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CAPACITY OF TWO-LANE ROADS

Prepared on behalf of the SOUTH AFRICAN ROADS BOARD

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SINOPSIS (AFR.)

Verbande tussen spoed vs digtheid, volume, en persentasie lusbesitting word ondersoek. Die uitwerking van verskillende rigtingsverdelings in verkeersvolumes word ook ondersoek. 'n Metode om die diensvlak van tweerigtingpaaie te bepaal in terme van die persentasie volgtyd, bereken van die verkeersvolume, word voorgestel.

SYNOPSIS (ENG.)

Relationships of speed vs density, volume and percentage loop occupation are investigated. The effect of differing directional splits in traffic volumes is also examined. A method of determining the Level-of-Service of two-lane roads in terms of the percentage time following, which is calculated from the traffic volume, is proposed.

TREFWOORDE
KEY WORDS Speed, flow, density, volume, capacity, level-of-service, platoons.

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DISCLAIMER

The views and opinions expressed in this report are those of the author and do not necessarily represent South African Roads Board policy.

SOUTH AFRICAN ROADS BOARD RESOLUTION

This report has been approved for general distribution by the South African Roads Board on 19 March 1992.

REVIEW

This report was reviewed by Messrs. P Fanner and HK Hoffmann.

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1. INTRODUCTION

This report discusses the analysis of traffic data which have been collected on various two-lane two-way roads in the Transvaal.

The objectives of this study are to establish the following parameters and relationships:

- The capacity of two lane roads;
- The percentage time following vs speed ;
- The percentage time following vs volume; and,
- The percentage time following appropriate to various levels of service.

Numerous computer programs were written to organise and analyse the data. These programs are discussed in detail in the appendix.

The following data relationships have been analyzed:

- Speed vs density;
- Speed vs volume;
- Speed vs percentage loop occupation;
- Average percentage followers vs volume;
- Average percentage followers vs speed.

All the analysis was conducted on previously collected data. These data were collected for a few days at each of the ten different locations over a period of a few months using TEL machines.

Methods of determining the Level-of-service of two-lane roads in terms of the percentage time following are devised and discussed. The percentage time following is calculated from:

- the traffic volume and/or capacity; or,
- the mean speed.

2. PREVIOUS WORK

2.1 DEFINITION OF VEHICLES IN A PLATOON:

The Highway Capacity Manual[1] (page 8-3) recommends that the percent time delay in a section is the same as the percentage of all vehicles travelling in platoons at headways less than five seconds. Joubert[2] found that this headway for South African conditions was four seconds. In this study vehicles with a headway of four seconds or less are considered to be in a platoon.

2.2 SITES:

Traffic Engineering Logger (TEL) data were collected at ten different sites. These sites were selected with the following attributes :

- Site located on a relatively straight section of roadway to minimize lane straddling;
- Vehicle speeds stable and reasonably representative of route;
- Adequate sight distance and roadside working space to ensure the safety of the personnel installing the equipment and retrieving the data.

The sites are depicted in Table 2.1.

Table 2.1 : Location, road number and type for each station.

Name	Road Number	Classification*
Chloorkop	51	B
Delmas	P36-1	B
Golden Highway	P73-1	B
Hartebeespoortdam	P2-4	B
Krugersdorp	-	B
Pietersburg	N1	A
Potchefstroom	P3-6	B
Randfontein	-	B
Rustenburg	P2-4	B
Vereeniging	P1-1	B

* A = Narrow road (3,4m lane width) with gravel shoulder
B = Standard road (3,7m lane width) with gravel shoulder

Two of the stations, namely, Golden Highway and Randfontein were considered dissimilar to the others because they were relatively close to an urban area. The vehicle speeds at these two sites were, on average, lower than at the other stations. When graphs and general relationships were produced for "all" stations combined, these two stations were excluded.

2.3 DATA COLLECTION:

The TEL's were configured to operate in Program 1. This is more detailed than Program 2 which only stores a summary of the data collected.

In Program 1 the following information is recorded for each passing vehicle :

- lane number;
- time;
- speed;
- length;
- vehicle classification (light, medium or heavy).

Each TEL was milked (stored information transferred to a cassette tape) once a day. During peak traffic periods milking was done twice a day. The data from the cassette tapes were transferred onto data discs of an IBM compatible Personal Computer. The numbers and types of vehicles recorded at each station are depicted in Table 2.2. The percentages of vehicle types are also reflected as pie charts in Figure 2.1

Table 2.2 : Volumes and classifications of vehicles recorded.

File	Total Volume (vehicles)				Percentage		
	Heavy	Medium	Light	Total	Heavy	Medium	Light
Chlo	3085	8065	114483	125633	2.5	6.4	91.1
Delm	2699	4256	51864	58819	4.6	7.2	88.2
Gold	5622	4825	102177	112624	5.0	4.3	90.7
Hart	3369	4516	88230	96115	3.5	4.7	91.8
Krug	3509	5354	52115	60978	5.8	8.8	85.5
Piet	1509	2090	23279	26878	5.6	7.8	86.6
Potc	7104	7759	108164	123027	5.8	6.3	87.9
Rand	4477	12323	102256	119056	3.8	10.4	85.9
Rust	2778	4737	75259	82774	3.4	5.7	90.9
Vere	3955	11793	155057	170805	2.3	6.9	90.8
all*	28009	48572	668461	745042	3.8	6.5	89.7

* The name "all" refers to a combination of all stations with similar characteristics and excludes Golden Highway and Randfontein as explained in Chapter 2.2 .

The file names in Table 2.2 correspond with the first four digits of the station names as depicted in Table 2.1.

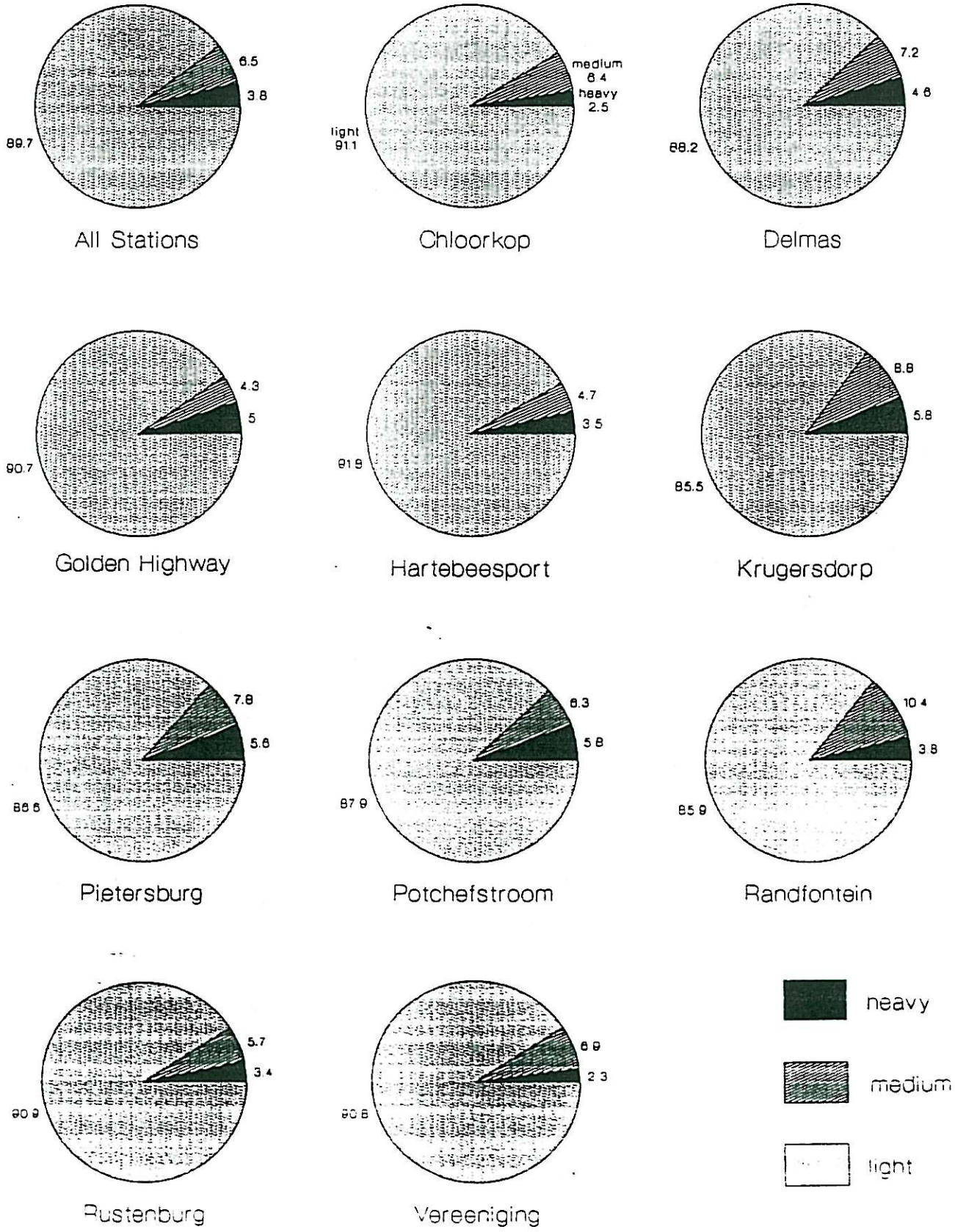

Figure 2.1 : Percentages of vehicles in classification types.

3 DATA ANALYSIS

A total of 976 709 vehicles were recorded. However, as mentioned in Chapter 2.2, Golden Highway and Randfontein were excluded when analysing "all" stations combined. (Which is why "all" in Table 2.2 depicts a total of only 745 042 vehicles). Due to the large numbers of vehicles recorded at each station, it was necessary to aggregate the data in order to present it in an uncluttered graphical form.

3.1 SPEED VS DENSITY:

3.1.1 Directional splits:

The data were divided into directional splits (according to the percentage of traffic travelling in each direction) and aggregated into 5 minute time intervals and then into density intervals with increments of one vehicle per kilometre. This was done for each station. Directional splits was considered in order to verify the factors reflected in the Highway Capacity Manual and then to use these factors when combining data of all directional splits to obtain greater accuracy in further analyses.

Directional splits appeared to have no effect on speed vs density relationships. This is discussed in greater detail in Chapter 4. Directional split was therefore not considered as a significant factor for the rest of this study.

3.1.2 No directional splits:

The data were aggregated into 5 minute time intervals and then into density intervals with increments of one vehicle per kilometre. For each density interval the mean and standard deviation as well as the minimum and maximum value of all the 5 minute space mean speeds in the interval were determined.

The speed vs density data was represented graphically using box and whisker graphs (See Appendix A for explanation of box and whisker). The "curves" drawn on each graph were calculated by performing unweighted linear regression on the means of each density interval. Unweighted linear regression was selected to remove the effects of heteroscedasticity. Heteroscedasticity is considered to be undesirable in statistics. Heteroscedasticity is when the data, on which regression analysis being performed, is not spread evenly throughout the range. For example, most of the vehicles are recorded during low density conditions. By aggregating the data into density intervals and representing each density interval by one point (which is the mean of all the 5 minute space mean speeds in that interval) the effects of heteroscedasticity are removed. However, it is important to take care that outlying points do not adversely

effect the curves fitted, since these outliers now carry the same weight as those points at lower densities which are represented by thousands of 5 minute periods.

3.2 SPEED VS VOLUME:

The intervals for volume are not specified, since these are calculated by transposing the density data. The graphs depicting speed vs volume were prepared in the same manner as that for the speed vs density graphs.

3.3 SPEED VS PERCENTAGE LOOP OCCUPATION:

Percentage loop occupation[3] is considered a more accurate means of defining traffic density than the normal number of vehicles per kilometre. It is a relatively new idea and is the percentage of time that the loop is occupied by a vehicle. The amount of time that a vehicle occupies a loop is calculated by dividing the vehicles's length by it's speed. For this study, the intervals chosen for percentage loop occupation were mostly 0,25 percent. The graphs depicting speed vs percentage loop occupation were prepared in the same manner as that for the speed vs density graphs.

3.4 VOLUME OR SPEED VS PERCENTAGE FOLLOWERS

One of the objectives of this study was to devise a method of estimating the level-of-service of a road at any time. As discussed later in Chapter 4.5, the Highway Capacity Manual[1] describes level-of-service criteria in terms of percent time delay. However, it is not easy to measure the percent time delay directly and therefore a means of estimating the percent time delay from some easily measurable variable, such as speed or volume, was sought.

The percentage time delay is approximately the same as the percentage of time following. This assumption is considered acceptable by the Highway Capacity Manual[1] (Page 8-2). The percentage of time following was assumed to be the same as the percentage followers at the TEL station.

The average percentage of vehicles following another vehicle was calculated for various volume intervals and again for various speed intervals.

4. RESULTS

4.1 DIRECTIONAL SPLITS:

The data were divided into directional splits and aggregated into 5 minute time intervals and then into density intervals with increments of one vehicle per kilometre. This was done for each station. The results were scattered and inconclusive, especially when individual sites were considered. This is because, although there was a large amount of data, these data still became too thinned out when divided into directional splits. Figure 4.1 is a graph of density vs speed (with directional splits) for "all" stations combined. The curves on Figure 4.1 were produced by performing linear regression on the density vs speed data. It was found that the linear regression results obtained when weighting[4] the points (where the weights were the square root of the number of 5 minute data points in any particular directional split and density group) gave the best results. It can be seen that, except for the 100-0 split (which includes splits to 95-5), the effect of considering the data in the different directional splits does not produce any conclusive trend. This remains so even when using other forms of weighting, or no weighting at all in the linear regressions.

These results are in contradiction to the findings of the Highway Capacity manual[1] (page 8-6). The following explanations are mooted:

- Our data did not contain enough high volume traffic.
- 745 000 vehicles is a large sample, but possibly not diverse enough to draw conclusions about the effects of directional splits.
- The reason why the 100-0 data looks so dissimilar to the rest is because there was a lack of high volume traffic data with such a high directional imbalance of traffic. Using holiday traffic data could fill this void.

When the data was recorded (not part of this project) it was not anticipated that such directional splitting would be investigated, otherwise data with more differing directional splits would have been gathered.

In view of the above findings, directional splits were not considered as a significant factor in the further analysis of the data.

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[4]Weighting methods and their relative merits are described in Appendix A under the section LINREG.

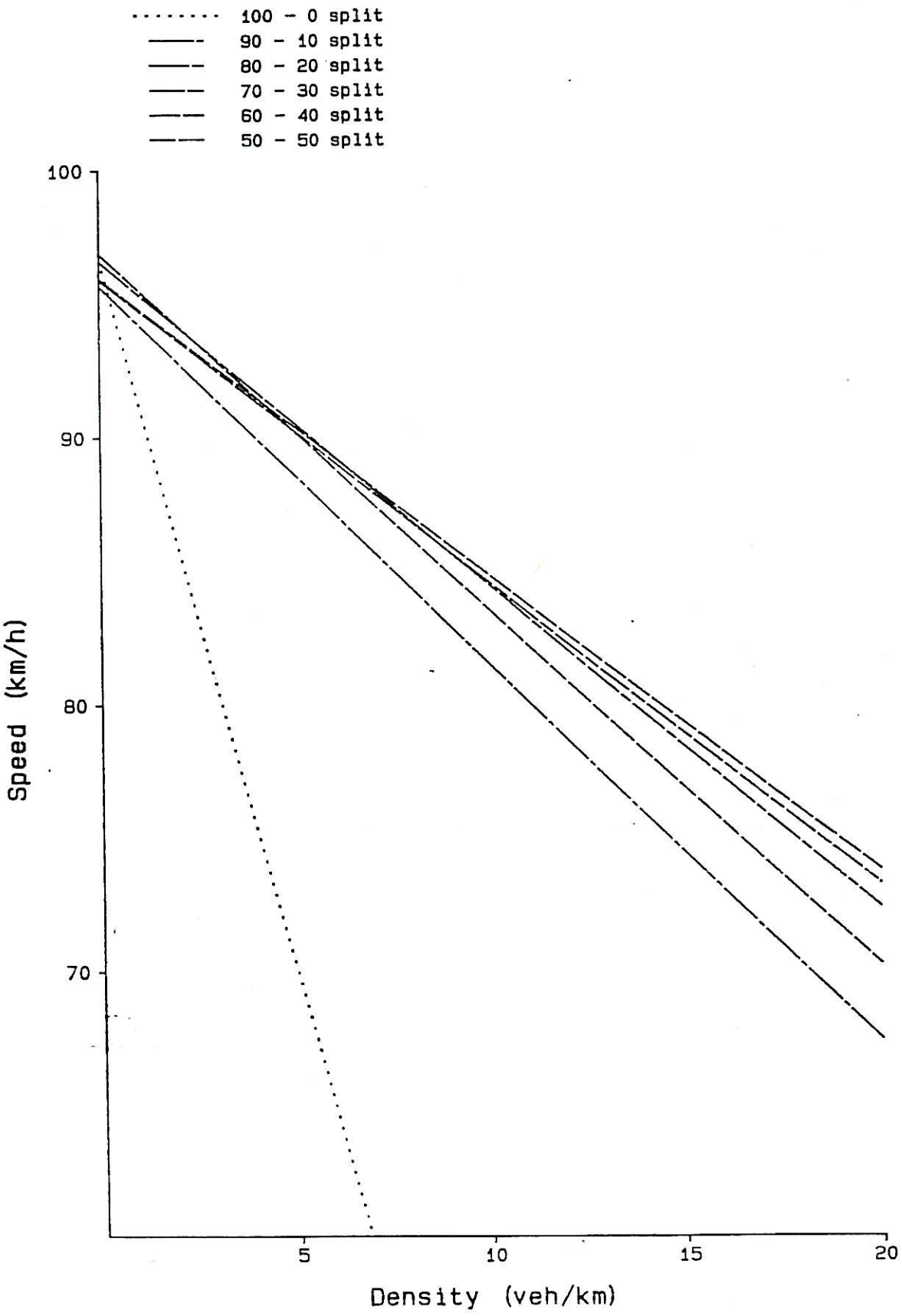


Figure 4.1 : Density vs Speed "all" stations combined. (Directional splits)

4.2 CAPACITY: (no directional splits)

The graphs of density vs speed, volume vs speed and percentage loop occupation vs speed for each individual station are shown in Appendices B, C and D respectively. The relationship of percentage loop occupation vs speed did not prove to be as successful as was expected. Examination of the raw data revealed that the lengths of vehicles appeared to be incorrect for a large number of vehicles. If this type of analysis is well received in other parts of the world, it is recommended that the accuracy of vehicle length measurements by the TEL be validated and, if necessary, improved.

The density vs speed and volume vs speed graphs for "all" the stations combined excluding Golden Highway and Randfontein are depicted in Figure 4.2.

The station at **Randfontein** is the only station where capacity volumes were reached and therefore where the "curves" can be trusted. The density vs speed and volume vs speed graphs for Randfontein are depicted in Figure 4.3. The free flow speed at this station was found to be 87.27 km/h and the jam density 76.5 veh/km. These values were determined by performing linear regression on the speed vs density data. The maximum 5 minute volume measured was 1685 veh/h.

Using the equation[4]: $$q_{max} = \frac{u_f \cdot k_j}{4} \qquad \text{[1]}$$

where : q_{max} = capacity flow (per direction)
u_f = free flow speed
k_j = jam density

the capacity flow is calculated to be 1669 veh/h in one direction. This compares very closely with the maximum measured figure of 1685 veh/h. Equation 1 is therefore considered valid.

For the same road configuration, the Highway Capacity Manual[1] suggests that capacity be estimated as follows:

Capacity = $2800 \times f_d \times f_w \times f_{HV} \times f_g$
= 2053 veh/h (sum of both directions of 80/20 split)
= 1642 veh/h (single direction comprising 80% of traffic)

where

f_d = 0,83 = Factor for directional splits (80/20 split)

f_w = 0,93 = Factor for 3.7m lanes and 0,6m shoulders

f_g = 1,00 = Factor for gradient (flat terrain)

f_{HV} = 0,95 = Factor for trucks (5% trucks {peak traffic} and level terrain)

It is clear that this road at Randfontein performs up to the expectations laid down by the Highway Capacity manual.

In Figure 4.3, volume vs speed curve for Randfontein, it can be seen that if the data points, where traffic flow appears to have started breaking down, are ignored, a linear regression line through the rest of the data points fits well giving a free flow speed of 80.8 km/h.

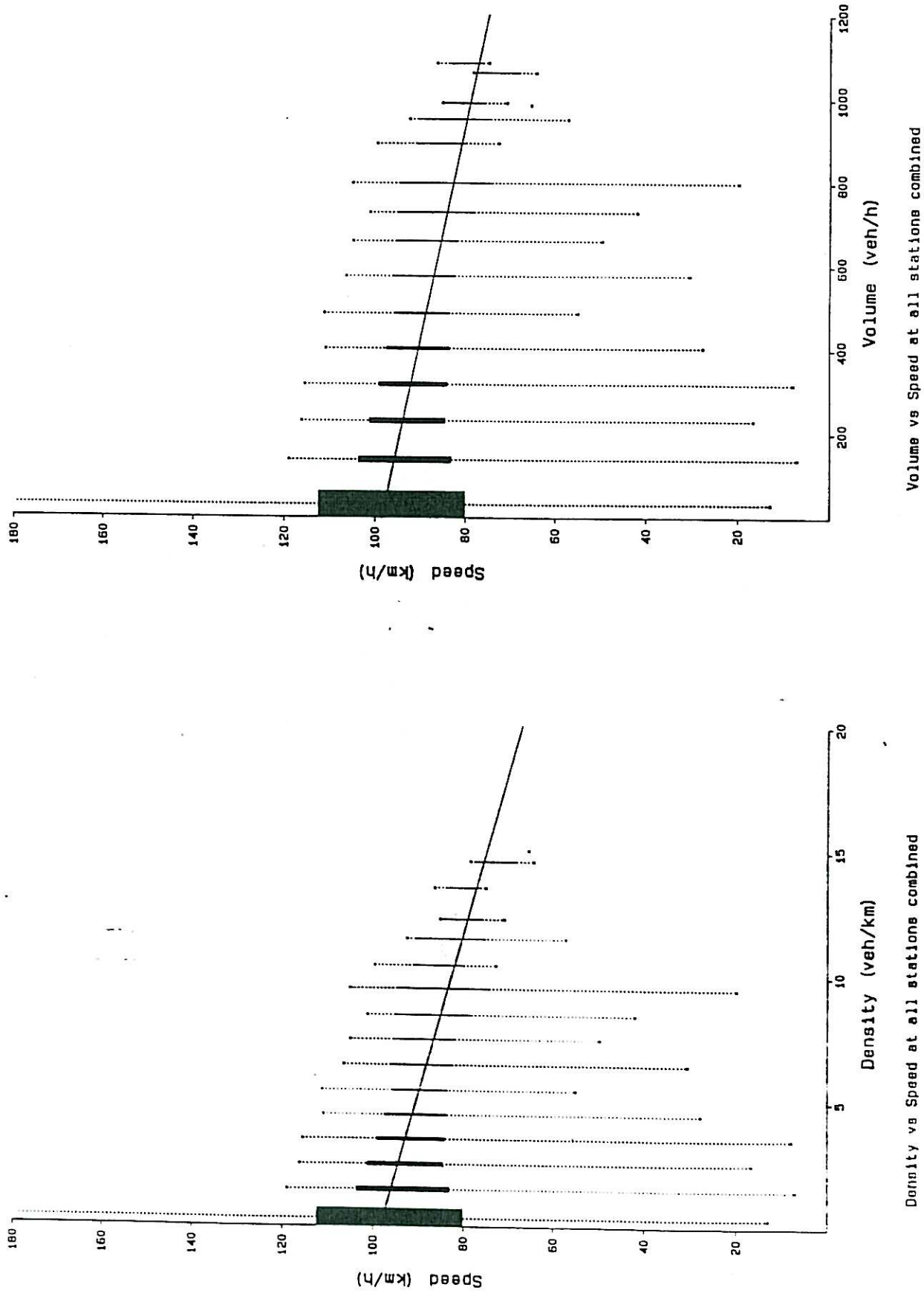
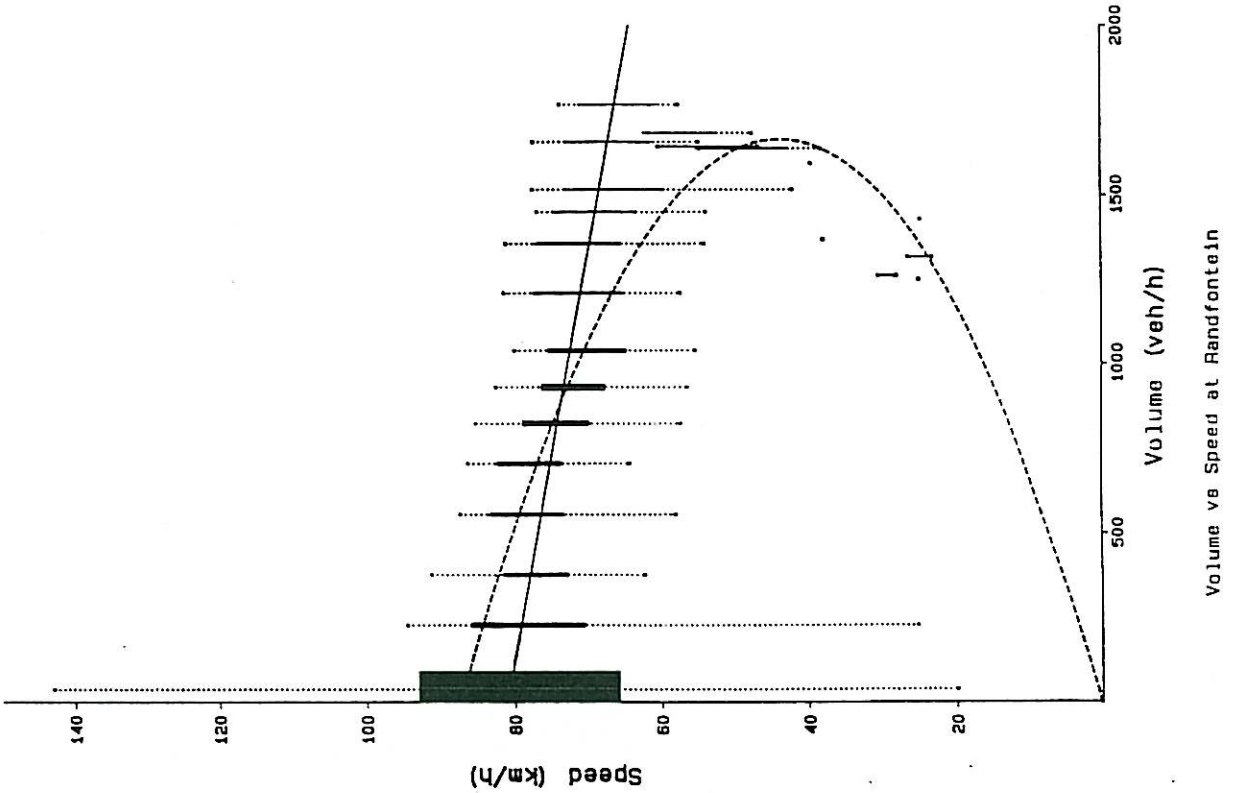


Figure 4.2 : "all" stations combined.



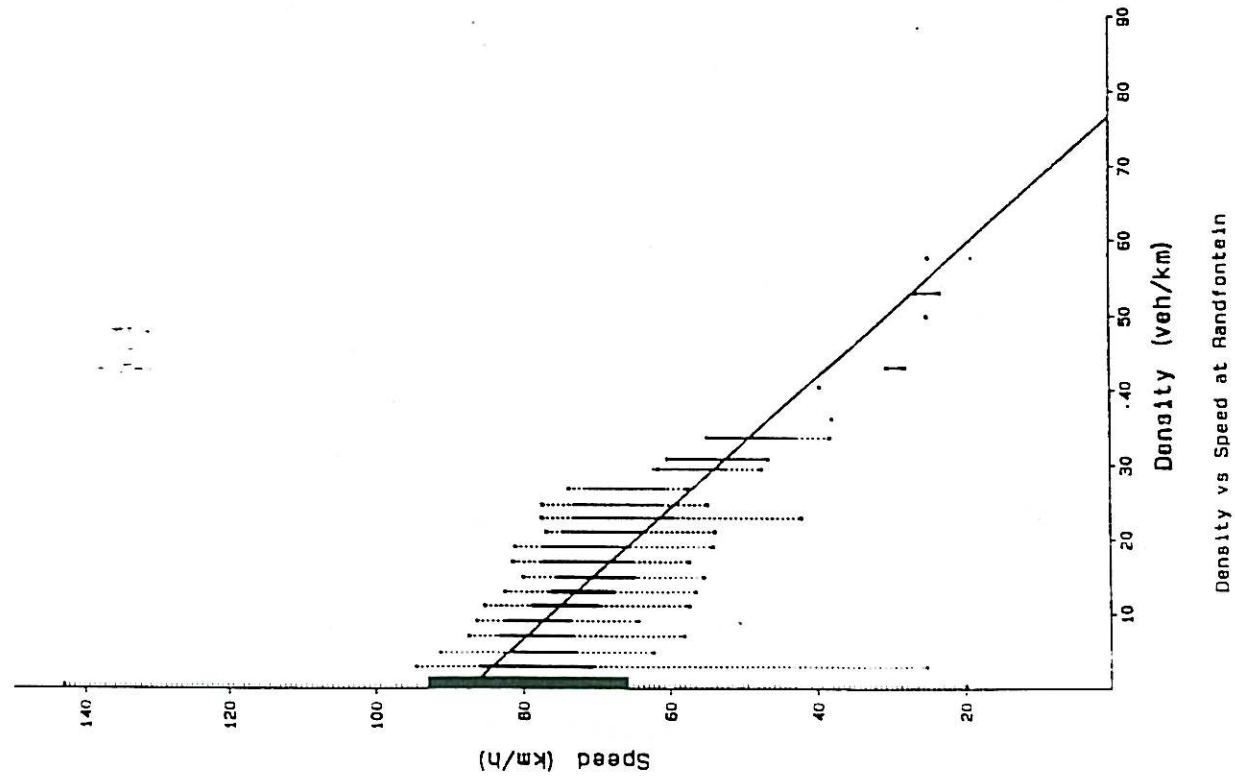


Figure 4.3 : Randfontein.

4.3 SPEED VS PERCENTAGE FOLLOWERS

Figure 4.4 is a graph of speed vs percent followers for "all" stations combined. A third degree polynomial was fitted to these speed vs percent followers data points, for "all" stations combined, and is shown in Equation 2:

$$\%\ \text{followers} = 5.4 + 0.275*s + 0.002s^2 - 0.000\ 03*s^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ [2]$$

where: s = space mean speed

When comparing all the graphs of speed vs percentage of vehicles following in Appendix E, it can be seen that the percentage followers at the highest point of the curves at each station respectively are significantly different. It is therefore concluded that speed is not a reliable means of predicting percentage of vehicles following.

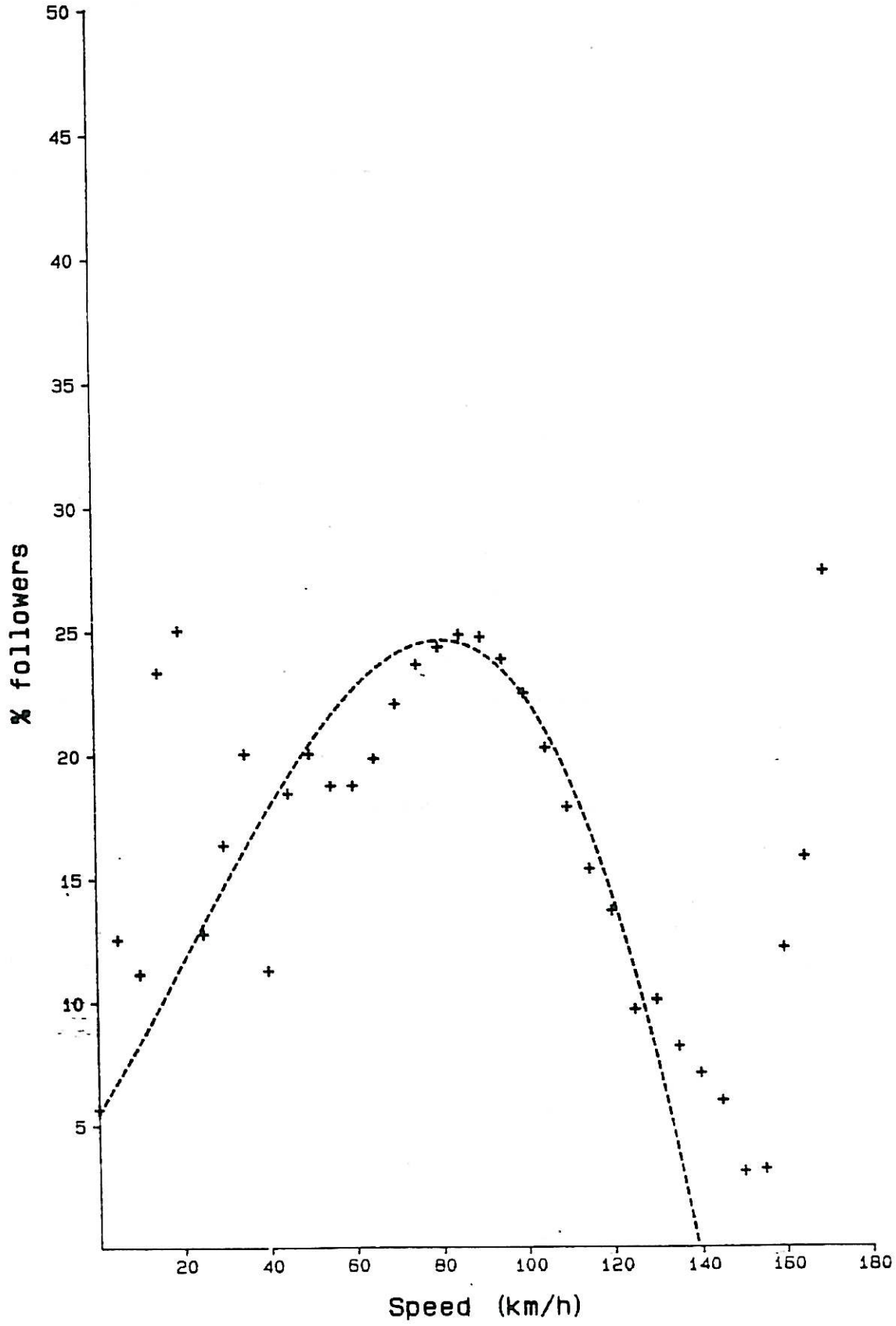
4.4 VOLUME VS PERCENTAGE FOLLOWERS

Figure 4.5 is a graph of volume vs percent followers for "all" stations combined. A third degree polynomial was fitted to these volume vs percent followers data points, for "all" stations combined, and is shown in Equation 3:

$$\%\ \text{followers} = 8.57 + 0.094*v - 0.000\ 094*v^2 + 0.000\ 000\ 032*v^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ [3]$$

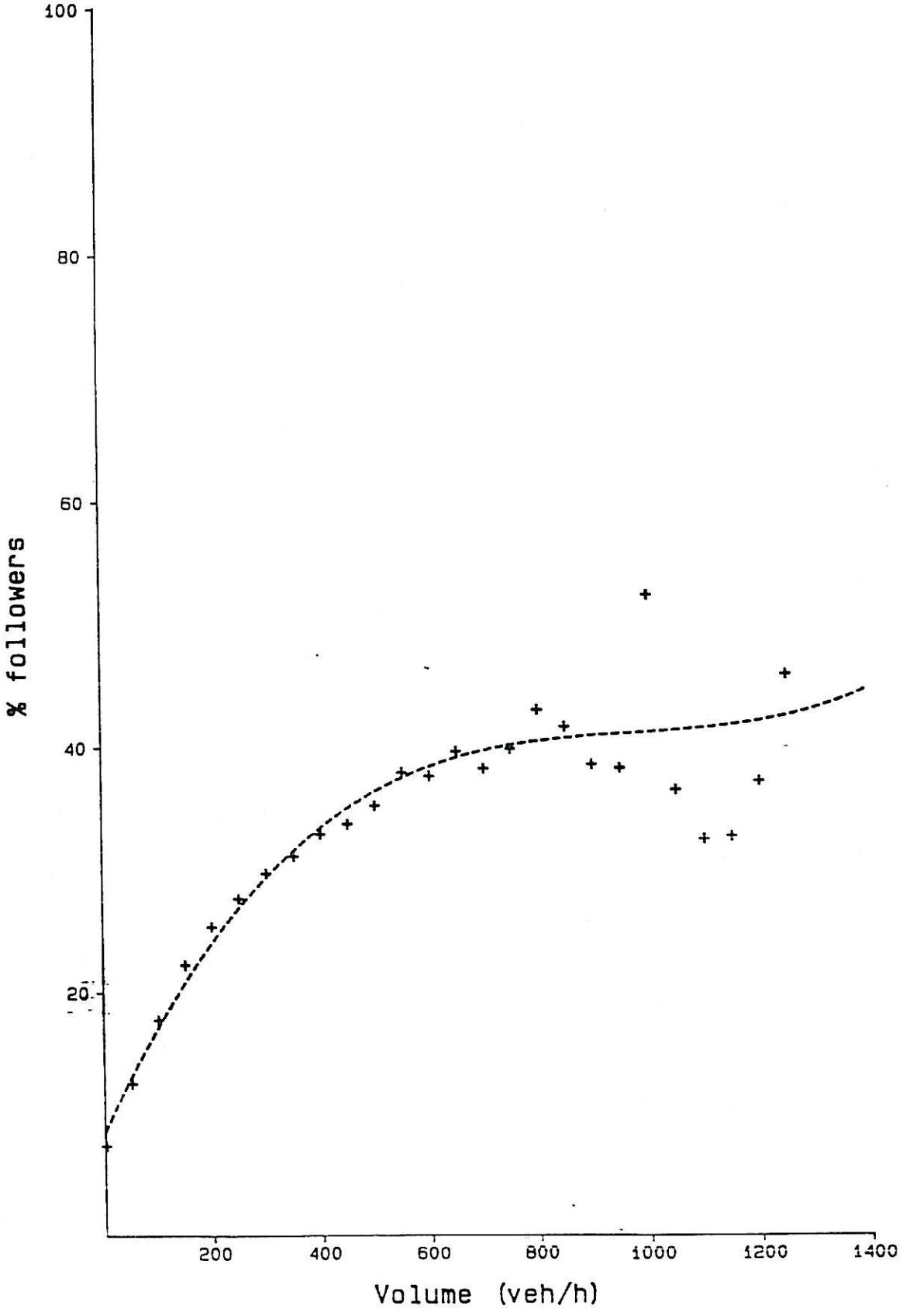
where: v = 2-way traffic volume

Equation [3] can be used to estimate the level-of-service, as discussed in Chapter 4.5. The correlation coefficient of Equation [3] is 0,955. The equations for all the other stations are depicted in Appendix F. The constants depicted in Table F1 appear to vary significantly between the different stations. However, baring Hartebeespoort, Krugersdorp and Pietersburg, where only low traffic volumes were recorded, the % followers calculated for each station at any particular volume are very similar. This is also clear when making comparisons between the different stations depicted in Figures F1-F6.



Speed vs % followers at all stations

Figure 4.4 : Speed vs percent followers for "all" stations combined.



Volume vs % followers at all stations

Figure 4.5 : Volume vs percent followers for "all" stations combined.

4.5 LEVEL-OF-SERVICE (LOS) :

In Table 8-1 of the Highway Capacity Manual[1], *level-of-service* is related to *percentage time delay*, where *percentage time delay* is defined as the average percent of the total travel time that all motorists are delayed in platoons.

This relationship is reproduced in Table 4.1 below. As mentioned earlier, *percentage followers* may be used as a surrogate measure for *percentage time delay*.

Table 4.1 : Level-of-Service criteria in terms of Percentage followers.

LOS	Percentage followers
A	≤ 30
B	≤ 45
C	≤ 60
D	≤ 75
E	> 75
F	100

The level-of-service for "all" stations can, therefore, be estimated from the traffic volume by using Equation 3 to calculate the percentage followers, after which, the level-of-service can then be read from Table 4.1

The degree of utilisation of capacity at any specific volume is calculated by dividing that volume by the volume at capacity.

It was originally postulated that the level-of-service could be estimated from the traffic speed. However, when comparing the different stations in Appendix E (Figures E1, E2, E3, E4, E5 and E6), it is clear that speed is not the dominant dependant variable for predicting percentage followers and therefore it is recommended that level-of-service may be estimated from volume vs percentage followers but not from speed vs percentage followers.

5. CONCLUSIONS

Differing directional splits in traffic volumes appears to have a negligible effect on capacities as well as on average speeds at various volumes. However, as mentioned previously, the data was not diverse enough to allow an absolute conclusion to be drawn.

The relationship between percentage loop occupation and speed should correlate better than the relationship between density and speed. However, the TEL was not designed to measure lengths accurately, it only estimates lengths. Apparently these estimations are not accurate enough to permit such relationships involving vehicle lengths to be derived.

Traffic volumes measured at most of the sites were not high enough to determine capacities with confidence, except at Randfontein where the maximum single-direction volume measured was very close to that calculated using Equation 1, namely; 1669 v/h. This figure compares very well with the capcity of 1642 (= 80% of 2053 .. for 80% of traffic in the peak direction) which was estimated using the Highway Capacity Manual.

A method of determining the Level-of-service of two-lane roads in terms of the percentage time following, was devised. The percentage time following is estimated on the basis of traffic volume.

The percentage time following and therefore, the level-of-service, cannot be calculated reliably from the space mean speed of traffic.

6. REFERENCES

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2. JOUBERT HS. Flow relationships on South African rural roads. Proceedings of the Annual Transport Convention, Pretoria, 1988.

3. HALL FL and GUNTER MA. Further analysis of the flow concentration relationship. Transportation Research Record 1091, Pages 1-9. Washington, D.C. 1988

4. INSTITUTE OF TRANSPORTATION ENGINEERS. Transportation and traffic engineering handbook. Printers Hall, Englewood Cliffs, New Jersey. United States of America, 1976.

Appendix A - Computer programs

Numerous computer programs were written in order to analyse the data. These programs, their uses, methods, inputs and outputs are discussed.

CONVER

This program converts the raw data, which has been milked from the TEL machines onto a PC, into a more useable format for use by all the other programs. The following operations and checks are performed :

- The internal clock of the TEL can only record times up to 99 999.9 seconds, thereafter it resets itself to zero again. This is dealt with;
- Checks for time swops are made and rectified;
- Vehicles with a headway of less than 0,6 seconds are assumed to be trailers and are therefore combined with the vehicle in front;
- Vehicle classifications are checked against vehicle length and these classifications are amended where considered necessary.

The output from CONVER is in binary form, by default. However, it can also output the data in ASCII format. The files produced in binary format are a quarter of the length of the files produced in ASCII format.

FLOWS

This program uses the output from CONVER (in binary or ASCII format). The data are grouped into specified time (eg. 5 minute) intervals and then into specified density, volume and percentage loop occupation intervals. These intervals are requested during each run of the program. For this study, the increments chosen for density were 1.0 vehicle per km. The intervals for volume are not specified, since these are calculated by transposing the density data. Percentage loop occupation is a relatively new idea and is the percentage of time that the loop is occupied by a vehicle. The amount of time that a vehicle occupies a loop is calculated by dividing the vehicles's length by it's speed. For this study, the intervals chosen for percentage loop occupation were mostly 0,25 percent. The average speed for each (density, volume or percentage loop occupation) interval as well as the number of 5 minute data points represented in that interval (for weighting purposes in linear regression and to aid the user in identifying outlying points) is then output. This grouping into intervals shortens the output files which makes them more manageable.

Program FLOWS also allows the user to divide the grouped data into directional splits, if required.

LINREG

This program performs linear regression on a 3-column file, where the third column consists of weights which can be applied to the data.

Linear regression equations with R and R^2 are produced using;

- data unweighted (normal)
- normal weighting
- square roots of weights
- logarithms of weights

Weighting is introduced to afford a user the opportunity to select the regression line which represents the data most realistically and is described as follows:

When the data is not evenly spread throught a range, as is the case with traffic volumes, the high concentration of data points at one end of the spectrum can dominate the regression analysis to such an extent that the low concentration of data points at the other end of the spectrum have little effect.

The solution is to divide the data into ranges, and to use the mean of each range to perform linear regression. However, cognisance must be taken of the fact that some of these means are represented by thousands of data points (and are therefore very reliable means), while others are represented by very few points. Weighting each mean by the number of points that it represents would negate the effect of dividing the data into ranges. Making use of the logorithms or square roots of these weights would appear to be a logical compromise. In this study regressions were performed using all forms of weighting, as well as no weighting at all. In each case, the resultant regression curve together with the data points were viewed graphically and the correlation coefficient checked before deciding which method of weighting gave the most representative result.

BOX

This program was used on the output from FLOWS and was used to generate files for producing box and whisker graphs.

Box and whisker graphs are used when numerous data points in a group are represented by a single value. Instead of plotting just this single value, the box indicates the 25 percentile to the 75 percentile values, while the whiskers represent the lowest and highest values respectively. When dealing with large data sets, finding the 25 and 75 percentile values presents memory capacity problems on a PC. Instead of using the 25 and 75 percentile values for the box, one standard deviation either side of the mean was used. For large data sets, this is an acceptable (and in my opinion, preferable) approximation. A further feature was added to the box and whisker plots, namely; the width of each box is directly proportional to the number of values represented by that box.

Box and whisker plots were made of density vs speed, volume vs speed and percentage loop occupation by vehicles vs speed for each station as well as for "all" stations combined.

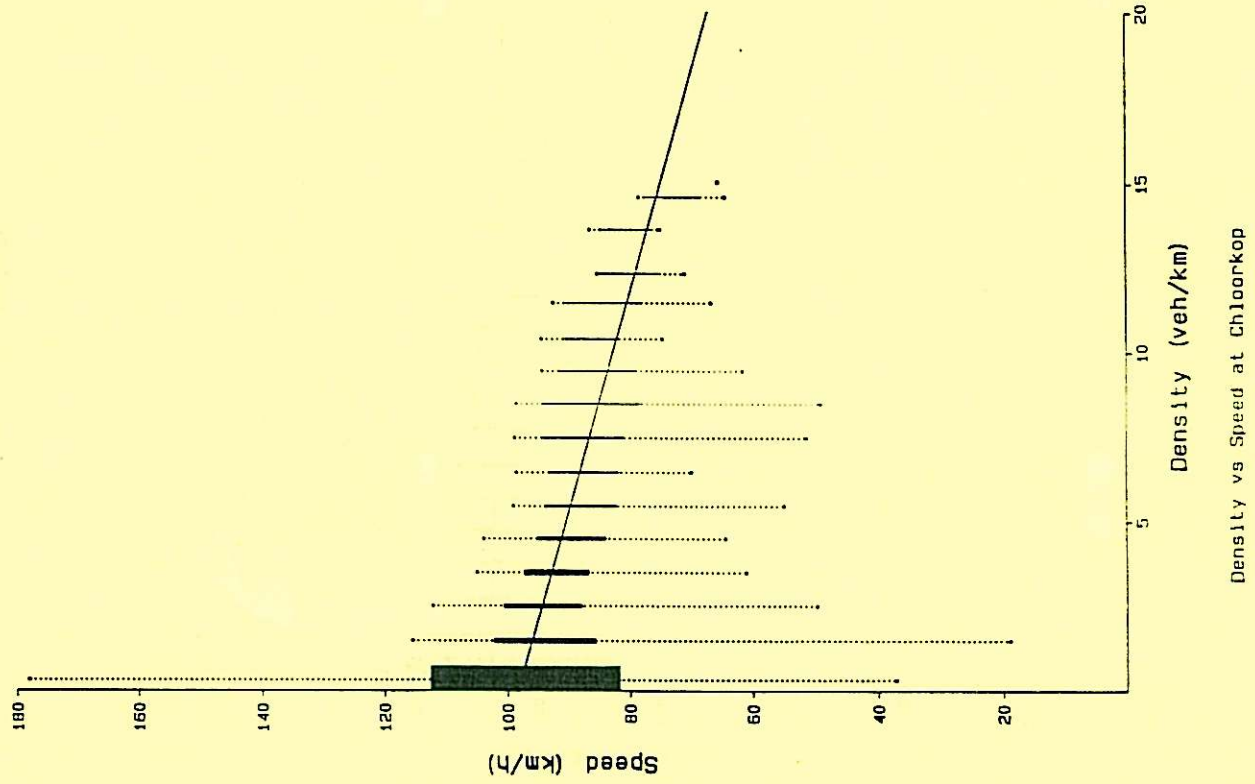
PLATA

This program uses the output from CONVER. The average platoon lengths, as well as the average percentage of vehicles following another vehicle, are calculated for various volume/density/speed intervals. For this study, the volume increments were specified as 50 veh/h, while the speed intervals were specified as 5 km/h. The relationships with densities were not investigated.

The percentage of time following is assumed to be the same as the percentage followers at the TEL station. This assumption is considered acceptable by the Highway Capacity Manual[1] (Page 8-2).

Appendix B - Traffic density vs speed

Figures B1, B2, B3, B4, B5 and B6 depict graphs of traffic density vs speed. Note the box and whisker type of presentation which conveys data-spread information graphically.



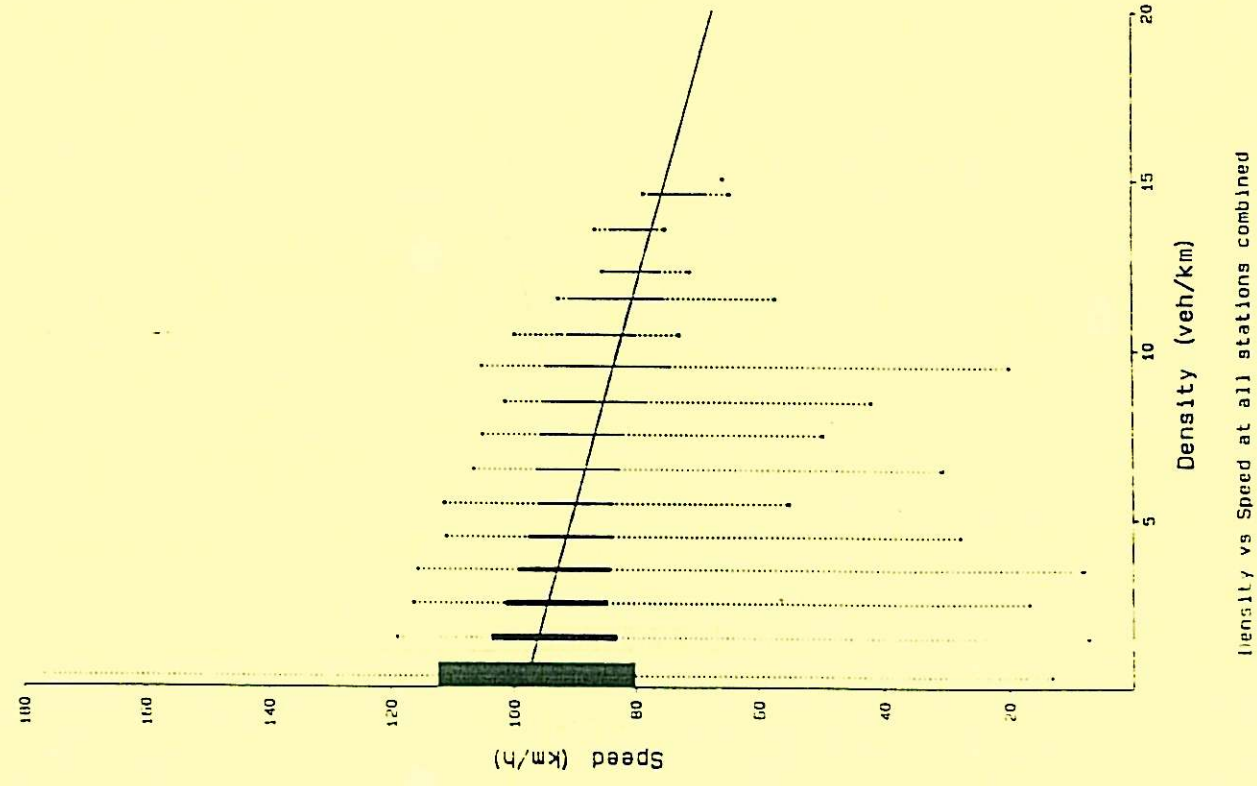
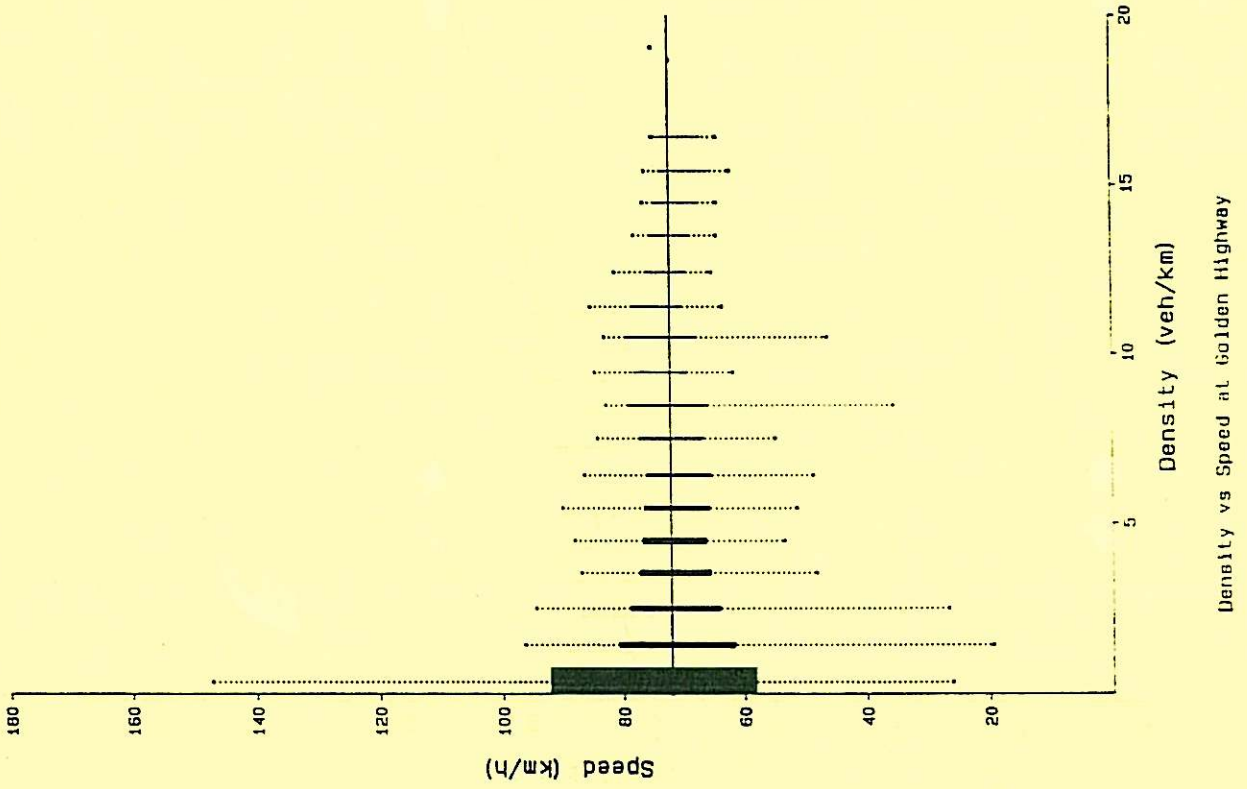


Figure B1 : Traffic density vs Speed.



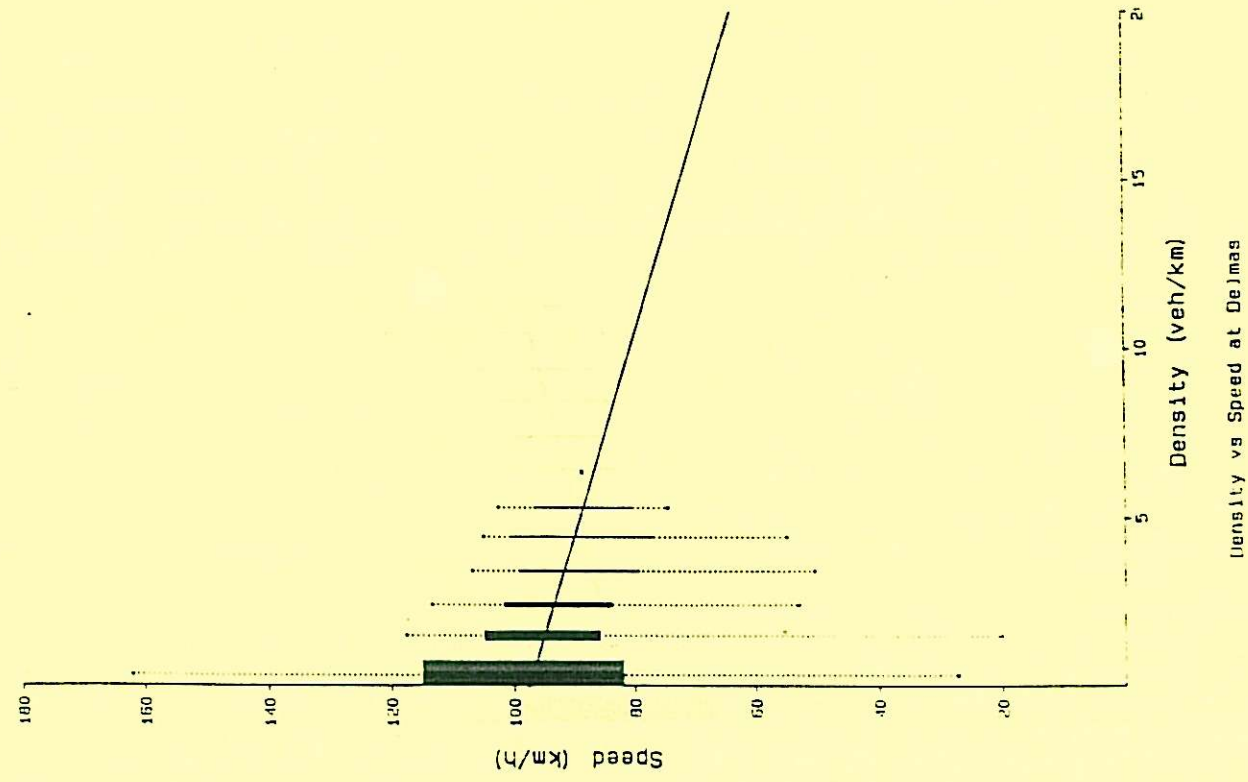
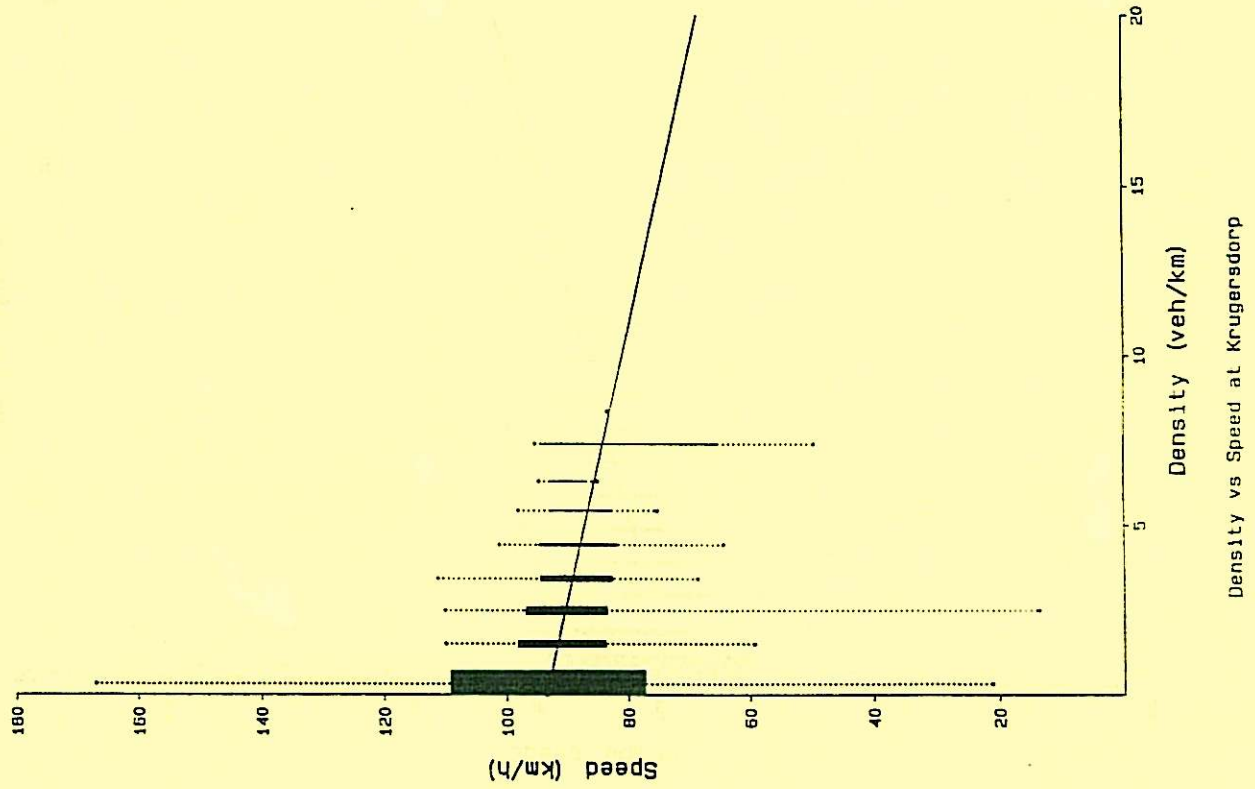


Figure B2 : Traffic density vs Speed (continued).



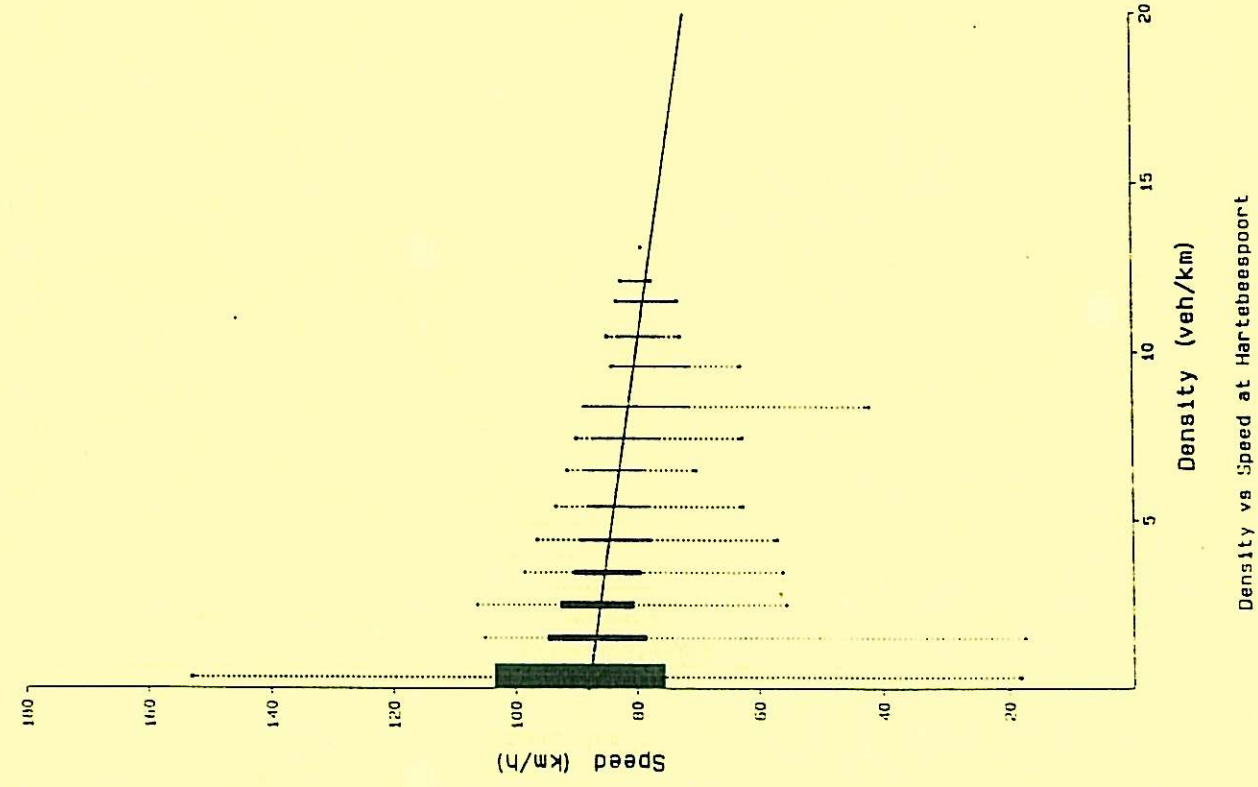
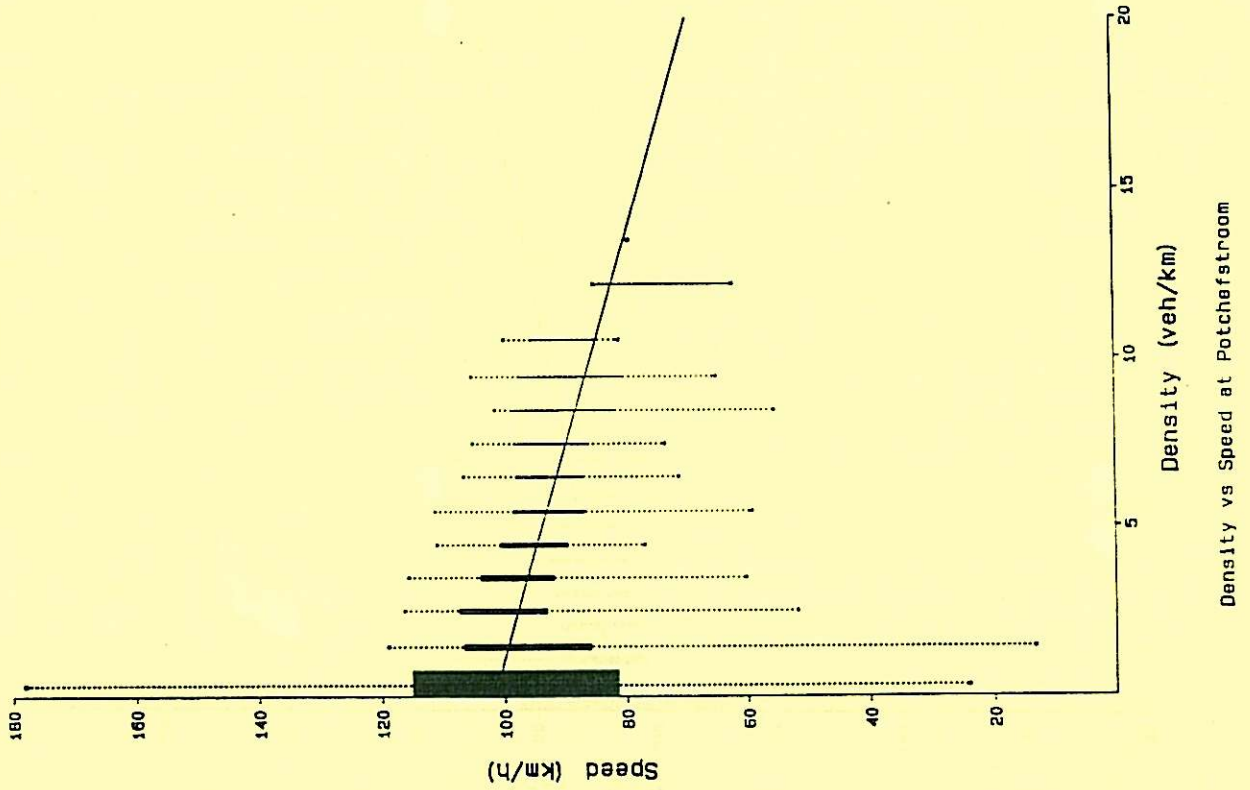


Figure B3 : Traffic density vs Speed (continued).



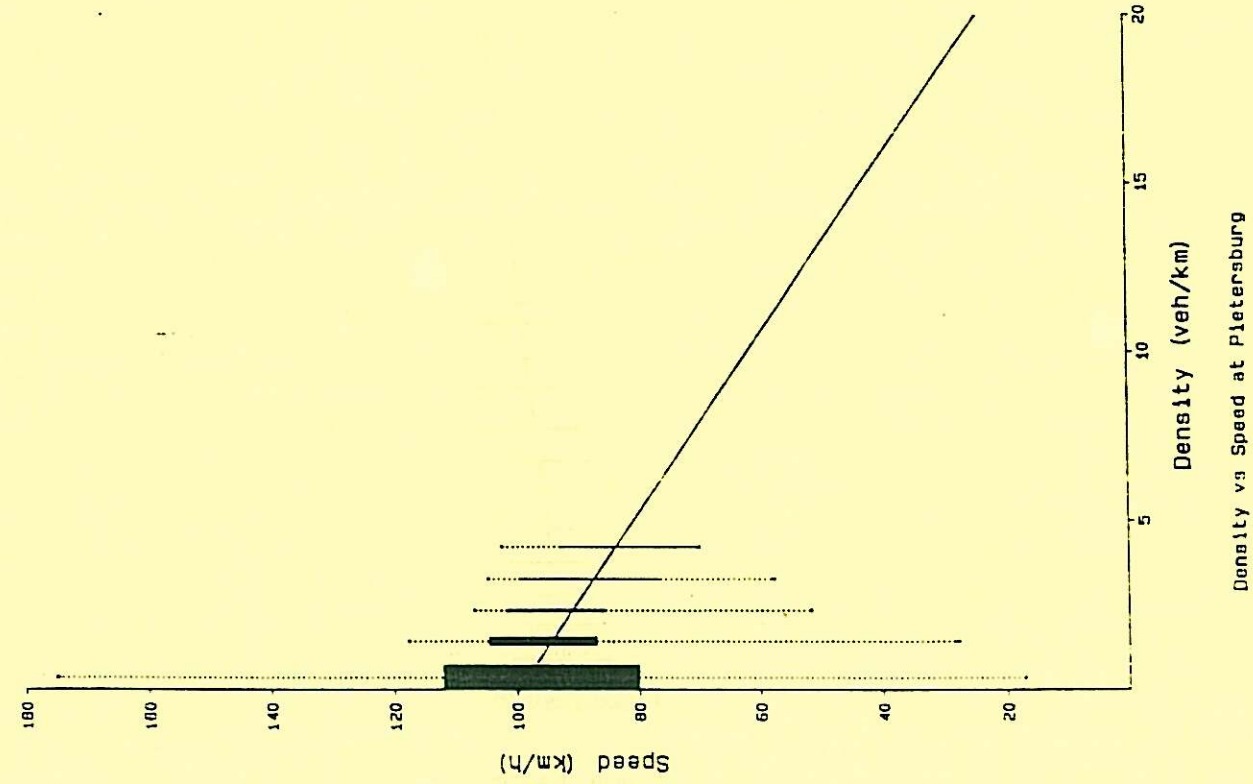
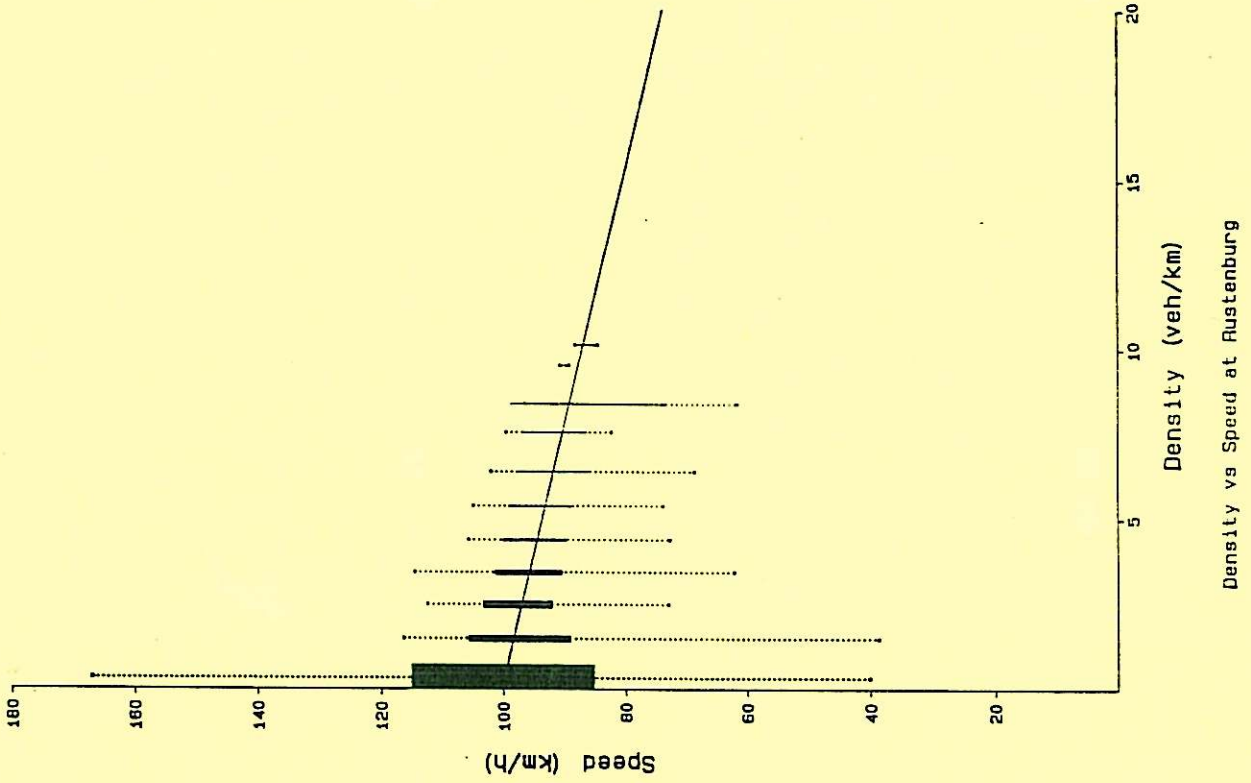


Figure B4 : Traffic density vs Speed (continued).



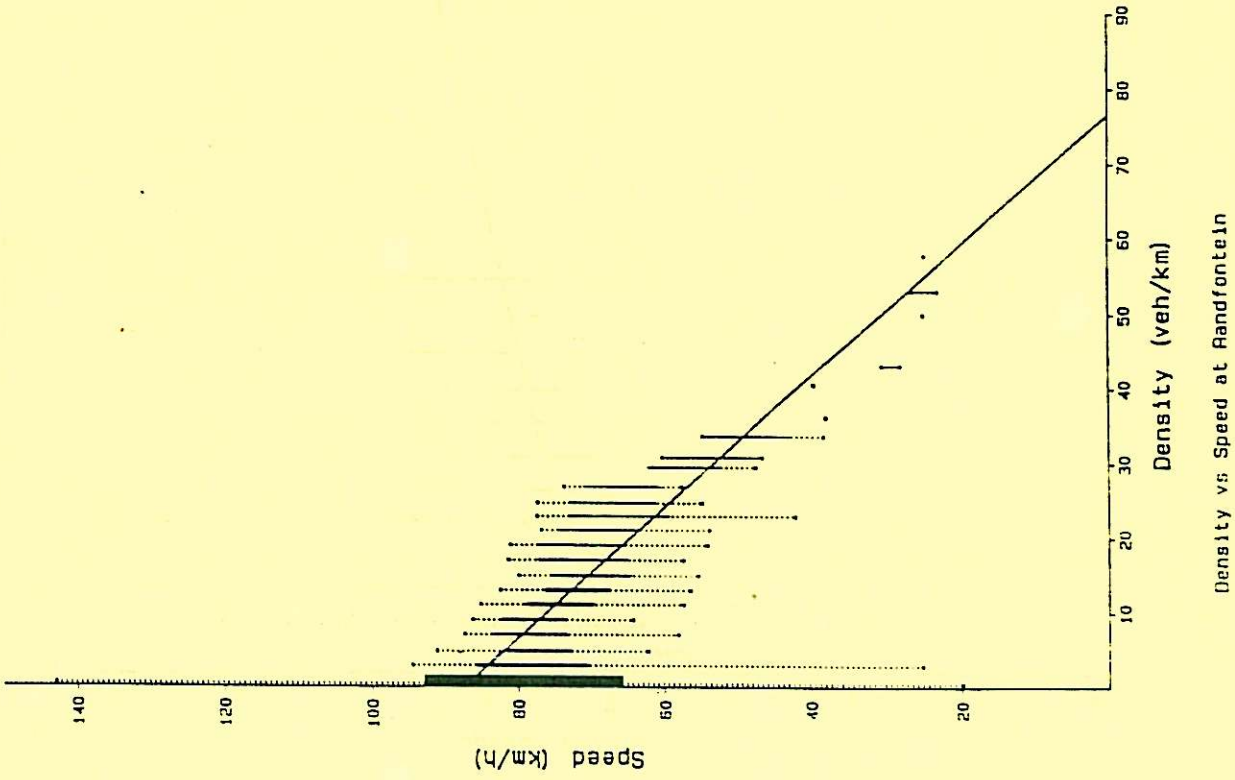


Figure B5 : Traffic density vs Speed (continued).

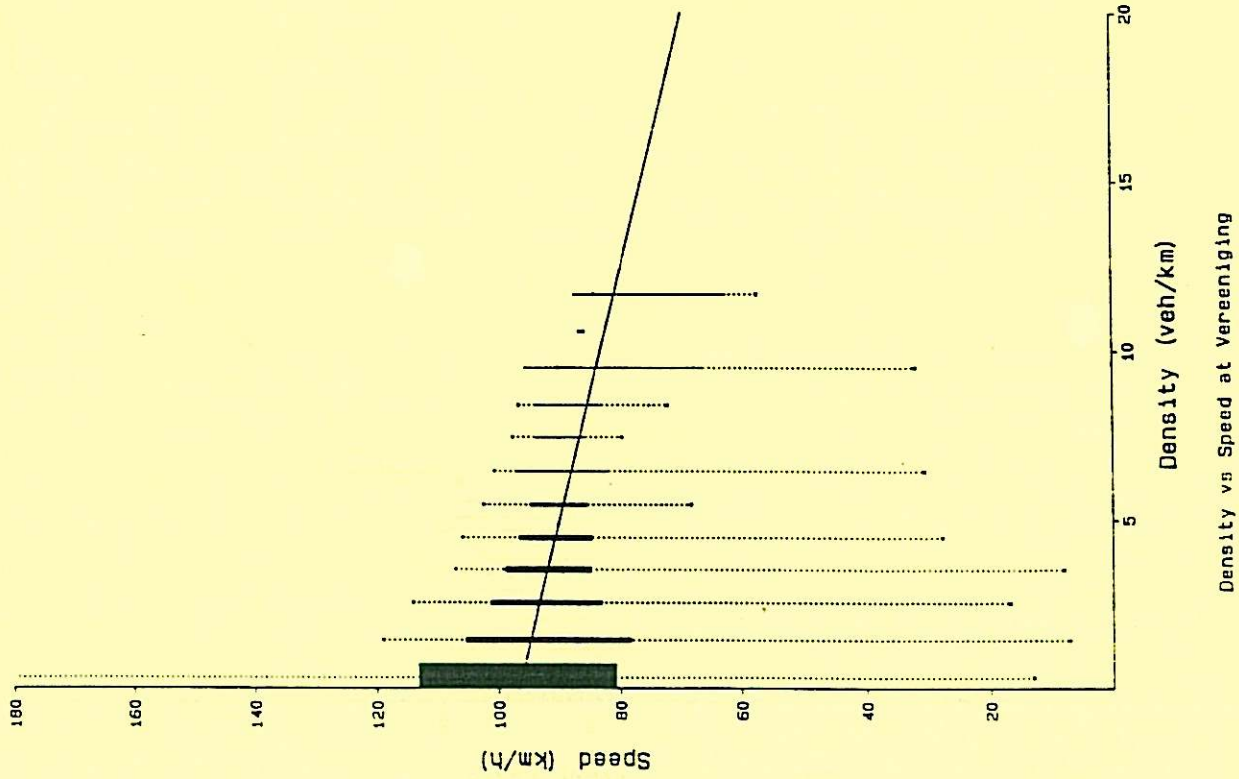


Figure B6 : Traffic density vs Speed (continued).

Appendix C : Traffic volume vs speed

Figures C1, C2, C3, C4, C5 and C6 depict graphs of traffic volume vs speed. Note the box and whisker type of presentation which conveys data-spread information graphically.

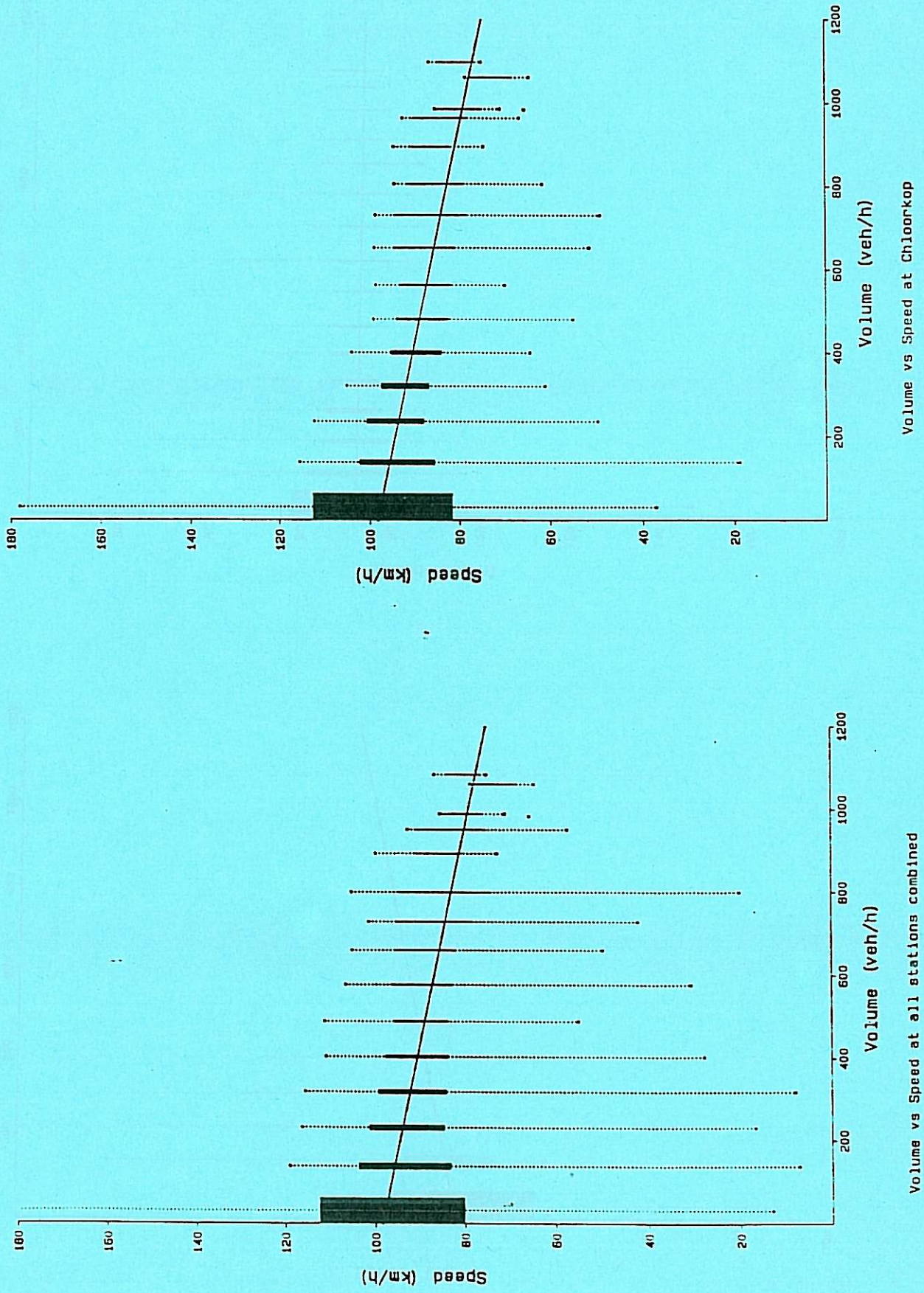


Figure C1 : Traffic volume vs Speed.

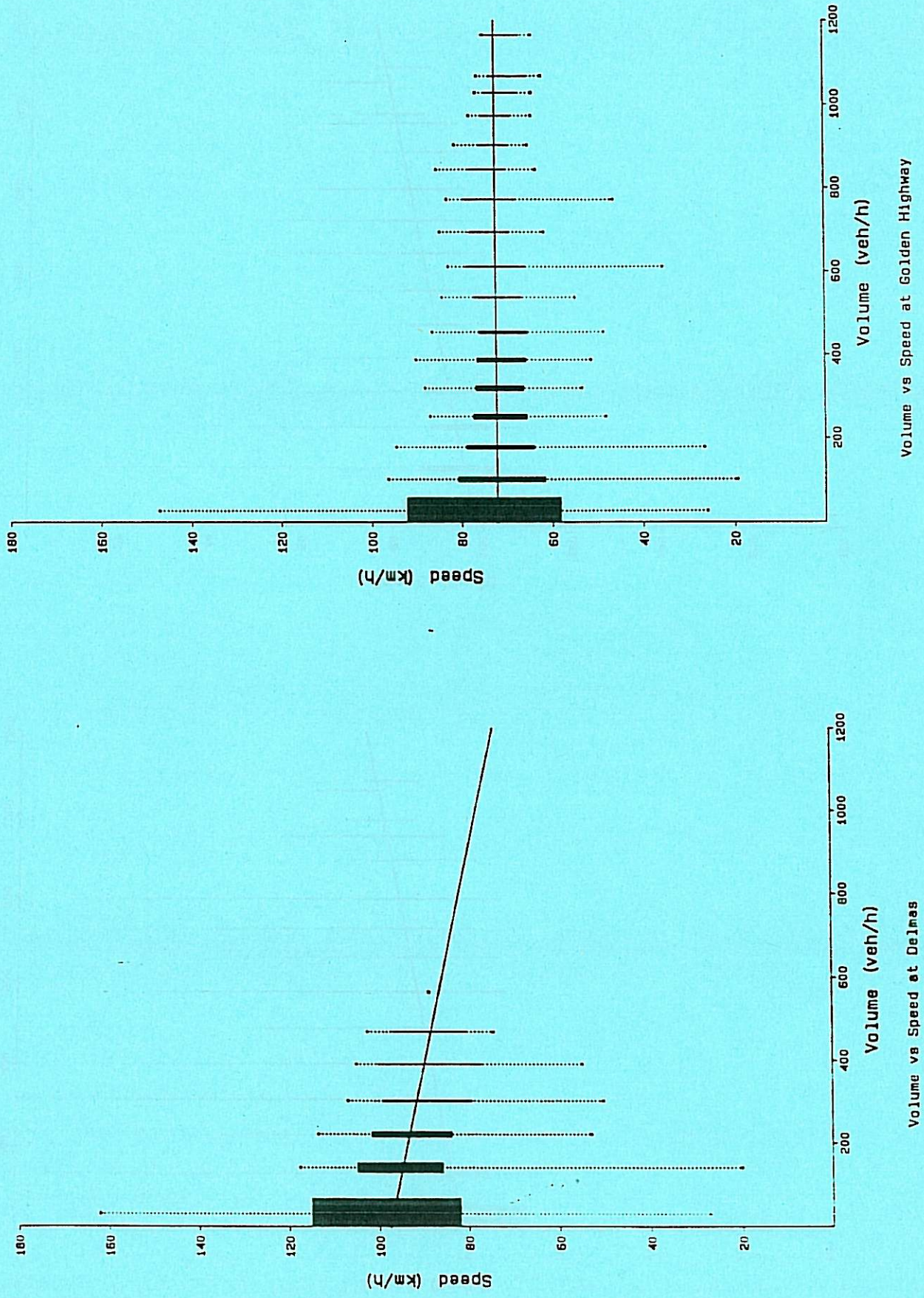


Figure C2 : Traffic volume vs Speed (continued).

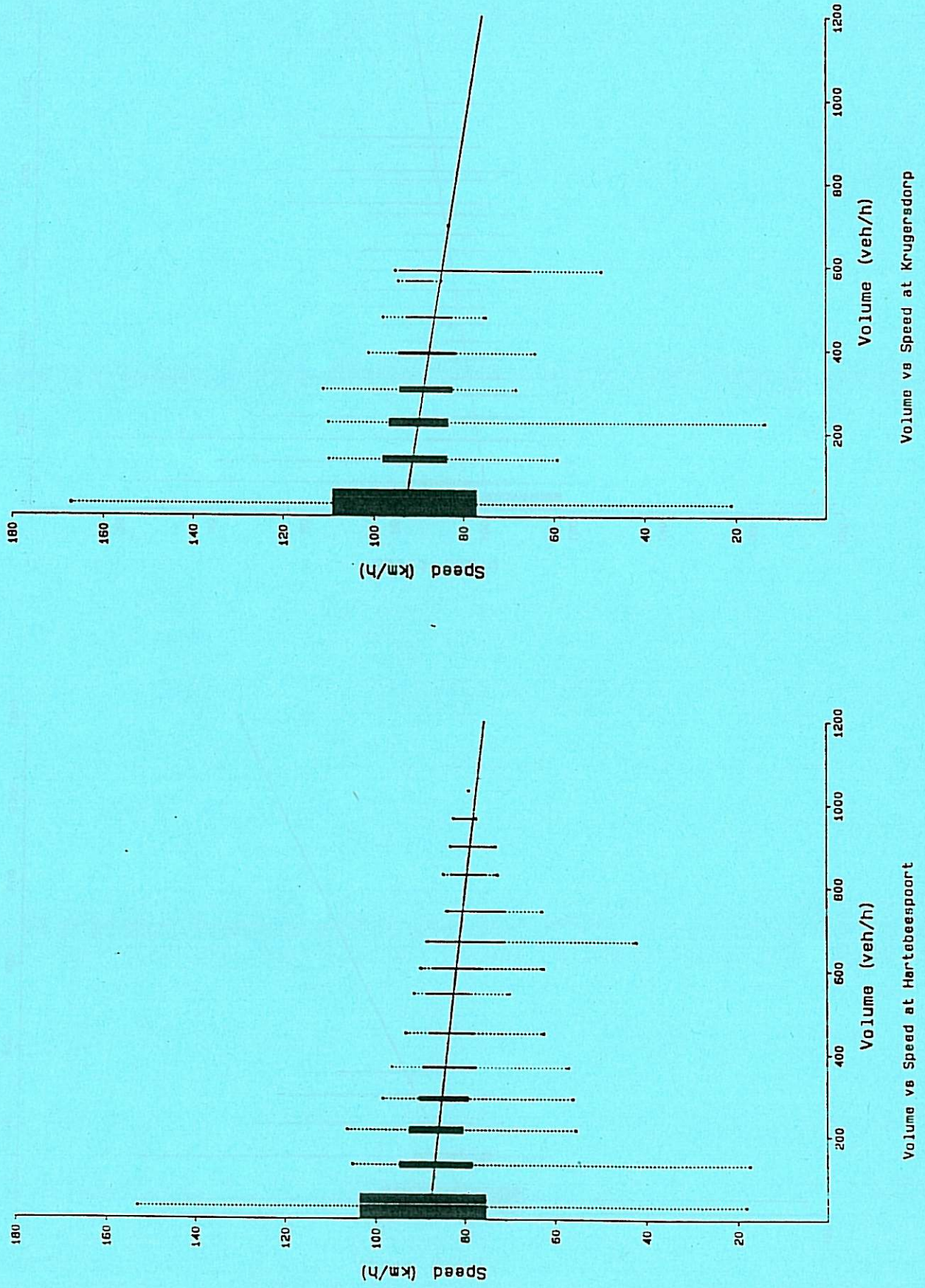
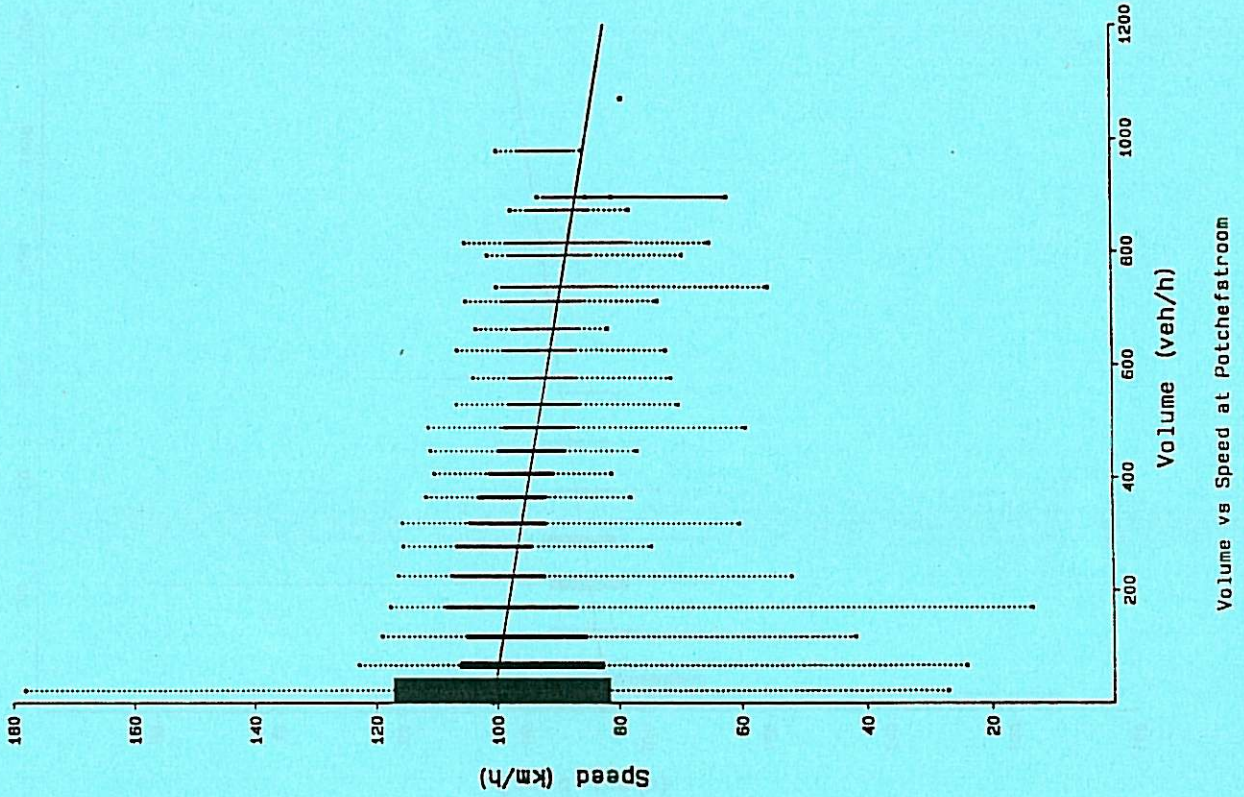


Figure C3 : Traffic volume vs Speed (continued).



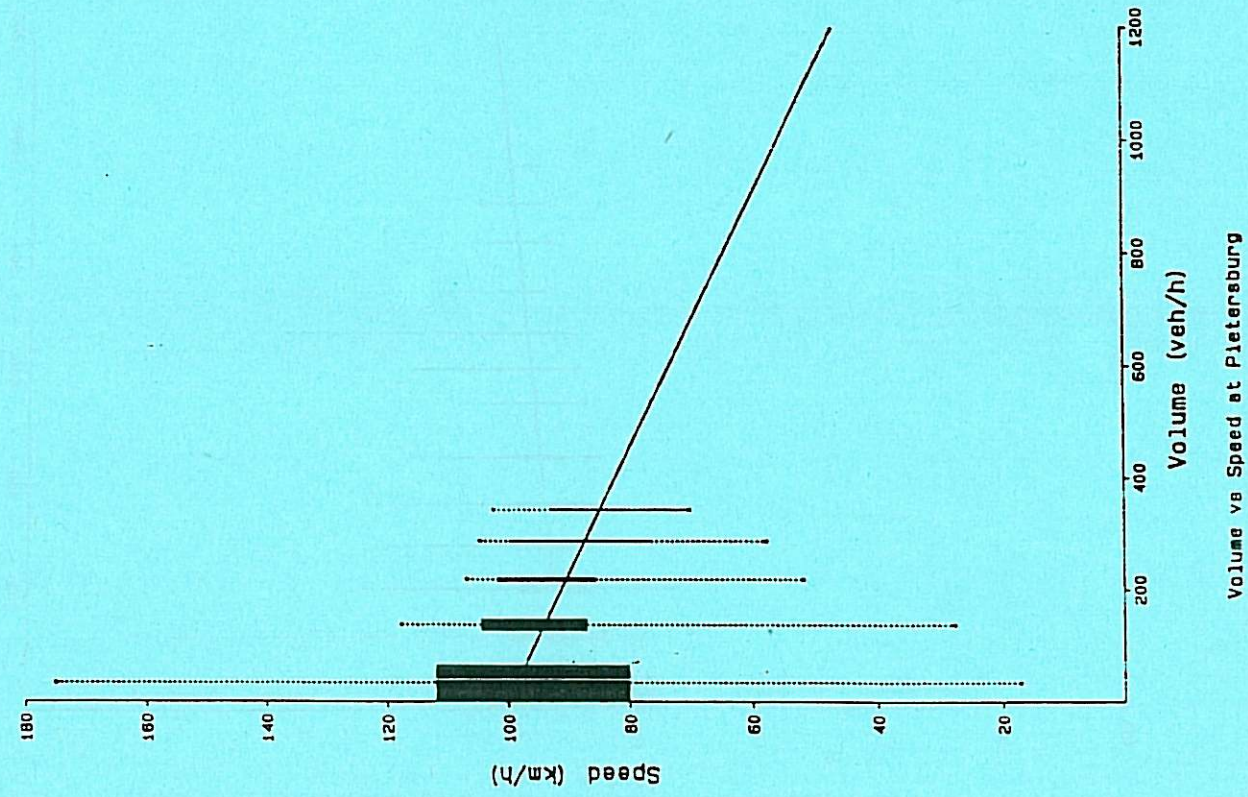
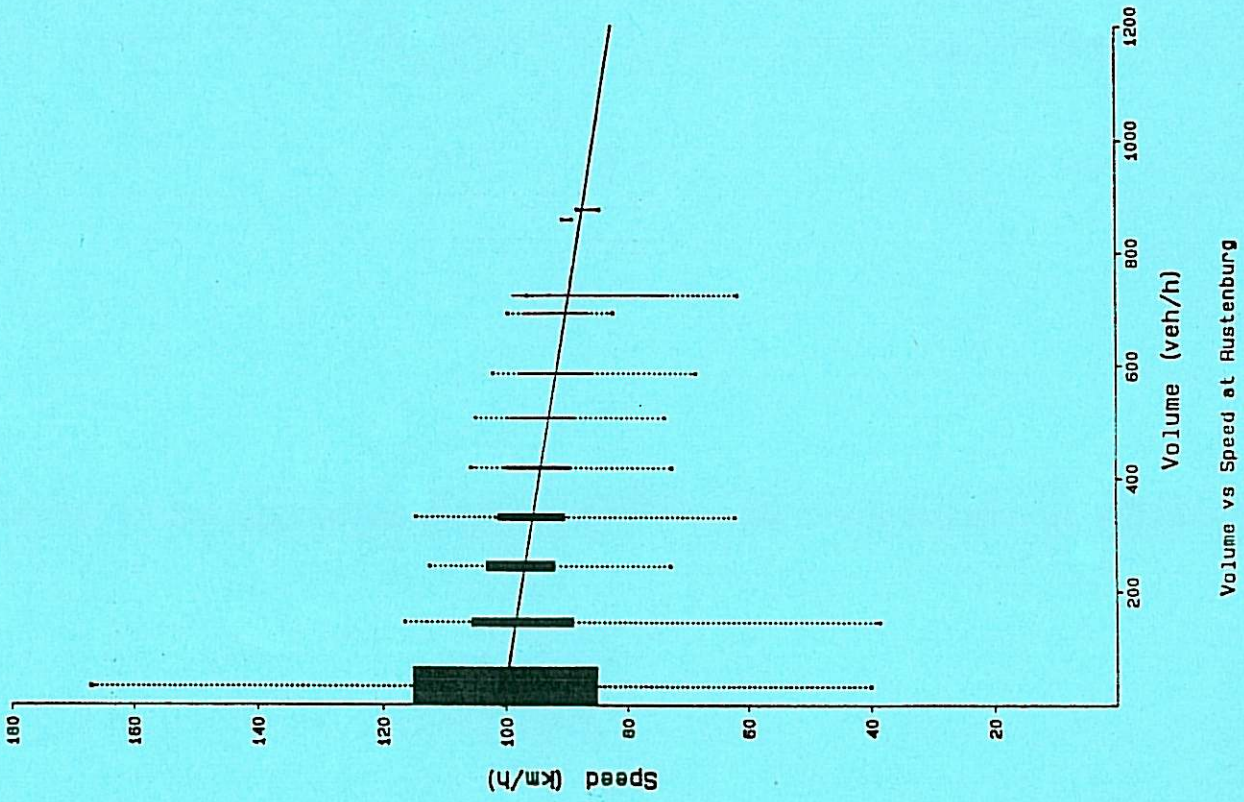


Figure C4 : Traffic volume vs Speed (continued).



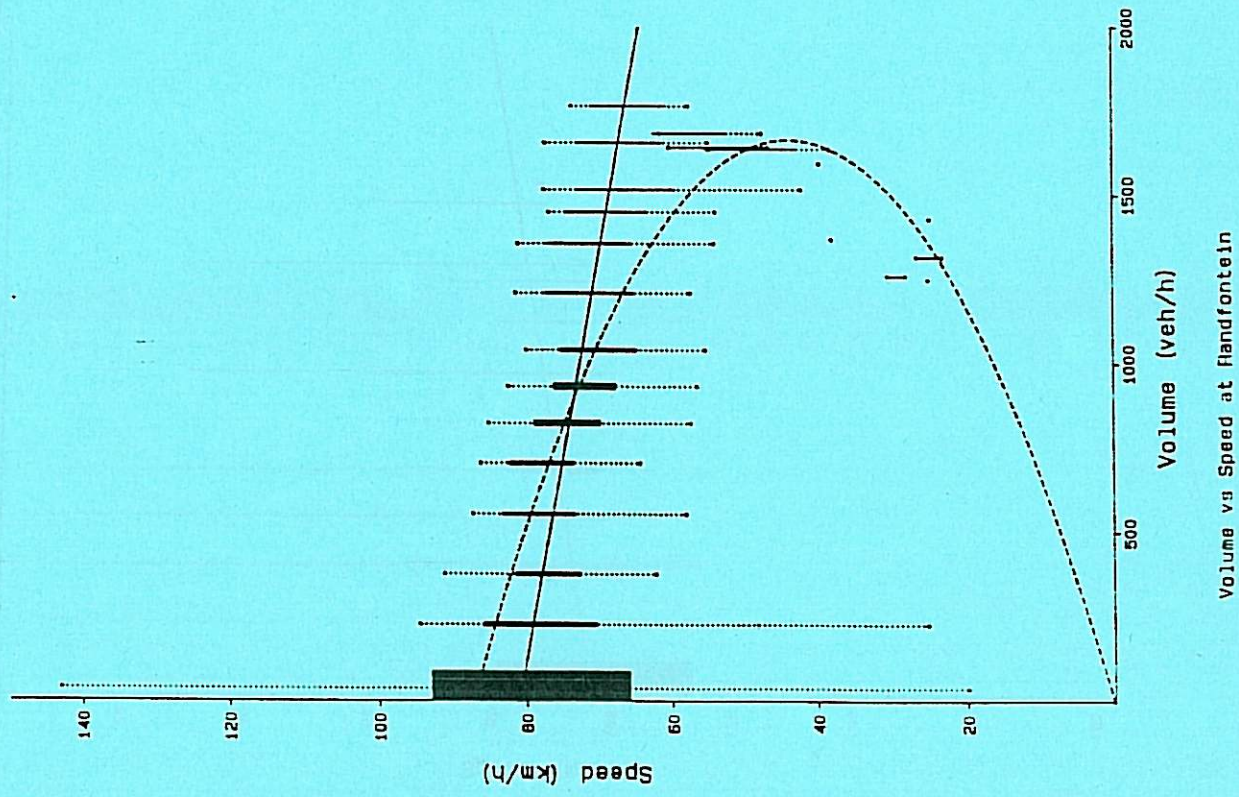


Figure C5 : Traffic volume vs Speed (continued).

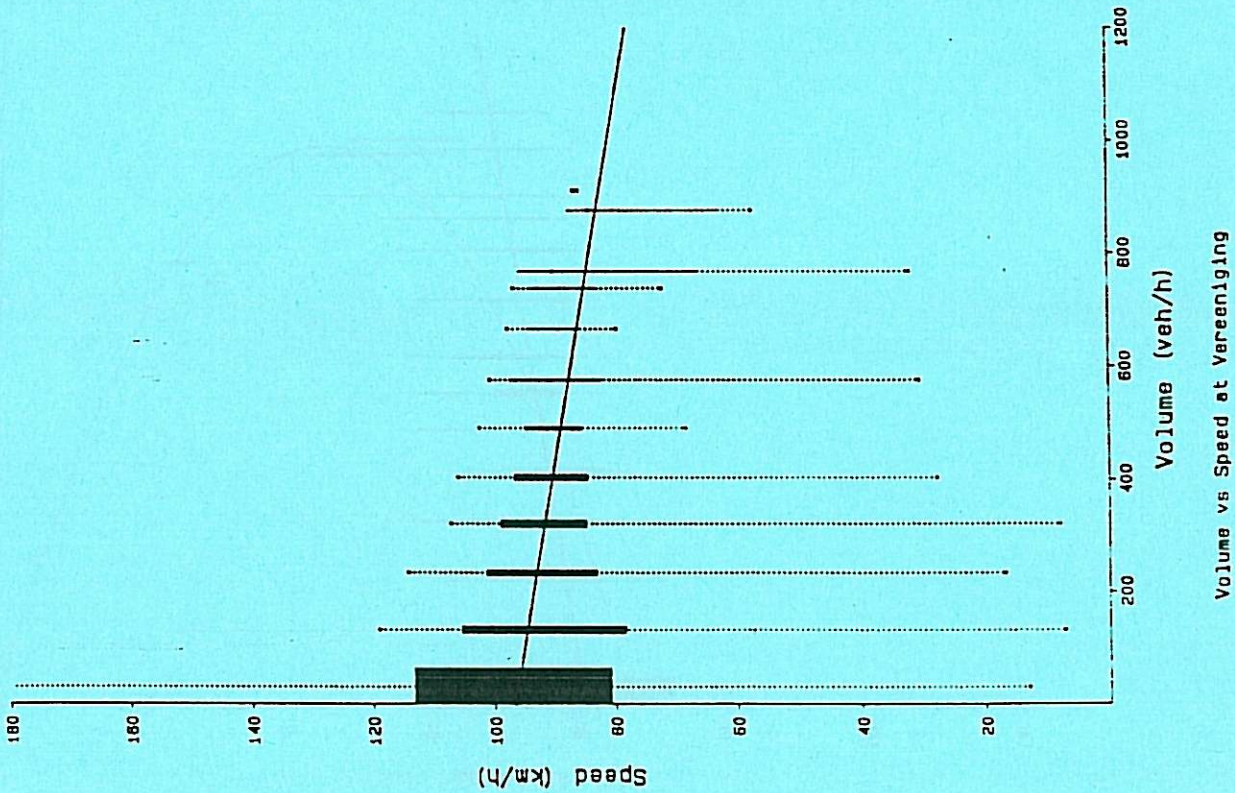


Figure C6 : Traffic volume vs Speed (continued).

Appendix D : Percentage loop occupation vs speed

Figures D1, D2, D3, D4, D5 and D6 depict graphs of traffic volume vs speed. Note the box and whisker type of presentation which conveys data-spread information graphically.

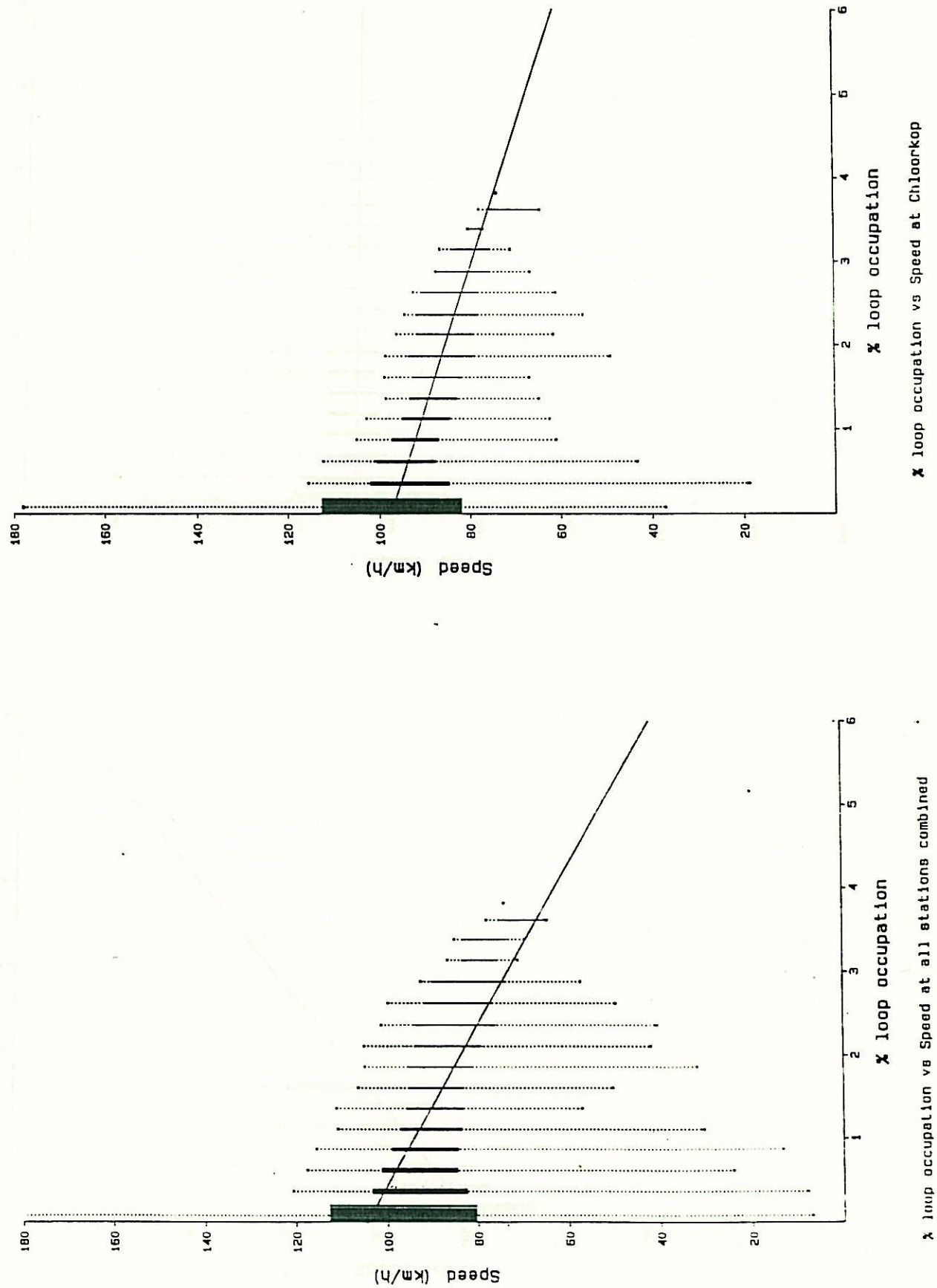
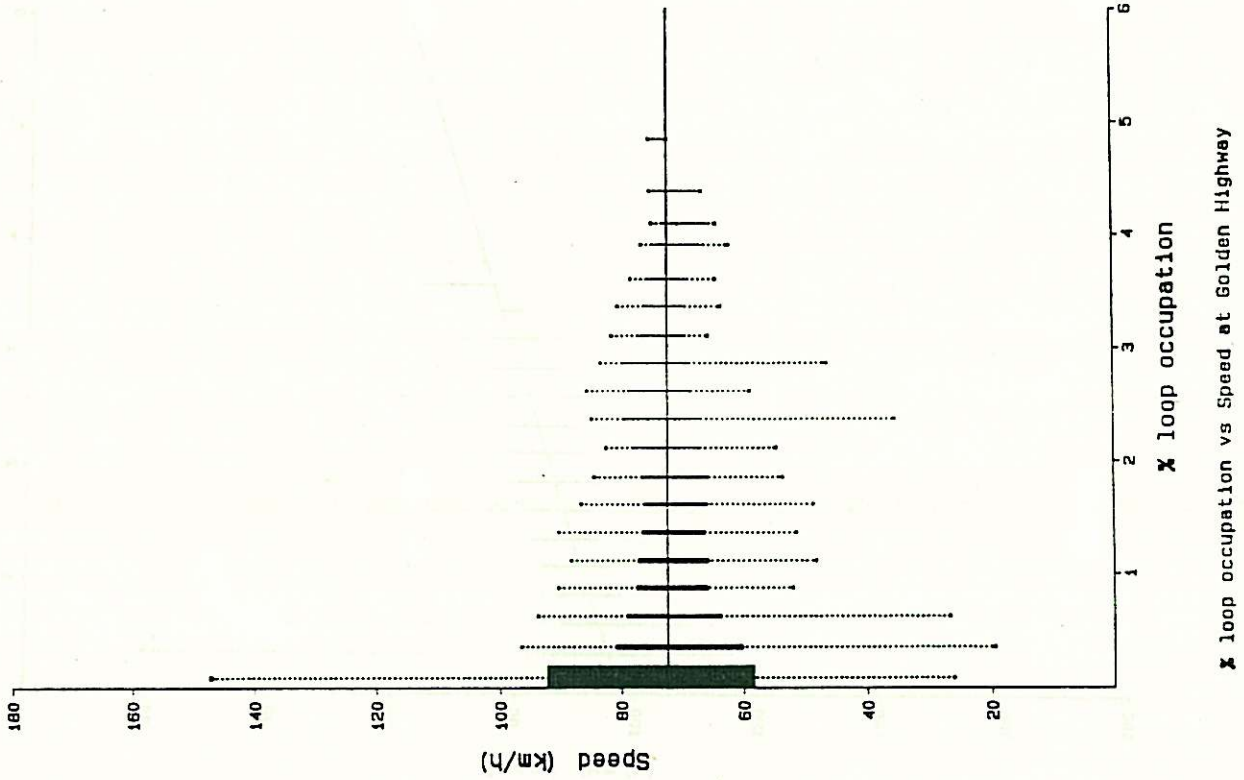


Figure D1 : Percentage loop occupation (by vehicles) vs Speed.



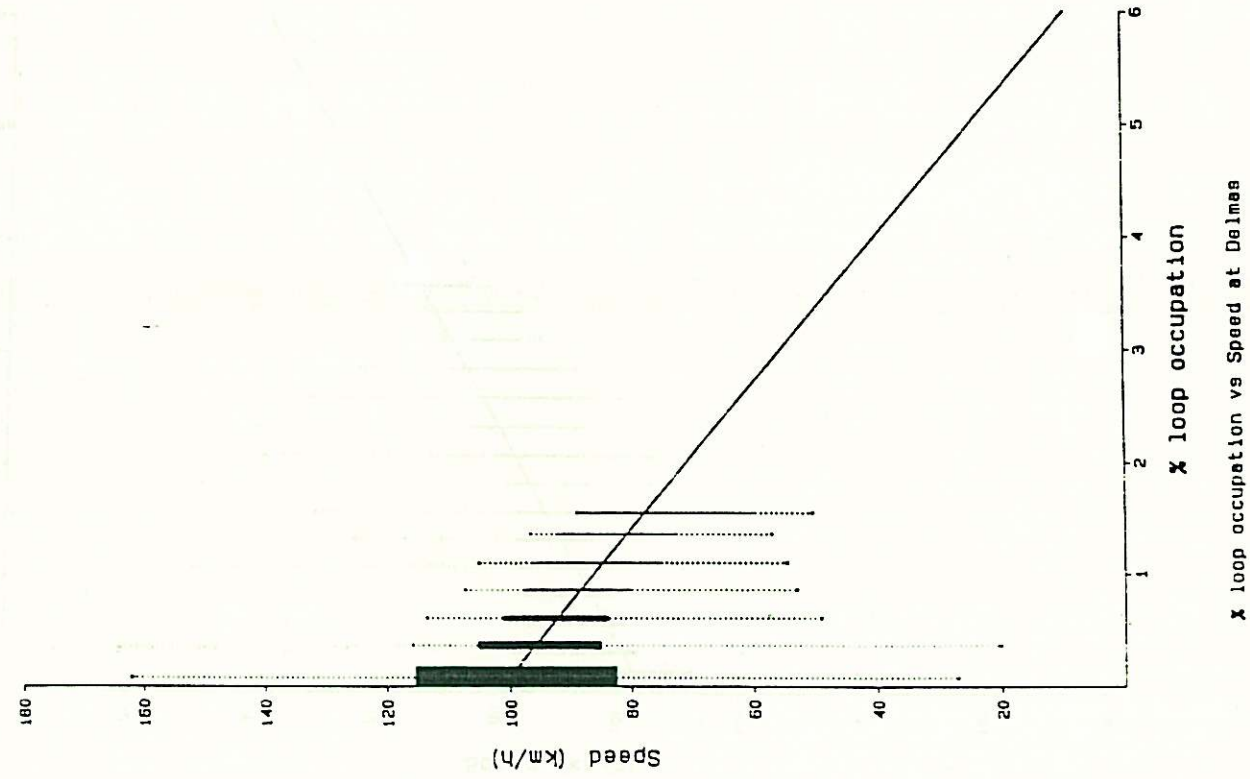


Figure D2 : Percentage loop occupation vs Speed (continued).

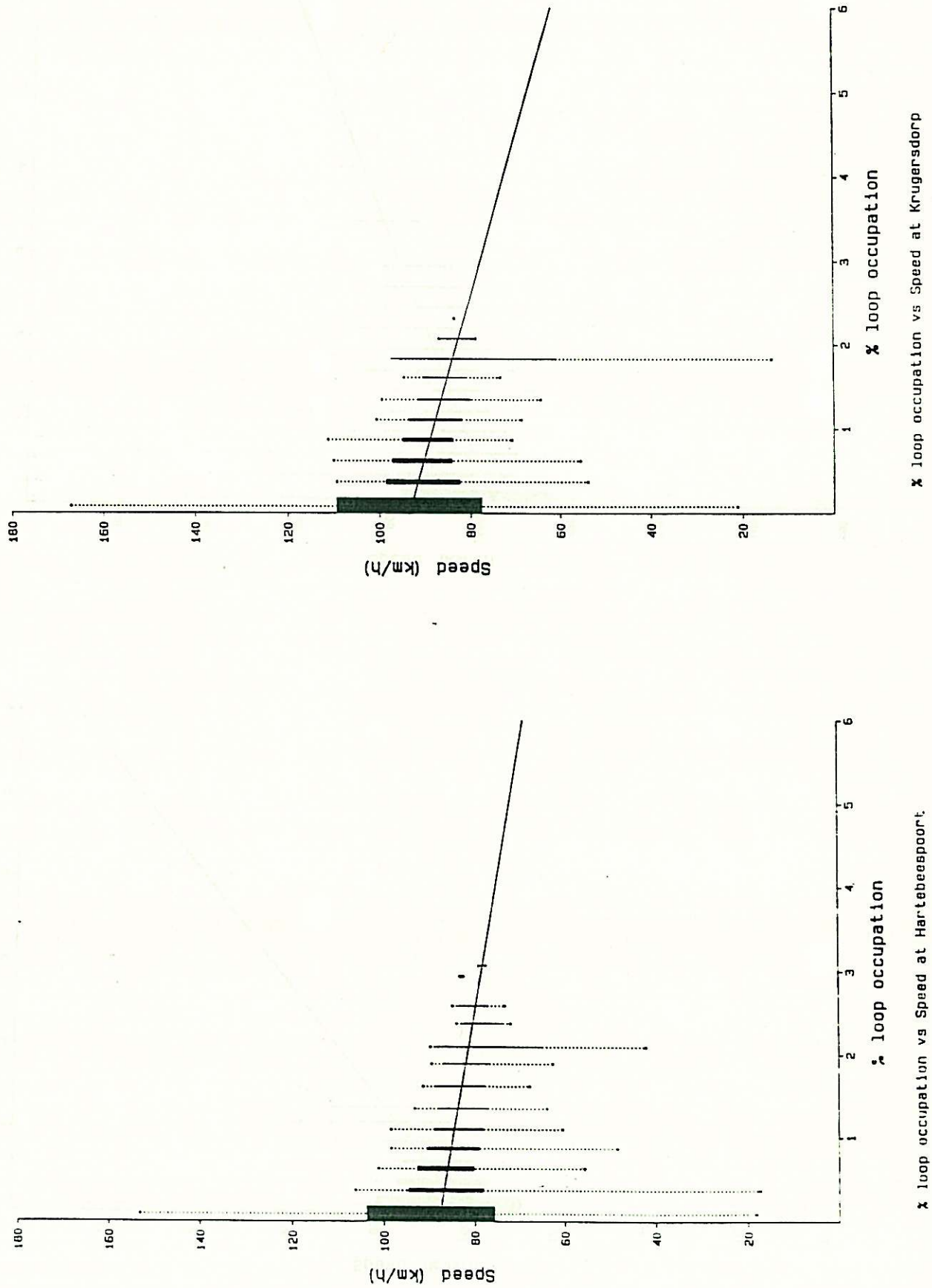
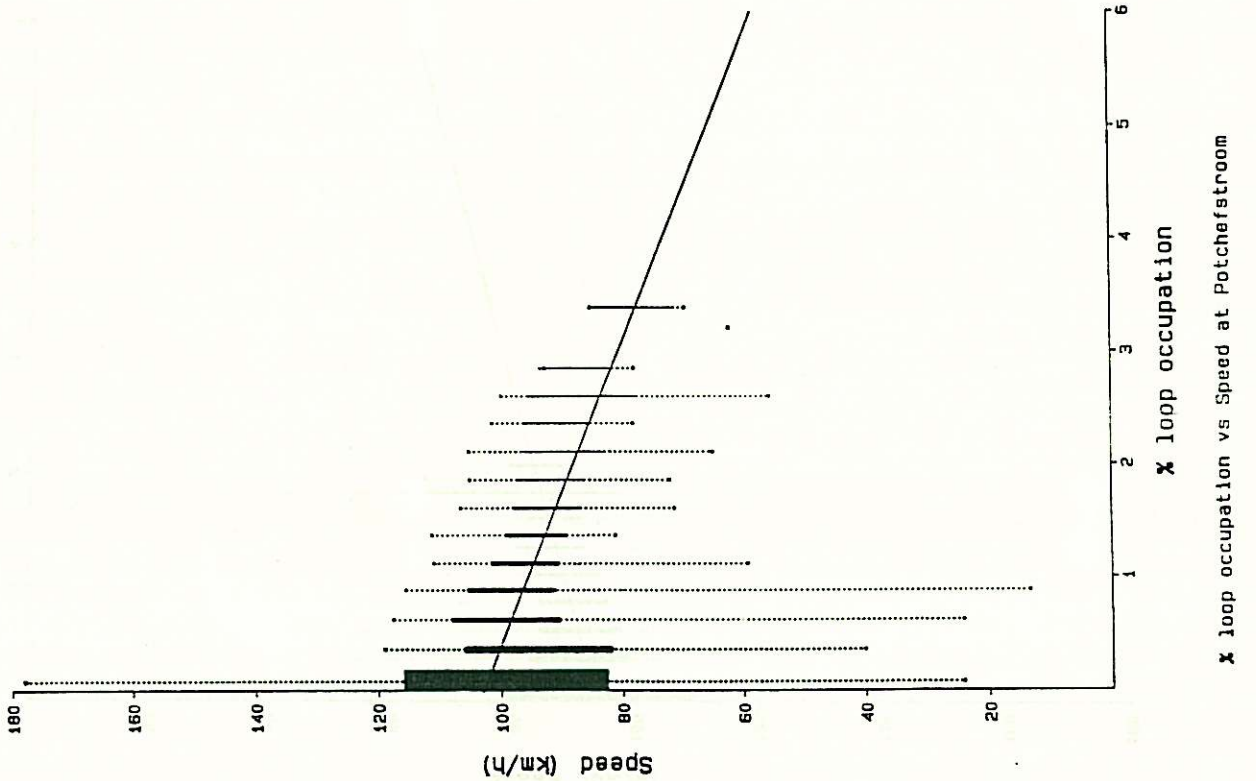


Figure D3 : Percentage loop occupation vs Speed (continued).



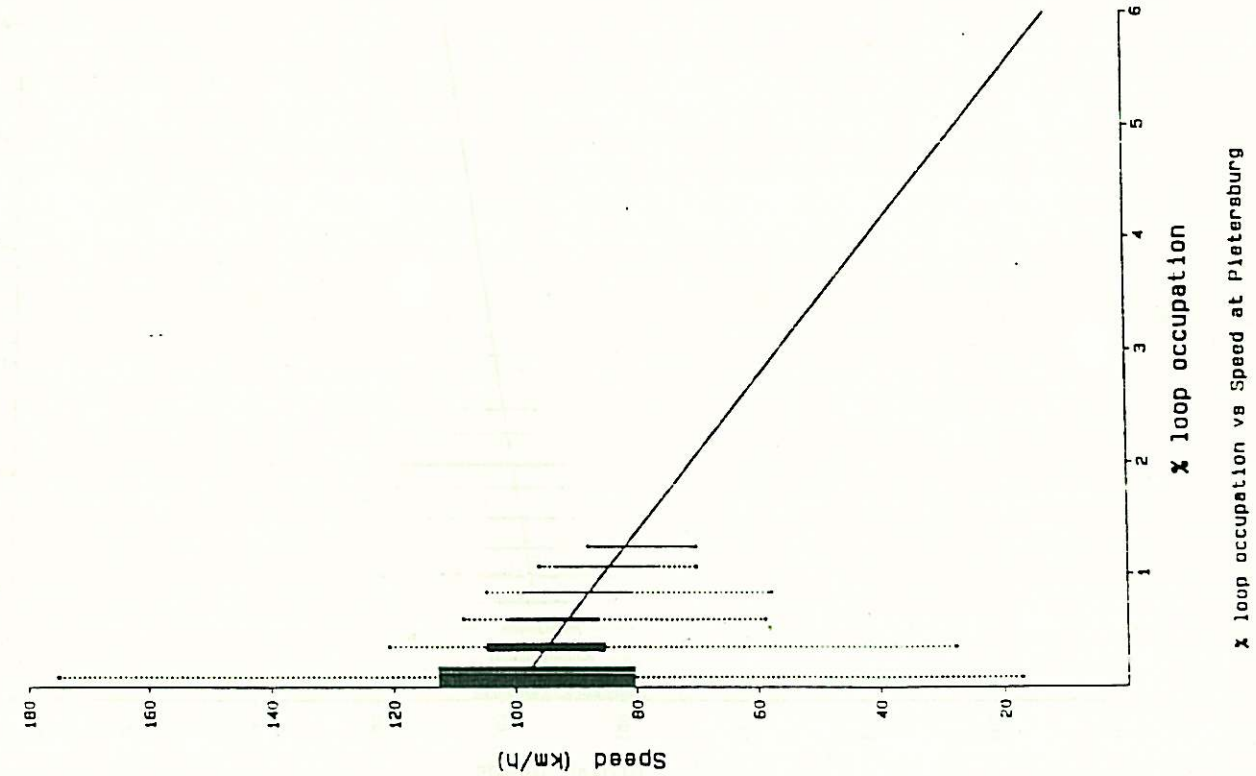


Figure D4 : Percentage loop occupation vs Speed (continued).

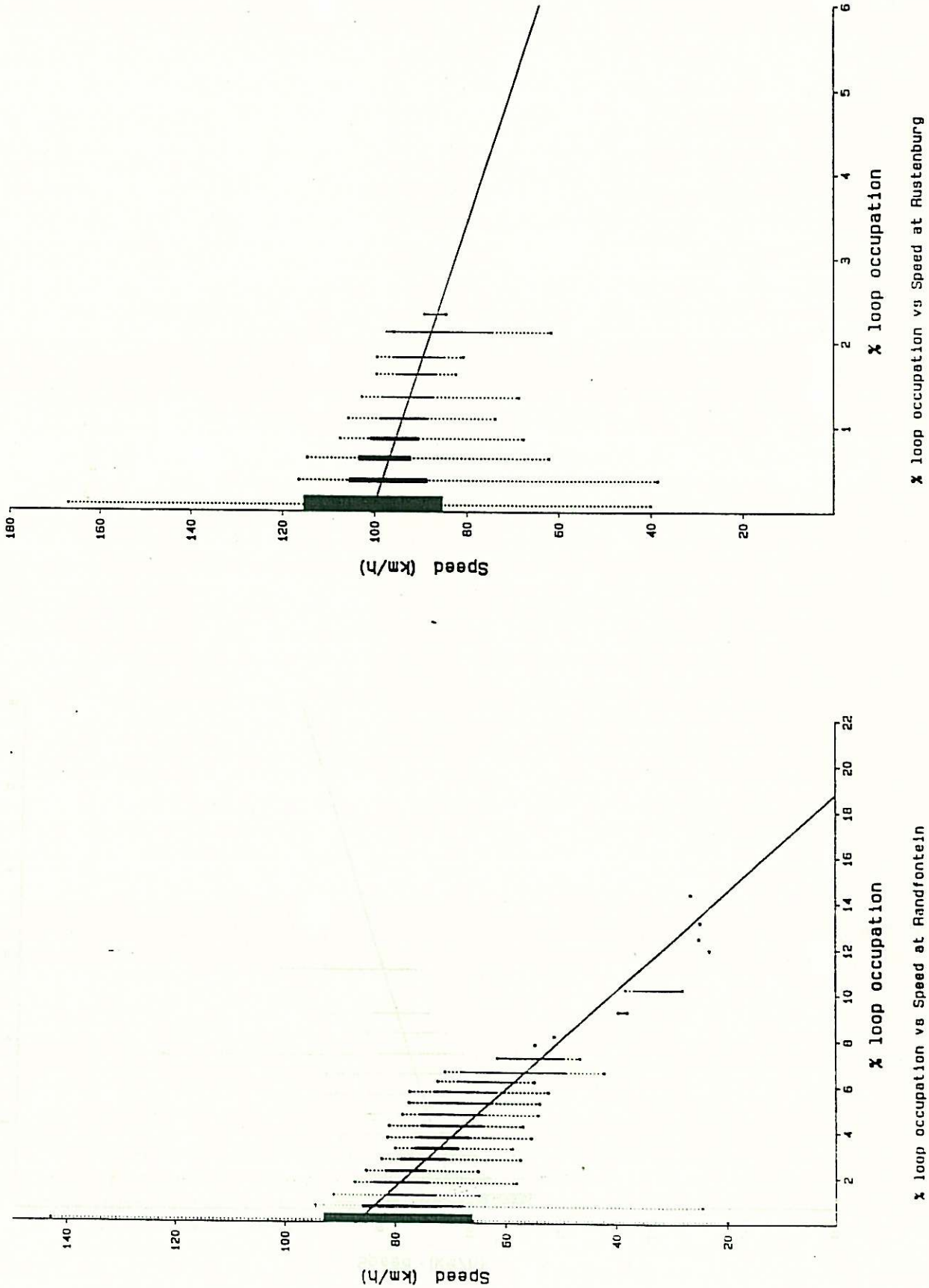


Figure D5 : Percentage loop occupation vs Speed (continued).

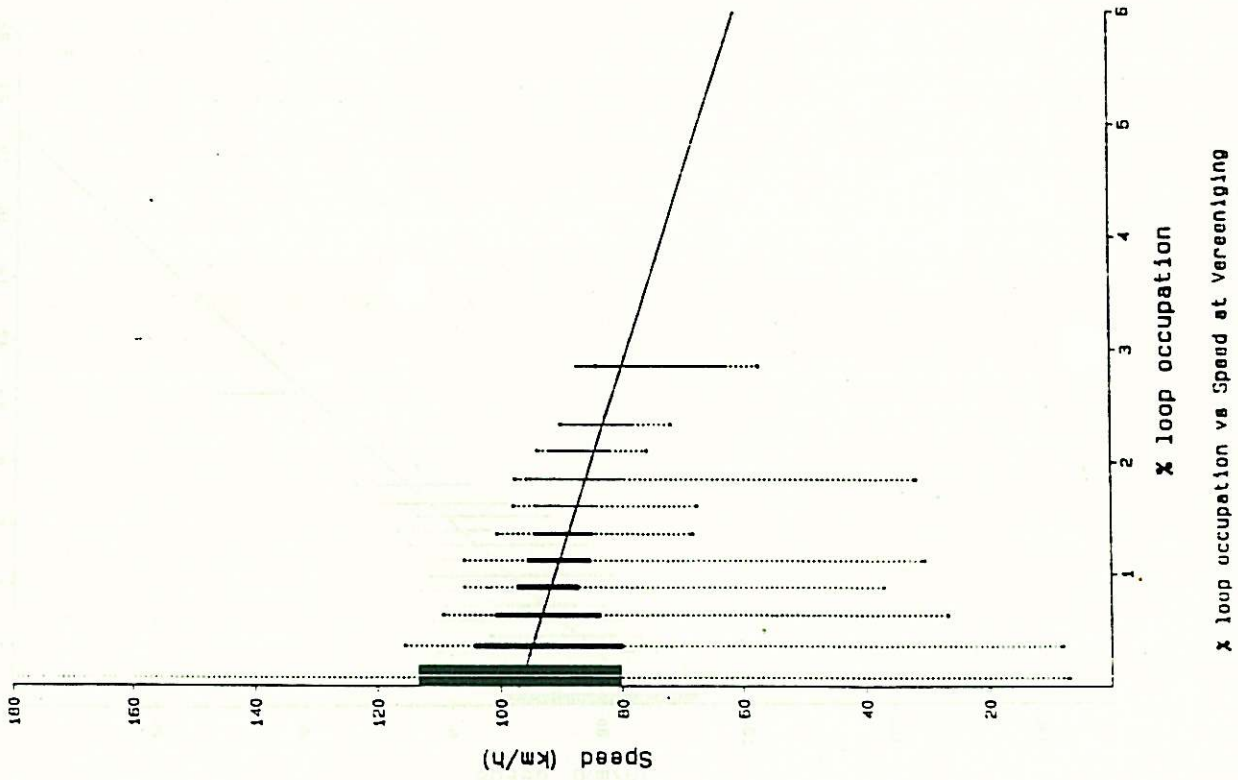


Figure D6 : Percentage loop occupation vs Speed (continued).

Appendix E : Speed vs percentage followers

Figures E1, E2, E3, E4, E5 and E6 depict graphs of traffic speed vs percentage followers, where percentage followers refers to the percentage of vehicles following. Third degree polynomials have been fitted to these data. The constants for each station are depicted in Table E1.

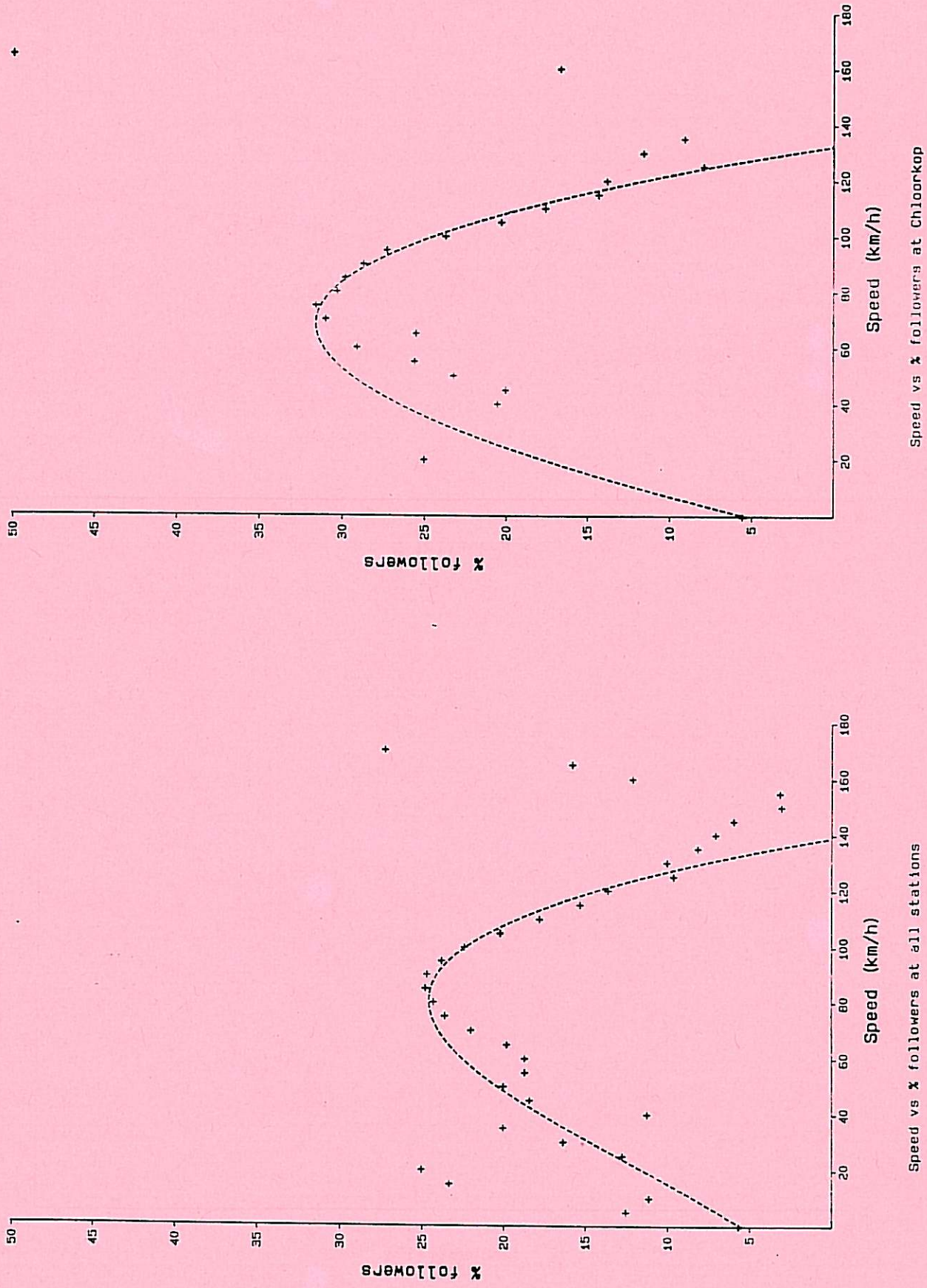


Figure E1 : Speed vs Percentage followers.

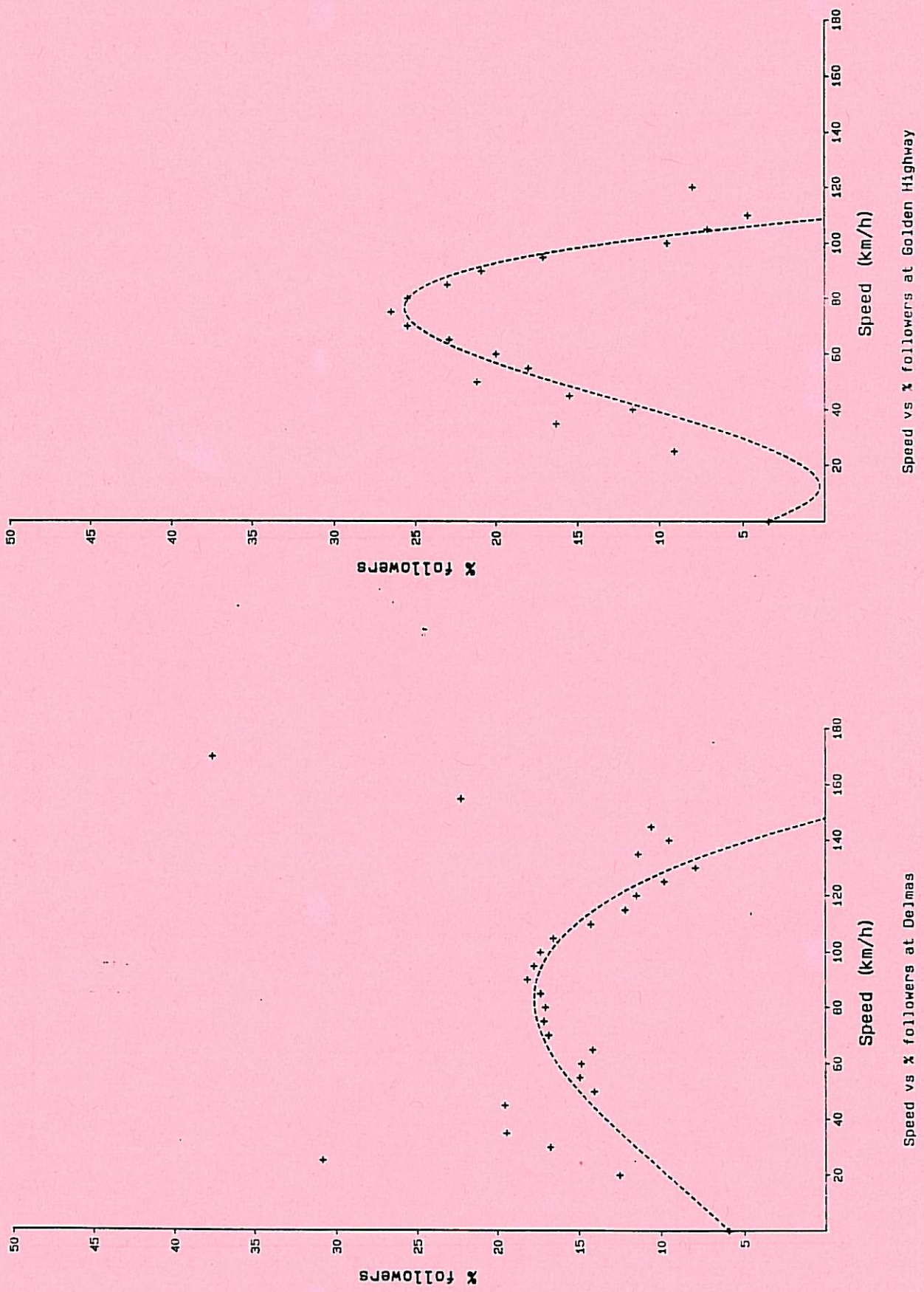


Figure E2 : Speed vs Percentage followers (continued).

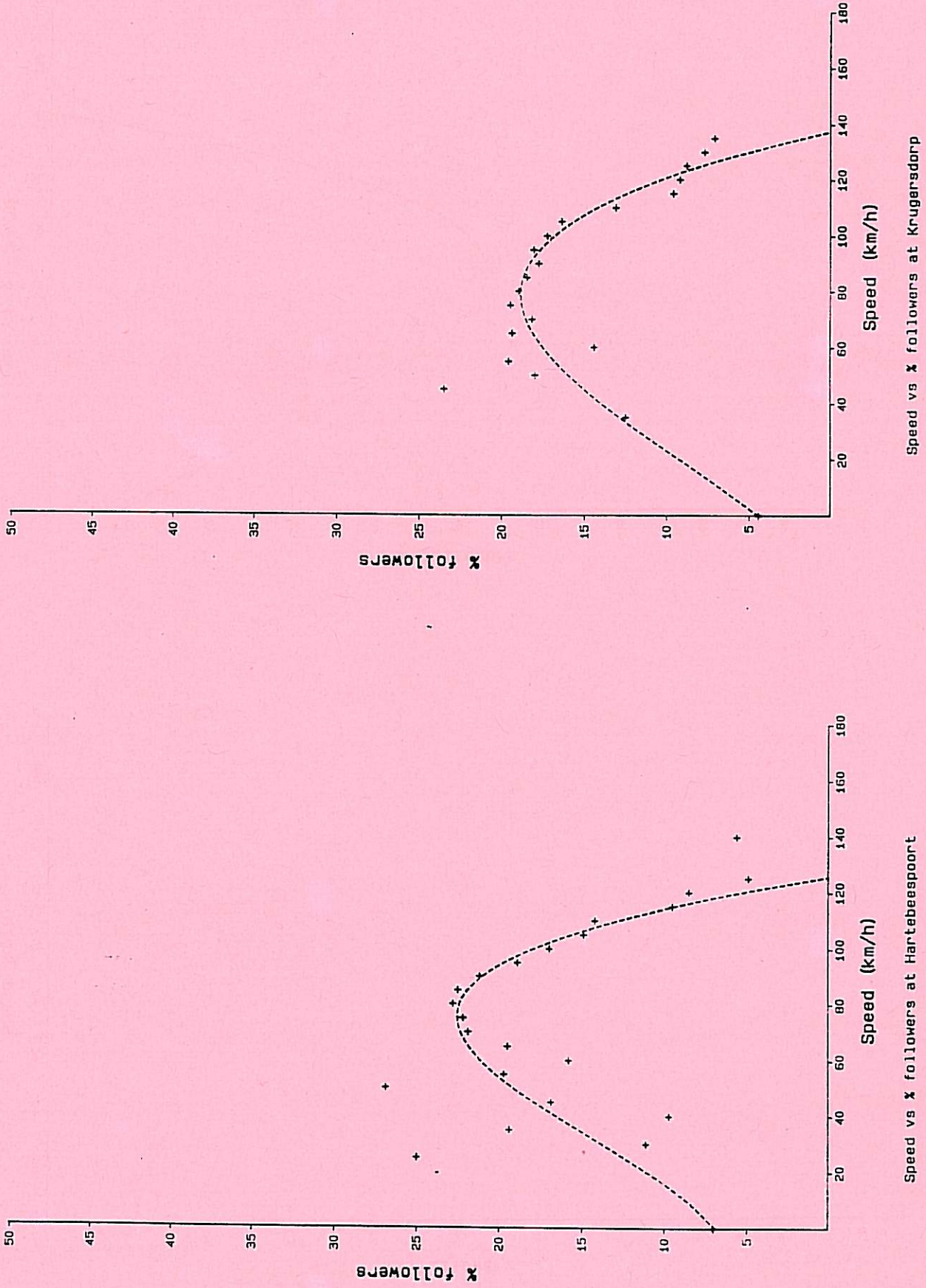


Figure E3 : Speed vs Percentage followers (continued).

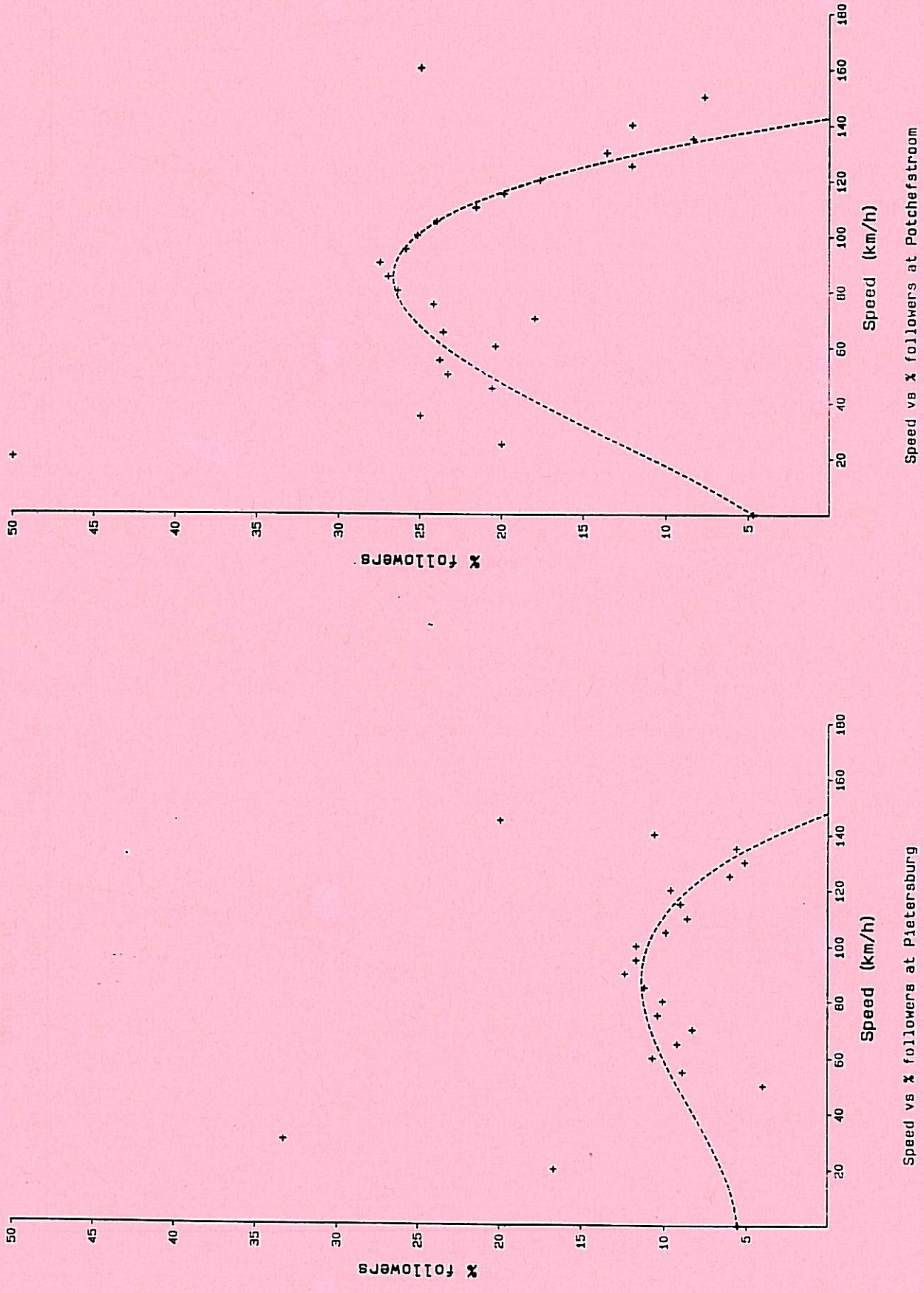
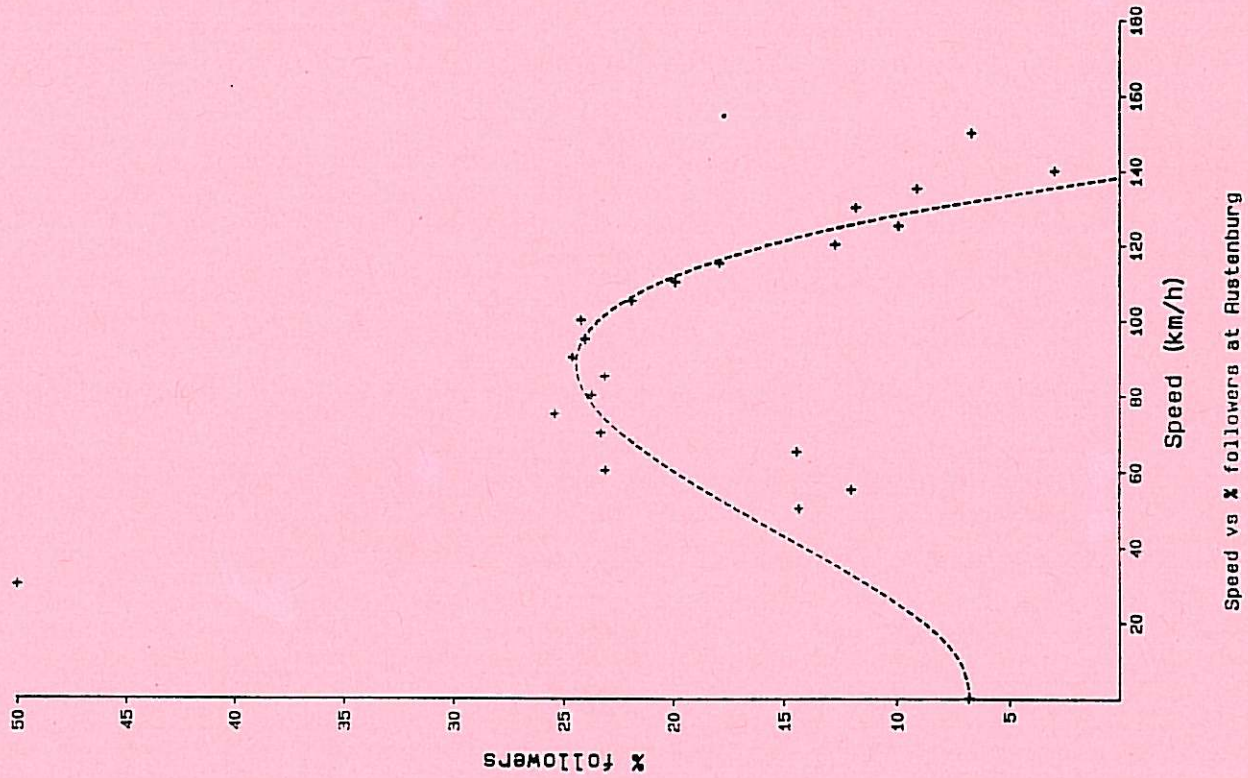


Figure E4 : Speed vs Percentage followers (continued).



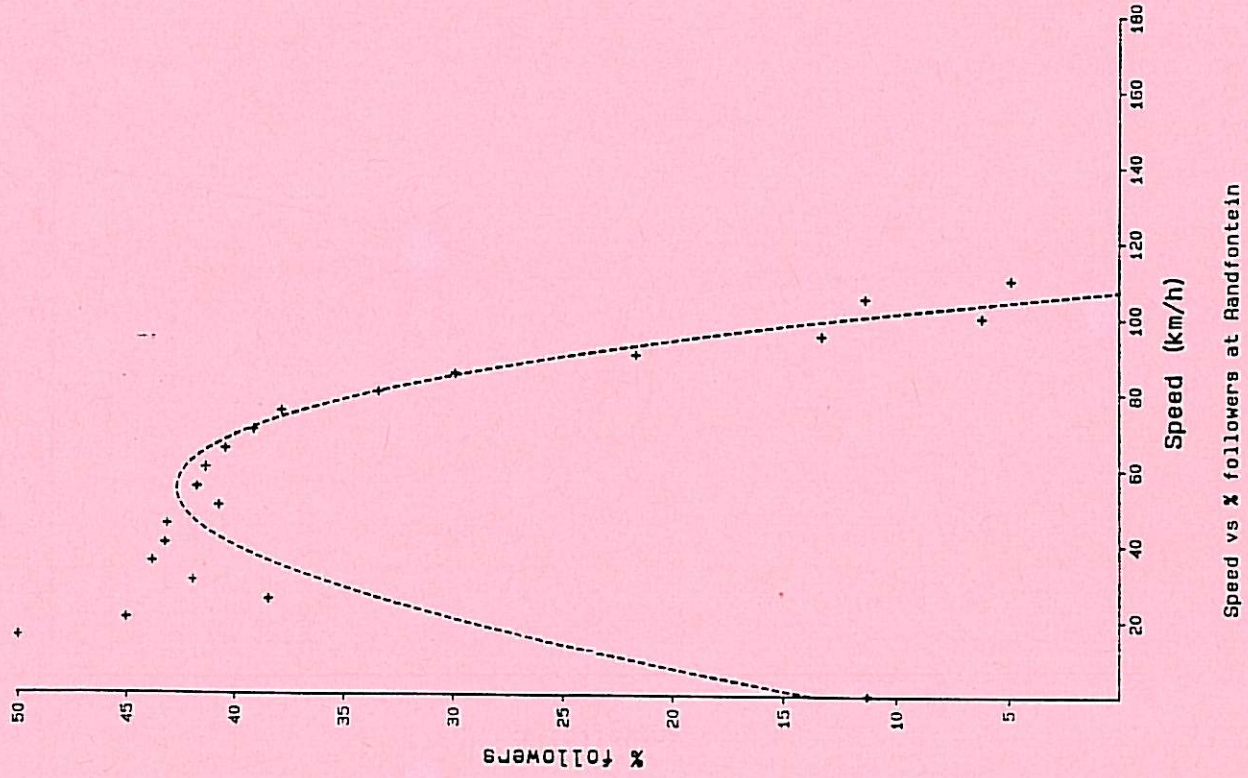


Figure E5 : Speed vs Percentage followers (continued).

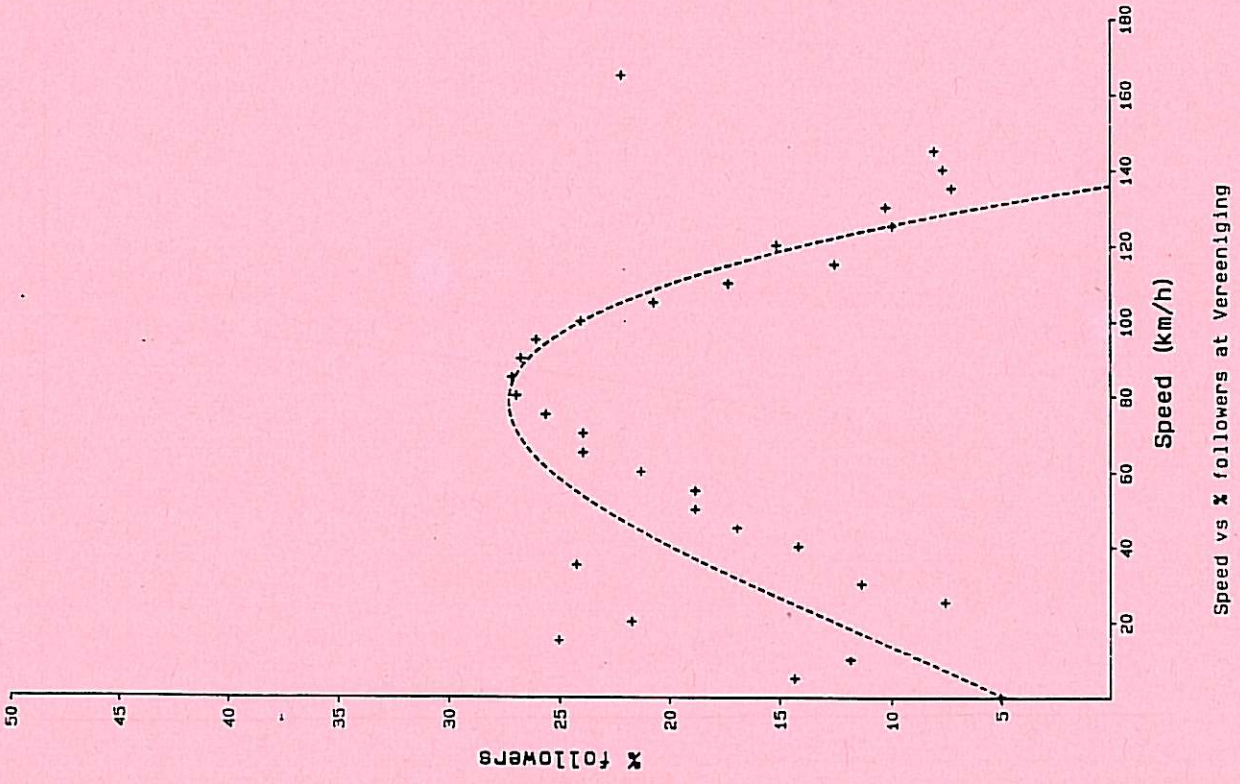


Figure E6 : Speed vs Percentage followers (continued).

Table E1 : Constants to describe curves for: Speed vs percentage followers

	Constant			
Station	a0	a1	a2	a3
"all" stations	5.40	0.275	0.00200	-0.0000307
Chloorkop	5.20	0.702	-0.00360	-0.0000150
Delmas	5.85	0.172	0.00100	-0.0000164
Golden Highway	3.43	-0.530	0.02520	-0.0001890
Hartebeespoort	6.89	0.133	0.00470	-0.0000493
Krugersdorp	4.43	0.225	0.00127	-0.0000228
Pietersburg	5.51	0.014	0.00196	-0.0000156
Potchefstroom	4.61	0.278	0.00265	-0.0000338
Randfontein	13.84	0.912	-0.00429	-0.0000504
Rustenburg	6.76	-0.017	0.00721	-0.0000538
Vereeniging	4.81	0.369	0.00156	-0.0000334

$$\% \text{ followers} = a0 + a1*s + a2*s^2 + a3*s^3$$

where: s = space mean speed

From Figures E1-E6, it can be seen that the percentage followers at the highest point of the curves at each station respectively are significantly different. It is therefore concluded that speed is not a reliable means of predicting percentage of vehicles following.

Appendix F : Volume vs percentage followers

Figures F1, F2, F3, F4, F5 and F6 depict graphs of traffic volume vs percentage followers. Third degree polynomials have been fitted to these data. The constants for each station are depicted in Table F1.

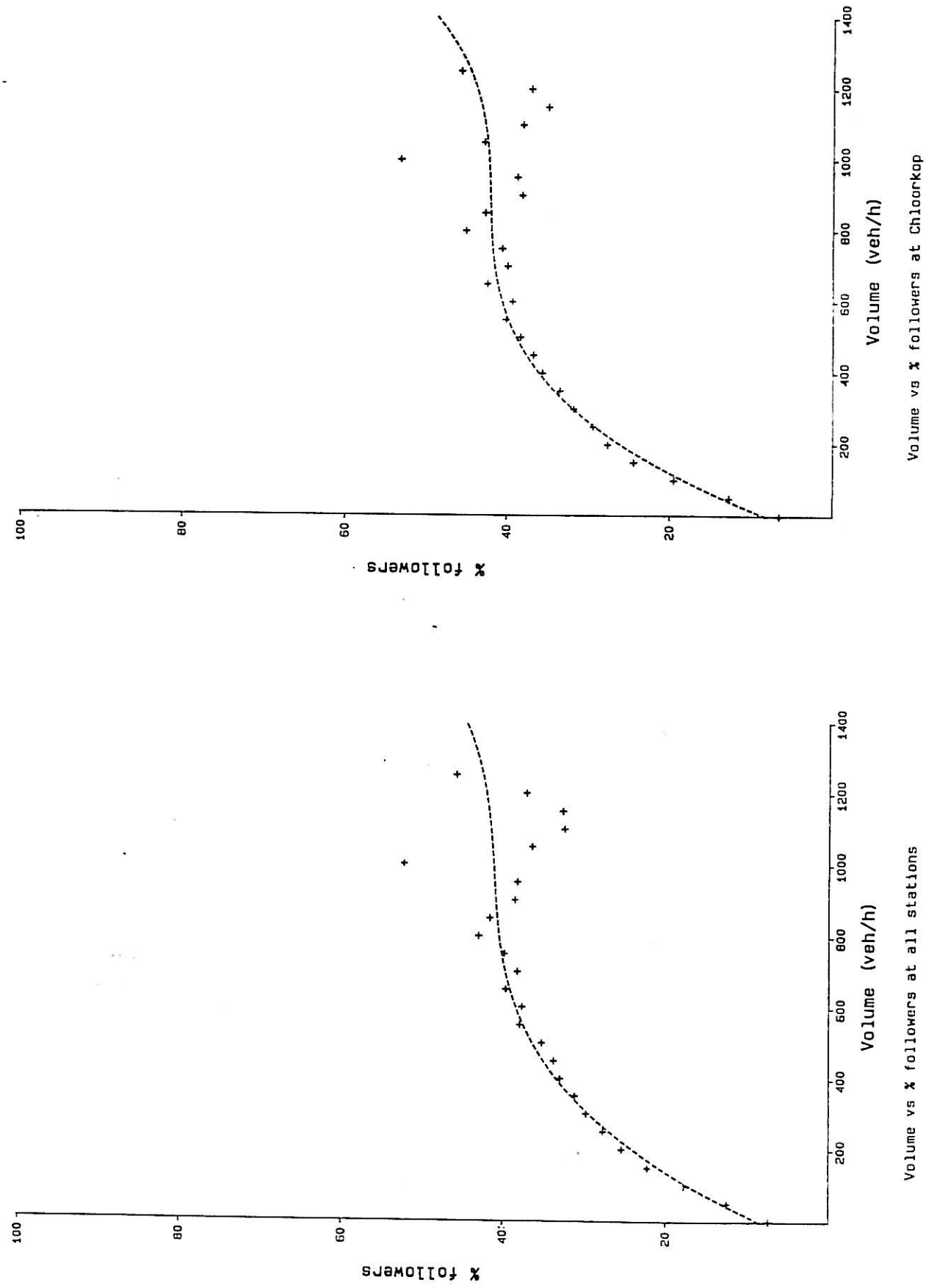


Figure F1 : Volume vs Percentage followers.

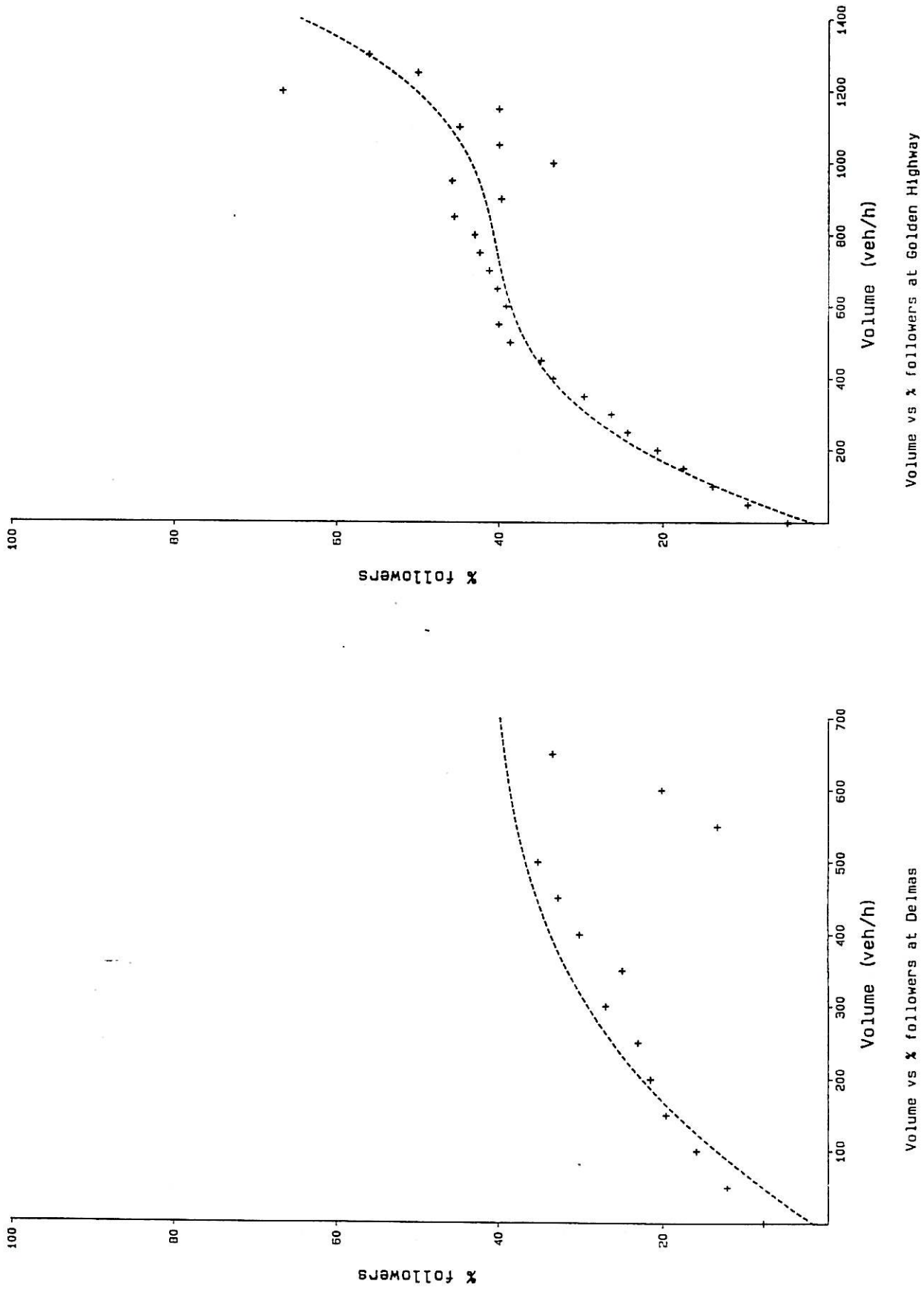
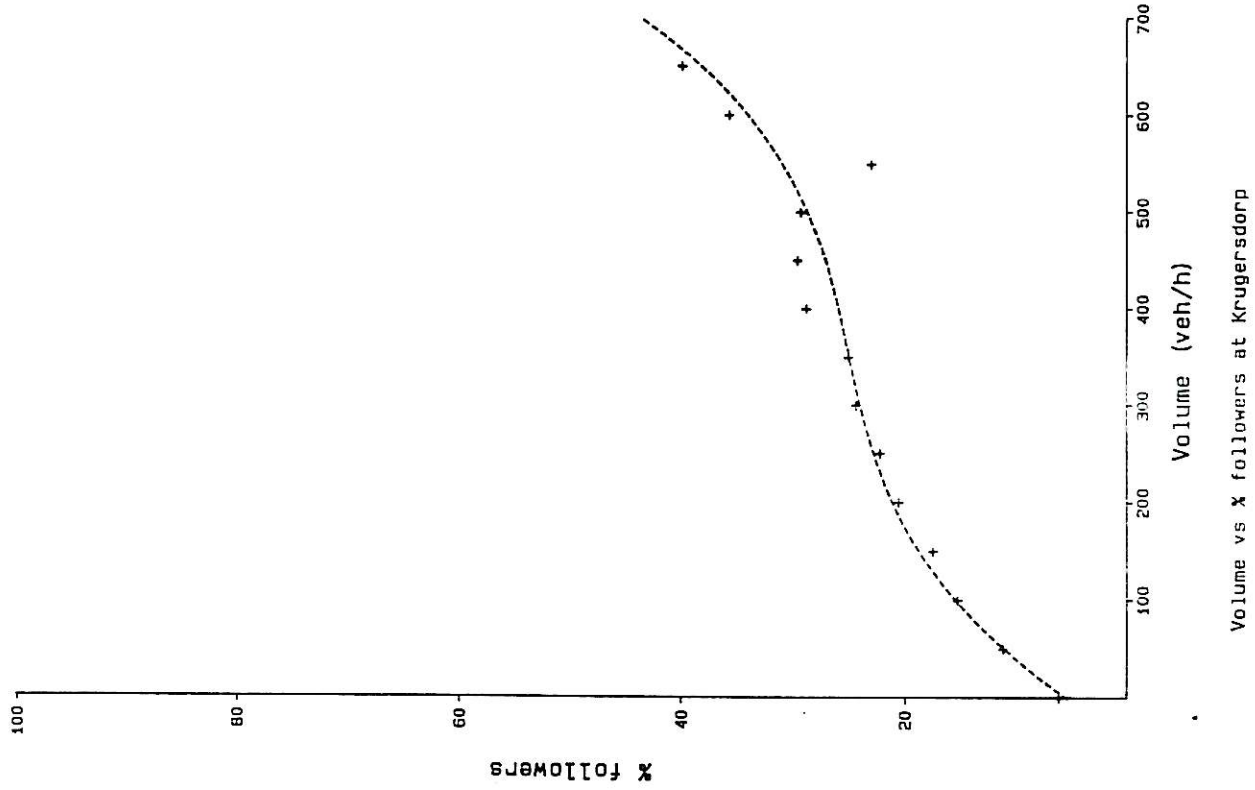


Figure F2 : Volume vs Percentage followers (continued).



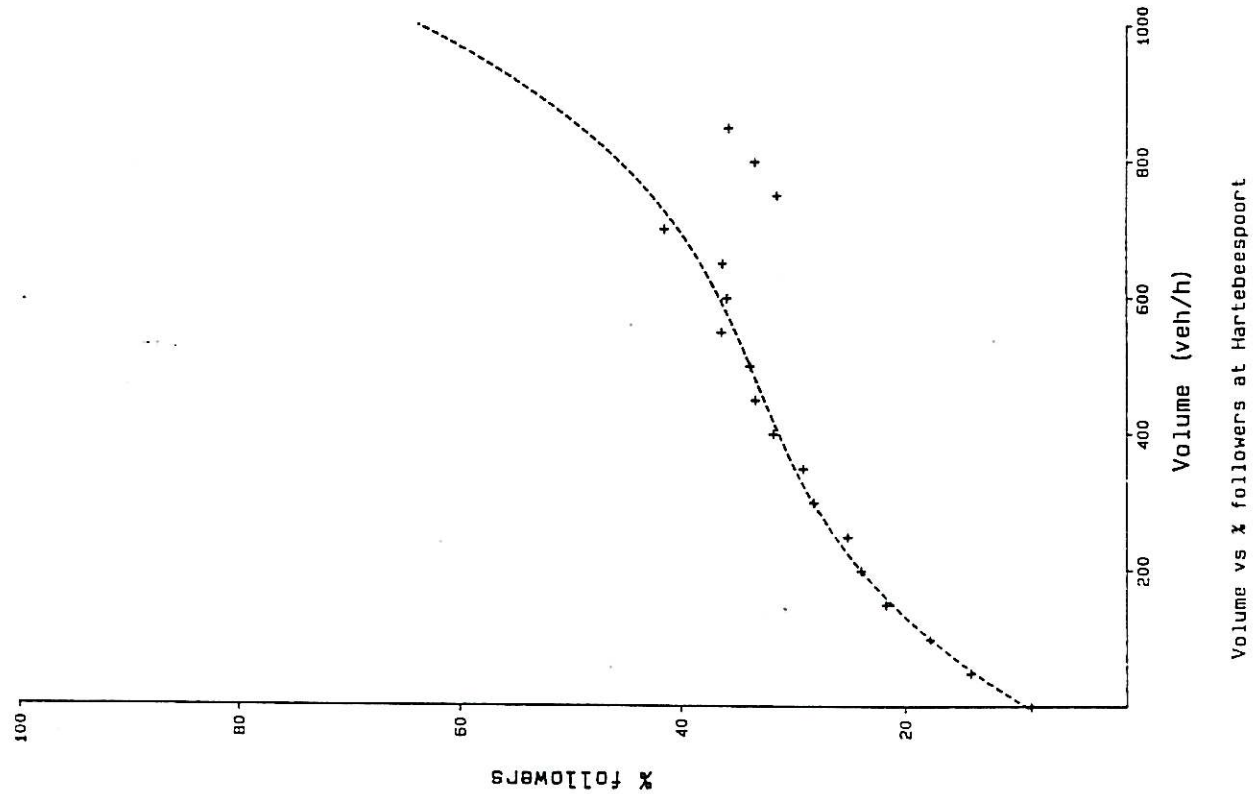


Figure F3 : Volume vs Percentage followers (continued).

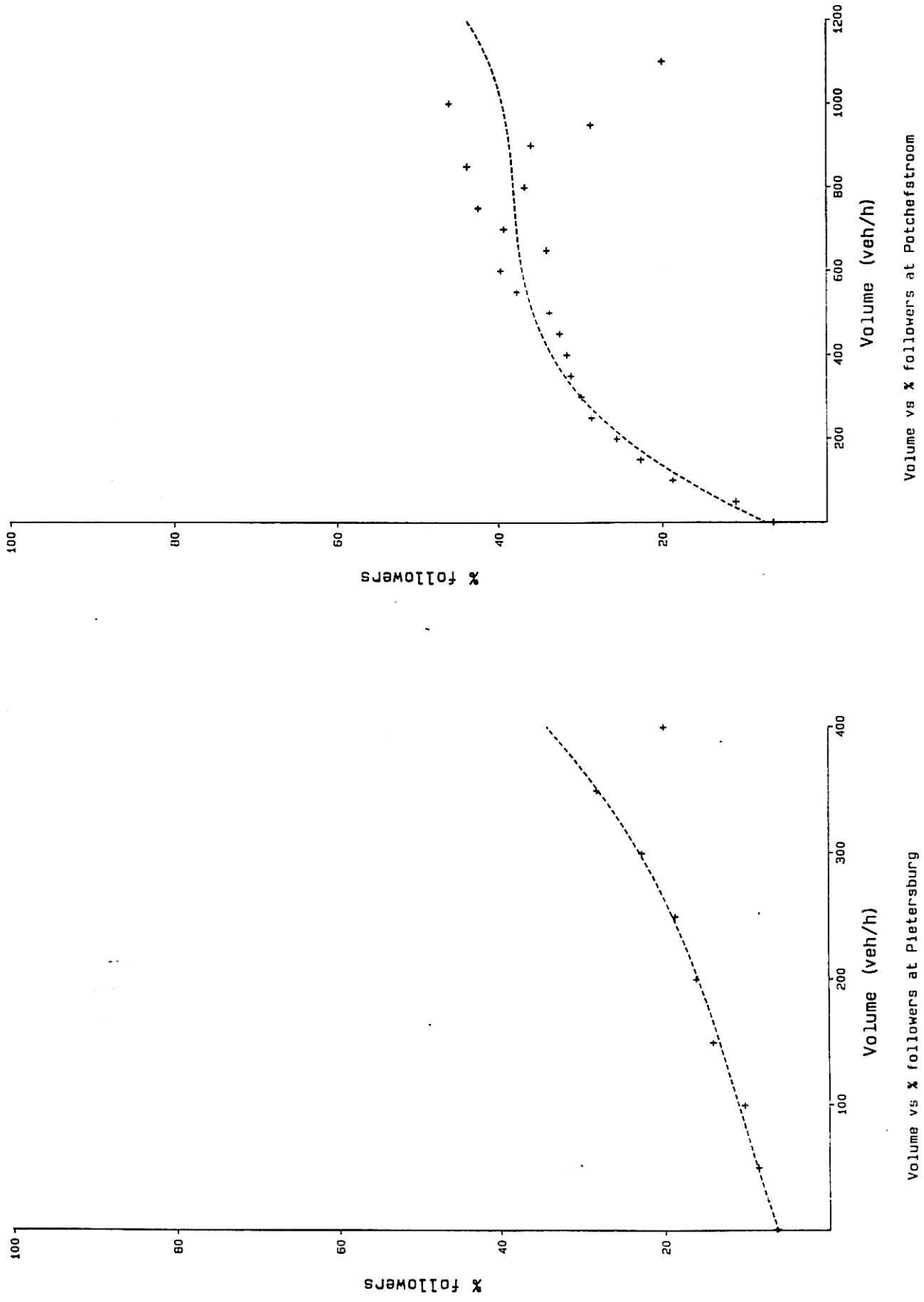


Figure F4 : Volume vs Percentage followers (continued).

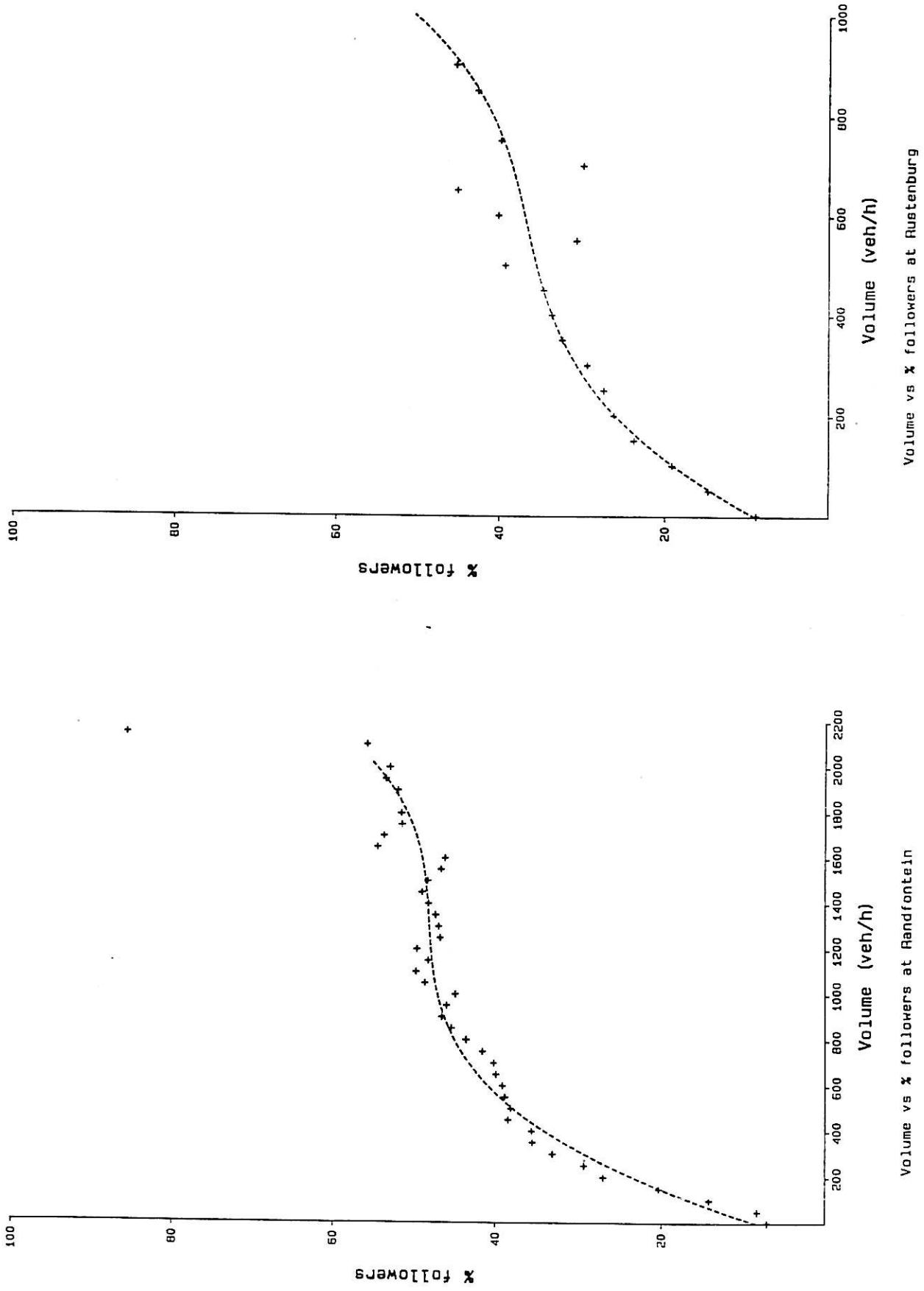


Figure F5 : Volume vs Percentage followers (continued).

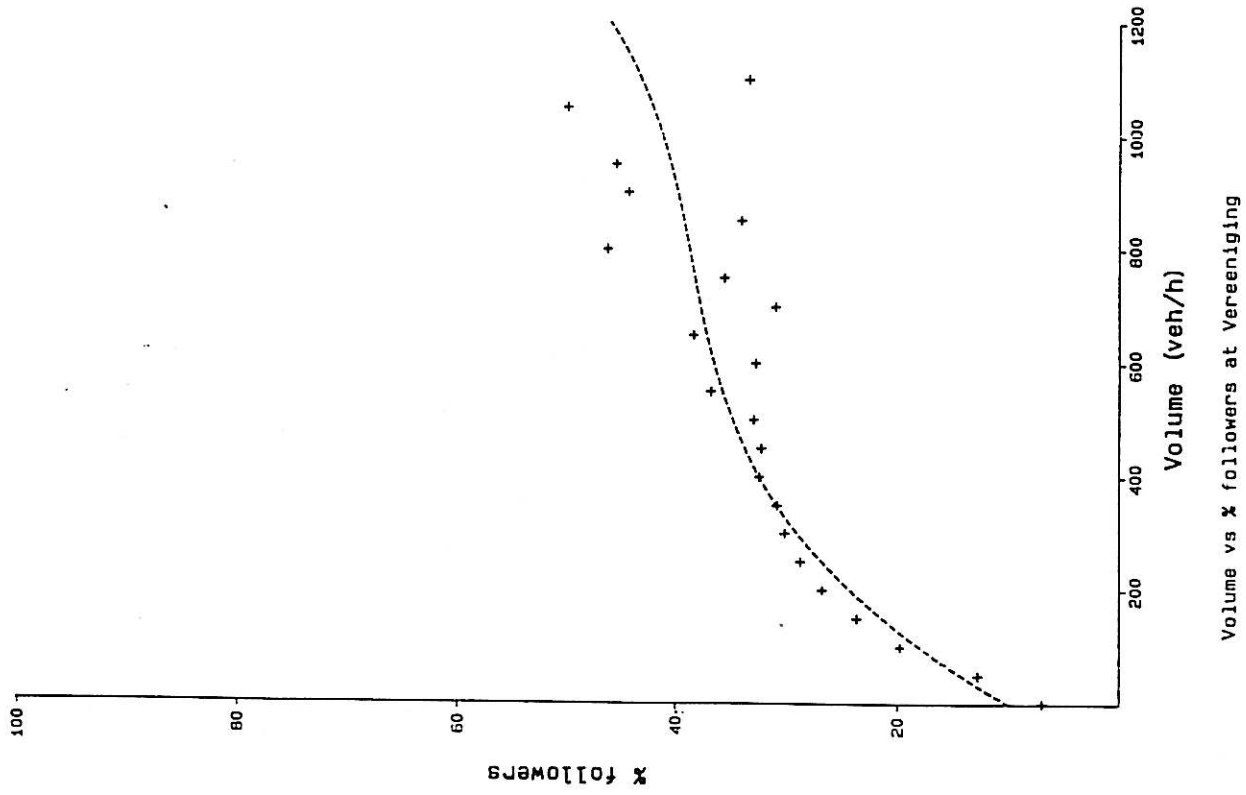


Figure F6 : Volume vs Percentage followers (continued).

Table F1 : Constants to describe curves for: Volume vs percentage followers

	Constant			
Station	a0	a1	a2	a3
"all" stations	8.57	0.094	-0.000094	0.000000032
Chloorkop	8.27	0.111	-0.000123	0.000000046
Delmas	7.57	0.107	-0.000253	0.000000298
Golden Highway	1.70	0.133	-0.000162	0.000000071
Hartebeespoort	9.01	0.102	-0.000163	0.000000115
Krugersdorp	5.43	0.129	-0.000315	0.000000297
Pietersburg	6.27	0.055	-0.000105	0.000000354
Potchefstroom	7.40	0.110	-0.000137	0.000000058
Randfontein	8.57	0.086	-0.000064	0.000000016
Rustenburg	9.09	0.116	-0.000178	0.000000103
Vereeniging	10.03	0.090	-0.000102	0.000000043

$$\% \text{ followers} = a0 + a1*v + a2*v^2 + a3*v^3$$

where: v = 2-way traffic volume

Note that the highest volumes shown in these curves are always higher than those shown in the volume vs speed graphs (Appendix C). This is because the volumes in the volume vs speed graphs are calculated from consecutive five-minute periods. Whereas, for the volume vs percentage followers graphs, the volumes are calculated as the mean of the three one-minute volumes surrounding any particular platoon. Eg: say, the platoon falls in minute 165. The volume would be calculated as the mean of the volumes in minutes 164, 165 & 166. This means that all the highest three minute volume periods, starting at any particular minute, are found.