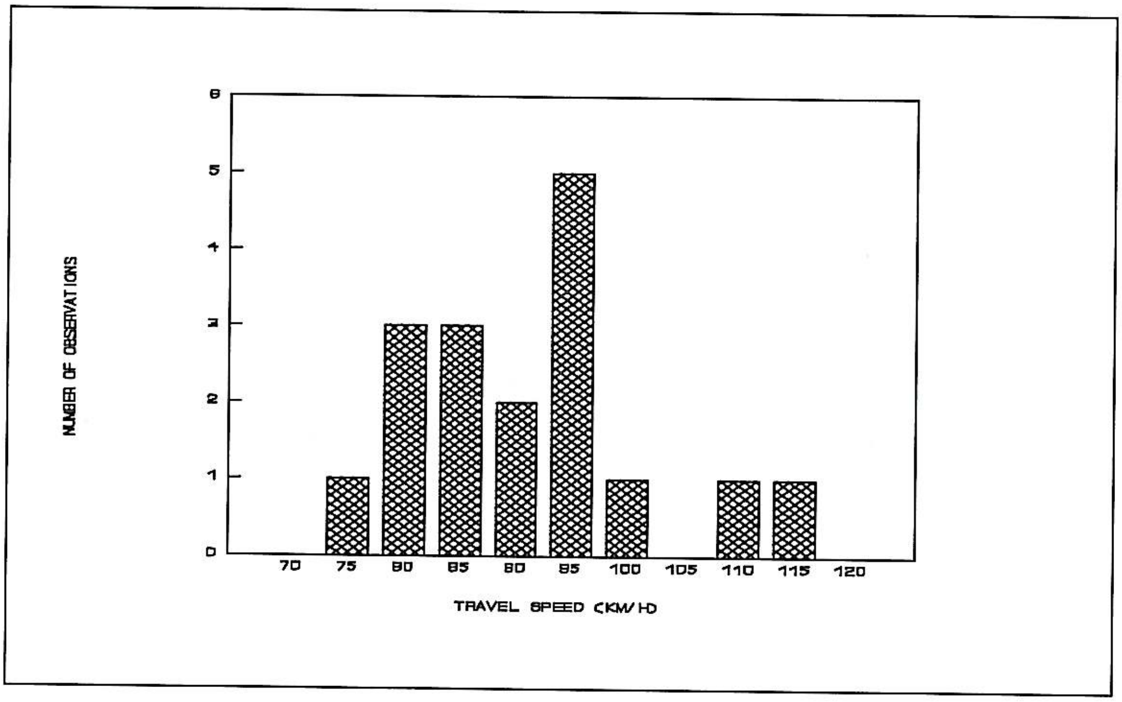


FIGURE B.19.2: LDVs

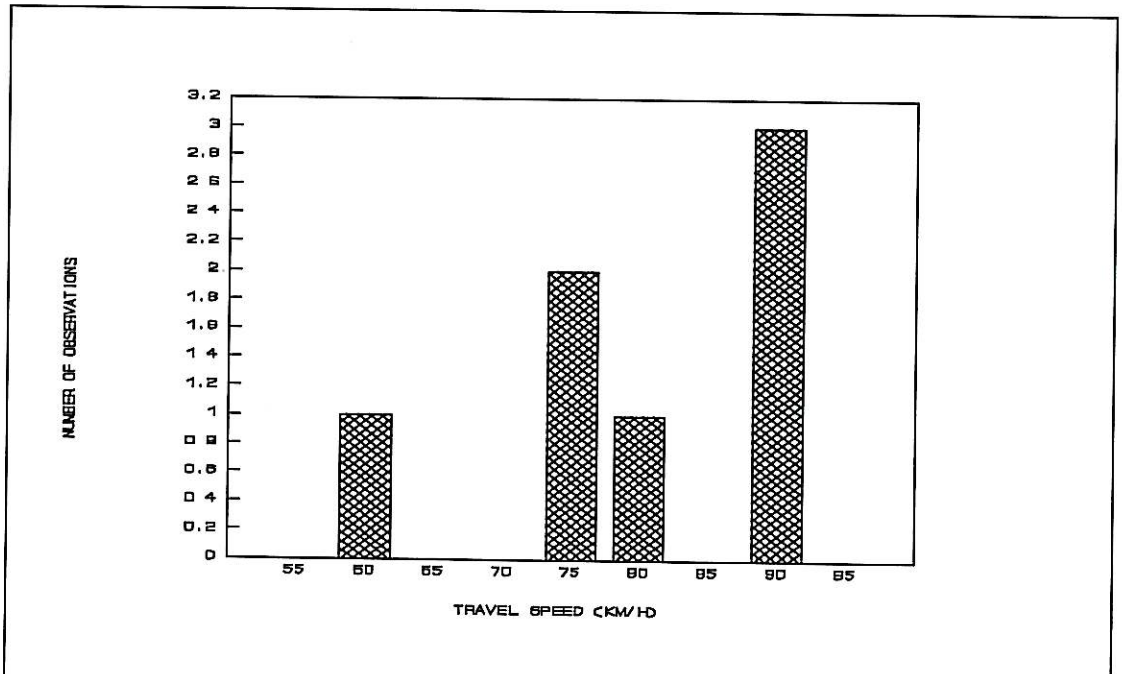


FIGURE B.19.3: MINI-BUSES

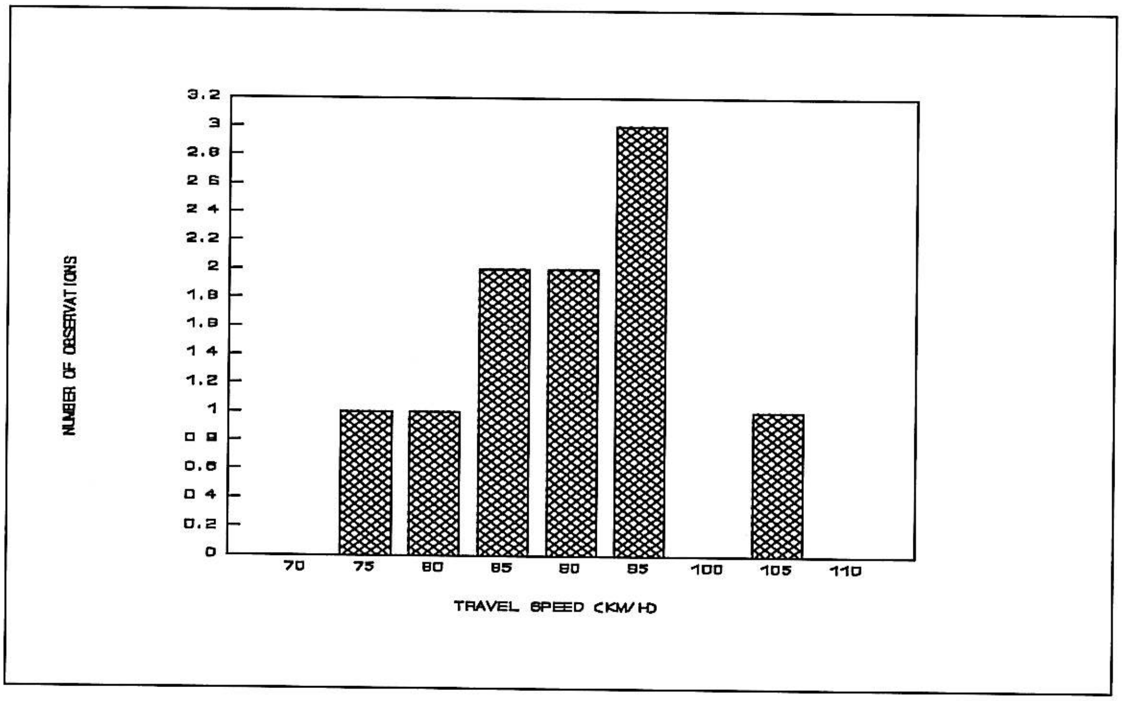


FIGURE B.19.4: MGVs

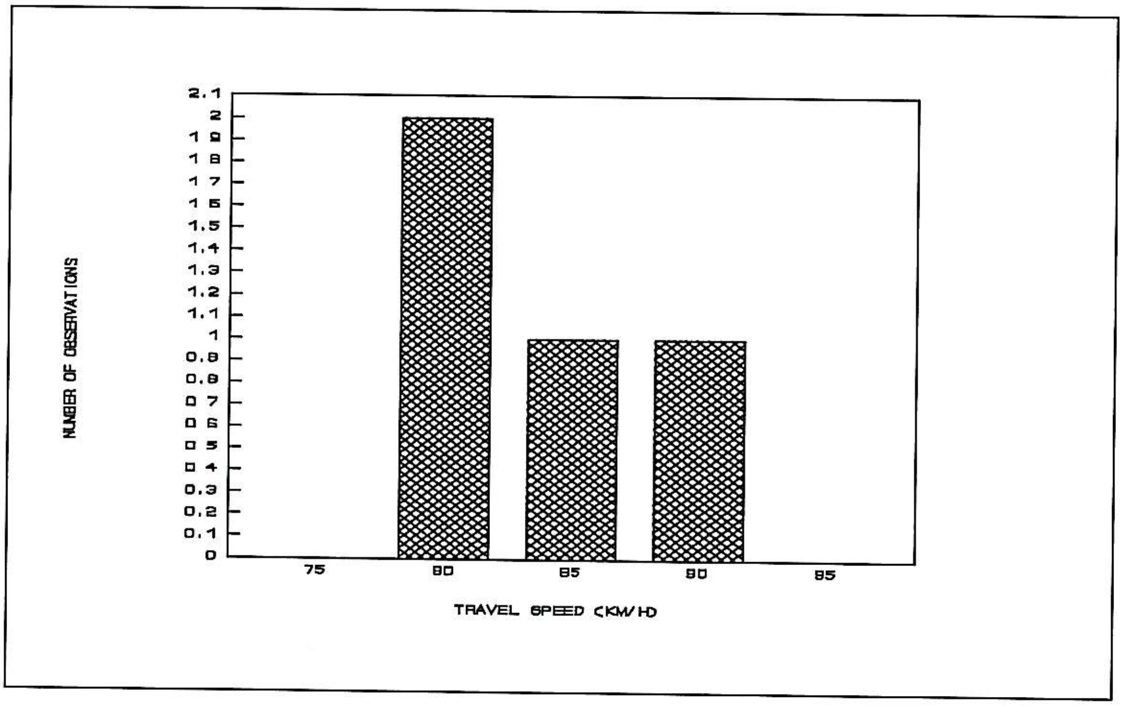
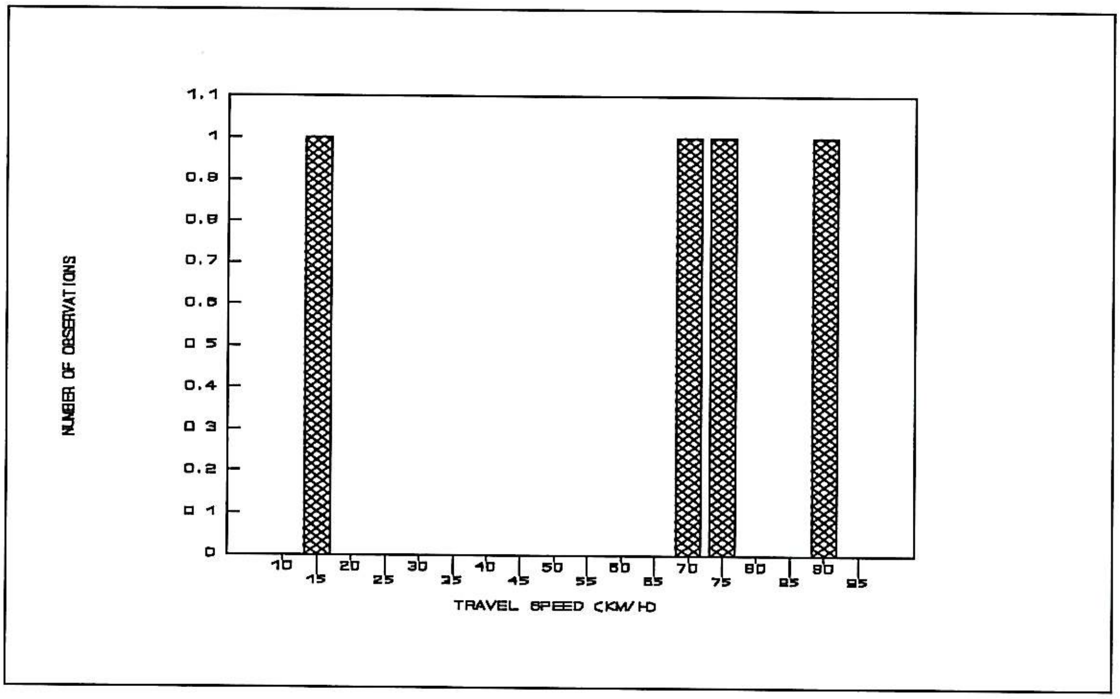


FIGURE B.19.5: HGVs



APPENDIX B.20: P122-1

FIGURE B.20.1: CARS

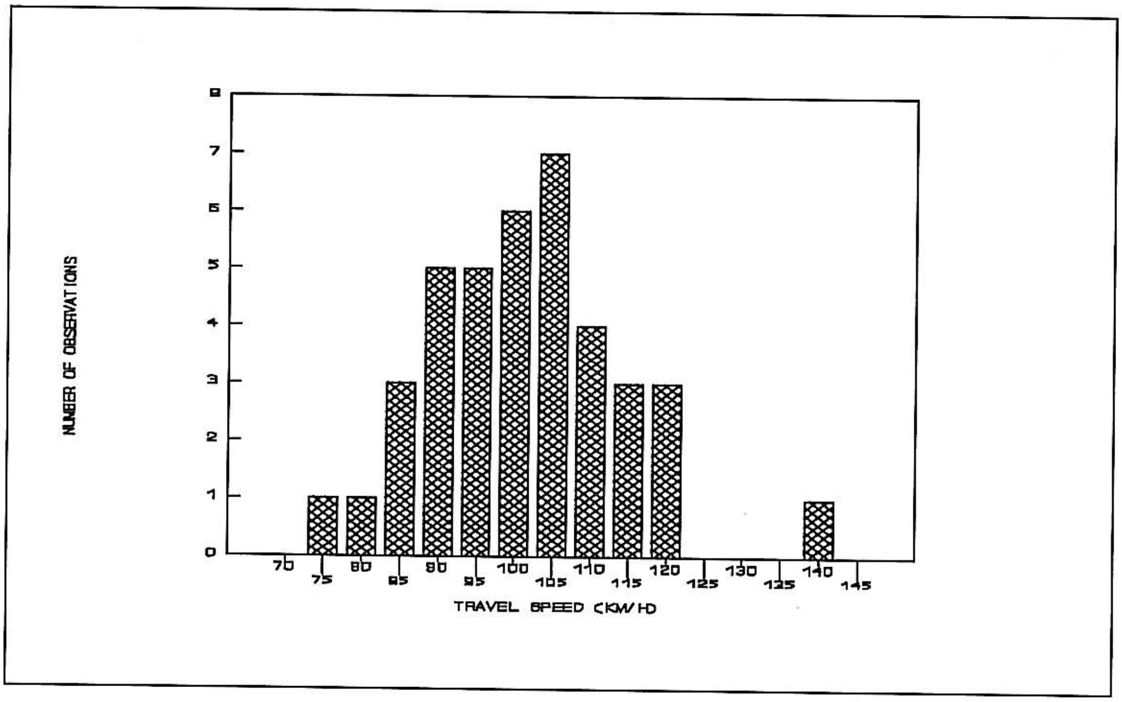


FIGURE B.20.2: LDVs

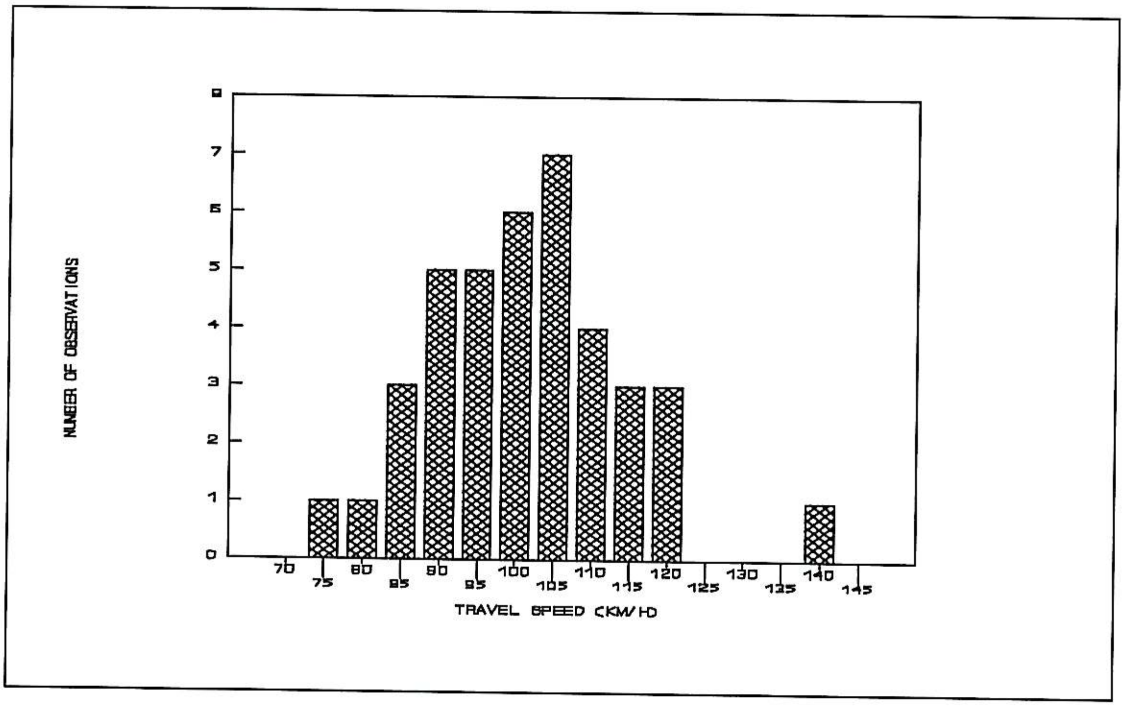


FIGURE B.20.3: MINI-BUSES

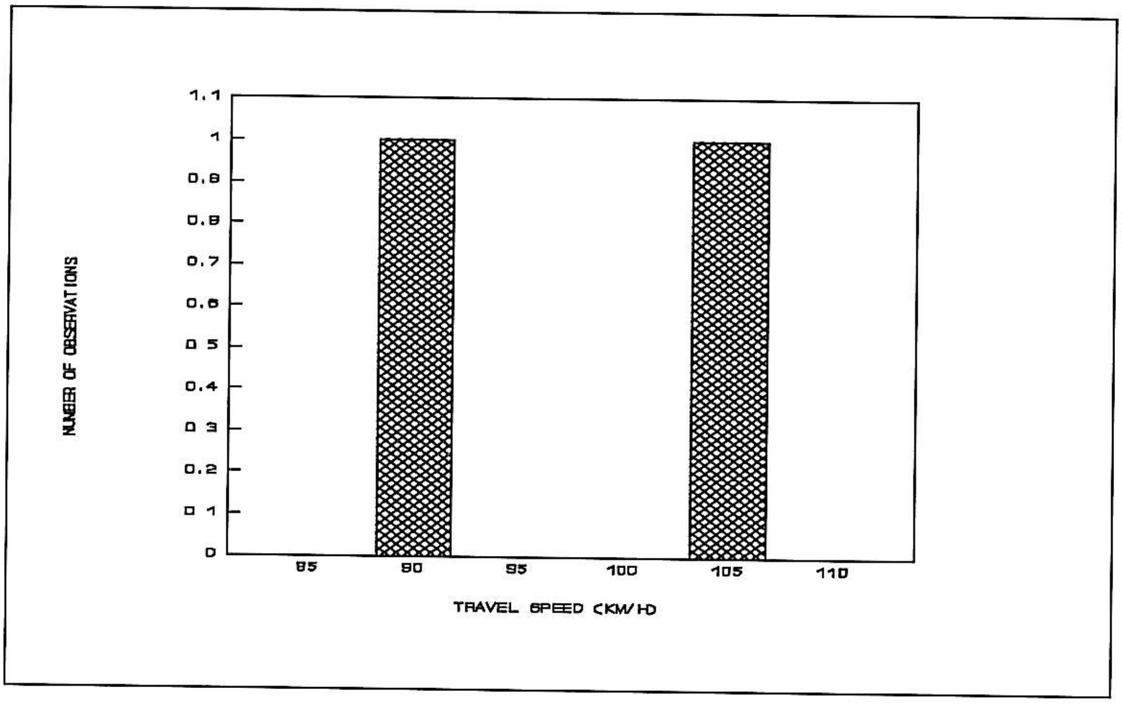


FIGURE B.20.4: MGVs

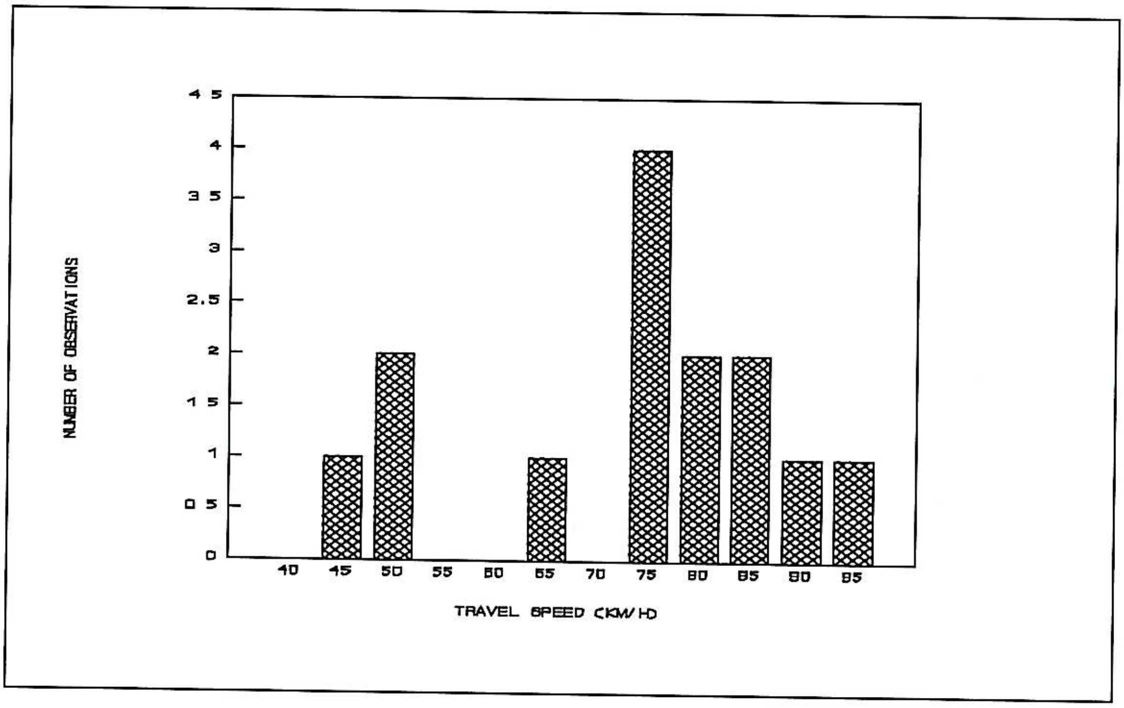
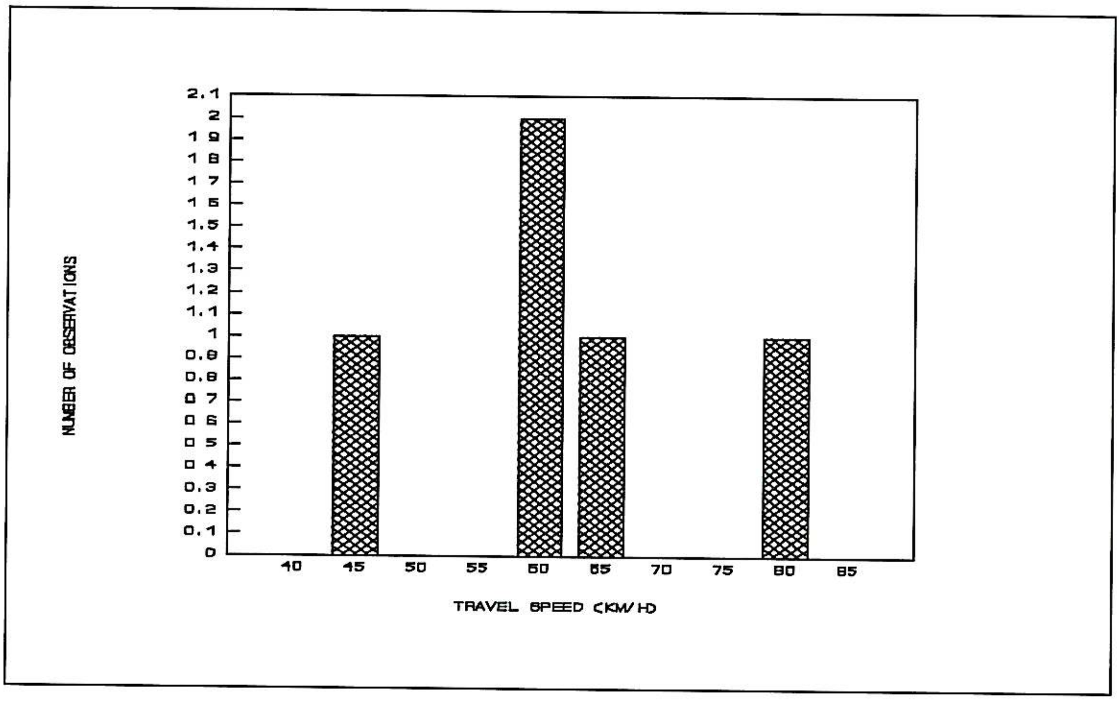


FIGURE B.20.5: HGVs



APPENDIX B.21: P2-5(E)

FIGURE B.21.1: CARS

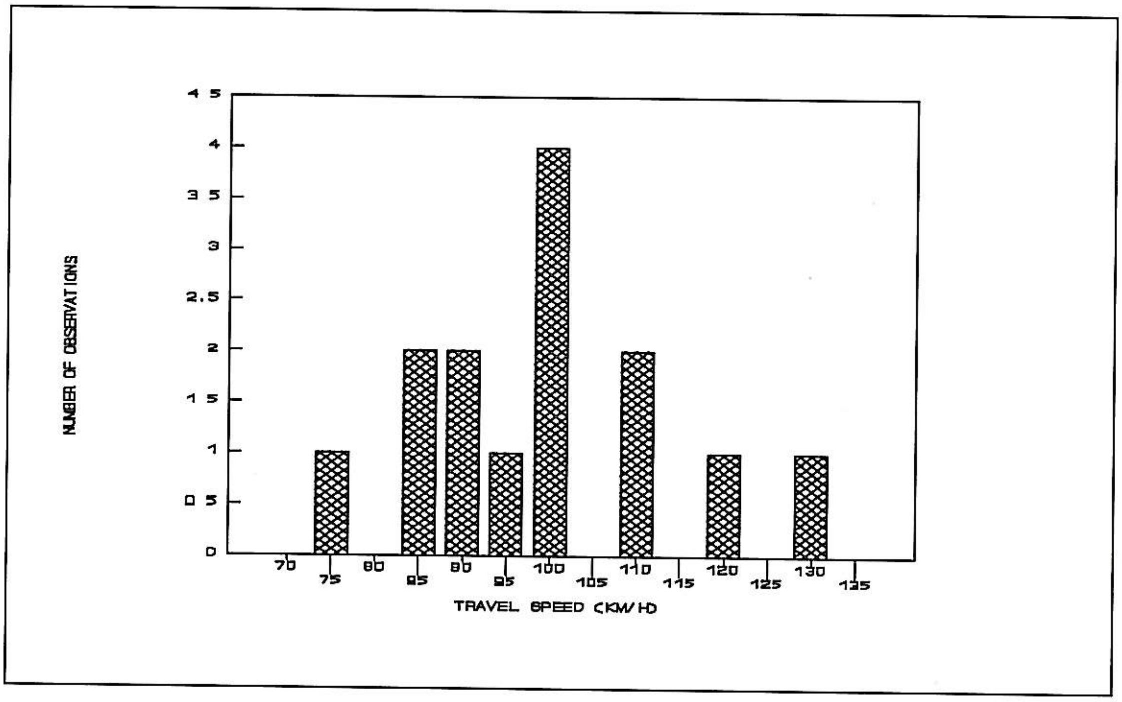


FIGURE B.21.2: LDVs

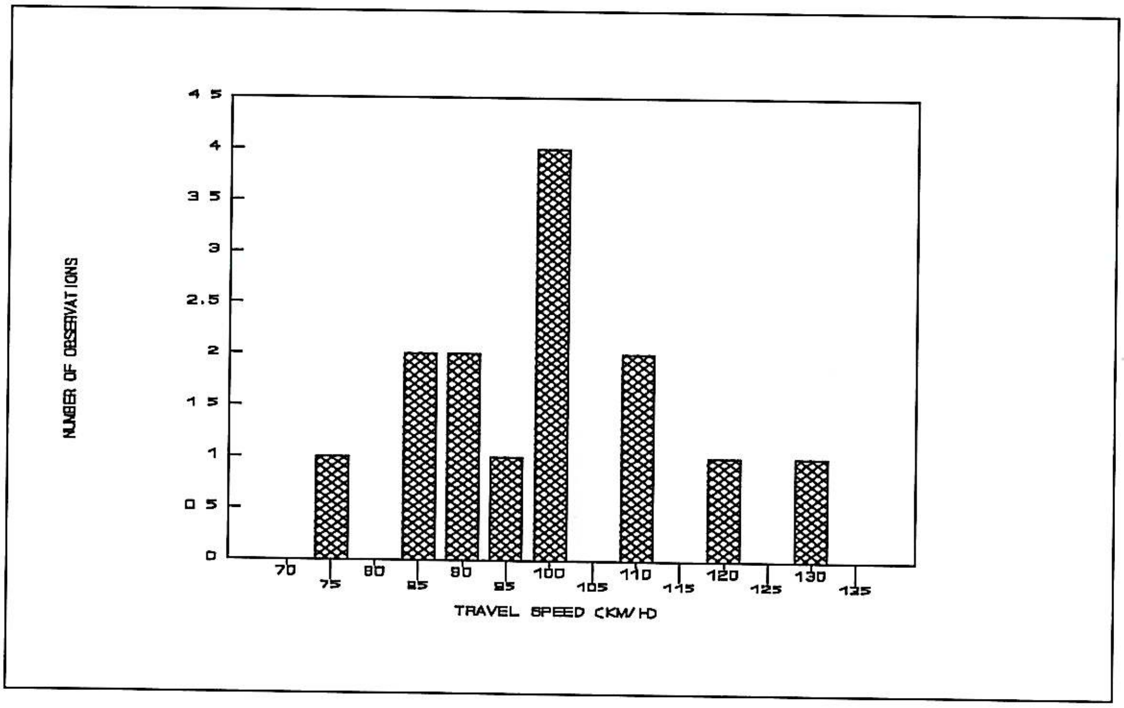


FIGURE B.21.3: MINI-BUSES

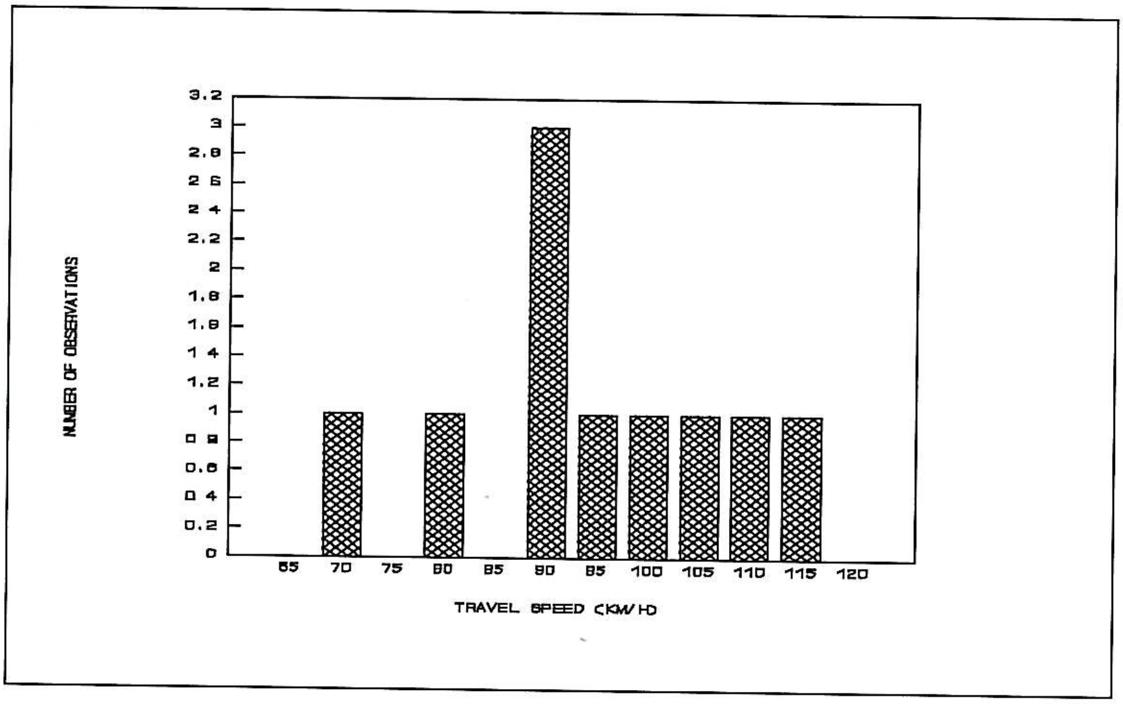


FIGURE B.21.4: BUSES

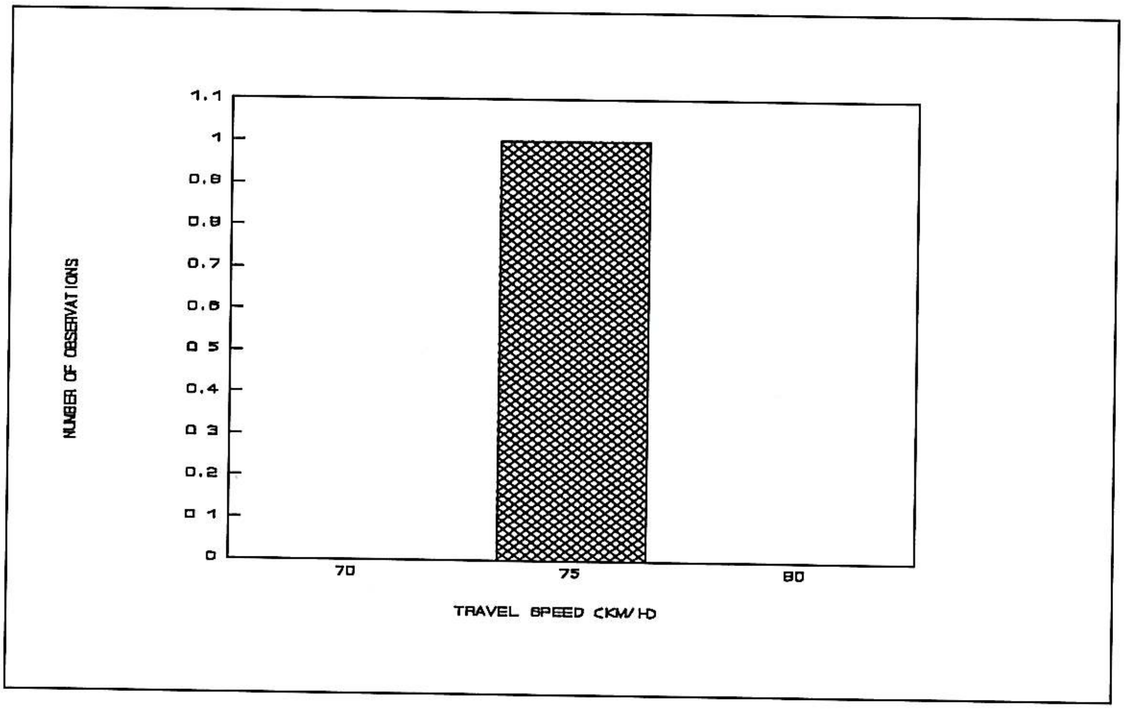


FIGURE B.21.5: MGVs

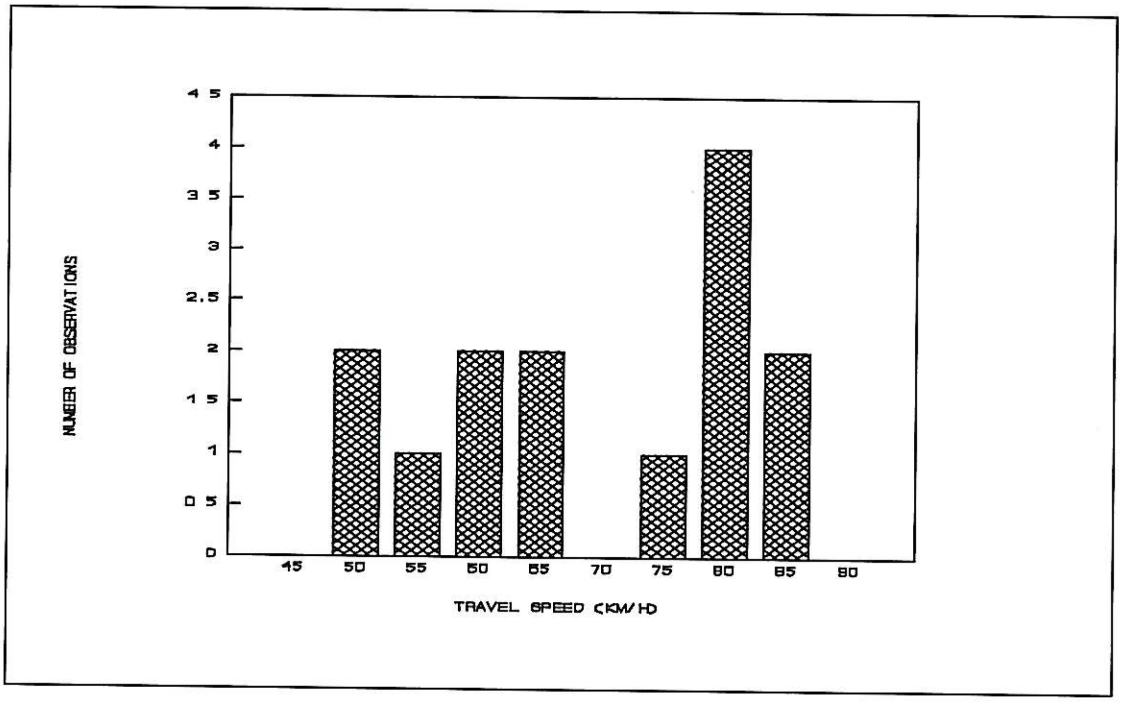
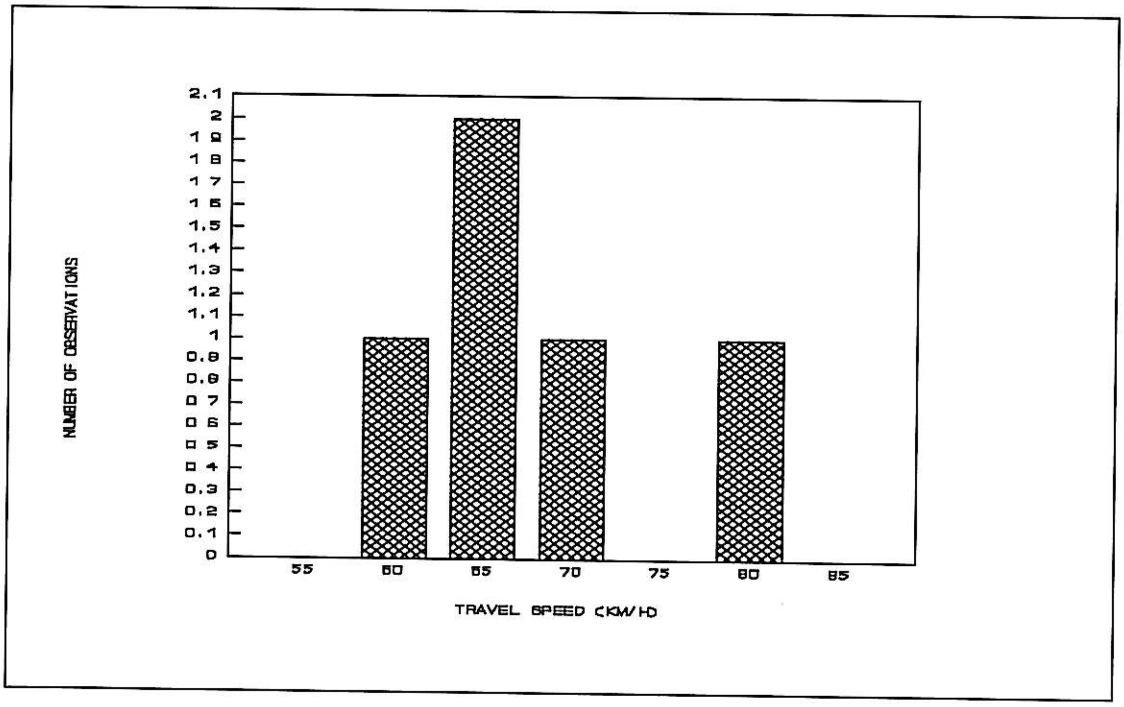


FIGURE B.21.6: HGVs



APPENDIX B.22: P2-5(W)

FIGURE B.22.1: CARS

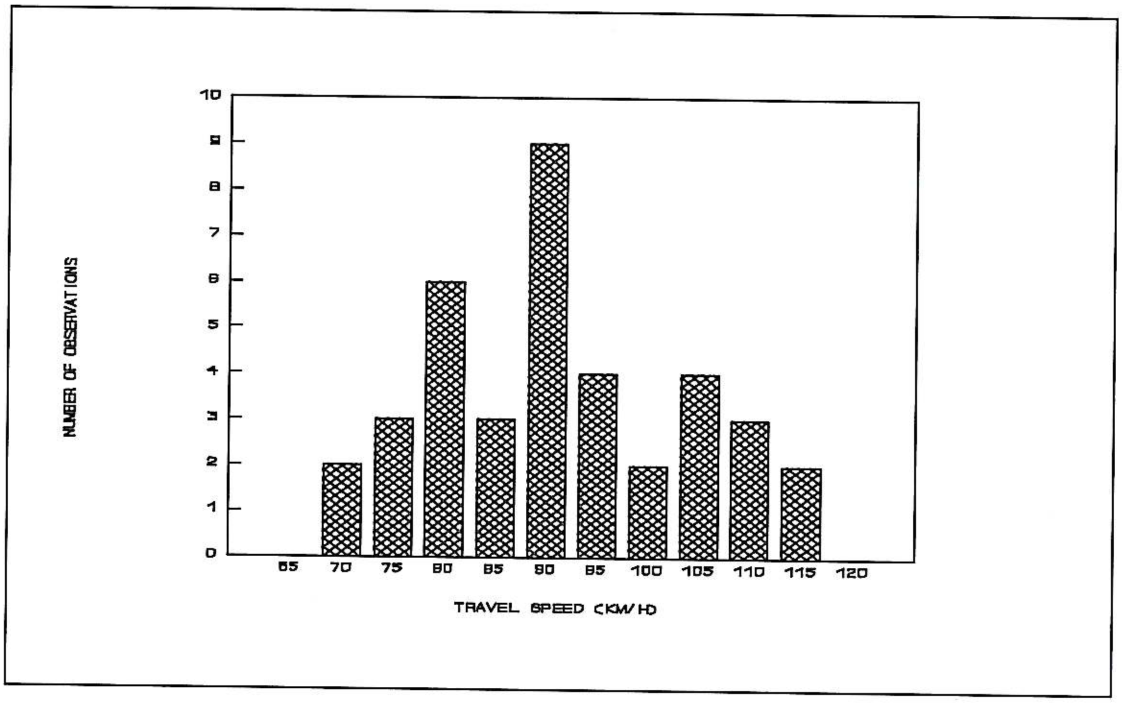


FIGURE B.22.2: LDVs

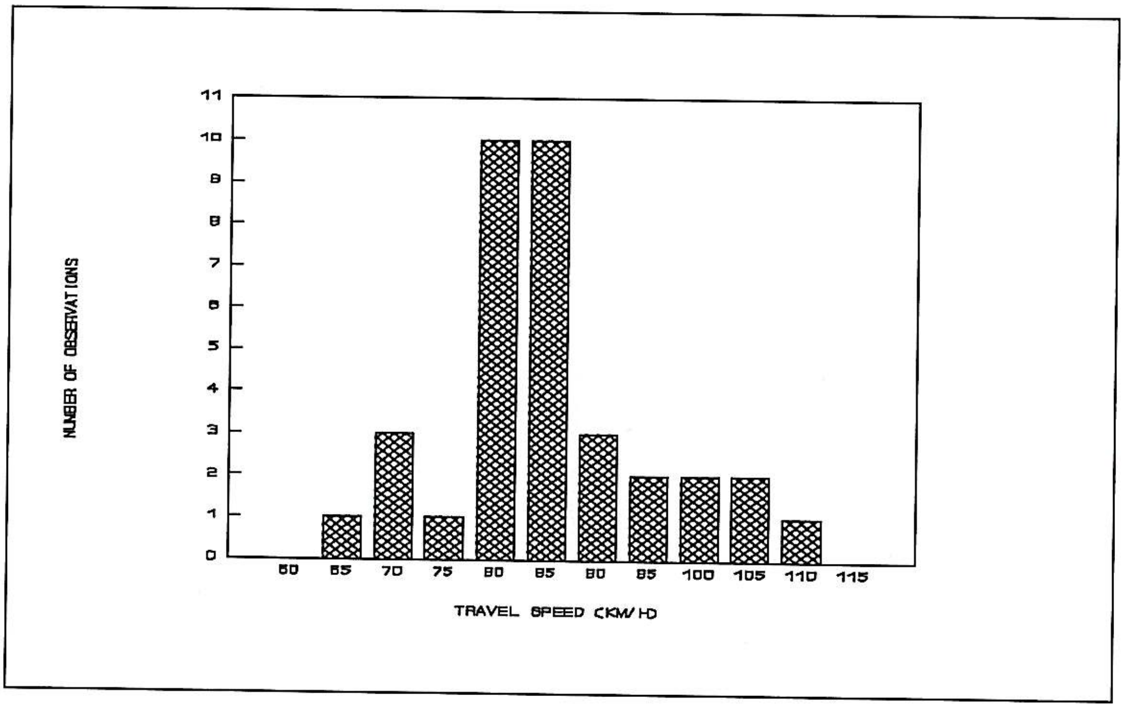


FIGURE B.22.3: MINI-BUSES

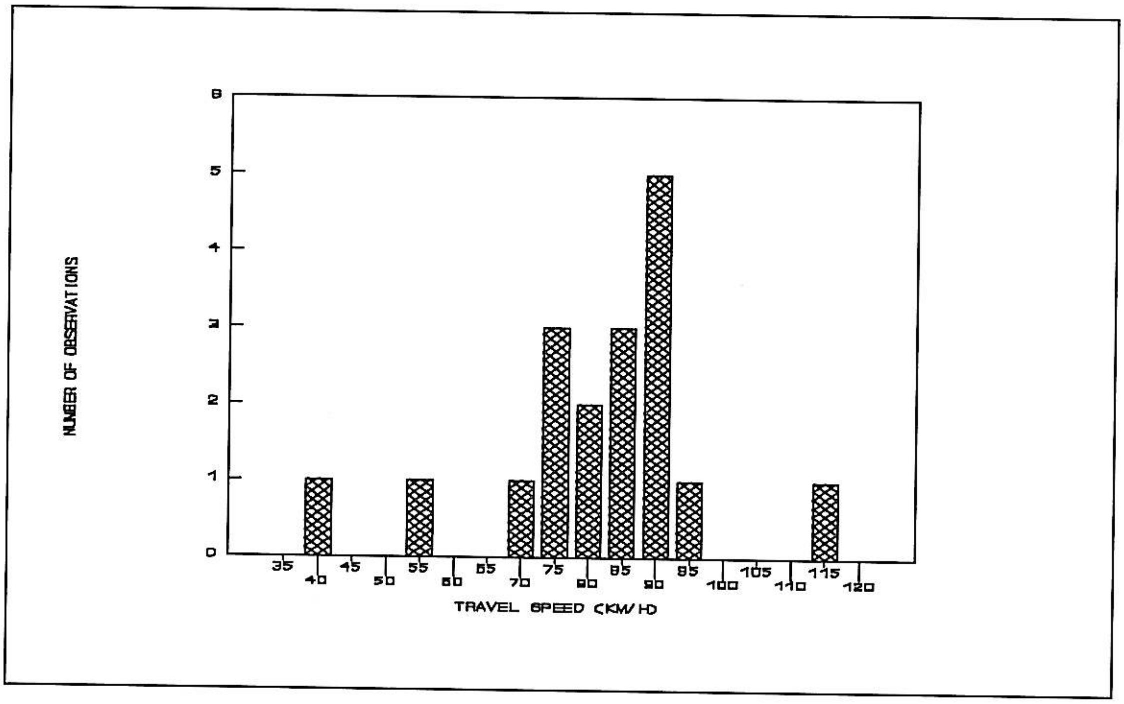


FIGURE B.22.4: BUSES

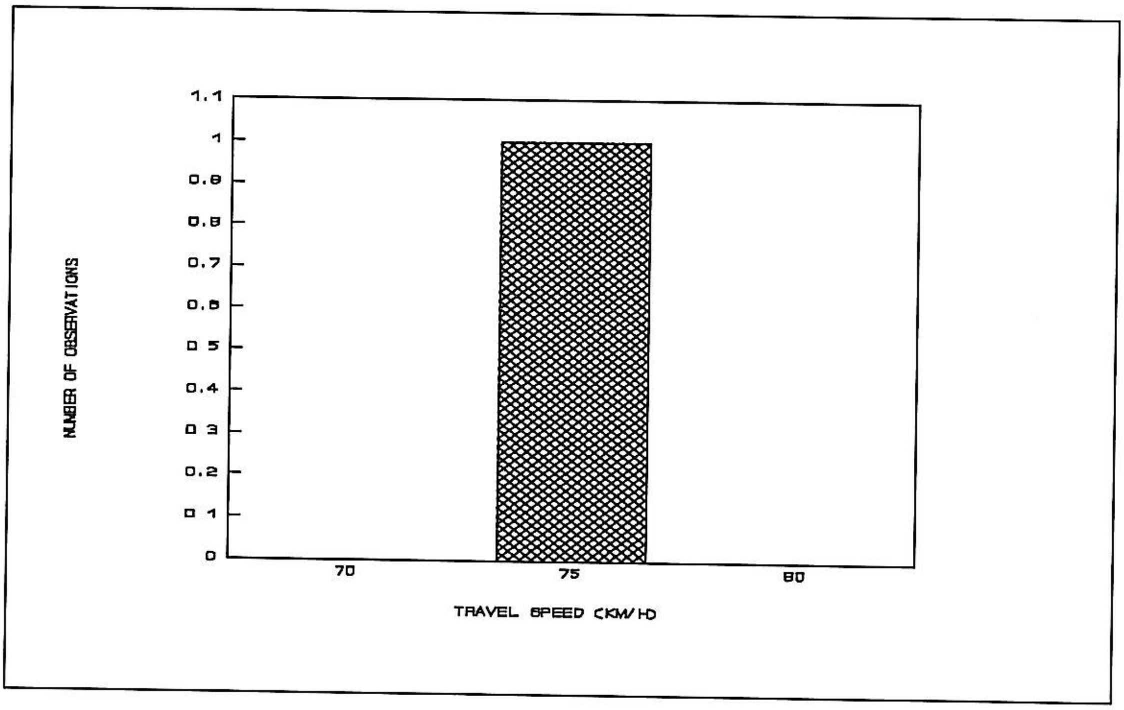


FIGURE B.22.5: MGVs

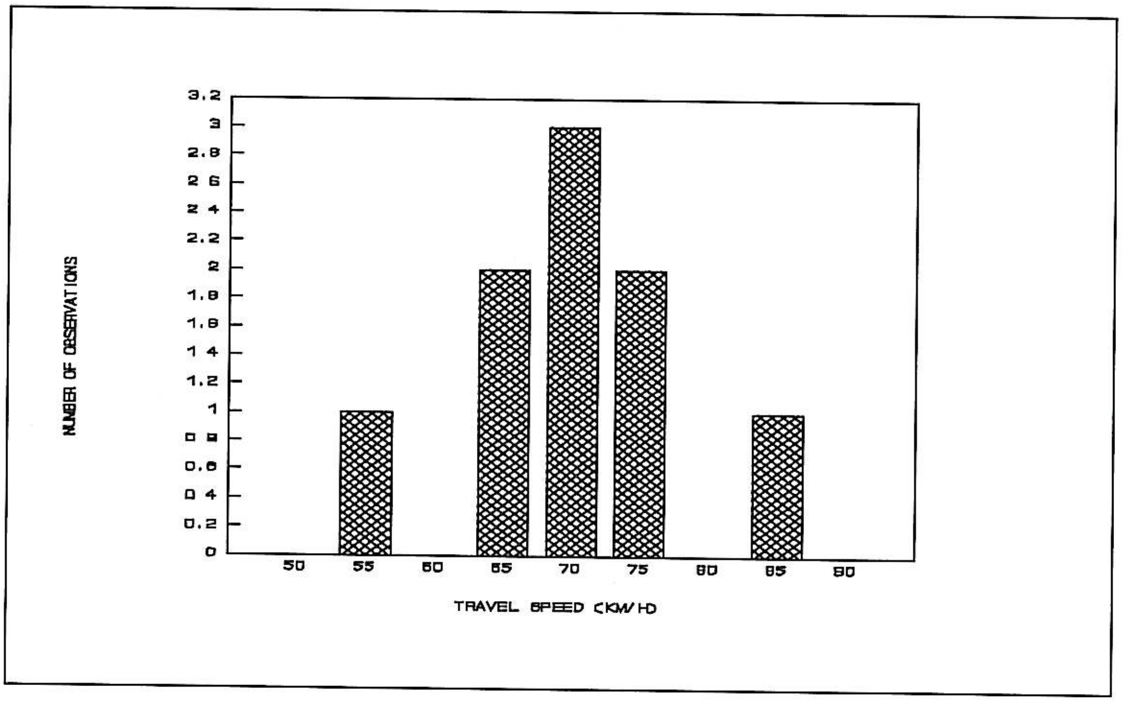
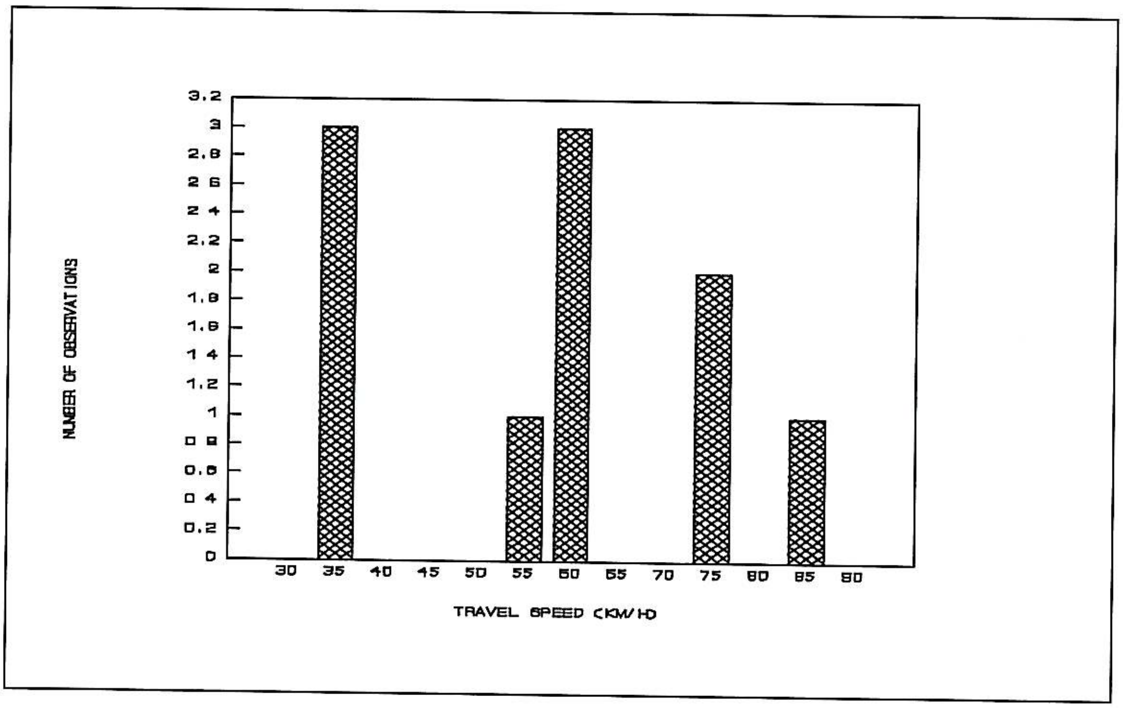


FIGURE B.22.6: HGVs



APPENDIX B.23: P2-5(E)

FIGURE B.23.1: CARS

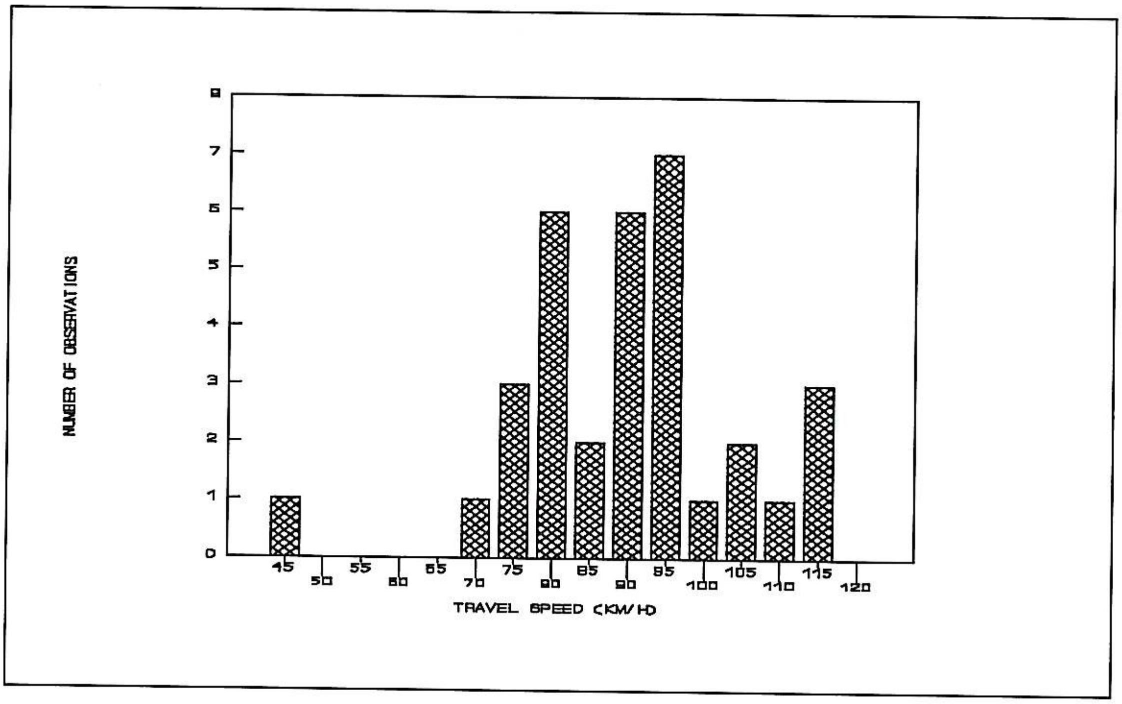


FIGURE B.23.2: LDVs

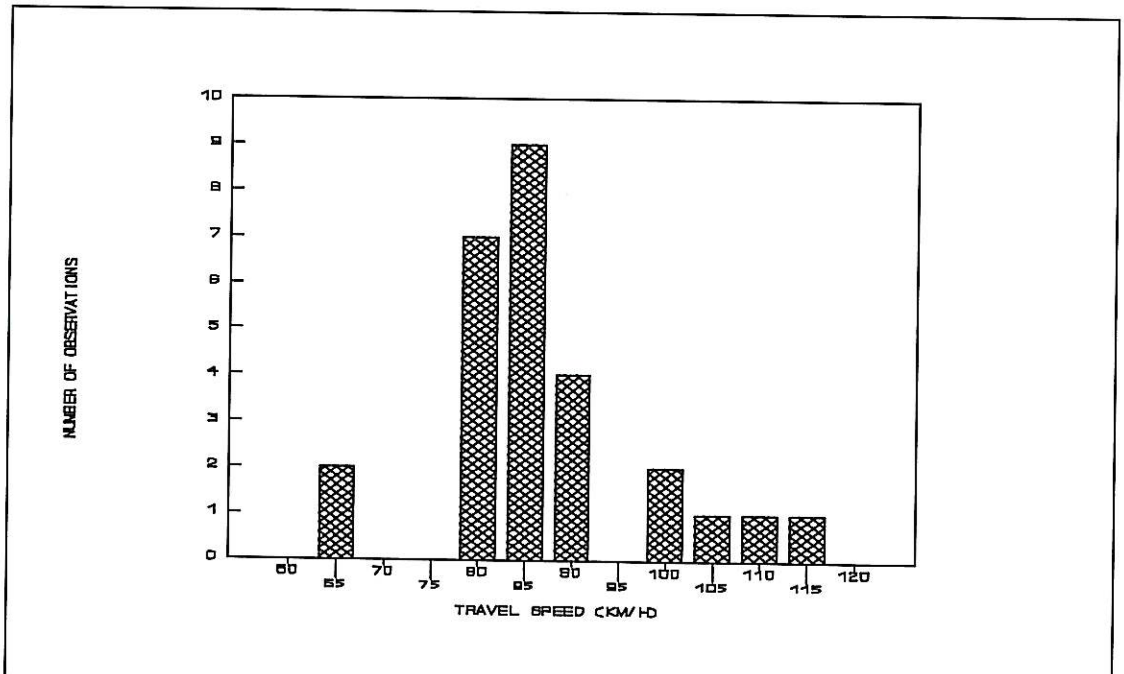


FIGURE B.23.3: MINI-BUSES

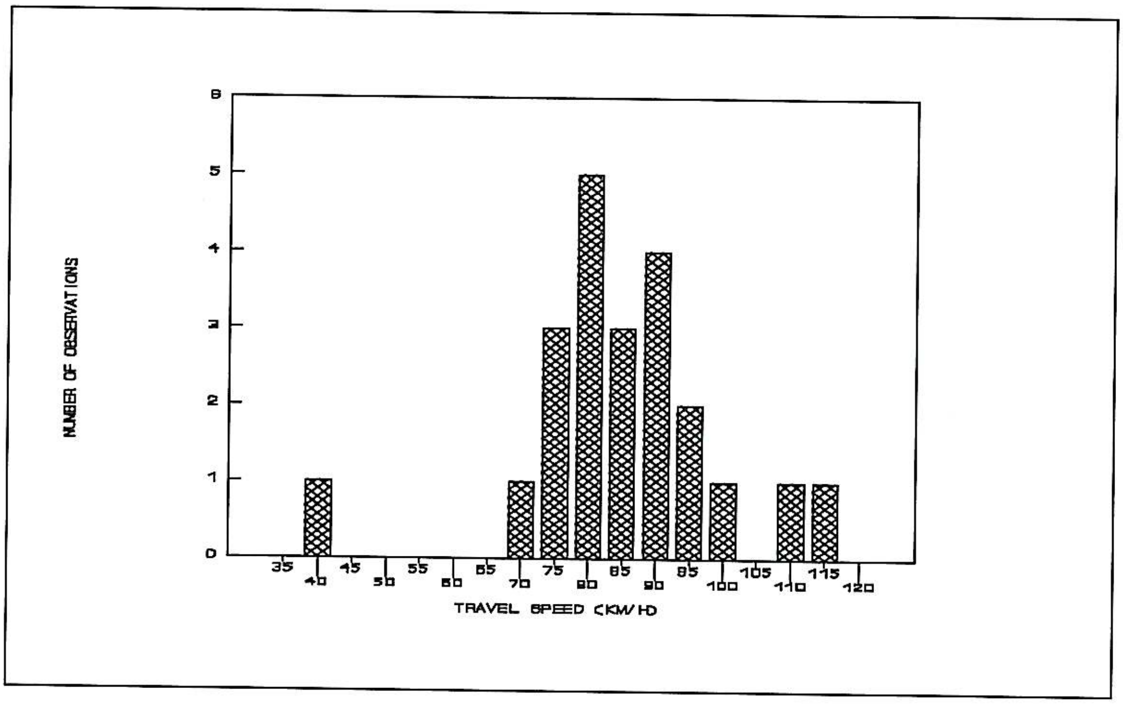


FIGURE B.23.4: BUSES

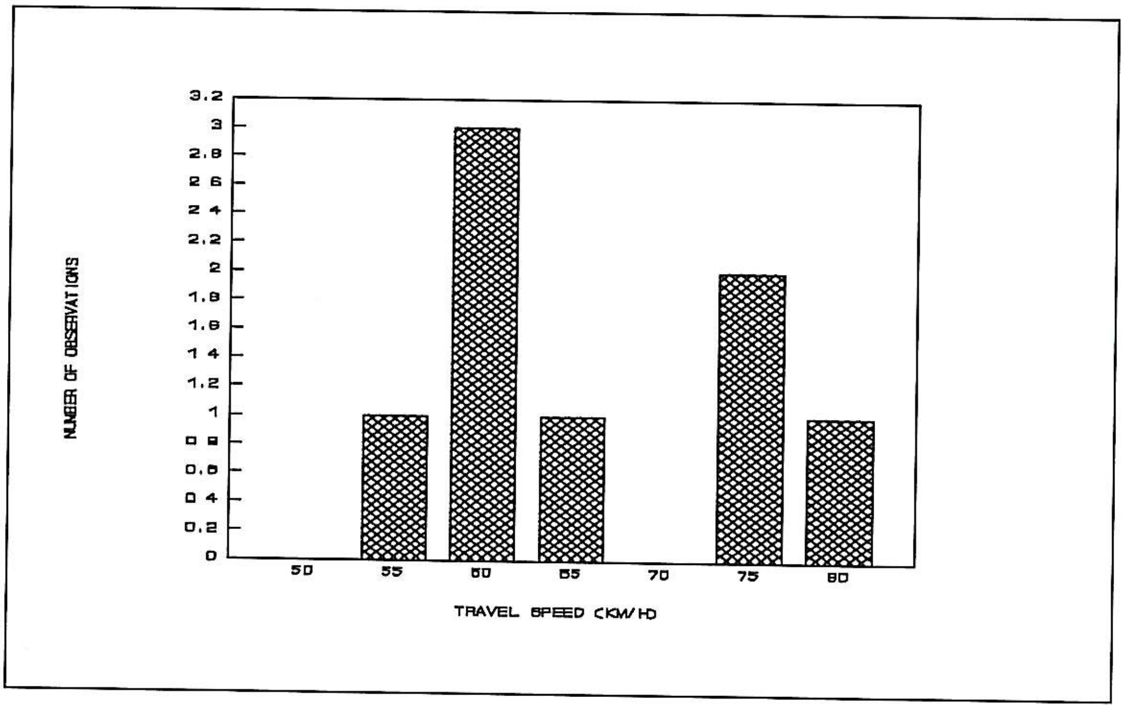


FIGURE B.23.5: MGVs

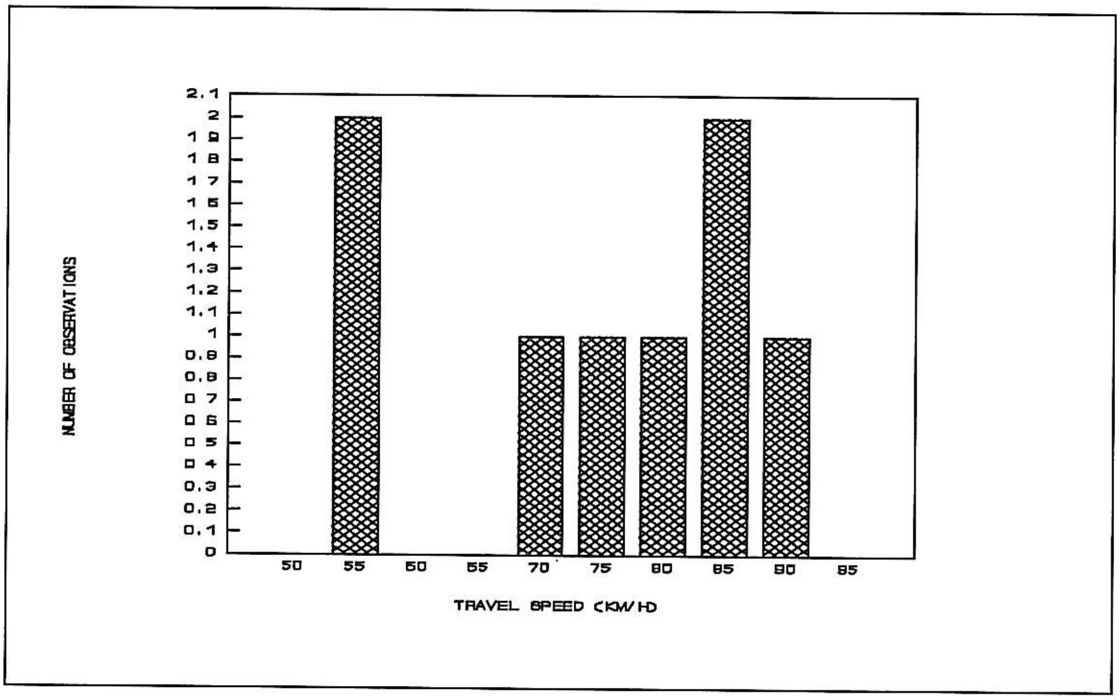
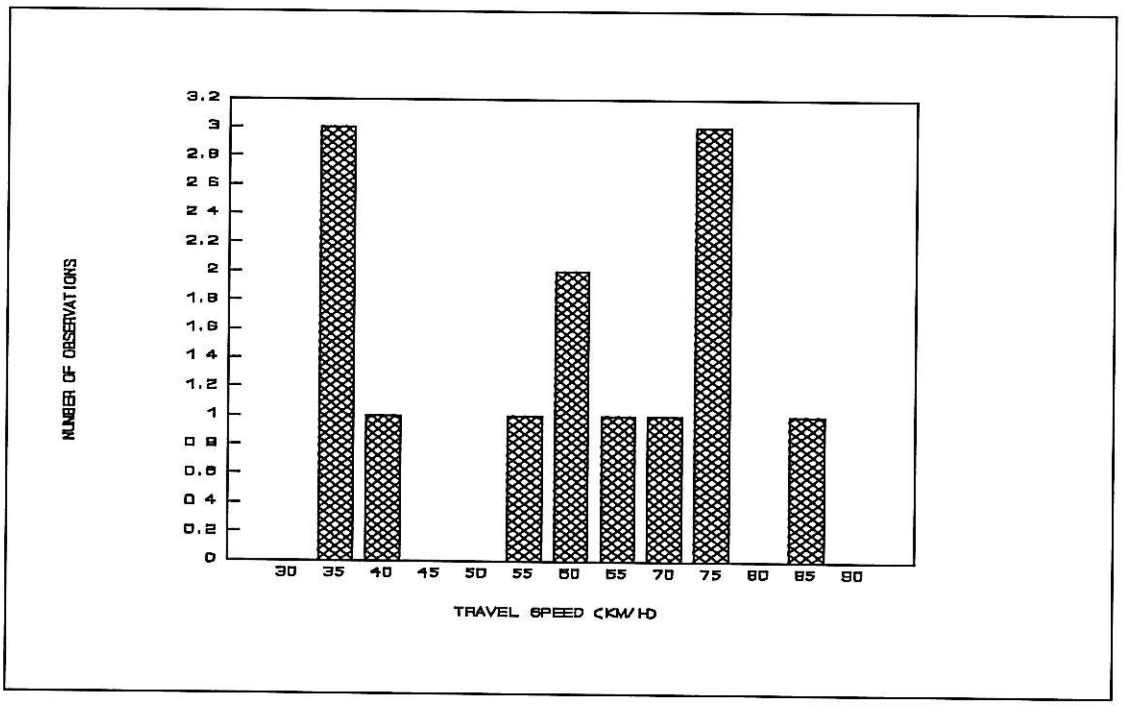


FIGURE B.23.6: HGVs



APPENDIX B.24: P2-5(W)

FIGURE B.24.1: CARS

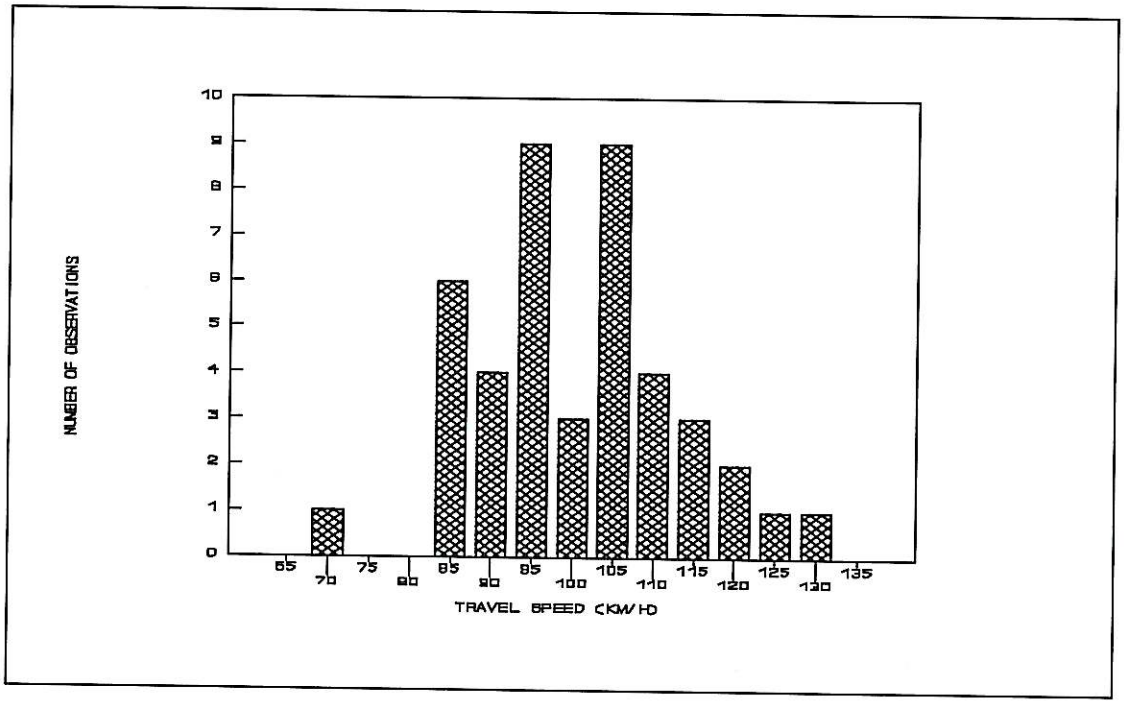


FIGURE B.24.2: LDVs

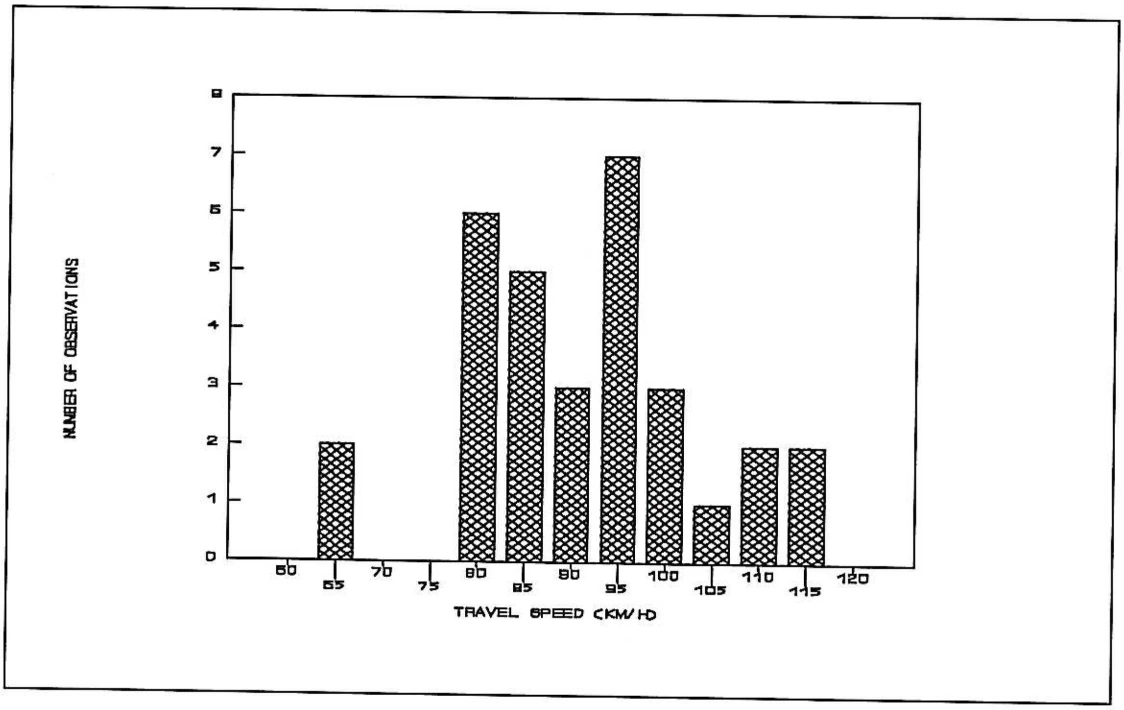


FIGURE B.24.3: MINI-BUSES

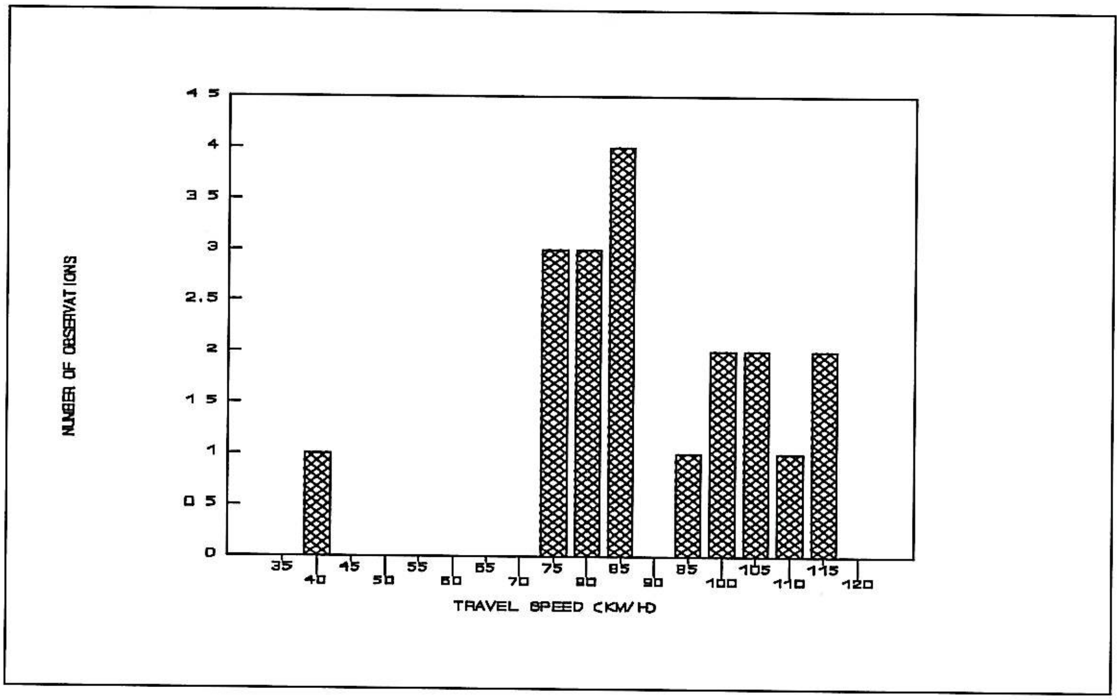


FIGURE B.24.4: BUSES

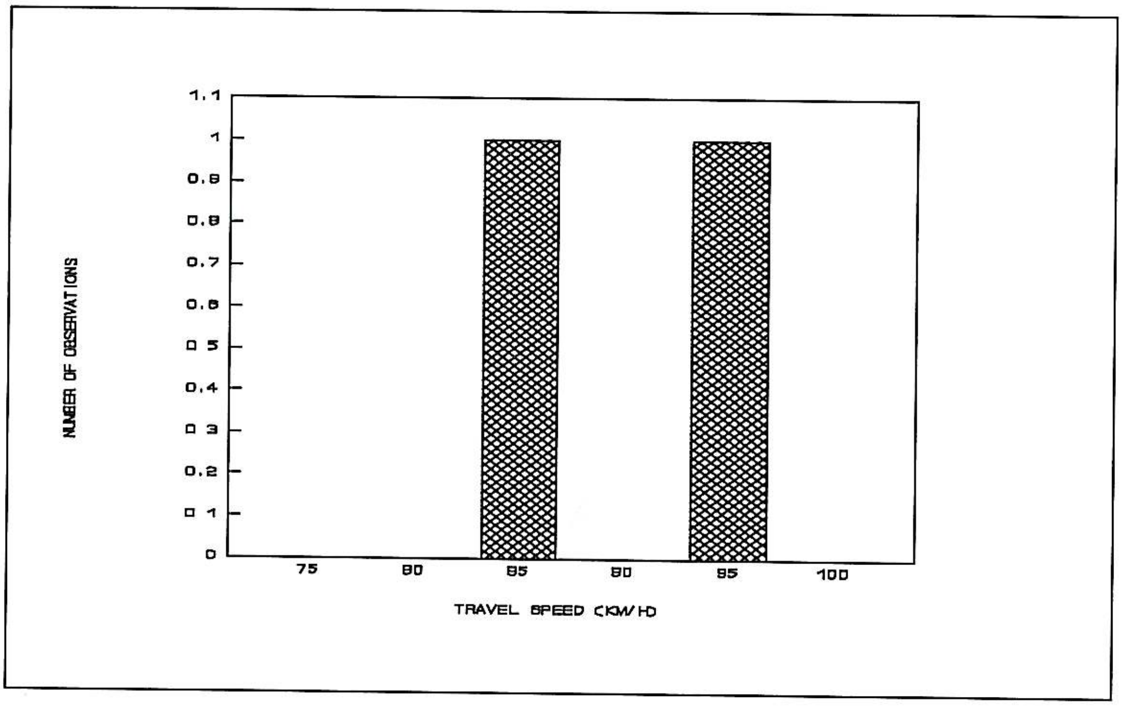


FIGURE B.24.5: MGVs

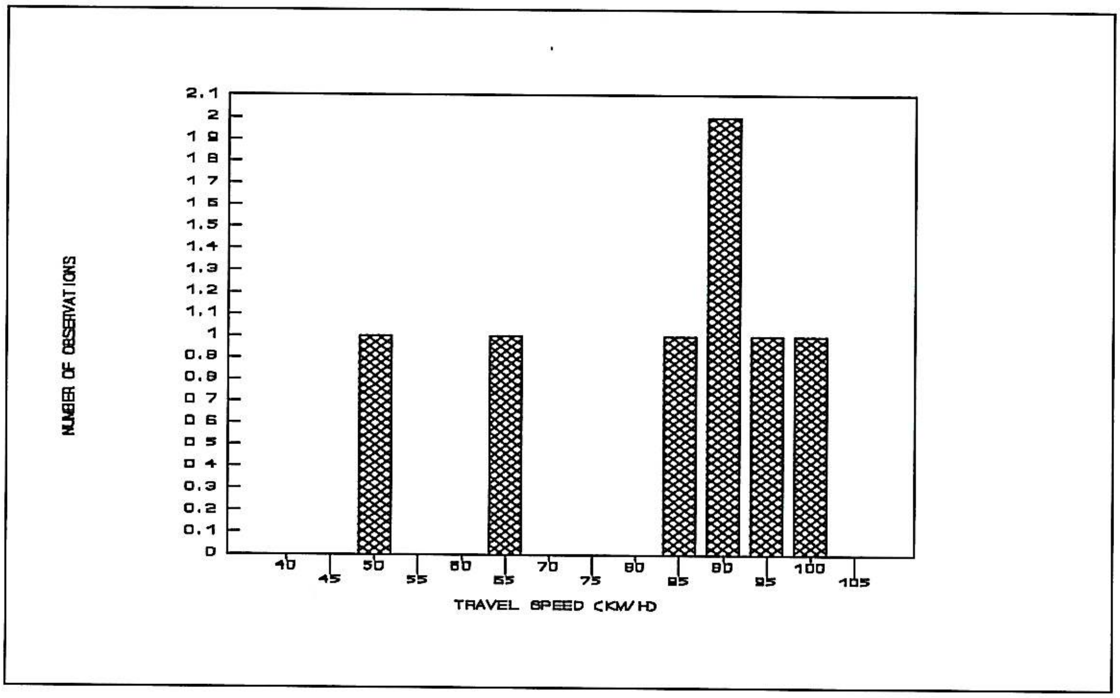
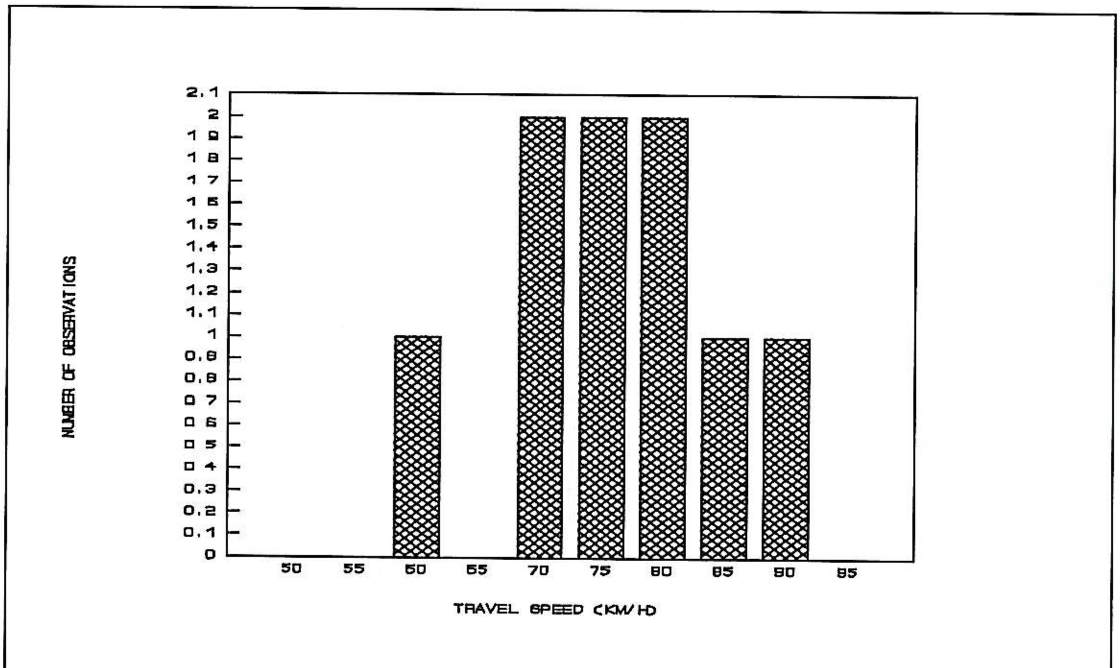


FIGURE B.24.6: HGVs



APPENDIX B.25: P1386

FIGURE B.25.1: CARS

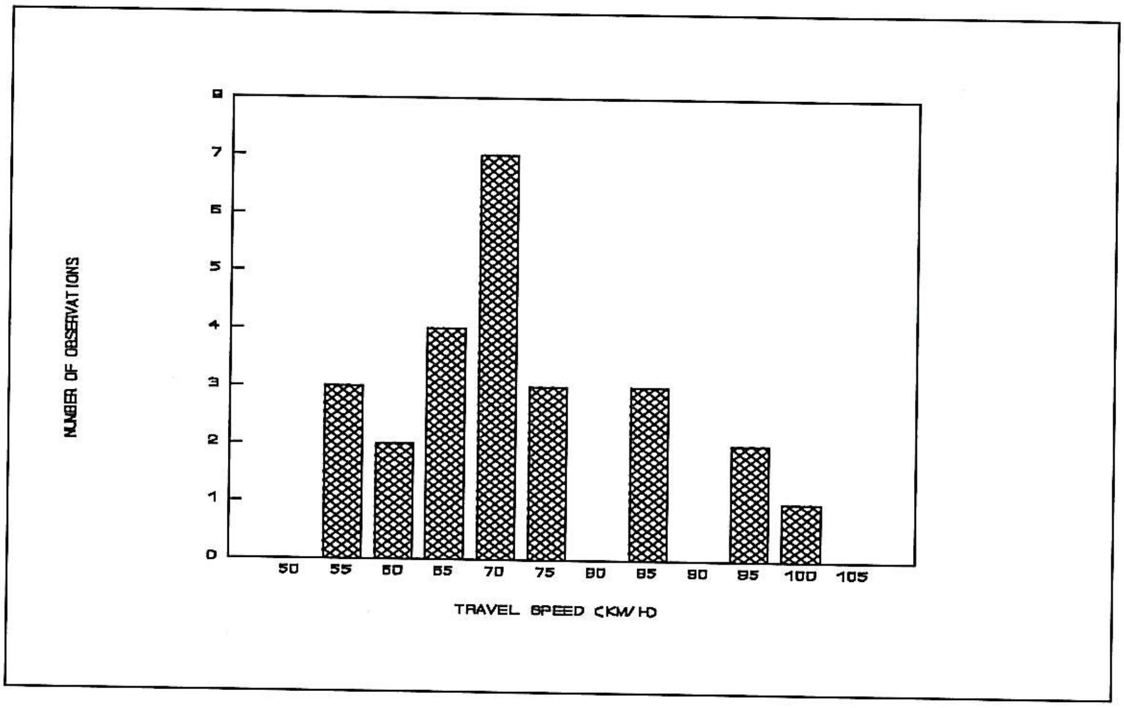


FIGURE B.25.2: LDVs

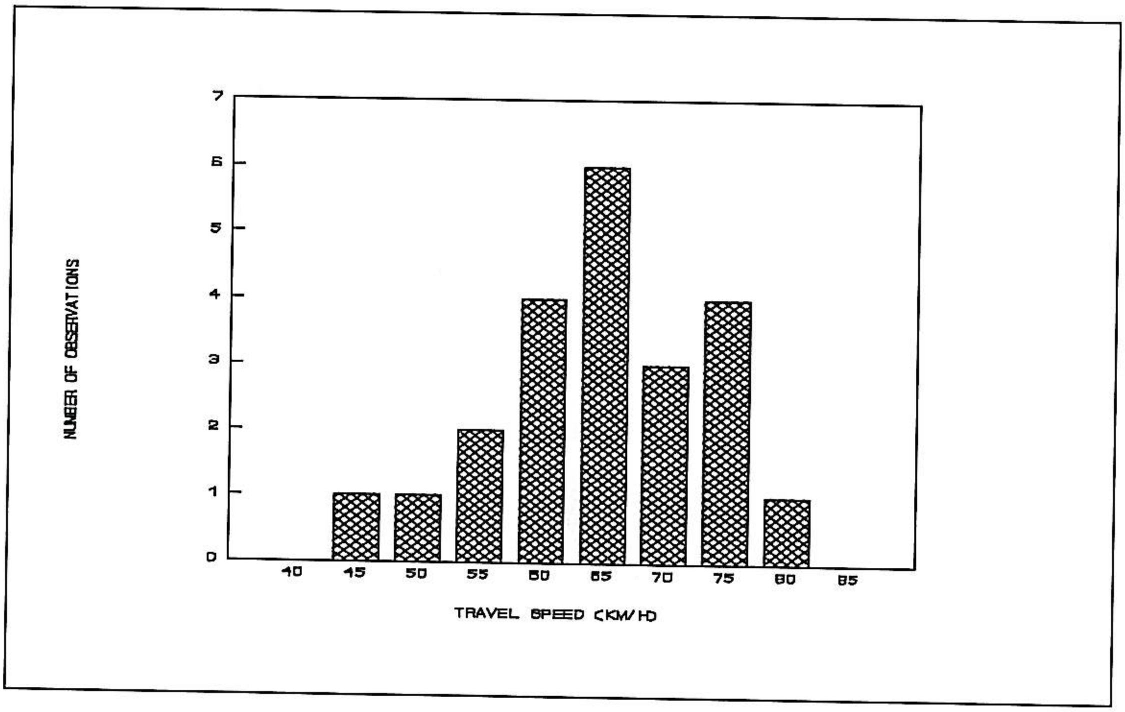


FIGURE B.25.3: MINI-BUSES

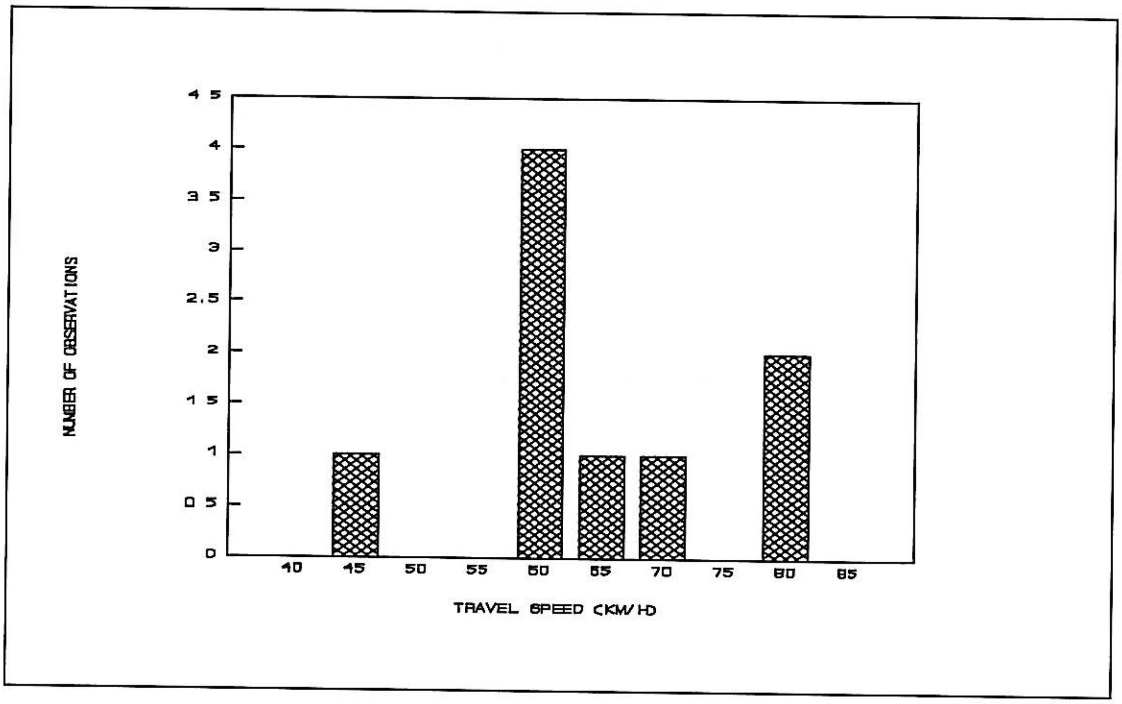


FIGURE B.25.4: BUSES

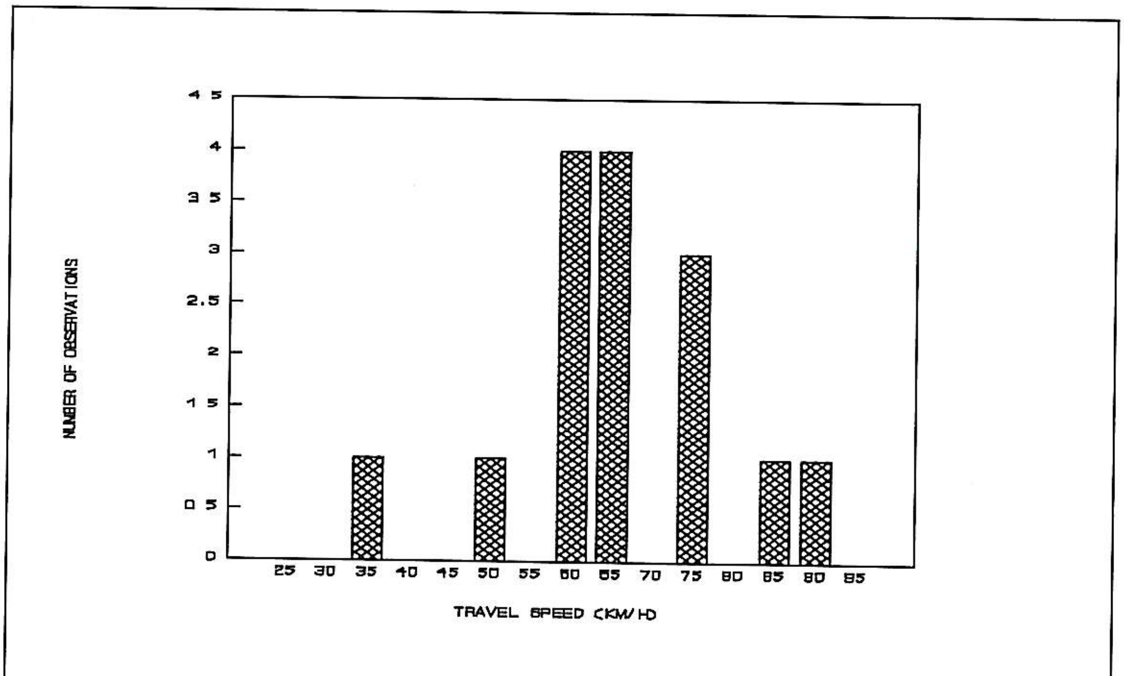


FIGURE B.25.5: MGVs

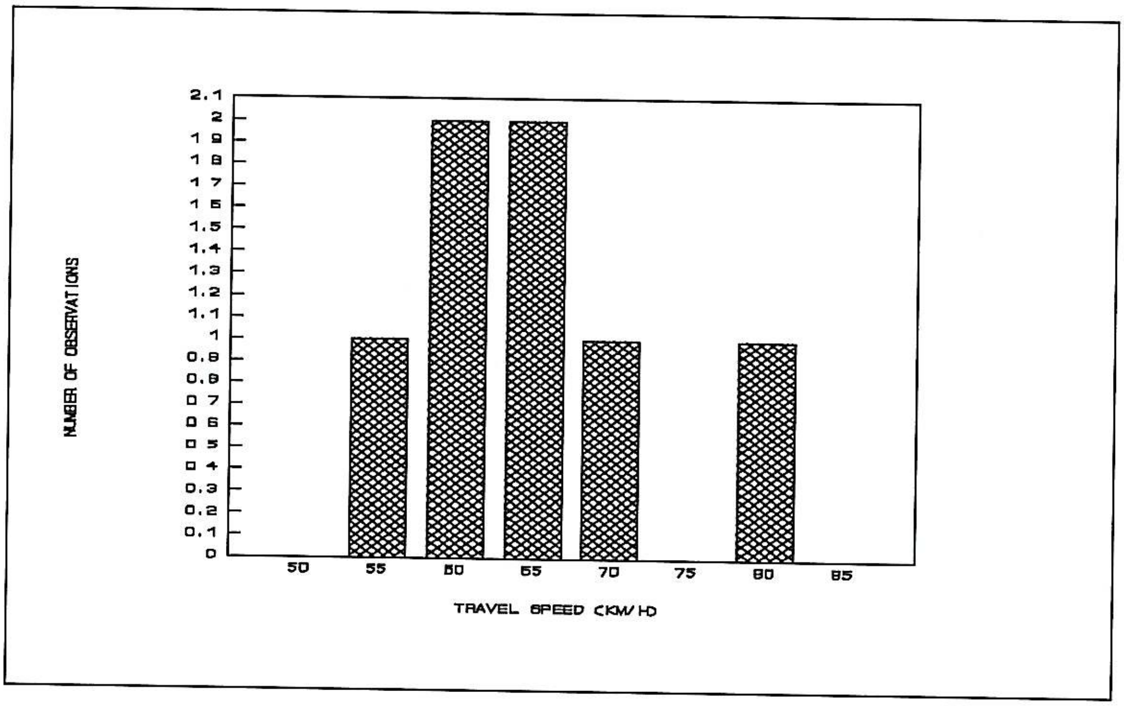
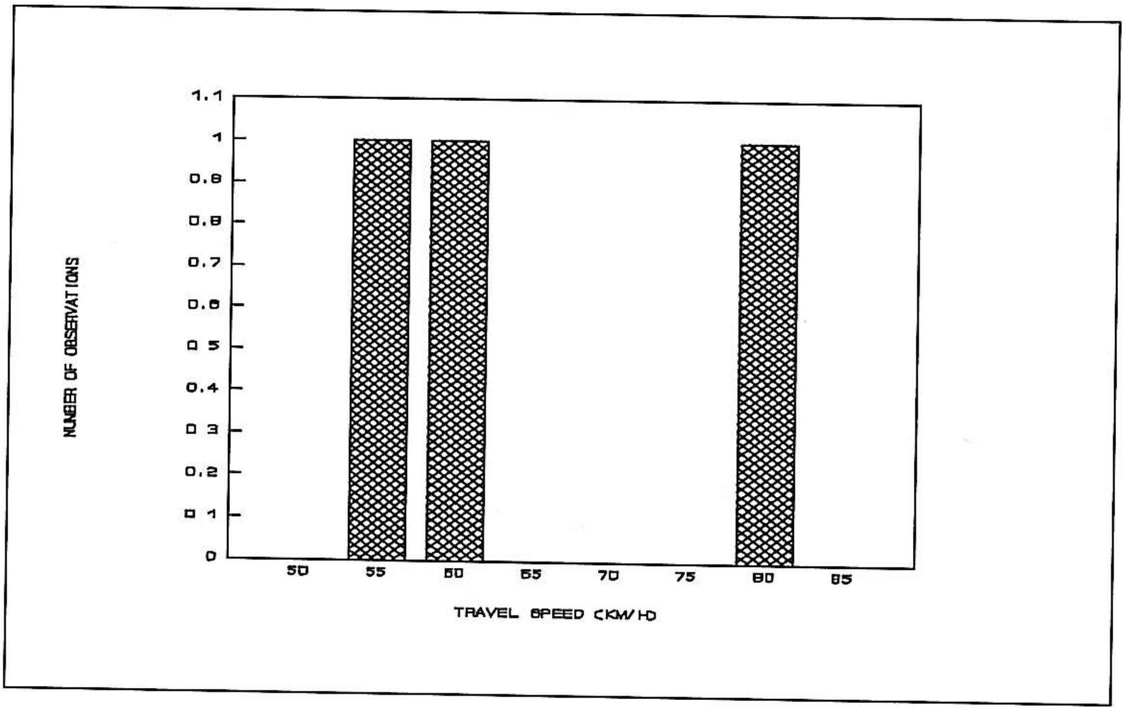


FIGURE B.25.6: HGVs



APPENDIX B.26: P1814

FIGURE B.26.1: CARS

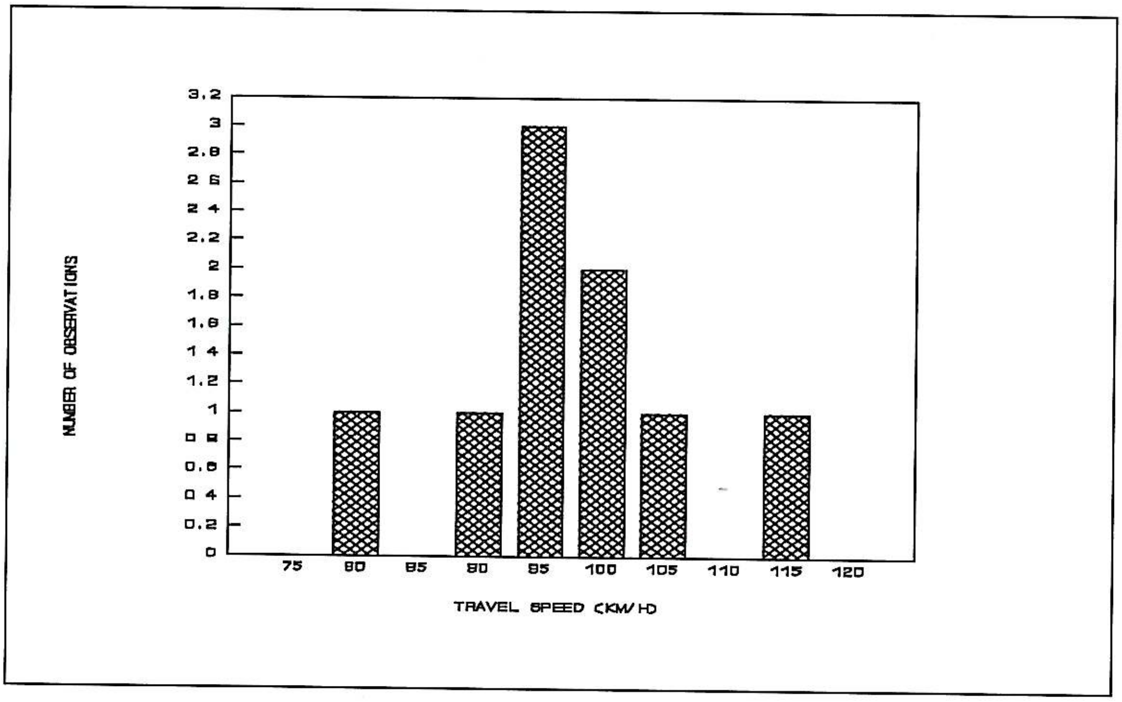


FIGURE B.26.2: LDVs

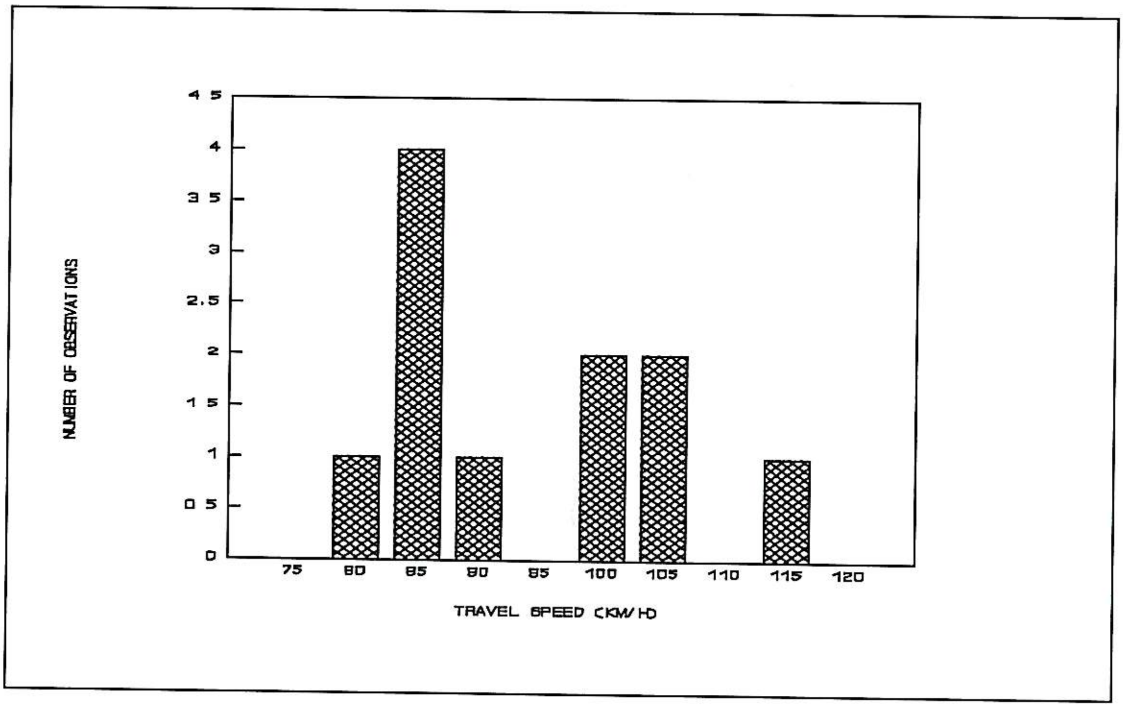
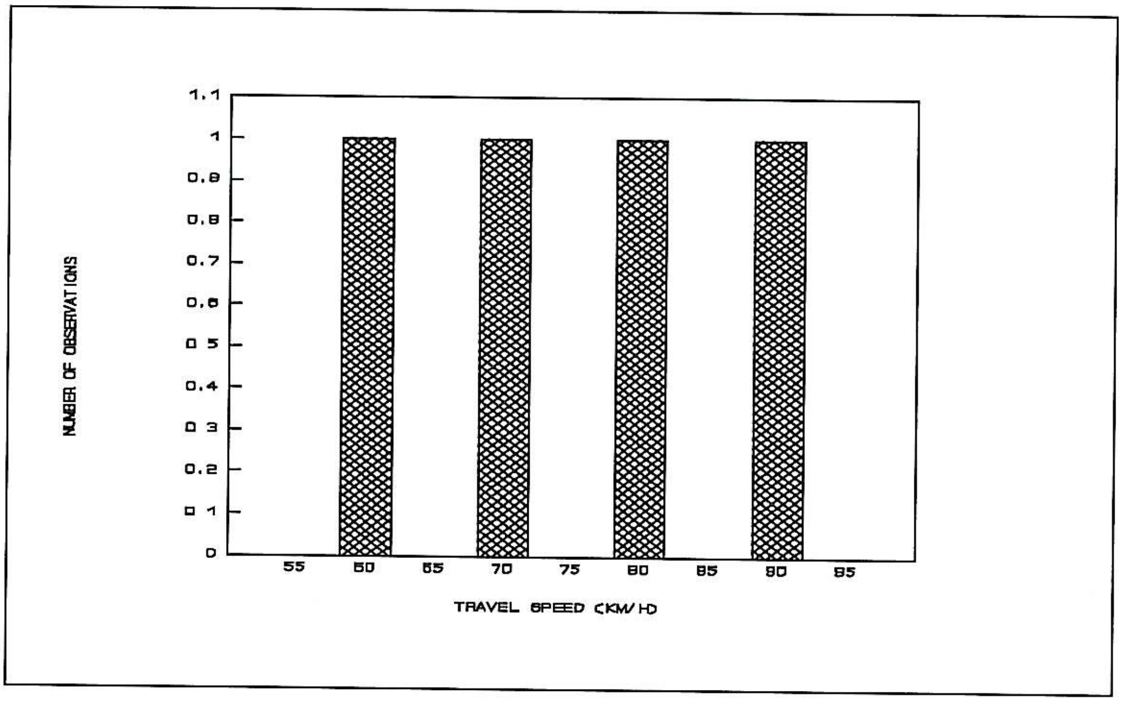


FIGURE B.26.3: MGVs



APPENDIX B.27: P734

FIGURE B.27.1: CARS

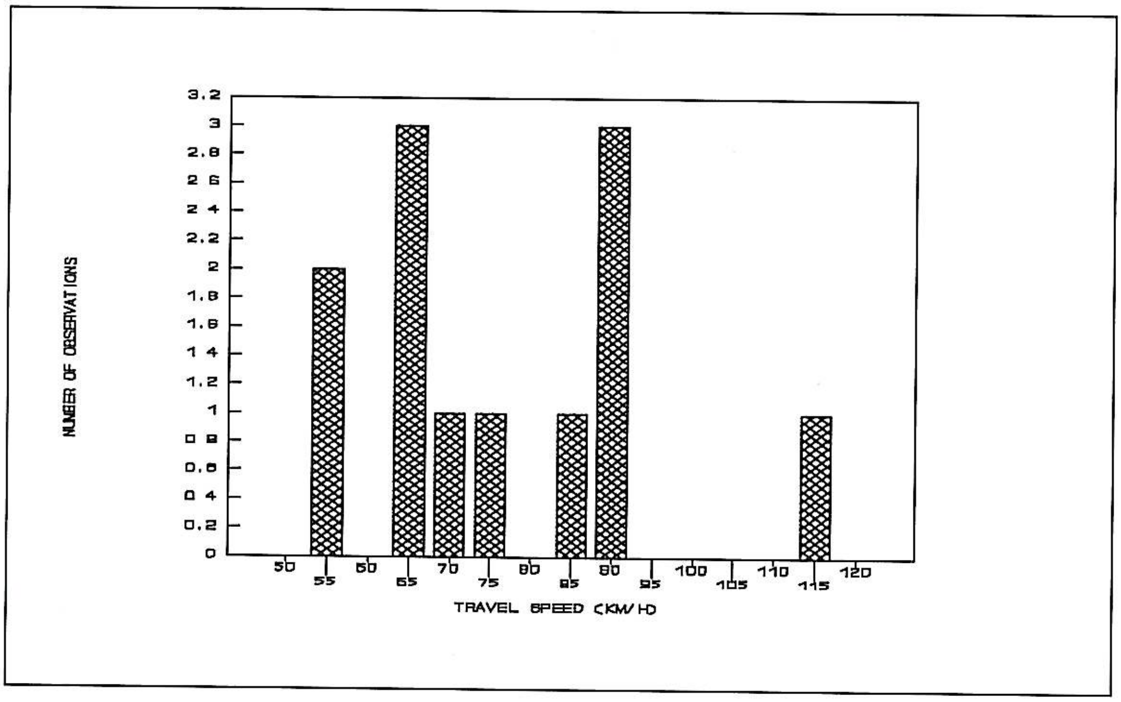


FIGURE B.27.2: LDVs

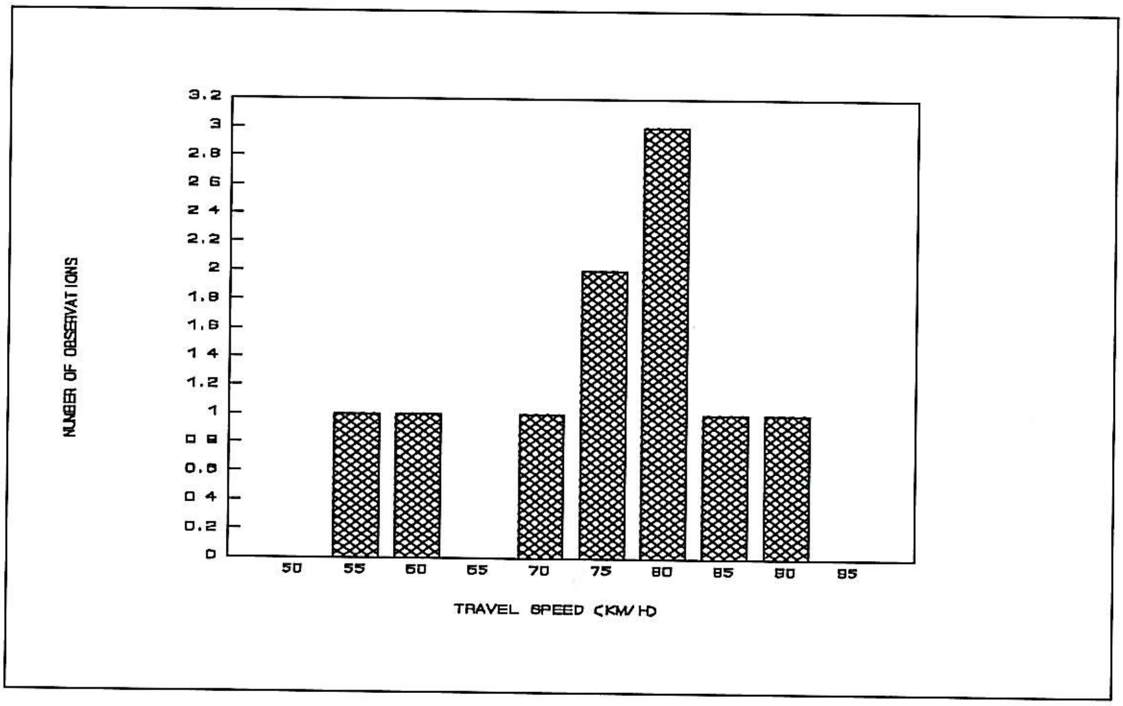
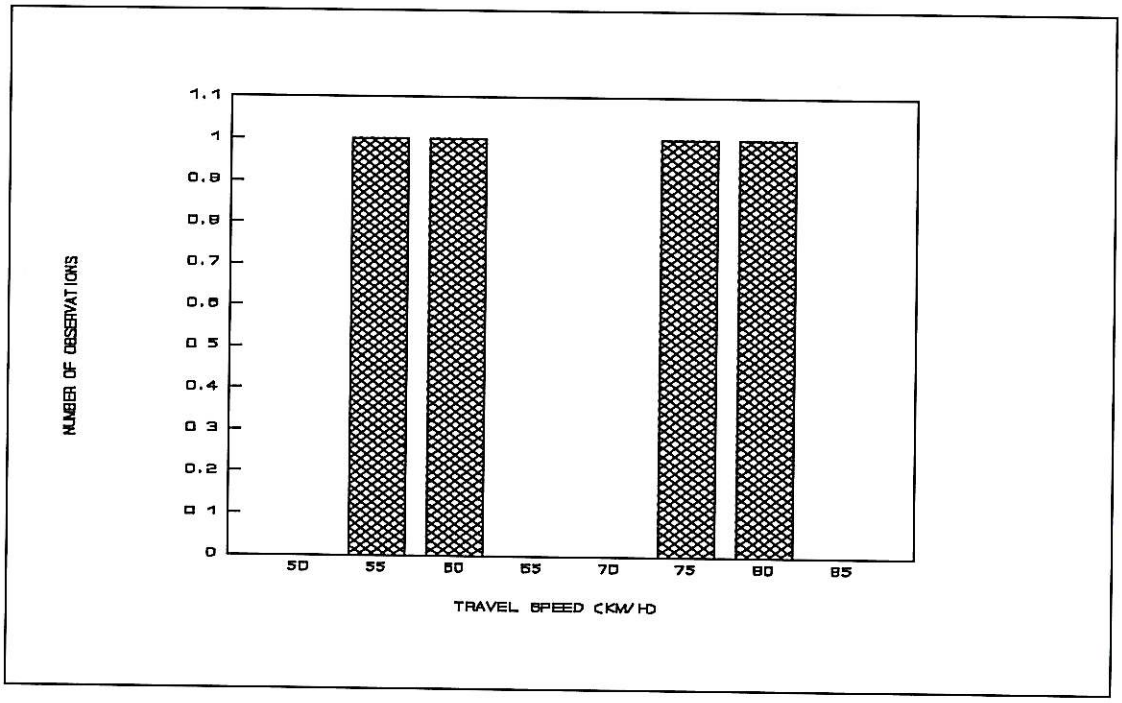


FIGURE B.27.3: MGVs



APPENDIX C

SPEED OBSERVATIONS AT SELECTED CTO STATIONS

TABLE C.1: FREEWAYS

ROUTE NUMBER AND STATION NAME	NO	SPEED LIMIT	AVERAGE SPEED LIGHT VEHICLES	AVERAGE SPEED HEAVY VEHICLES
N1-15 Bloemfontein	1	120	114,2	84,2
N1-19 Sebokeng	2	120	116,7	87,2
N1-19 Grasmere	3	120	113,1	79,2
N1-20 Halfway house	4	120	112,4	72,9
N1-21 John Vorster	5	120	115,9	82,1
N1-21 Eastlynn	6	120	111,0	82,3
N1-22 Wallmanstal	7	120	115,0	84,7
N1-23 Settlers	8	120	118,0	88,0
N2-23 Park Rynie	9	120	112,4	81,4
N3-11 Heidelberg	10	120	114,5	84,8

TABLE C.2: MULTI-LANE ROADS: FOUR LANES

ROUTE NUMBER AND STATION NAME	NO	SPEED LIMIT	AVERAGE SPEED LIGHT VEHICLES	AVERAGE SPEED HEAVY VEHICLES
N2-07 Mosselbaai	1	120	119,4	85,6
N2-10 Van Stadens	2	120	114,7	86,2
N2-16 East London BP	3	120	106,7	77,2
N6-01 Berlin	4	120	112,8	79,4
N3-07 Warden south	5	120	121,0	87,5
N4-04 Middelburg	6	120	115,7	79,0
N7-01 Caltex north	7	120	108,5	77,1
R29 Potchefstroom W	8	120	113,6	83,7
R29 Eldorado Park	9	120	109,2	77,1
R071 Moria	10	120	102,0	82,4

TABLE C.3: TWO-LANE ROADS: 120 KM/H SPEED LIMIT

ROUTE NUMBER AND STATION NAME	NO	SPEED LIMIT	AVERAGE SPEED LIGHT VEHICLES	AVERAGE SPEED HEAVY VEHICLES
N1-04 Touwsrivier	1	120	113,8	85,3
N1-15 Kafferrivier	2	120	117,5	86,7
N1-17 Ventersburg	3	120	119,7	63,9
N1-25 Naboomspruit	4	120	97,9	80,9
N2-02 Caledon	5	120	113,6	80,1
N2-08 Sedgefield	6	120	110,6	86,1
N2-13 Grahamstown W	7	120	112,9	78,2
N4-04 Lemoenfontein	8	120	114,7	79,9
N7-08 Steinkopf	9	120	112,6	83,7
N10-3 Cradock	10	120	111,9	84,2

TABLE C.4: TWO-LANE ROADS: 100 KM/H SPEED LIMIT

ROUTE NUMBER AND STATION NAME	NO	SPEED LIMIT	AVERAGE SPEED LIGHT VEHICLES	AVERAGE SPEED HEAVY VEHICLES
N2-13 Grahamstown	1	100	92,4	75,6
N2-21 Kokstad east	2	100	99,1	65,7
N2-21 Harding west	3	100	97,5	66,5
N2 MR 3-01 Hibberdene	4	100	103,6	77,6
N2-27 Tinley	5	100	103,9	75,8
N2 P02-03 Stanger	6	100	98,3	77,8
N2-31 Mkuze	7	100	90,8	56,8
N6-06 Smithfield	8	100	103,5	77,0
N10-01 Paterson	9	100	94,3	65,6
R27 Schurveberg	10	100	93,7	71,4

APPENDIX D

RESULTS OF SPEED OBSERVATIONS PER SURVEY SITE

N1-23(S) (2,372 KM)						H1.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	131	119	121	100	89	93
STANDARD DEVIATION	20	14	10	8	6	14
NUMBER OF OBSERVATIONS	35	22	18	2	9	16
AVE RANGE: TRAVEL SPEED	3	3	3	NA	2	4
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	83	52	43	5	21	38
SUM OF TRAVEL TIMES (SEC)	2340	1605	1277	172	873	1527
MACROSCOPIC SPEED	128	117	120	99	88	89

N1-23(N) (2,354 KM)						H2.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	135	128	121	109	104	85
STANDARD DEVIATION	14	18	14	9	8	9
NUMBER OF OBSERVATIONS	24	22	21	5	6	19
AVE RANGE: TRAVEL SPEED	2	4	3	6	4	2
REQ MIN NUMBER OBS	3	3	3	4	3	3
SUM OF DISTANCES (KM)	56	52	49	12	14	45
SUM OF TRAVEL TIMES (SEC)	1527	1489	1496	392	490	1921
MACROSCOPIC SPEED	133	125	119	108	104	84

N1-22(S) (2,96 KM)						H3.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	113	NA	NA	NA	75	55
STANDARD DEVIATION	11	NA	NA	NA	13	18
NUMBER OF OBSERVATIONS	12	NA	NA	NA	3	12
AVE RANGE: TRAVEL SPEED	4	NA	NA	NA	14	6
REQ MIN NUMBER OBS	3	NA	NA	NA	7	4
SUM OF DISTANCES (KM)	36	NA	NA	NA	9	36
SUM OF TRAVEL TIMES (SEC)	1142	NA	NA	NA	442	2713
MACROSCOPIC SPEED	112	NA	NA	NA	72	47

N4-1(E) (1,4 KM)						H4.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	117	107	120	NA	85	87
STANDARD DEVIATION	11	12	11	NA	8	12
NUMBER OF OBSERVATIONS	39	32	12	NA	8	9
AVE RANGE: TRAVEL SPEED	1	2	4	NA	3	4
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	55	45	17	NA	11	13
SUM OF TRAVEL TIMES (SEC)	1691	1524	507	NA	480	533
MACROSCOPIC SPEED	116	106	119	NA	84	85

N4-2(W) (1,563 KM)						H5.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	123	112	115	NA	92	86
STANDARD DEVIATION	9	13	9	NA	4	6
NUMBER OF OBSERVATIONS	14	19	10	NA	4	12
AVE RANGE: TRAVEL SPEED	3	3	3	NA	3	2
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	22	30	16	NA	6	19
SUM OF TRAVEL TIMES (SEC)	654	980	516	NA	252	801
MACROSCOPIC SPEED	120	109	109	NA	89	84

N4-2(E) (1,2 KM)						H6.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	118	105	103	64	69	68
STANDARD DEVIATION	11	14	16	ERR	20	11
NUMBER OF OBSERVATIONS	34	16	23	1	8	15
AVE RANGE: TRAVEL SPEED	1	4	2	NA	8	3
REQ MIN NUMBER OBS	3	3	3	NA	4	3
SUM OF DISTANCES (KM)	41	19	28	1	10	18
SUM OF TRAVEL TIMES (SEC)	1261	668	992	67	551	981
MACROSCOPIC SPEED	116	103	100	64	63	66

N12-2(W) (6,8 KM)						H7.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	126	118	118	93	85	80
STANDARD DEVIATION	16	16	14	1	6	10
NUMBER OF OBSERVATIONS	54	40	15	3	12	25
AVE RANGE: TRAVEL SPEED	1	2	4	1	2	2
REQ MIN NUMBER OBS	3	3	3	3	3	3
SUM OF DISTANCES (KM)	367	272	102	20	82	170
SUM OF TRAVEL TIMES (SEC)	10696	8498	3165	788	3490	7726
MACROSCOPIC SPEED	124	115	116	93	84	79

N12-2(E) (5,0 KM)						H8.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	122	108	111	NA	78	77
STANDARD DEVIATION	16	13	8	NA	9	11
NUMBER OF OBSERVATIONS	29	23	16	NA	7	16
AVE RANGE: TRAVEL SPEEDS	3	3	2	NA	5	3
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	145	115	80	NA	35	80
SUM OF TRAVEL TIMES (SEC)	4356	3892	2605	NA	1637	3893
MACROSCOPIC SPEED	120	106	111	NA	77	74

N12-2(W) (4,995 KM)						H9.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	122	114	114	100	89	73
STANDARD DEVIATION	12	9	14	8	6	9
NUMBER OF OBSERVATIONS	33	18	20	3	6	15
AVE RANGE: TRAVEL SPEEDS	2	2	2	9	4	2
REQ MIN NUMBER OBS	3	3	3	4	3	3
SUM OF DISTANCES (KM)	165	90	100	15	30	75
SUM OF TRAVEL TIMES (SEC)	4909	2867	3189	543	1223	3756
MACROSCOPIC SPEED	121	113	113	99	88	72

P29(W) (2,O KM)						H10.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	95	86	87	68	81	75
STANDARD DEVIATION	15	19	20	11	8	11
NUMBER OF OBSERVATIONS	31	34	24	7	7	24
AVE RANGE: TRAVEL SPEEDS	2	3	3	6	5	2
REQ MIN NUMBER OBS	3	3	3	4	3	3
SUM OF DISTANCES (KM)	62	68	48	14	14	48
SUM OF TRAVEL TIMES (SEC)	2420	3026	2112	761	625	2355
MACROSCOPIC SPEED	92	81	82	66	81	73

P29(E) (2,0 KM)						H11.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	89	85	93	72	78	70
STANDARD DEVIATION	10	19	10	19	10	7
NUMBER OF OBSERVATIONS	23	17	16	3	25	23
AVE RANGE: TRAVEL SPEEDS	2	4	3	21	2	2
REQ MIN NUMBER OBS	3	3	3	13	3	3
SUM OF DISTANCES (KM)	46	34	32	6	50	46
SUM OF TRAVEL TIMES (SEC)	1891	1541	1255	326	2351	2396
MACROSCOPIC SPEED	88	79	92	66	77	69

P91(W) (1,25 KM)						H12.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	107	97	97	NA	76	77
STANDARD DEVIATION	14	10	18	NA	11	7
NUMBER OF OBSERVATIONS	45	28	21	NA	26	11
AVE RANGE: TRAVEL SPEED	1	2	4	NA	2	3
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	56	35	26	NA	33	14
SUM OF TRAVEL TIMES (SEC)	1928	1312	1006	NA	1580	650
MACROSCOPIC SPEED	105	96	94	NA	74	76

P91(E) (1,25 KM)						H13.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	100	89	93	NA	75	69
STANDARD DEVIATION	13	16	13	NA	12	9
NUMBER OF OBSERVATIONS	46	27	22	NA	22	17
AVE RANGE: TRAVEL SPEEDS	1	3	3	NA	3	2
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	58	34	28	NA	28	21
SUM OF TRAVEL TIMES (SEC)	2106	1415	1089	NA	1347	1126
MACROSCOPIC SPEED	98	86	91	NA	73	68

N17-2(W) (2,486 KM)						H14.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	114	110	110	92	81	73
STANDARD DEVIATION	16	14	15	ERR	9	11
NUMBER OF OBSERVATIONS	62	25	11	1	4	14
AVE RANGE: TRAVEL SPEEDS	1	3	5	NA	8	4
REQ MIN NUMBER OBS	3	3	3	NA	4	3
SUM OF DISTANCES (KM)	154	62	27	2	10	35
SUM OF TRAVEL TIMES (SEC)	4971	2079	912	97	446	1764
MACROSCOPIC SPEED	112	108	108	92	80	71

N17-2(E) (2,486)						H15.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	111	93	100	NA	112	81
STANDARD DEVIATION	14	13	5	NA	0	0
NUMBER OF OBSERVATIONS	27	6	3	NA	1	1
AVE RANGE: TRAVEL SPEED	2	8	5	NA	NA	NA
REQ MIN NUMBER OBS						
SUM OF DISTANCES (KM)	67	15	7	NA	2	2
SUM OF TRAVEL TIMES (SEC)	2215	589	269	NA	80	110
MACROSCOPIC SPEED	109	91	100	NA	112	81

P35(N) (1,490 KM)						H16.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	108	99	94	NA	78	83
STANDARD DEVIATION	14	17	8	NA	12	8
NUMBER OF OBSERVATIONS	25	24	7	NA	7	14
AVE RANGE: TRAVEL SPEEDS	3	3	4	NA	5	2
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	37	36	10	NA	10	21
SUM OF TRAVEL TIMES (SEC)	1257	1355	404	NA	496	916
MACROSCOPIC SPEED	107	95	93	NA	76	82

P35(S) (1,490 KM)						H17.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	108	92	90	NA	54	53
STANDARD DEVIATION	15	16	14	NA	11	19
NUMBER OF OBSERVATIONS	46	28	12	NA	20	25
AVE RANGE: TRAVEL SPEEDS	1	3	5	NA	2	4
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	69	42	18	NA	30	37
SUM OF TRAVEL TIMES (SEC)	2325	1690	735	NA	2064	2941
MACROSCOPIC SPEED	106	89	88	NA	52	46

P30(N) (1,0 KM)						H18.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	72	73	60	47	41	41
STANDARD DEVIATION	10	10	8	5	17	17
NUMBER OF OBSERVATIONS	21	21	13	5	8	3
AVE RANGE: TRAVEL SPEEDS	2	2	2	4	7	29
REQ MIN NUMBER OBS	3	3	3	3	4	16
SUM OF DISTANCES (KM)	21	21	13	5	8	3
SUM OF TRAVEL TIMES (SEC)	1069	1061	791	390	838	300
MACROSCOPIC SPEED	71	71	59	46	34	36

P30(S) (1,0 KM)						H18.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	90	78	88	NA	82	60
STANDARD DEVIATION	11	10	9	NA	3	27
NUMBER OF OBSERVATIONS	17	7	10	NA	4	4
AVE RANGE: TRAVEL SPEEDS	2	5	4	NA	3	24
REQ MIN NUMBER OBS	3	3	3	NA	3	13
SUM OF DISTANCES (KM)	17	7	10	NA	4	4
SUM OF TRAVEL TIMES (SEC)	693	328	415	NA	177	390
MACROSCOPIC SPEED	88	77	87	NA	81	37

P122-1 (3,014 KM)						H20.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	98	91	95	NA	71	60
STANDARD DEVIATION	13	15	6	NA	15	11
NUMBER OF OBSERVATIONS	39	20	2	NA	14	5
AVE RANGE: TRAVEL SPEEDS	2	3	12	NA	4	9
REQ MIN NUMBER OBS	3	3	7	NA	3	4
SUM OF DISTANCES (KM)	118	60	6	NA	42	15
SUM OF TRAVEL TIMES (SEC)	4368	2442	229	NA	2279	934
MACROSCOPIC SPEED	97	89	95	NA	67	58

P2-5(E): CULLINAN (1,999 KM)						H21.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	97	85	91	73	67	66
STANDARD DEVIATION	14	10	13	0	12	7
NUMBER OF OBSERVATIONS	14	7	10	1	14	5
AVE RANGE: TRAVEL SPEEDS	4	5	5	NA	3	5
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	28	14	20	2	28	10
SUM OF TRAVEL TIMES (SEC)	1062	602	804	98	1554	548
MACROSCOPIC SPEED	95	84	90	73	65	66

P2-5(W): CULLINAN (2,003 KM)						H22.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	89	83	79	74	67	55
STANDARD DEVIATION	12	10	16	ERR	9	17
NUMBER OF OBSERVATIONS	38	35	18	1	9	10
AVE RANGE: TRAVEL SPEEDS	1	1	3	NA	4	5
REQ MIN NUMBER OBS	3	3	3	NA	3	3
SUM OF DISTANCES (KM)	76	70	36	2	18	20
SUM OF TRAVEL TIMES (SEC)	3139	3097	1734	98	980	1467
MACROSCOPIC SPEED	87	81	75	74	66	49

P2-5(E) (2,003 KM)						H23.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	87	84	82	63	72	56
STANDARD DEVIATION	14	11	14	8	13	17
NUMBER OF OBSERVATIONS	33	27	22	8	8	13
AVE RANGE: TRAVEL SPEEDS	2	2	4	3	5	4
REQ MIN NUMBER OBS	3	3	3	3	3	3
SUM OF DISTANCES (KM)	66	54	44	16	16	26
SUM OF TRAVEL TIMES (SEC)	2813	2348	2018	931	824	1862
MACROSCOPIC SPEED	85	83	79	62	70	50

P2-5(W) (2,003 KM)						H24.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	98	89	86	86	80	73
STANDARD DEVIATION	12	12	18	6	17	9
NUMBER OF OBSERVATIONS	43	31	19	2	7	9
AVE RANGE: TRAVEL SPEEDS	1	2	4	11	9	4
REQ MIN NUMBER OBS	3	3	3	7	4	3
SUM OF DISTANCES (KM)	86	62	38	4	14	18
SUM OF TRAVEL TIMES (SEC)	3216	2564	1679	169	673	898
MACROSCOPIC SPEED	96	87	82	85	75	72

P1386 (1,490 KM)						H25.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	70	62	61	63	62	63
STANDARD DEVIATION	12	9	10	13	8	10
NUMBER OF OBSERVATIONS	25	22	9	15	7	3
AVE RANGE: TRAVEL SPEEDS	2	2	4	4	4	12
REQ MIN NUMBER 0BS	3	3	3	3	3	7
SUM OF DISTANCES (KM)	37	33	13	22	10	4
SUM OF TRAVEL TIMES (SEC)	2003	1933	810	1353	612	261
MACROSCOPIC SPEED	67	61	60	59	61	62

P1814 (2,0 KM)						H26.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	94	92	NA	NA	75	NA
STANDARD DEVIATION	9	10	NA	NA	11	NA
NUMBER OF OBSERVATIONS	9	11	NA	NA	4	NA
AVE RANGE: TRAVEL SPEEDS	4	3	NA	NA	10	NA
REQ MIN NUMBER OBS	3	3	NA	NA	4	NA
SUM OF DISTANCES (KM)	18	22	NA	NA	8	NA
SUM OF TRAVEL TIMES (SEC)	693	867	NA	NA	394	NA
MACROSCOPIC SPEED	94	91	NA	NA	73	NA

P734 (2,92 KM)						H27.WK1
	CARS	LDVs	M-BUSES	BUSES	MGVs	HGVs
AVERAGE SPEED	74	72	NA	NA	65	NA
STANDARD DEVIATION	17	10	NA	NA	10	NA
NUMBER OF OBSERVATIONS	12	10	NA	NA	4	NA
AVE RANGE: TRAVEL SPEEDS	6	4	NA	NA	8	NA
REQ MIN NUMBER OBS	4	3	NA	NA	4	NA
SUM OF DISTANCES (KM)	35	29	NA	NA	12	NA
SUM OF TRAVEL TIMES (SEC)	1786	1486	NA	NA	659	NA
MACROSCOPIC SPEED	71	71	NA	NA	64	NA