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16. Abstract

The data collected statewide indicates a linear relationship between speed and volume over a wide range of volumes for freeways, and multilane rural highways. The slope of the speed/volume curve is nearly horizontal. For 2-lane rural and all urban highways, the slope of the speed/volume curve is a function of a number of factors which in many cases also result in a linear speed/volume curve.

For the purpose of this study, a single speed/volume curve was developed for each of several classes of highway. These relationships can not be expected to represent all highways in a given category. However, the relationships developed should allow for a reasonable screening of projects. If unusual conditions exist for a particular project, then a site specific study should be undertaken to obtain site specific speed data. The site specific speed data can be used in the delay saving model developed as a part of this project and reported separately in Research Report 327-1 entitled "A Model to Calculate Delay Savings for Highway Improvement Projects."

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SPEED/VOLUME RELATIONSHIPS

ON TEXAS HIGHWAYS

by

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Research Report 327-2F

A Delay Based Method of Highway Project Evaluation
Research Study 2-8-82-327

Texas Transportation Institute
The Texas A&M University System
College Station, Texas

April 1984

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DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

IMPLEMENTATION STATEMENT

The principal product of the project is a computer program to prioritize highway projects based on delay which is reported separately in Research Report 327-1 entitled "A Model to Calculate Delay Savings for Highway Improvement Projects". The program should replace the current method of having individual districts use their own techniques to estimate delay. The result should be a consistent evaluation on a statewide basis. The materials contained in this report also allow manual estimation of delay which can be used to screen individual projects. Report 327-1 also contains a simple graphical method for a limited number of typical improvement projects.

SUMMARY

The data collected statewide indicates a linear relationship between speed and volume over a wide range of volumes for freeways, and multilane rural highways. The slope of the speed/volume curve is nearly horizontal. For 2-lane rural and all urban highways, the slope of the speed/volume curve is a function of a number of factors which in many cases also result in a linear speed/volume curve.

For the purpose of this study, a single speed/volume curve was developed for each of several classes of highway. These relationships can not be expected to represent all highways in a given category. However, the relationships developed should allow for a reasonable screening of projects. If unusual conditions exist for a particular project, then a site specific study should be undertaken to obtain site specific speed data. The site specific speed data can be used in the delay saving model developed as a part of this project and reported separately in Research Report 327-1 entitled "A Model to Calculate Delay Savings for Highway Inprovement Projects".

TABLE OF CONTENTS

I. BACKGROUND

Delay is one measure of transportation system effectiveness which motorists can easily understand. Policy makers in Texas have expressed interest in using delay as one possible criteria for prioritizing highway projects. However, no simple methodology existed to evaluate a variety of different highway projects on a consistent basis. This study is the result of the need to develop a simple procedure for evaluating a large number of projects with minimal data requirements on individual projects.

Delay is a simple concept; it may be simply defined as the time lost to travel because of traffic frictions and traffic control devices. However, delay may be measured and expressed in many different ways. For example, delay on an individual facility can be computed by comparing desired travel time with actual travel time. For this study, delay is calculated by relating a proposed project with existing conditions. Therefore, a delay savings is computed based on a comparison between a proposed project and existing conditions.

It should be noted that the nature of the procedure limits it application to sections of roadway. For example, it is not applicable to single intersection improvements or to widening of narrow bridges. These "spot" type improvements would have to be evaluated using some other technique.

The objective of the study was to develop a technique for estimating delay. The actual program developed and users manual is presented in Research Report 327-1 entitled "A Model to Calculate Delay Savings for Highway Improvement Projects". This document describes the data collected and the actual relationships implemented in the computer program. These relationships can, of course, be modified as the result of future research or if experience indicates any inconsistency in results.

1

II. DATA COLLECTION

The data collection methodology originally selected for this study was the floating car technique. However, after collecting data on a variety of roadways, it was apparent that speeds were more sensitive to driver desires than to traffic volume. This is consistent with recent research which indicates that speeds are relatively insensitive to changes in volume over a wide volume range. The "floating car" technique was, therefore, limited to congested roadway sections where speed could not be measured by the alternative technique selected.

An alternative data collection procedure was selected using a moving radar unit. Use of the moving radar allowed speeds to be measured and averaged over a one to two mile roadway section. Volumes were also measured from the survey vehicle using a technique that accounts for the speed of the survey vehicle. The methodology is documented in Appendix B. The data collected was consistent with other research (1, 2) using different data collection techniques. The influence of radar detectors is, therefore, believed to be small.

III. STUDY SITES

Data was initially collected at a large number of sites (See Table 1) with particular emphasis on two-lane rural roadways. The data collected indicated that only volumes at or near capacity were speeds appreciably affected by volume. Two-lane rural roadways with average geometrics and paved shoulder had only modest speed reductions even under high volumes.

Although vehicles on two-lane roadways were able to maintain 55 mph at relatively high rates of flow (1,000 vph), platooning was noticeable. It was decided to collect additional data at several other sites. In addition to speed/volume data, license plate numbers were recorded so that roadway users could be surveyed concerning their perceptions of traffic operations. The additional study sites are noted in Table 1.

In addition to data collected as part of this study, data collected by the Texas State Department of Highways and Public Transportation for compliance with the 55 mph speed limit were analyzed. One monitoring station on IH-20 in Tarrant County provided useable data in that volumes approached capacity of the facility.

TABLE 1: STUDY SITES

Highway	County	Number of Lanes	Shoulders
FM 60	Brazos	2	Yes
FM 2818	Brazos	2	Yes
FM 2154	Brazos	2	No
SH 6	Brazos	4	Yes
SH 6	Waller	2	Yes
SH 6	Harris	5	No
US 290	Waller	4	No
FM 146	Galveston	2	No
FM 1960	Harris	5	Yes
FM 544	Collin	2	No
US 59	Harris	6	Yes
IH 45	Harris	10	Yes
IH 35	Travis	4	Yes
SH 21	Brazos	2	Yes
US 59*	Cass	4	No
US 49*	Titus	2	No
SH 96*	San Augustine	2	No
SH 19*	Walker	2	Yes
SH 289*	Collin	2	Yes
SH 121*	Dallas/Collin	2	Yes
SH 149*	Harris	2	No
IH 20**	Tarrant	4	Yes

* Motorist survey locations

** 55 mph speed monitoring station

IV. SPEED/VOLUME RELATIONSHIPS

The relationship between speed and volume has been the subject of much empirical and theoretical research. Theoretical considerations may have resulted in the classical parabolic shape of the speed/volume curve which can easily be derived from linear speed-density function. However, such theoretical considerations may obscure the fact that much empirical work supports a linear speed-volume curve. This study suggests that except in the case of some 2-lane highways and urban streets, the speed-volume relationships for volumes below capacity is not only linear, but has a relatively flat slope.

The 1950 Highway Capacity Manual (3) states "Investigations conducted on an extensive scale have definitely shown, however, that there is a straight line relationship between traffic volume and average speed when other conditions are identical and the critical density is not exceeded". Figure 5 of the 1950 Highway Capacity Manual shows a relationship for high speed existing highways that could be expressed as $u = 48 - 0.014Q$ where u is in mph and Q is in vehicles per hour.

The 1965 Highway Capacity Manual (4) continued to support the concept of a linear speed-flow relationship. Page 60 of the 1965 Highway Capacity Manual states "The fundamental speed-flow relationship for a given population of drivers can be simply stated as follows: As traffic flow increases, the space mean speed of traffic decreases". It further states "Investigations conducted on an extensive scale have shown that a straight line relationship reasonably represents the speed-flow relationship in the range below critical density, for uninterrupted flow conditions on all ordinary multilane highways without access control, as well as most four-lane freeways".

The 1965 Highway Capacity Manual also states that where speeds are rigidly enforced below desired speeds, a flatter average speed-flow curve will arise. It seems reasonable that the imposition of the 55 mph speed limit would have such an effect of speed-flow relationships. Furthermore, trends have over the years have resulted in raised speeds at higher flow levels.

General Findings

The data collected under controlled access conditions supports the concept of a linear speed/volume relationship. Furthermore, the slope of the speed/volume line is nearly flat; that is, volume has very little effect on speeds up to a point very close to capacity. Once the freeway breaks down due to demands reaching capacity, no meaningful speed/volume relationship exists.

Relating speed and volume on facilities without control of access is more difficult. There tends to be more scatter in the data. This may be partly due to vehicles entering roadway and due to limitations in passing on 2-lane roadways. Although all the data is not statistically reliable, visual examination of the data for most highway types indicates relatively high speeds at high volumes.

Another difficulty exists on rural highways, especially those with 2-lanes. It is very difficult to find high volume sections. It is especially hard to find 2-lane highways in rural areas with ADT's over 5,000. This is partly due to the fact that highways with ADT's over 5,000 are generally candidates for upgrading. Highways having an ADT of 5,000 or less would generally have flow rates of less than 300 during the peak period. Given the normal fluctuations in speed at a given volume and the limited range of existing rural volumes, it extremely difficult to determine relationships for rural highways.

Lastly, urban highways are generally characterized as interrupted flow. This further exasperates the problem of developing speed/volume relationships. Although it is possible to smooth the data and only report the relationships developed, it is more appropriate to present the actual data. While considerable judgement was used in recommending relationships, the results should be consistent, if not always precise.

Freeways

Examination of a simple bottleneck section in Austin demonstrates the speed/volume relationship for freeways. The study location is a 2.8 mile section of IH-35 in Travis County. The site is a four-lane freeway (2-lane each direction) in rolling terrain with 12-foot lanes, a 3-foot paved left shoulder and a 10-foot paved right shoulder.

The bottleneck occurs during the morning peak southbound at the Rundberg Lane on-ramp. This high volume ramp results in a regular breakdown at the merge point. Further downstream, the freeway expands to 6-lanes at the next on-ramp. The bottleneck is well defined, occurs daily, and results in a queue that nearly extends the length of the section.

The study involved a floating car driving the right lane through the study section every 5 minutes. The vehicle recorded travel time to designated points along the section. In addition, traffic volumes were counted at the beginning, end, and at each ramp along the section. The study was conducted from 6:35 a.m. to 8:30 a.m. on November 16, 1982. The weather was clear and the temperature in the 40's.

Figure 1 shows the results of the study based on travel time over the 2.8 mile section. Points A-H represent free-flow prior to breakdown and points I-N represent free-flow following dissipation of the queue. Points 1 to 9 represent the period of forced-flow.
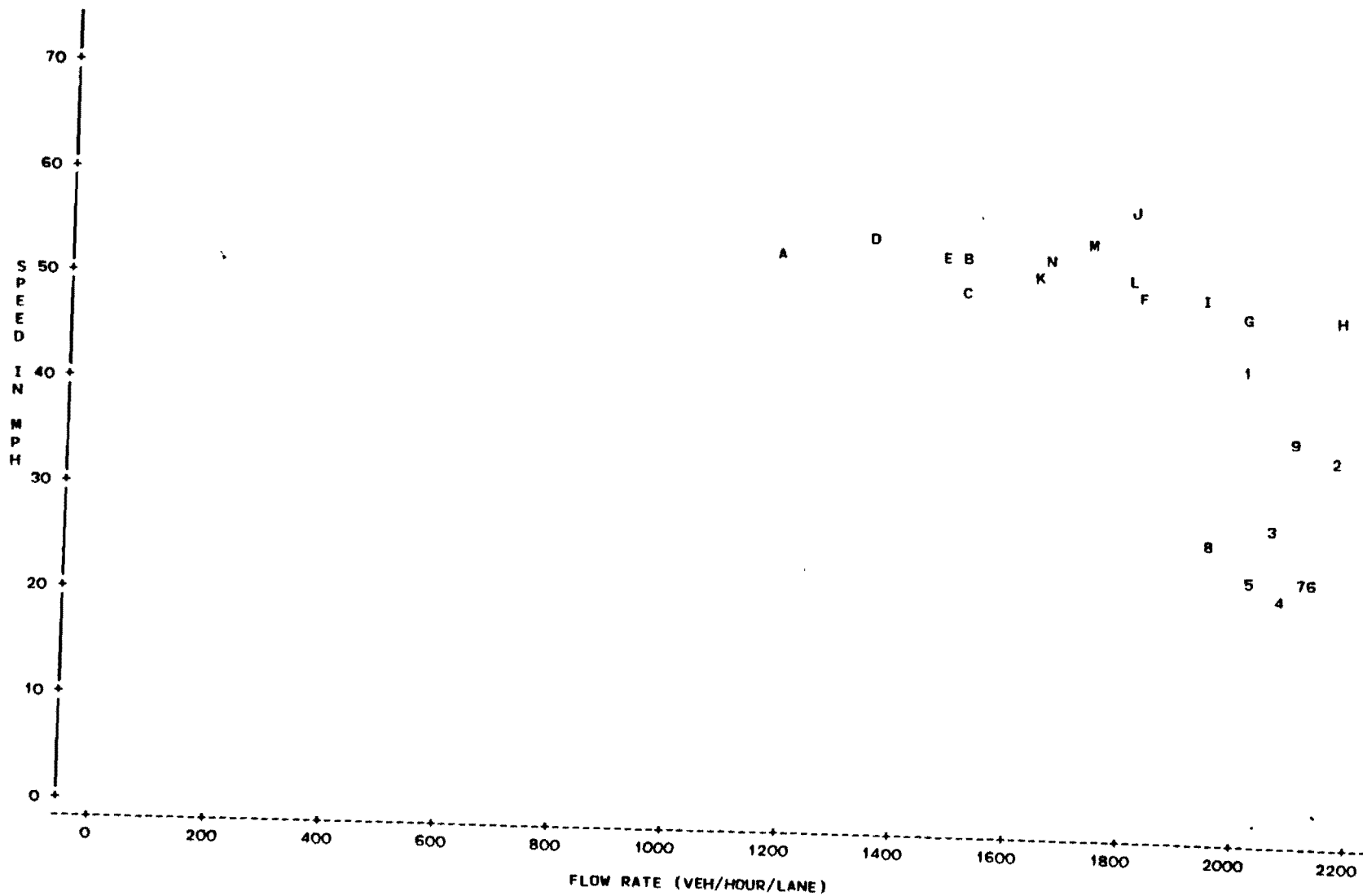
9

Figure 1. Speeds Through Rundberg Lane Bottleneck, IH-35, Austin, Texas

Although one could draw many different curves through the data in Figure 1, it is suggested that two regimes exist. Free-flow is characterized by a nearly horizontal straight line. A linear regression indicates the slope to be .002 mph per vehicle. The region of force flow is more nearly characterized by a vertical line. That is to say speed over the section is a function of the queue length. The fluctuation in flow is due to driver factors, vehicle factors and the capacity of the bottleneck. Excess demand does not significantly reduce the flow through the bottleneck.

One can, however, demonstrate the traditional parabolic speed flow relationship where flows deteriorate significantly under force flow by re-evaluating the data. By making the analysis point one-mile upstream, the curve shown in Figure 2 results. This second curve shows flow rates reduced by 40 percent. This reduced flow results from ramp traffic utilizing a significant portion of the mainlane capacity. The flow rate upstream is dictated by the results of two merging flows. The upstream speed-flow relationship is not representative of section capacity. That is likely the reason that the 1965 Highway Capacity Manual indicates that volume to capacity ratios are not meaningful for forced flow. Likewise, the bottom half of the speed-flow curve is drawn dotted in the Manual.

A linear regression of the free-flow portion of the IH-35 data yield the following relationship:

$$SPEED = 57.0 - (0.002 \times VOLUME)$$

A second data source also confirmed the basic linear speed volume relationship for free-flow conditions. Speed data is collected using a speed trap comprised of two closely spaced road tubes by the Department as part of the federal monitoring program for the 55 mph speed limit. A high volume station on I-20 in Tarrant County was analyzed based on hourly volumes.
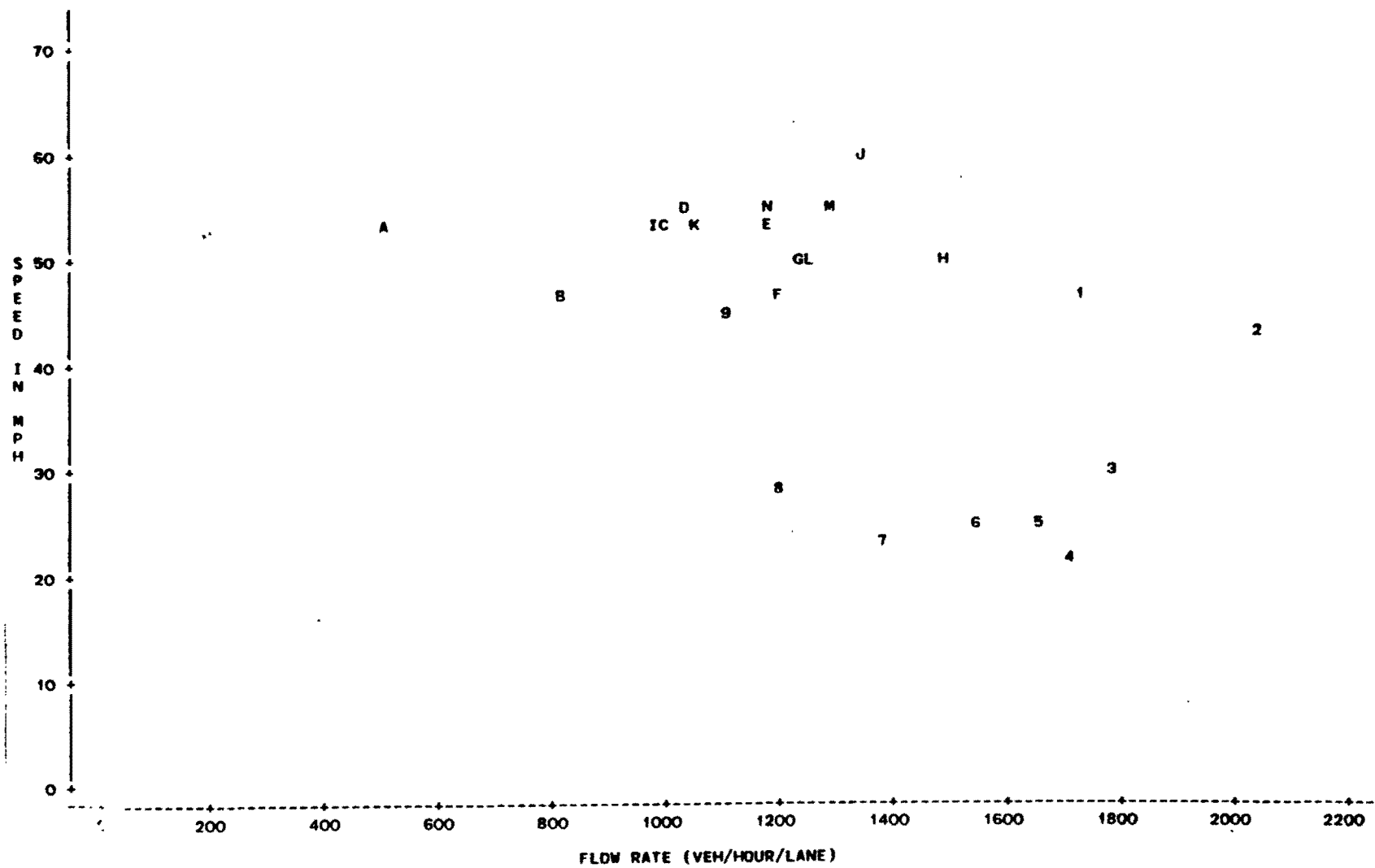
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Figure 2. Speeds 1-mile Upstream of Rundberg Lane Bottleneck, IH-35, Austin, Texas

12

Data from several different quarters of the year consistently showed slopes of -.002 or -.003 mph per vehicle and intercepts of 55 to 57 mph over volumes up to 1,800 vehicles per hour (based on data collected on an hourly basis). A typical relationship was:

$$SPEED = 57.1 - (0.002 \times VOLUME)$$

The R^2 was 0.70 indicating a good linear relationship between speed and volume as shown in Figure 3.

The importance of these relationships is reflected in the delay estimation technique produced in this study. The methodology used follows the two regime model hypothesized above. For under capacity sections, speeds are predicted based on the equation:

$$SPEED = 60.0 - (0.002 \times VOLUME)$$

For over capacity conditions, speeds are predicted assuming speeds decrease linearly and sharply to 25 mph at volumes of 1.2 times capacity. Speeds are then reduced moderately to 15 mph at volumes of 2.0 times capacity.

Although a queueing methodology was originally implemented in the model, it generated unrealistically high delays in that it did not account for the fact that some motorists will divert to alternate routes. The technique implemented moderates the results obtained when the projected volume is well in excess of capacity.

Urban Arterials

Urban arterials were also principally studied using the floating car technique. A number of sections in Houston and Dallas were studied in order to develop a speed/volume relationship. Data collected were highly scattered in most cases.
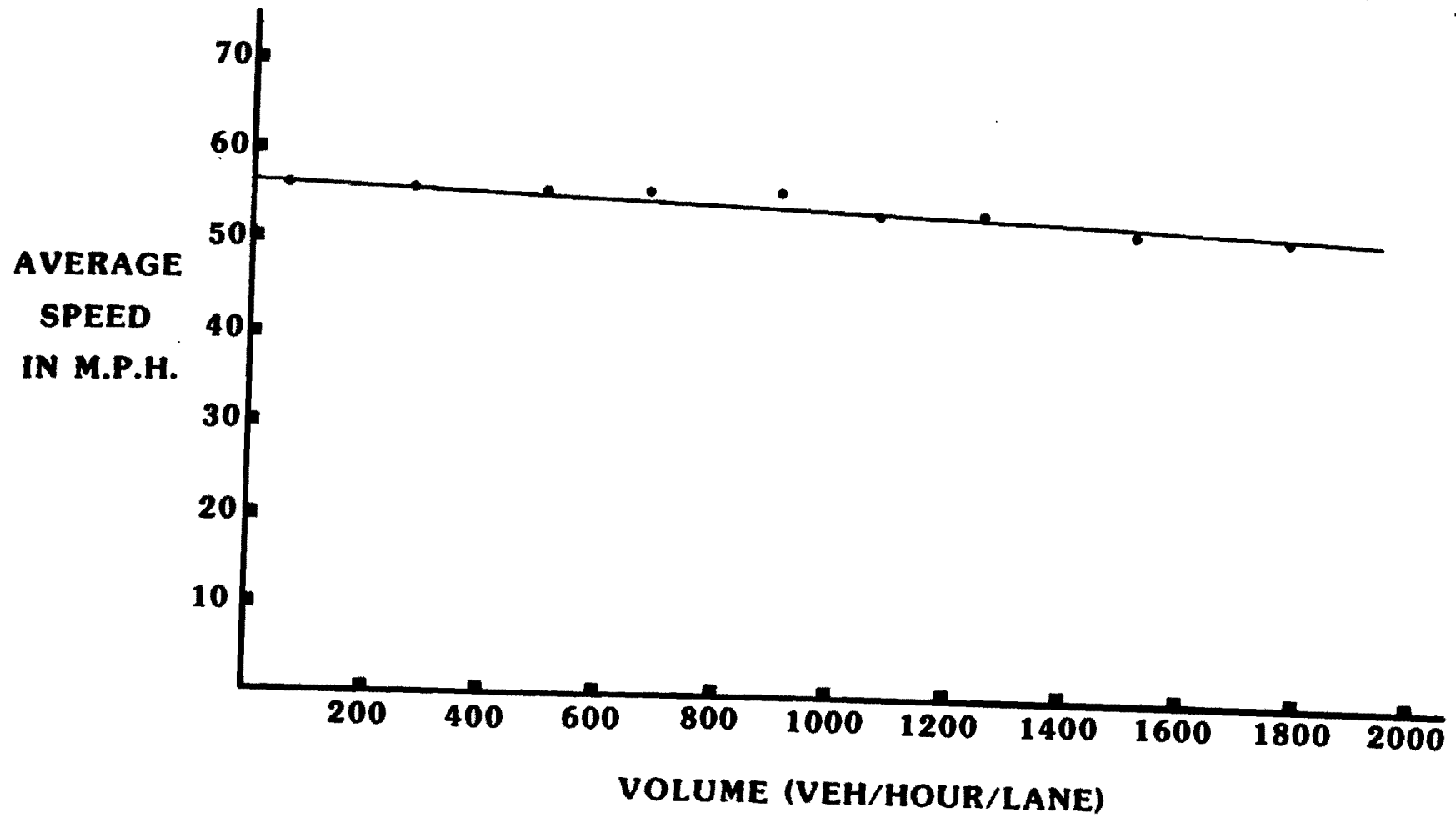
Figure 3. Speed/Volume Data On IH-20, Tarrant County

14

A 2-lane section of SH-289 in Collin County between FM 544 and Snowbird Trail was one of the sections studied. The section has 12-foot lanes and 10-foot paved shoulders. Two intersections are signalized. In the northbound direction, the following relationship was found.

$$SPEED = 61.6 - (0.033 \times VOLUME)$$

An R^2 of 0.81 indicated good fit of the data as seen in Figure 4.

A 4-lane section of SH-6 with a continuous left turn lane was studied in Harris County. The study section has 12-foot lanes and 10-foot paved shoulders. One study section produced the following relationships:

$$SPEED = 59.8 - (0.010 \times VOLUME)$$

The R^2 of 0.19 was relatively poor. The data is shown in Figure 5.

Based on the data from the study sections the slopes and capacities in Table 2 were included in the delay estimation procedure.

TABLE 2. URBAN SPEED/VOLUME RELATIONSHIP

Number of Lanes	Shoulders*	Left Turn Lane	Capacity	Intercept	Slope
2	No	No	350	60	0.040
2	Yes	Yes	500	60	0.020
4	No	No	500	60	0.015
4	Yes	No	500	60	0.014
4	No	Yes	650	60	0.012
4	Yes	Yes	650	60	0.010

*Full width paved shoulders

Multilane Rural

The data collected on the four-lane rural section of US 59 Cass County (See Figure 6) resulted in a statistically poor ($R^2 = 0.05$) relationship that indicated a slight (0.004) increase in speed with volume. However, given the

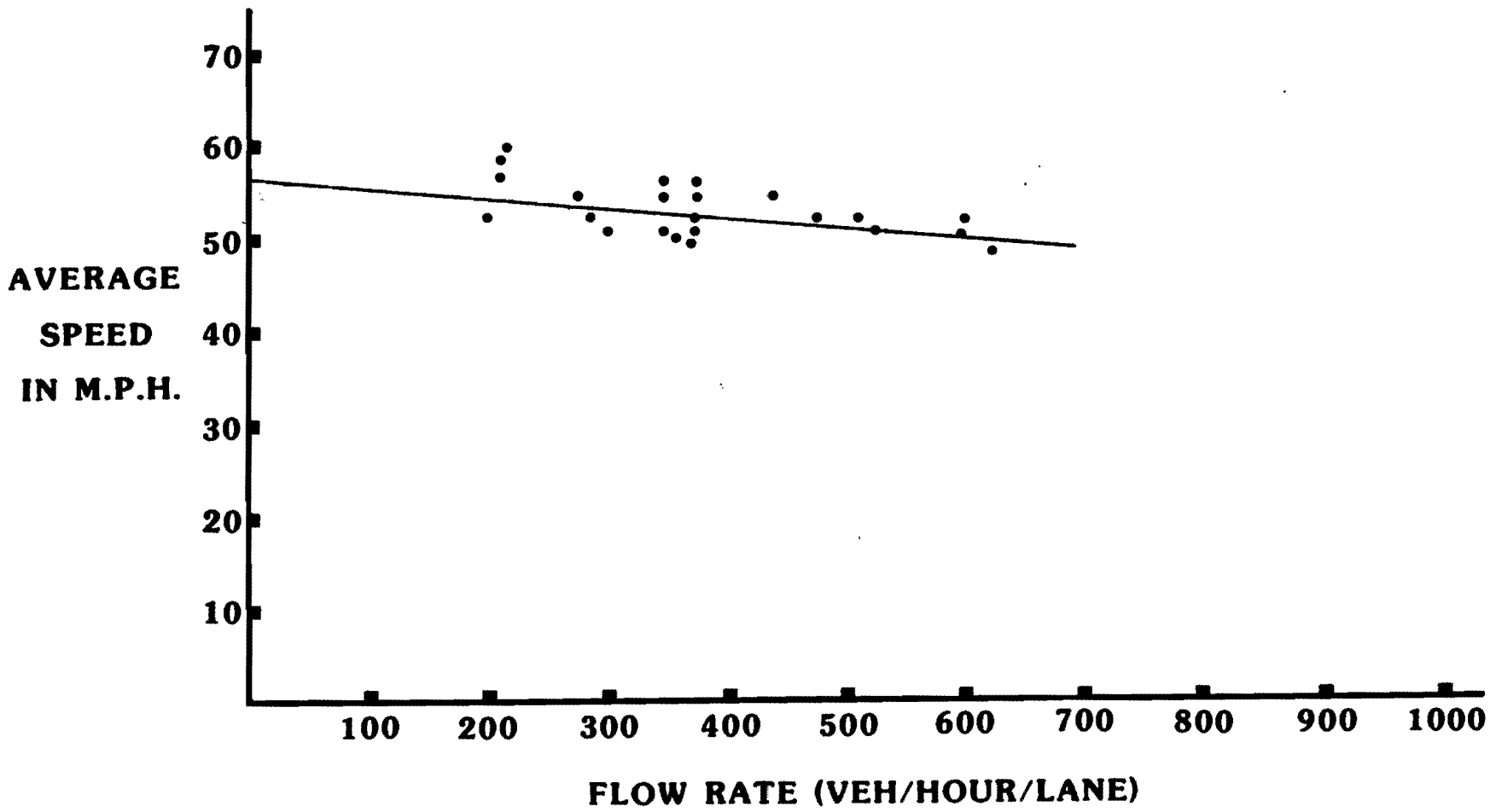Figure 4. Speed/Volume Data On SH-289 in Collin County

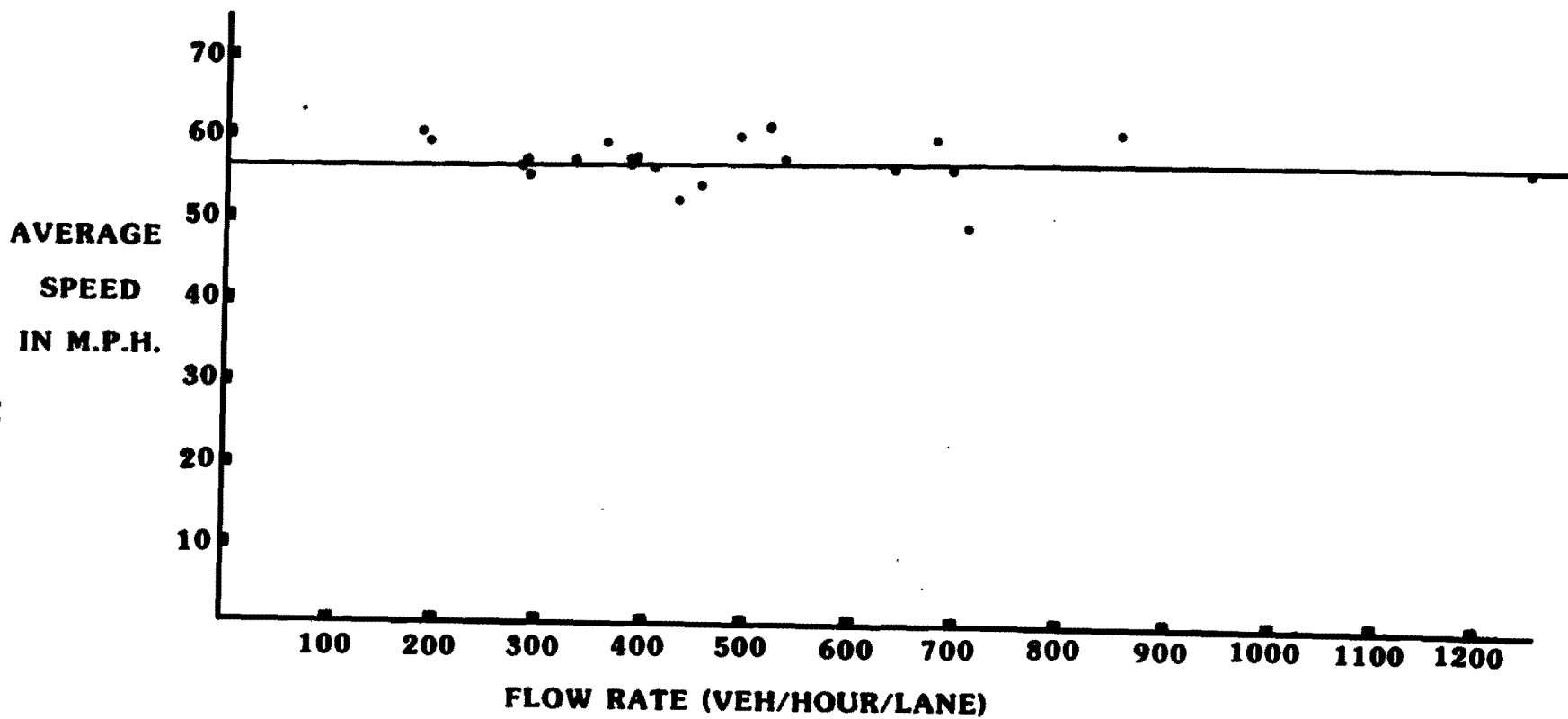Figure 5.   Speed/Volume Data On SH-6 in Harris County

17

Figure 6. Speed/Volume On US 59 in Cass County

large flow rates (up to 1,000 vph) surveyed, it is reasonable to conclude that speeds do not decrease significantly even at relatively high volumes.

Based on other available data and to maintain consistency between road types, it appears reasonable to assume a slope for multilane rural highways between those obtained for two-lane and those obtained for freeways. Furthermore, multilane highways operate more nearly like freeways than two-lane highways. Lastly, some two-lane highways in flat country with good geometrics also show very small changes in speed as volume increases. Slopes of 0.003 for four-lane rural highways with shoulders and 0.0035 for four-lane rural highways without shoulders appear to be reasonable estimates for the purposes of this study.

2-Lane Rural

Two-lane rural roadways received the greatest attention in this study. This intense study was principally the result of initial data collection and analysis which indicated that 2-lane rural speeds were high even at relatively high volumes (i.e., rates of flow in excess of 1,000 vph). These initial findings resulted in additional data collection including a motorist survey which is described later in the report. It should be noted, however, that the additional data collected suggests that certain conditions do result in reduced speeds under modest traffic volumes.

As described earlier, the initial data collection effort using a "floating car" could not discern any measurable speed reduction due to increasing traffic volumes. Upon changing to the moving radar methodology, a 2-lane section of SH-6 between Navasota and Hempstead was selected for data collection. The section has 12-foot lanes and a 8-foot shoulder. However, a overlay on the through lanes results in an adverse cross slope on the shoulders. Therefore, few slow vehicles pull onto the shoulder.

19

In order to obtain high flow rates, data was collected before and after a home football game at Texas A&M University. Flow rates in excess of 1,000 vehicles per hour had very little effect on speed. For example, a linear regression resulted in the following expression:

$$SPEED = 58.8 - (0.0006 \times VOLUME)$$

Again, a poor R^2 of 0.07 makes the relationship statistically unacceptable. However, as can be seen from the data in Figure 7, it is reasonable to conclude that speeds are relatively insensitive to volumes.

Given the initial results of the new data collection technique (i.e., moving radar) were similar to the floating car technique, another strategy appeared necessary for collecting some useful data. The third strategy was to search out some additional study highways and collect both quantitative speed/volume data and attitudinal data. The attitudinal data would be used to determine if perceptions were different from measured results.

The method selected for attitudinal data was a survey of motorists using the highway. The concept and details of the survey will be reported later. Selection of the sites and the quantitative data will be discussed now.

Two principal criteria were used in selecting the seven study sites which are shown in Table 1. First, the site had to be considered as being perceived by the public as possibly requiring improvement. Second, the site had to be of uniform cross section over a section that could easily be related to motorist using the road.

The sites selected were all two-lane highways except for one 4-lane section. The four-lane section and three two-lane sections had no shoulders. Geometrics range from relatively flat and straight to winding and hilly. One
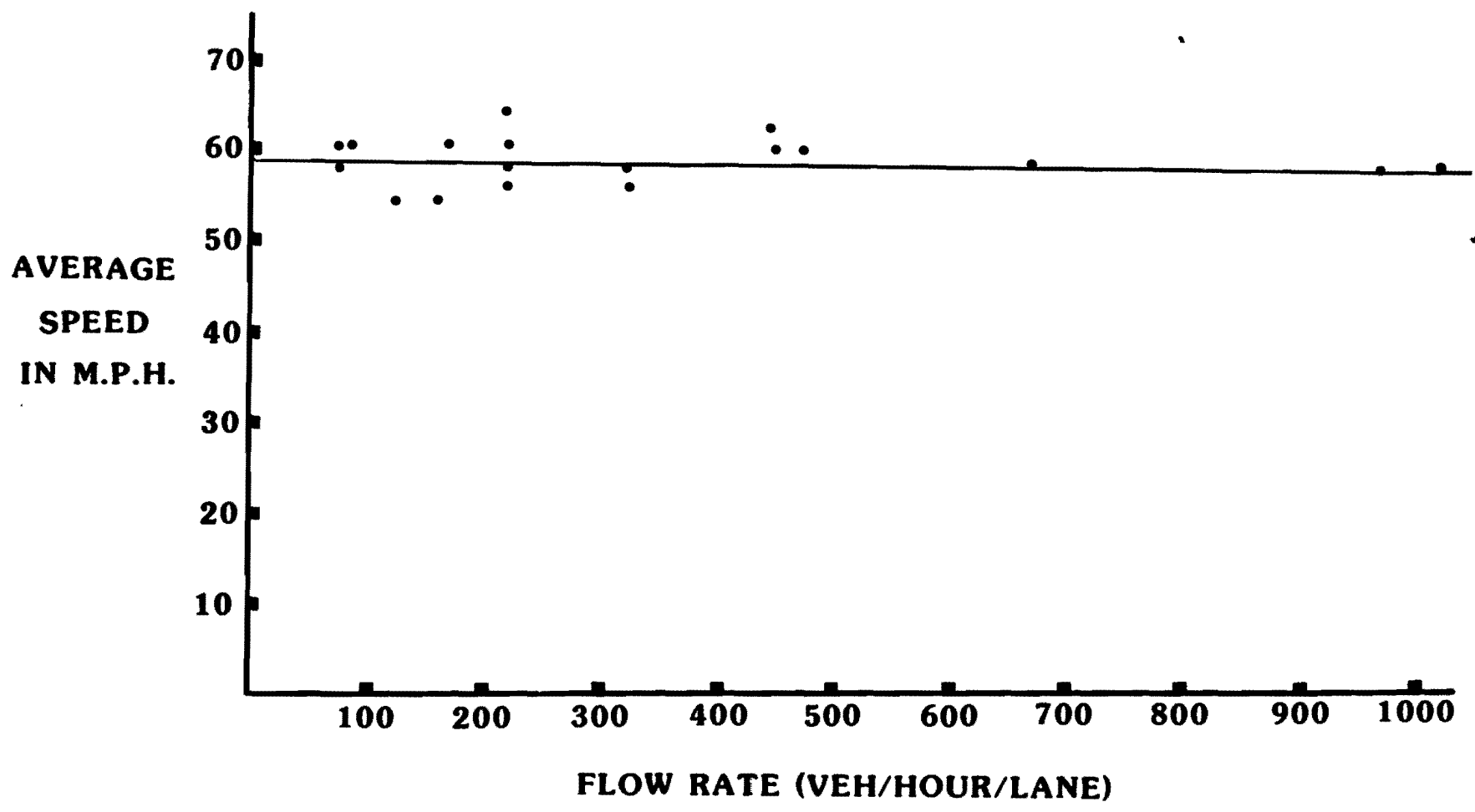
Figure 7.　Speed/Volume Data On SH-6 in Waller County

section, SH-289, is urban in character and contains signalized intersections. All the other sections do not have traffic signals within a distance to influence speeds.

The site selected to represent 2-lane rural highways with shoulders was SH-19 in Walker County. The section has 12-foot lanes and 10-foot paved shoulders. The area has about 50% no passing. There are few driveways and intersections. The ADT is 4,500 vehicles per day. The relationship found on one of the study sections at the site was:

$$SPEED = 60.0 - (0.017 \times VOLUME)$$

The R^2 of 0.26 was relatively poor, however, analysis of other study sections indicated similar, but generally statistically poor results. The actual data are shown in Figure 8.

Another study site was US 96 in Shelby County. This 2-lane rural section had no shoulders and 11-foot lanes. The terrain was hilly and the no-passing percentage was about 50%. The ADT is 2,500.

The relationship found was:

$$SPEED = 61.1 - (0.072 \times VOLUME)$$

with an R^2 of 0.41. The actual data is shown in Figure 9 although relationship developed is statistically better than that for SH-19, the US-96 data (See Figure 8) appears to be similar. However, the smaller range of volume data for US 96 results in a better fit.

These two 2-lane-rural sites illustrate the problem developing relationship given the relatively small volume range on many two-lane highways. The variability in speeds at a given speed is nearly as great as the total variability in speeds over the entire range of data.
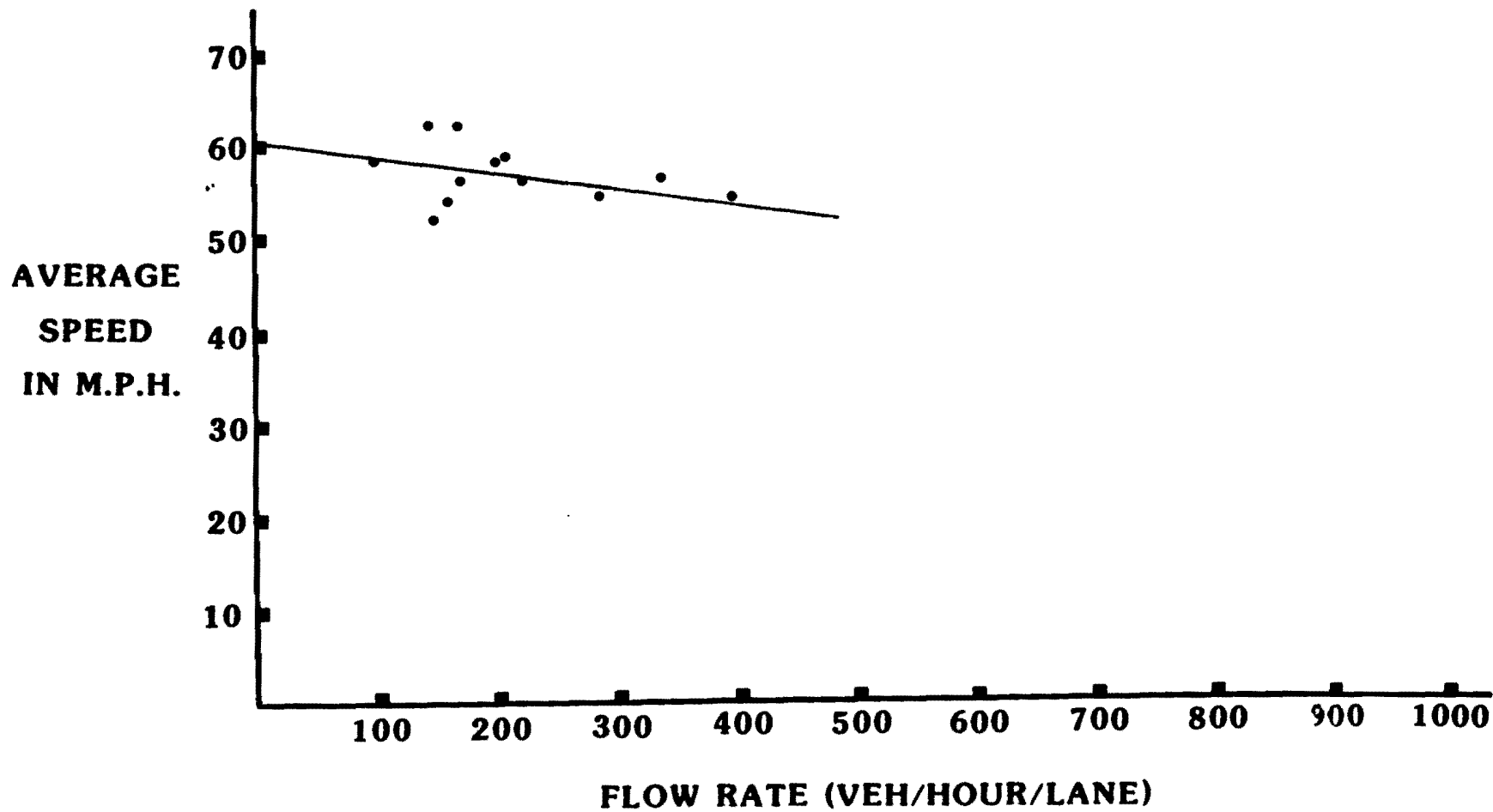
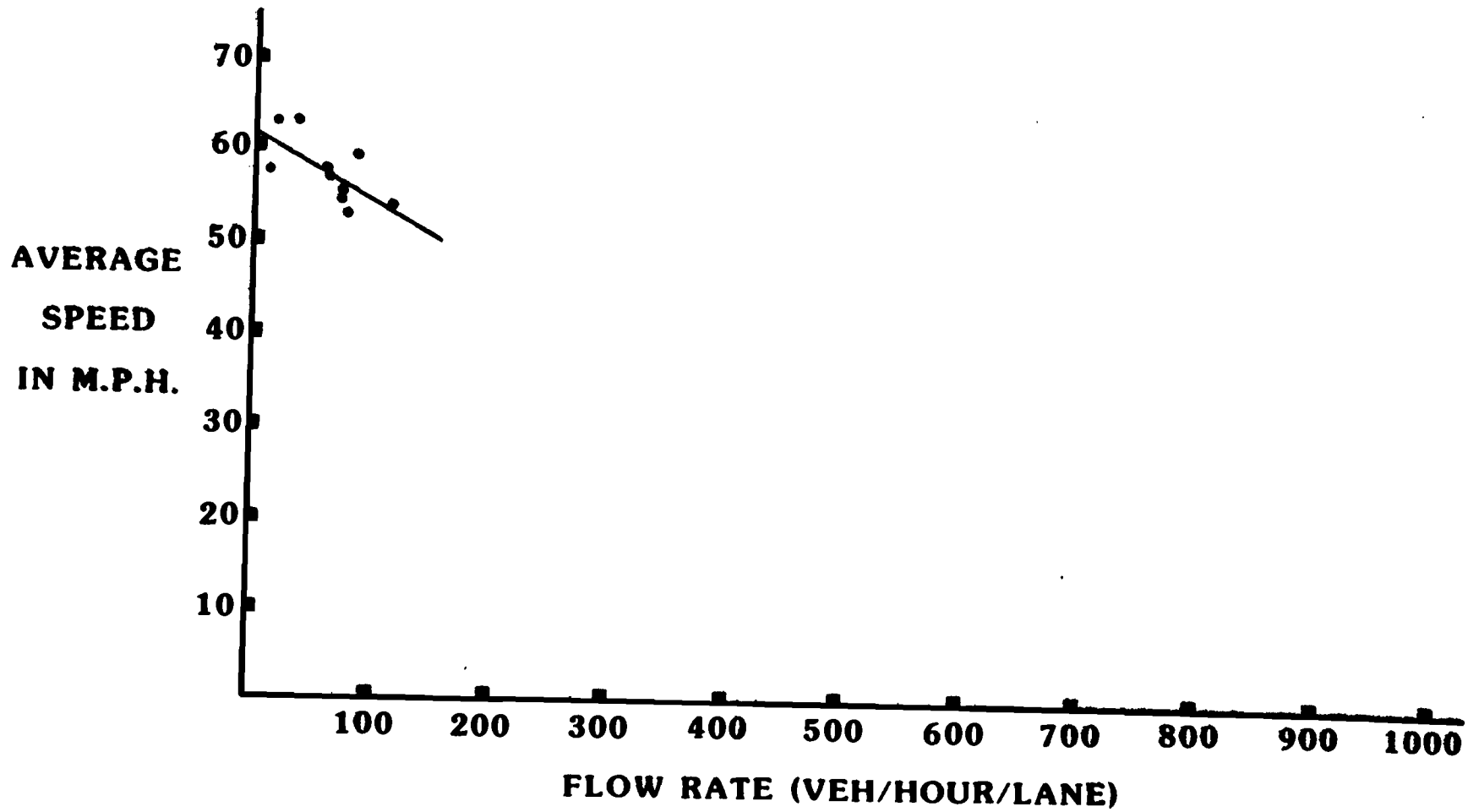Figure 8.   Speed/Volume Data On SH-19 in Walker County

Figure 9.   Speed/Volume Data On US 96 in Shelby County

Two other "suburban" type sites also illustrate two-lane speed/volume relationships at higher flow rates. Both are two-lane roadways without signals. The first site is FM 149 in Harris County. The study section has 12-foot lanes and no shoulders. The speed/volume data as shown in Figure 10 yielded the following relationship with an R^2 of 0.36:

$$SPEED = 56.4 - (0.012 \times VOLUME)$$

The second "suburban" site was FM 2818 in Brazos County. This site had 12-foot lanes and 10-foot paved shoulders. The speed/volume data as shown in Figure 11 yielded the following relationship with an R^2 of 0.15:

$$SPEED = 53.3 - (0.006 \times VOLUME)$$

Based on the data collected and other research, the recommended slopes for two-lane rural highways is 0.035 for 2-lanes without shoulders and 0.017 for 2-lanes with shoulders. It should be noted, however, that some highways will operate at higher speed than those stated above. This would be especially true in flat terrain with good passing sight distance and minimal side friction.
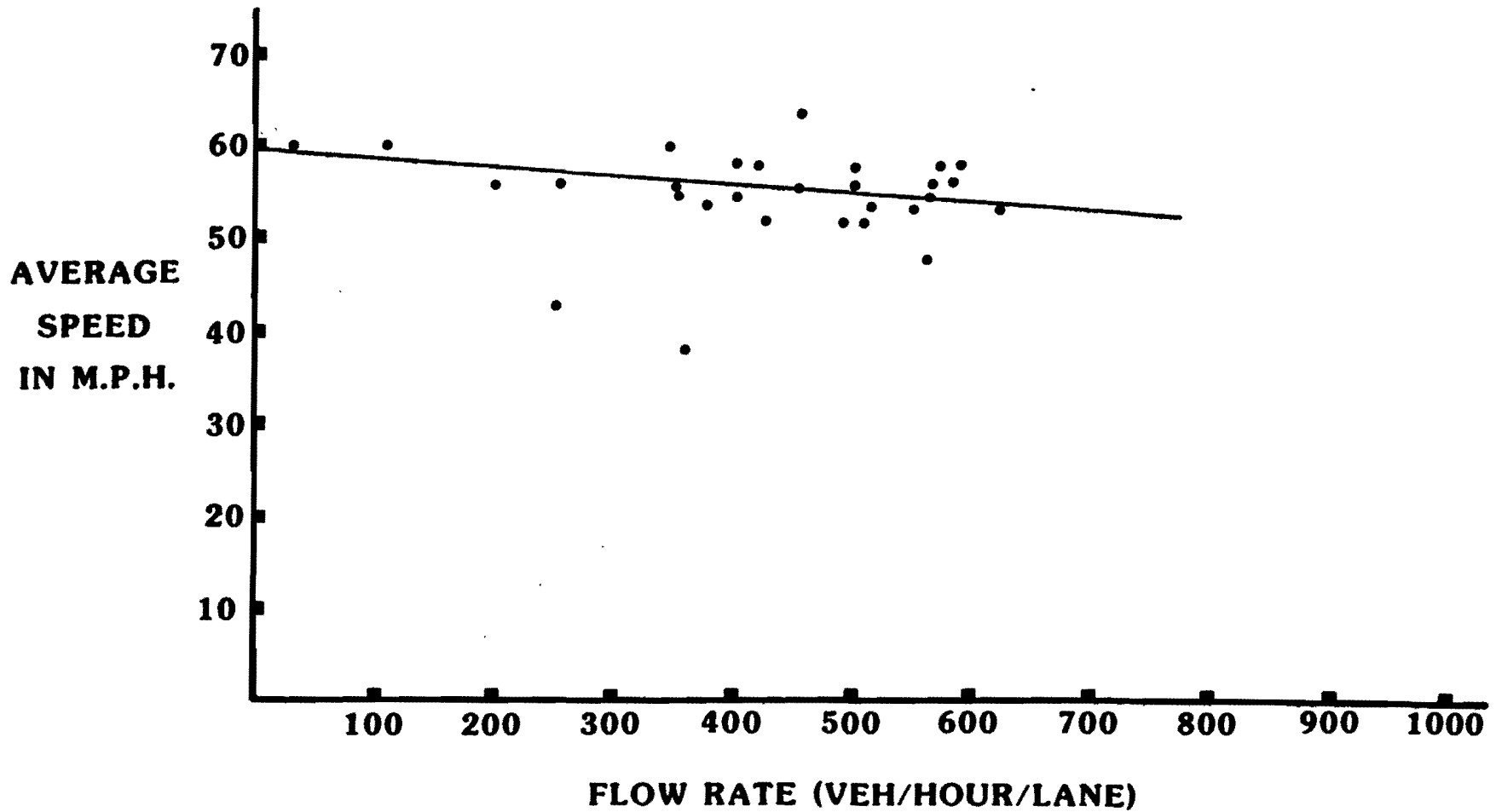
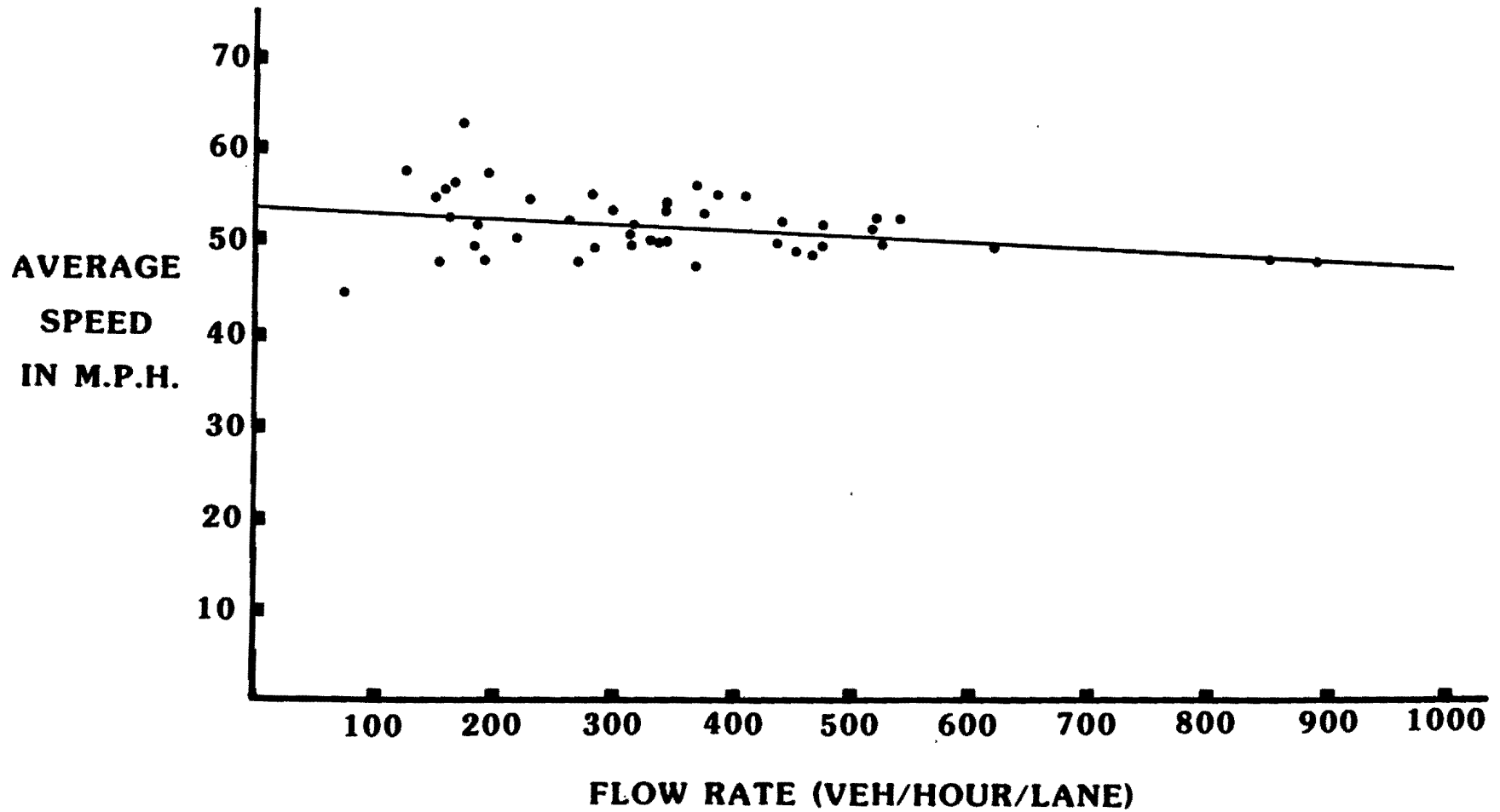Figure 10. Speed/Volume Data On FM 149 in Harris County

Figure 11. Speed/Volume Data On FM 2818 in Brazos County

V. ROAD USER SURVEY

The delay study involved a variety of techniques in data collection to achieve the study objectives. The road user survey was used to obtain motorist perceptions of the study area and it's operating characteristics. The road user survey was not in the original study objectives, but was included after data over a large range of traffic volumes showed little variation.

The survey was designed to gather information concerning the motorists previous experiences with the study site perceived operational characteristics, and attitudes towards possible improvements. A copy of the survey form is included in Appendix A.

Study Areas

Seven study areas were evaluated in the road user survey. The first site is State Highway 19 between Huntsville and Country Campus Road. The area is basically rural and north of Huntsville's City Limits. The road has two 12-foot lanes and a 10-foot paved shoulder. The terrain has gentle hills, moderate curves and the road study sections averages 60 percent no-passing. There are no major intersections and a few driveways. The ADT is 4,500.

The second site is State Highway 49 between FM 144 and FM 1000. The area is located between the towns of Mt. Pleasant and Daingerfield. The area is rural with a terrain of rolling hills and sharp curves. The road has two 11-foot lanes, no paved shoulders and about 60 percent no-passing. There are minor intersections and driveways; but they do not significantly influence traffic flow. The ADT is 2,900.

The third site is US 96 between San Augustine and Center. The terrain is gentle to rolling hills in a rural setting. The road has two 11-foot lanes and no paved shoulders. No passing zones average 60 percent. The ADT is 2,500.

The fourth site is US 59 about four miles north of Atlanta. The area is rural but has some commercial activity adjacent to the study area. The road has four 12-foot lanes and no paved shoulders. The terrain is gently sloping hills. There are several intersections but the traffic flow is relatively unaffected. The ADT is 11,000.

The fifth site is State Highway 121 between FM 3040 and Texas 26. The site is a combination of rural, residential and commercial use. There are two major influences to the site. The first is a Texas Instruments Plant located at the north end which has a high number of employee vehicles and the second is a construction project which uses a considerable number of dump trucks. The site has a few intersections but they contribute a substantial amount of traffic. The Road has two 12-foot lanes and 12-foot paved shoulders. The terrain is relatively level with slight grades. A common condition on this road is a group of vehicles following a slow-moving vehicle. The ADT is 12,200.

The sixth site is State Highway 289 between FM 544 and Maple Shade Lane. This is the northern continuation of Preston Road. The study area is primarily an arterial which runs through a residential area with a small number of commercial uses. The traffic is dominated by two signalized intersections. The signals tend to cause congestion during peak hours. The road has two 12-foot lanes and 10-foot paved shoulders. The terrain is relatively flat with a lot of area that is being developed. The ADT is 13,400.

The seventh site is FM 149 south of Tomball to Cypress-Springs Road. The area is a combination of rural and residential property. The road has two 12-foot lanes with no paved shoulders. The terrain is flat with flat curves in the road. The study area handles a lot of commuter traffic to and from Houston. The ADT is 13,100.

Survey Form

The survey form used was identical on all sites except the FM 149 Study Area. Questions concerning bridges and hills were eliminated because of the lack of existing features. It was subsequently decided to leave all questions in even if they did not apply as a check on the survey results. The FM-149 survey location was the first use of the survey. It is important to note that all study areas are two lanes except for US 59 which is four lanes. It will not, therefore, be possible to use US 59 in several of the comparisons used in the evaluations.

Survey Distribution and Collection

The surveys were distributed to motorists driving through the study area while speed data was being gathered. A mailing address was acquired from the motor vehicle registration file based on the license plate number of the observed vehicle. Vehicles not registered in the general area of the study site were eliminated due to infrequent use of the road and an unfamiliarity with the area. Since this part of the study was not in the original work plan, the amount of effort that could be expended was limited.

A total of 2,892 surveys were mailed out; of this total, 685 surveys were received. This is a response rate of 24%. Figure 12 shows the response rate of each of the study areas.
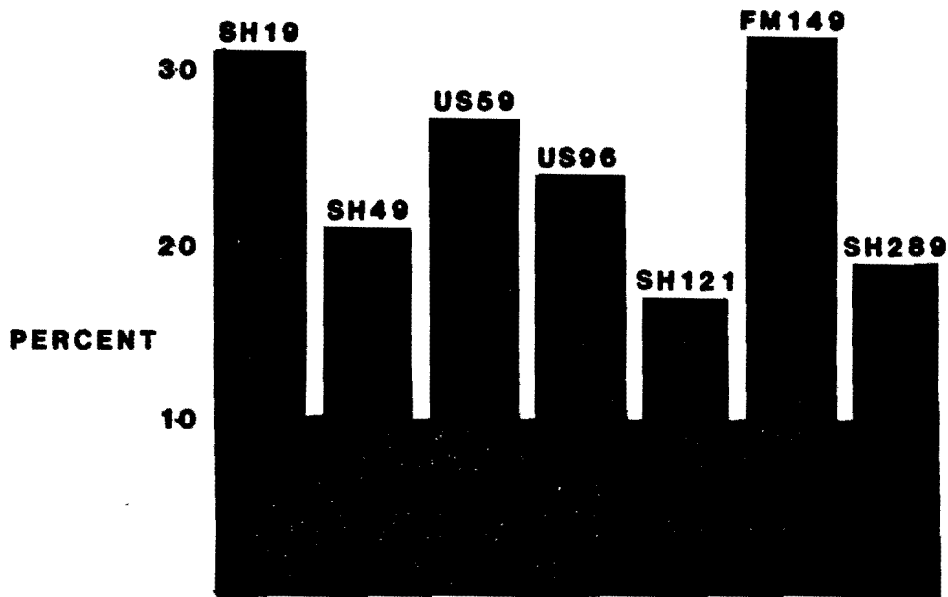
Figure 12. Survey Response Rates

Previous Experiences and Attitudes

The first section of the survey contains four questions concerning the user's previous experiences and attitudes concerning the study area. Additional questions concerning population of the area and years of driving experience were included. The average number of years of driving experience was found to be higher in areas of low population and traffic volume. Four sites (SH-19, SH-49, US 59 and US 96) have an average of 30.5 years of driving experience and the three sites (SH-121, FM 149, and SH-289) average 23.7 years.

The question concerning congestion or traffic delay received an overall score of 2.3 on a 3 point scale which is occasional to frequent congestion. By categorizing, the study areas by average daily traffic, relationships can be shown relating survey scores to average daily traffic. In later comparisons the study areas were grouped into two categories; high population

32

and average daily traffic which includes SH-121, FM 149, and SH-289, and low population and average daily traffic which includes SH-19, SH-49, and US 96. The congestion or traffic delay survey scores are 2.6 for the high average daily traffic survey areas and 2.0 for the low average daily traffic survey areas. Scores are ranked one for uncongested, two for occasional congestion and three for frequent congestion.

Operational Characteristics

The second section of this survey obtained information concerning the operational characteristics of the study area. Five operational characteristics were selected and rated from much worse than desired to much better than expected on a scale from one to five. Figure 13 shows the average responses given for the five characteristics.

The comparison based on average daily traffic shows a tendency for scores to be in the less than desirable range in high average daily traffic areas. Another observation is that all responses average between much worse than desired and acceptable scores. Figure 14 shows the relationship of survey scores to average daily traffic showing a slight downward movement as Average Daily Traffic increases. There appears to be a more pronounced variation at the very high and very low Average Daily Traffic numbers.

Given that congestion is related to ADT, the results shown in Figure 14 are clearly consistent with congestion increasing with ADT. There also appears to be a marked increase in perceived congestion between 2,500 and 3,000 ADT.

It is interesting to compare US 96 with SH-49. Both highways are similar in most respects and with only small differences in traffic volume. The other differences include poor horizontal alignment on SH-49 (and not US 96) and the
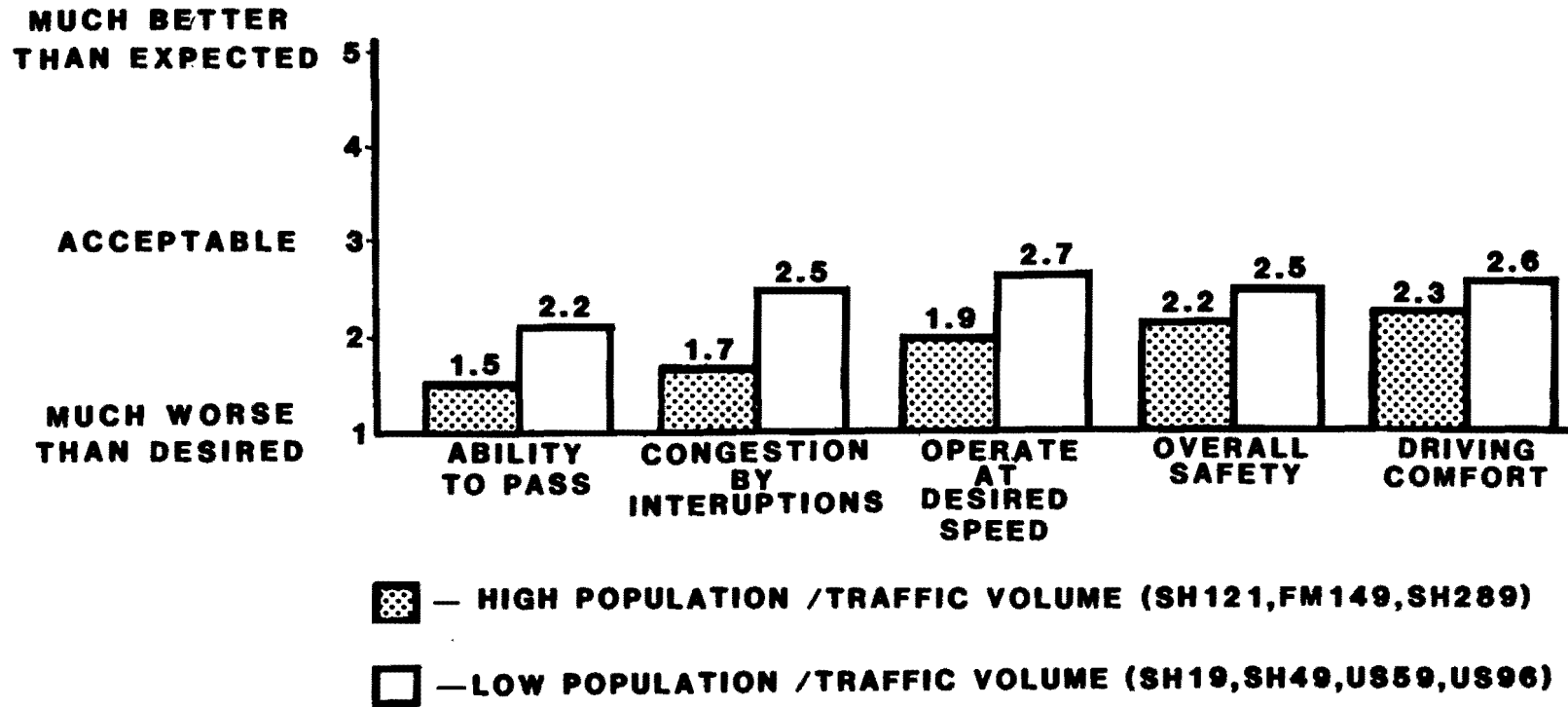
33

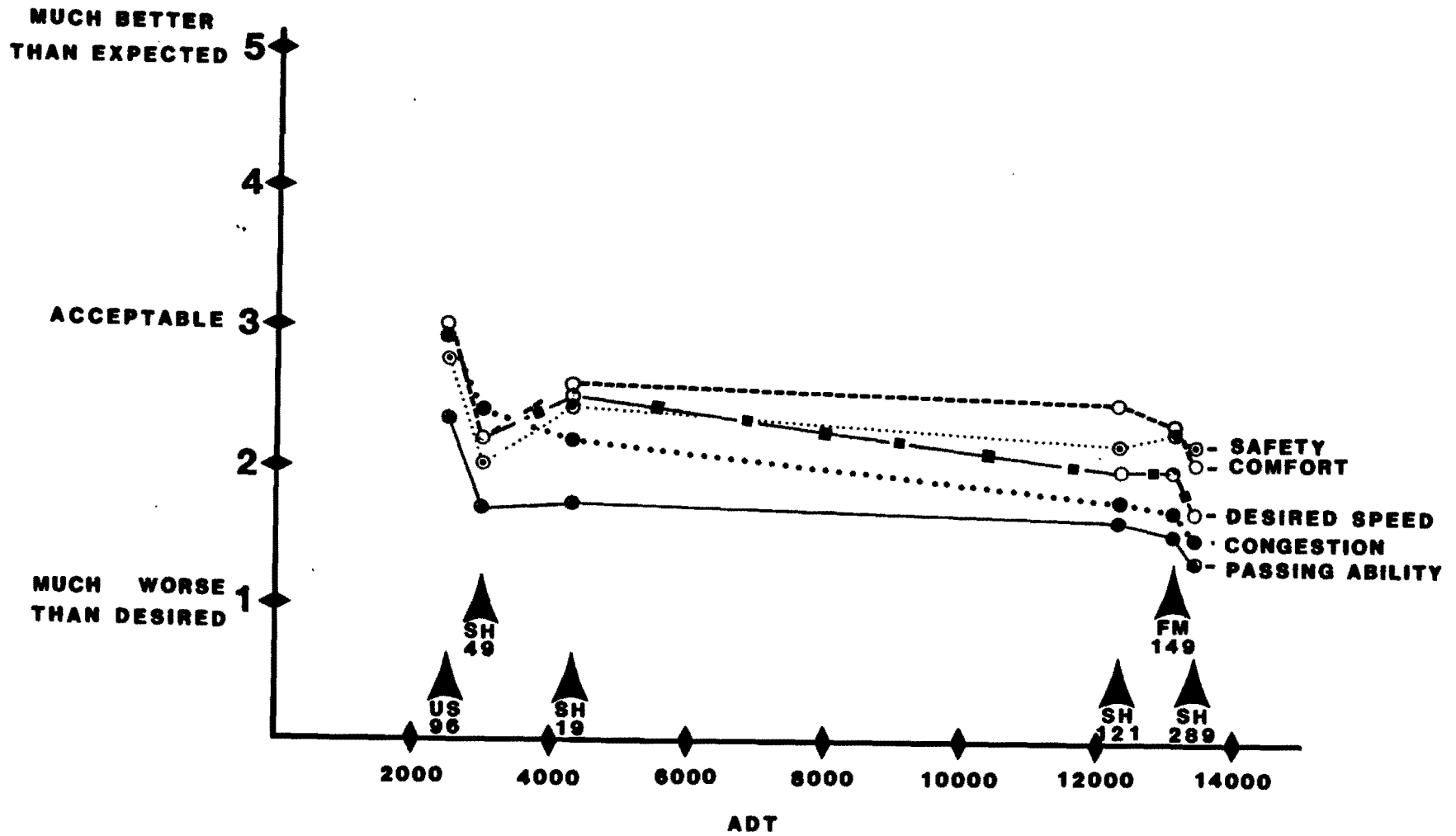Figure 13. Average Response Scores for Operational Characteristics

34

Figure 14. Ratings of Operational Characteristics

presence of climbing lanes on portions of US 96. It is possible to speculate as to the cause of SH-49 being rated differently than US 96. As will be shown later, SH-49 rated high relative to the need to reduce curves.

Comparison to Other Texas Highways

The third section of this survey is a single question which concerns the individual study areas and a comparison to other Texas Highways. The comparison concerns the overall need for improvements along the route. The survey grades the responses; much less need, average need and much greater need on a scale from one to five. The overall score for this was 3.8 which is a greater need score. As seen before, the high Average Daily Traffic study areas average higher with a score of 4, as compared to the low Average Daily Traffic Survey Score of 3.6.

Possible Improvements

The fourth section of this survey obtained information on possible improvements to the study sites, scores were rated from not needed on a scale of one to five. Improvements receiving a "much needed" rating included adding surfaced shoulders with a score of 3.5, providing left turn lanes at 3.5 and widening the pavement for through lanes at 3.6. Improvements receiving a "not needed" rating included reducing the sharpness of curves at 2.2, installing signals at 2.3, providing interchanges at 2.3 and upgrading to a freeway at 2.2.

To better understand the survey responses the scores for each study area have been examined by comparison to average daily traffic figures. Figures 15 through 20 show the responses relative to ADT at the various sites.
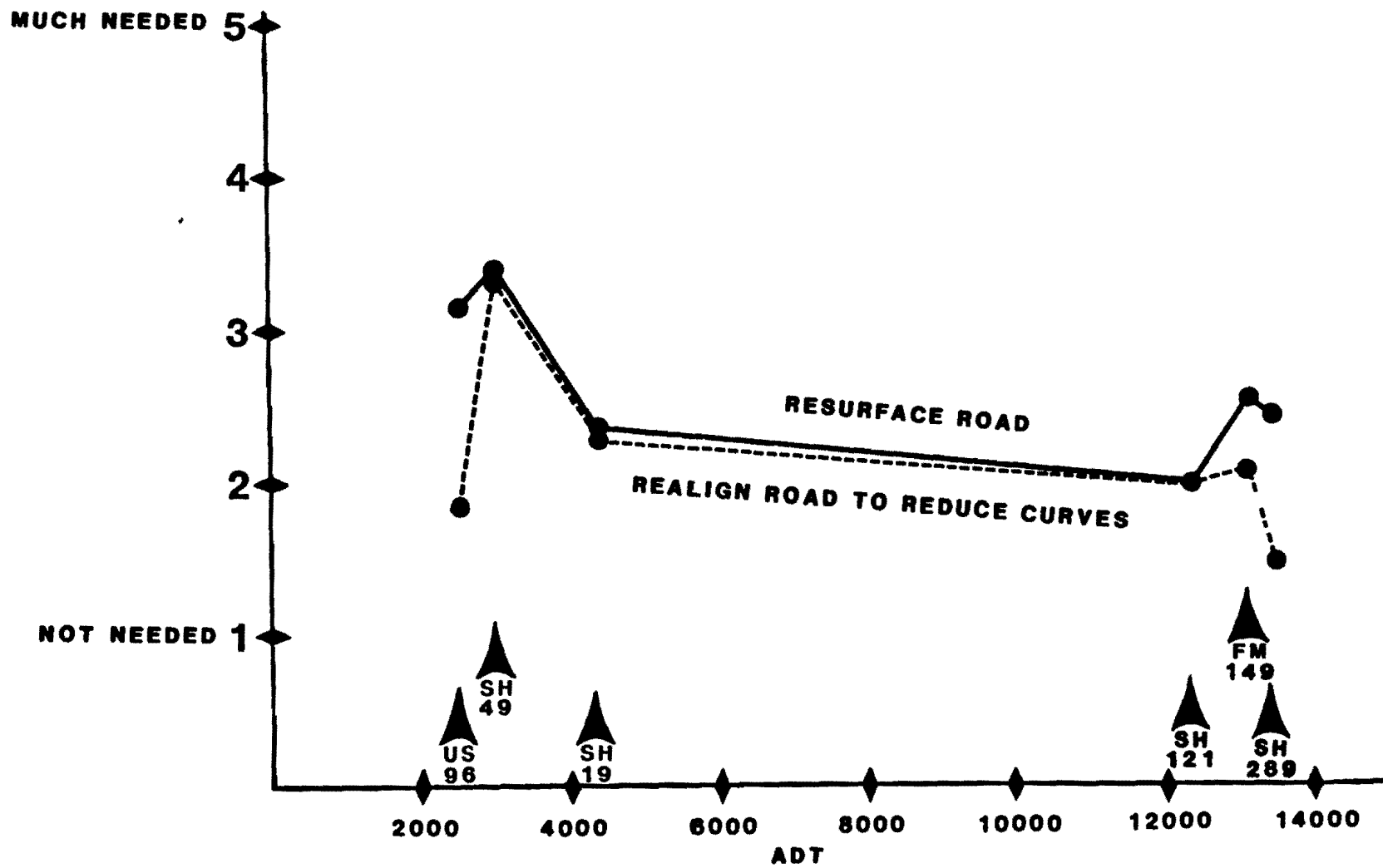
Figure 15. Ratings of Possible Improvements
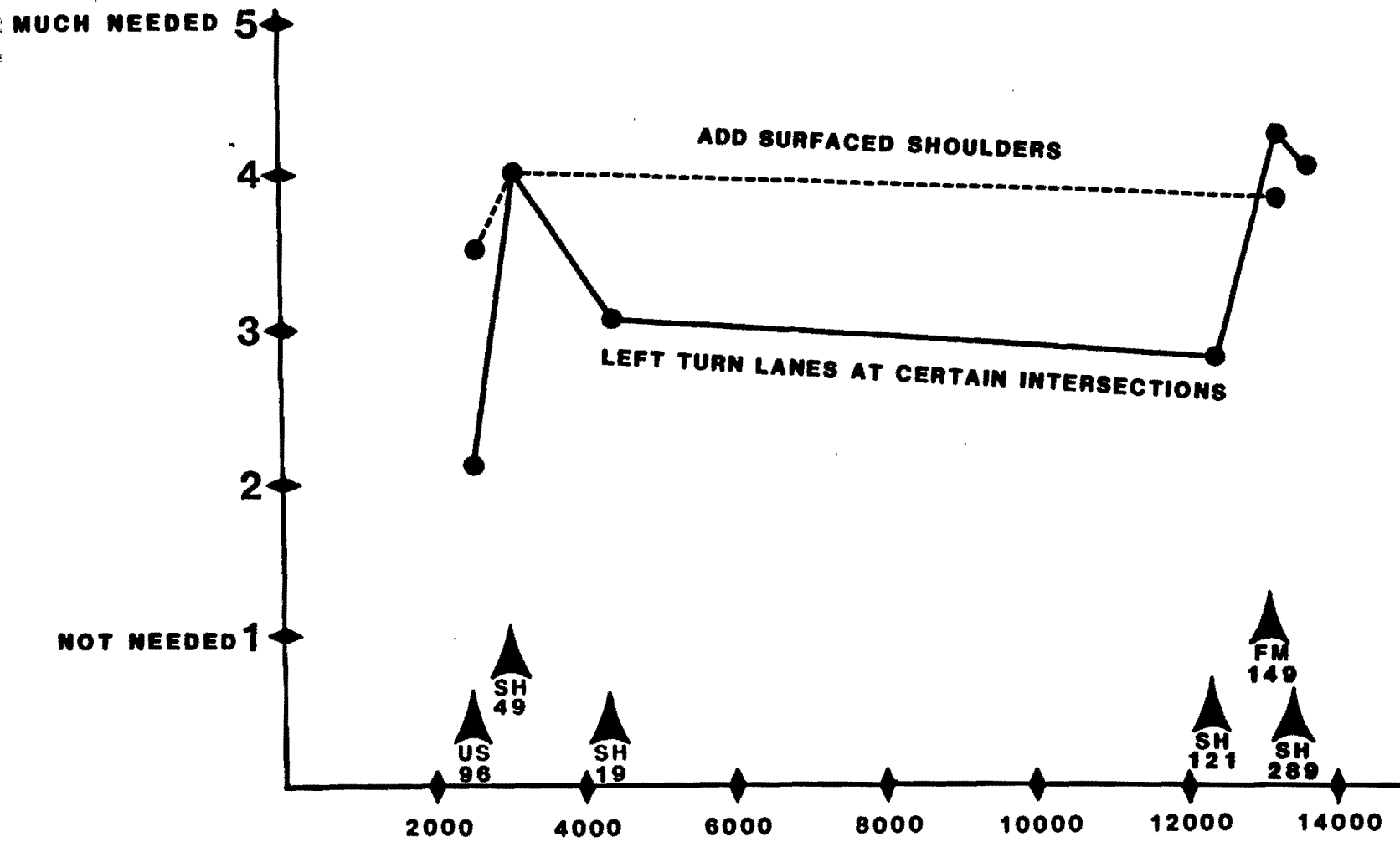
MUCH NEEDED 5

4

3

2

NOT NEEDED 1

ADD SURFACED SHOULDERS

LEFT TURN LANES AT CERTAIN INTERSECTIONS

US 96   SH 49   SH 19   SH 121   SH 289   FM 149

2000   4000   6000   8000   10000   12000   14000

38

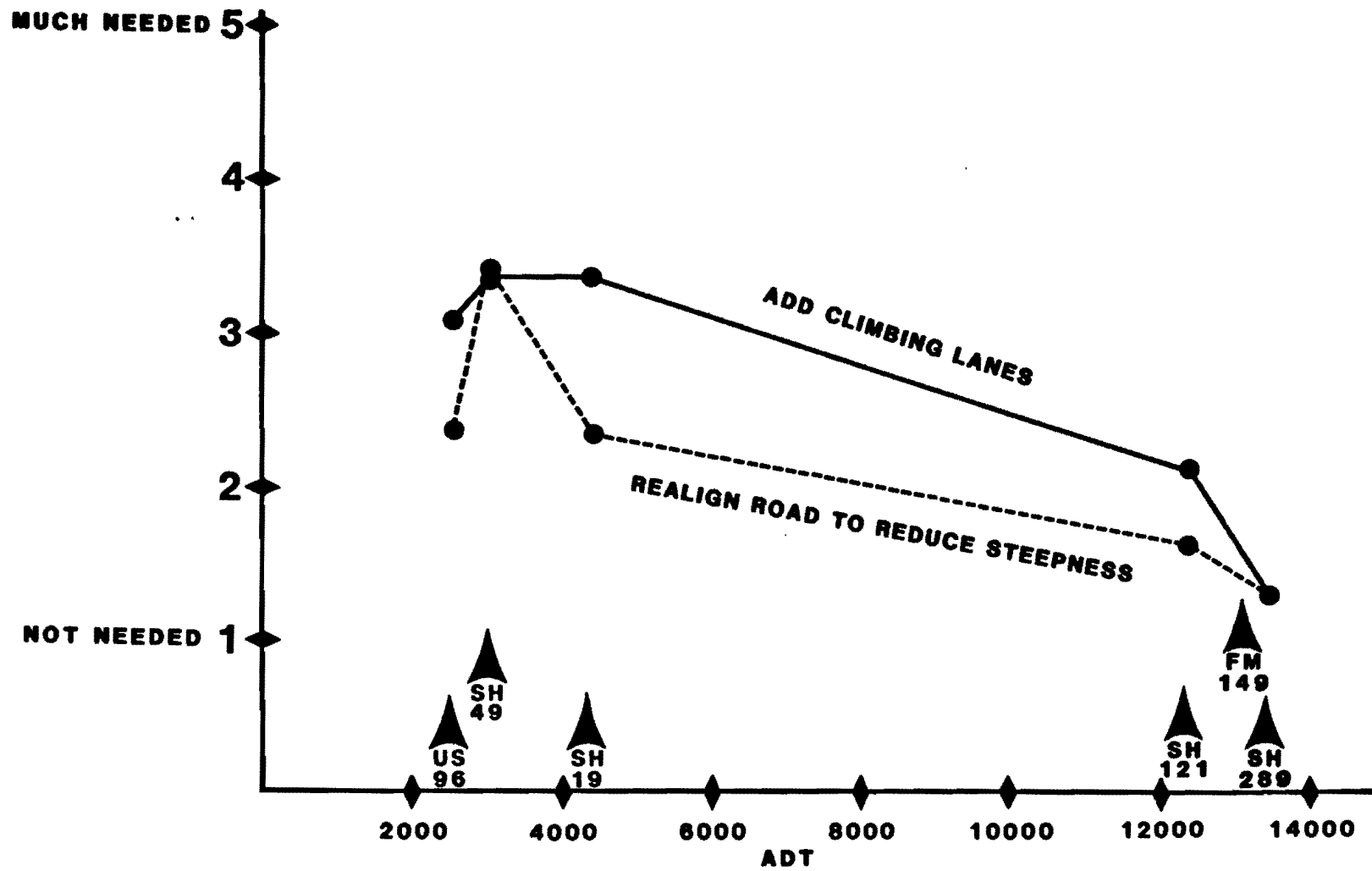Figure 16. Ratings of Possible Improvements
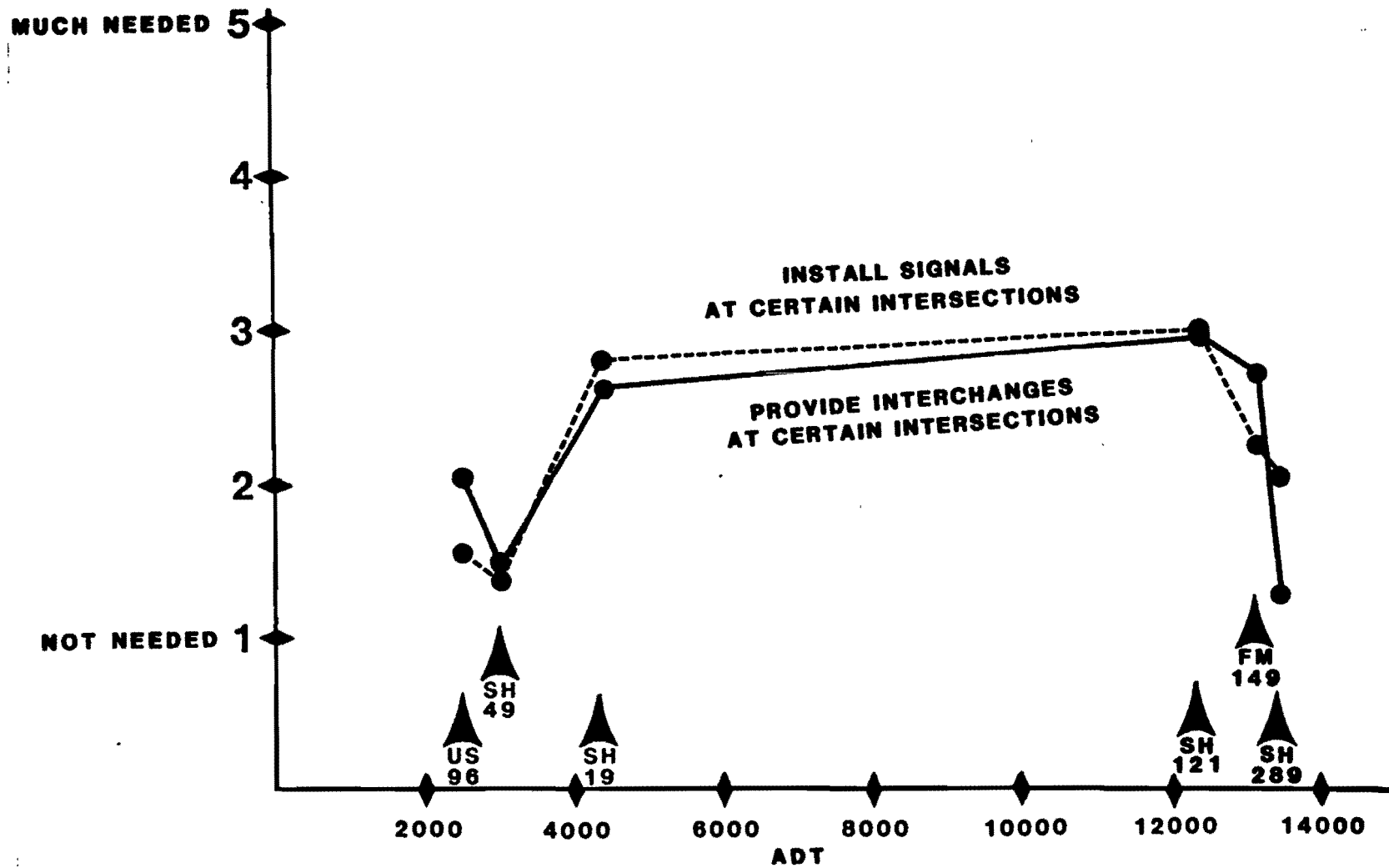

Figure 17. Ratings of Possible Improvements

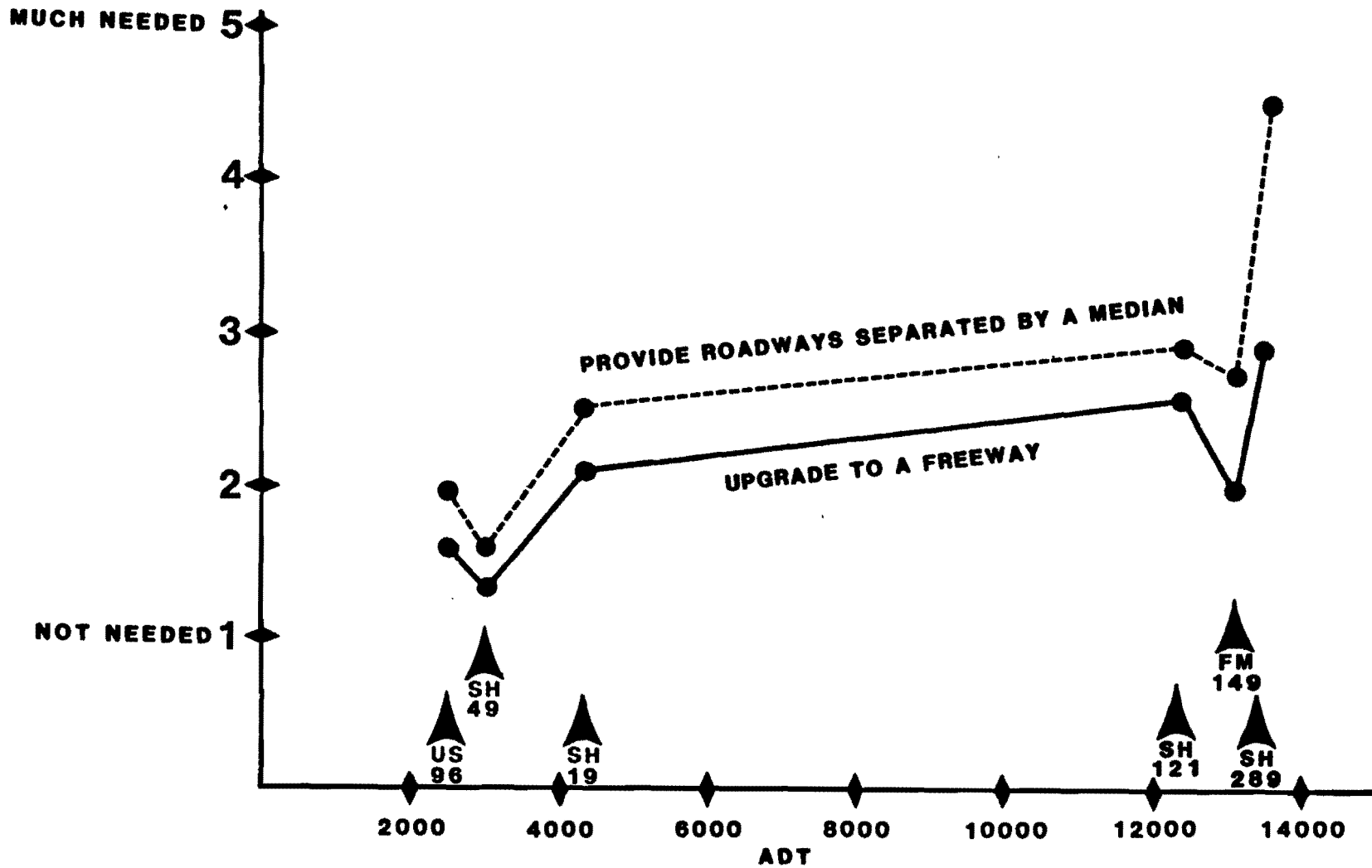Figure 18. Ratings of Possible Improvements
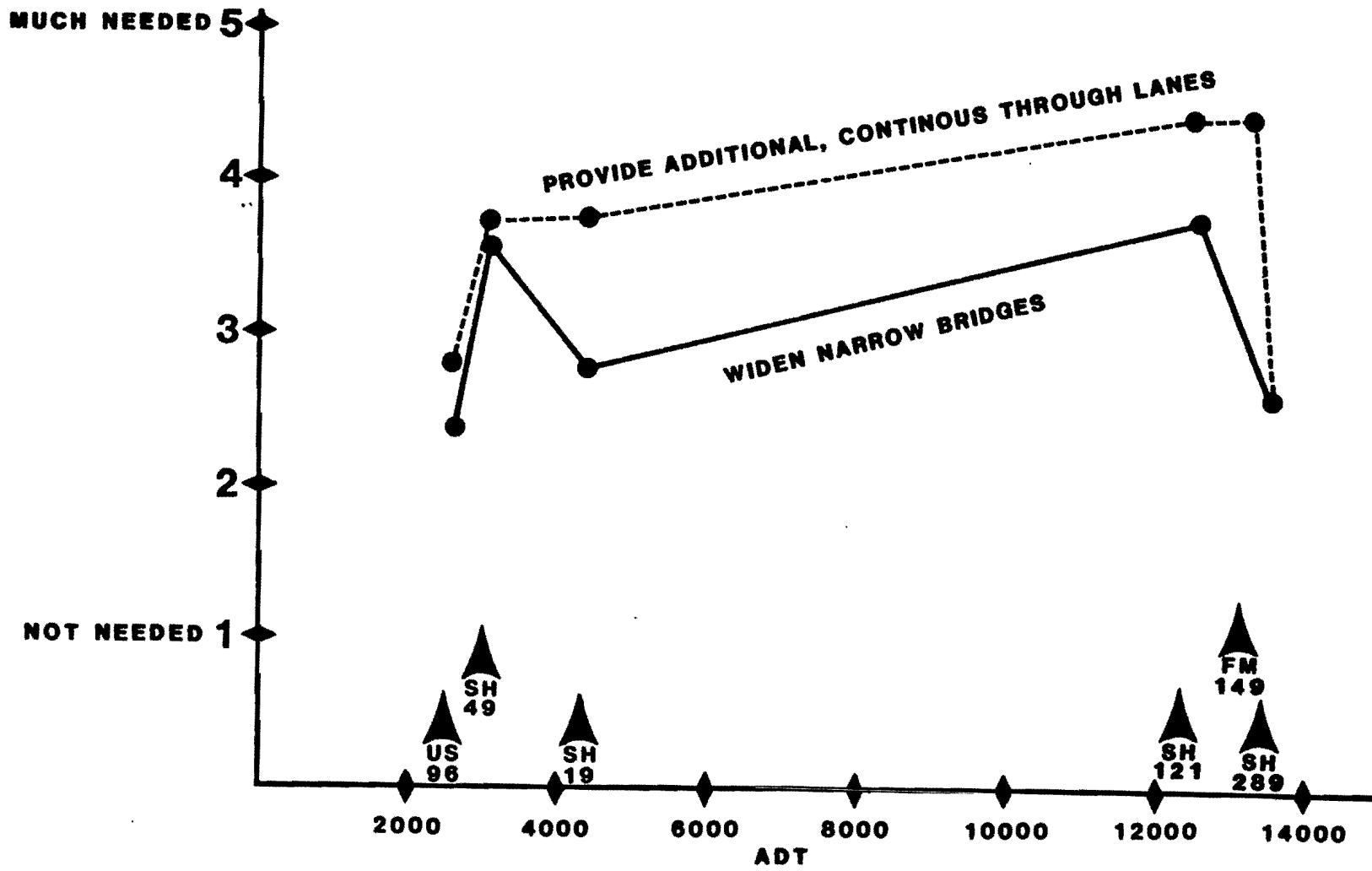
Figure 19. Ratings of Possible Improvement

Figure 20. Ratings of Possible Improvements

Overall driver perceptions appear to be consistent with observations made at the sites. Motorists seem to locate existing problems and relate that to possible improvements. Looking at each of the study areas, a picture develops as to existing conditions and the motorists perceived solutions.

Figure 15 shows motorists perceptions of the need to improve horizontal alignment on SH-49. This apparently corresponds to the relatively poor operational characteristics on SH-49 as shown in Figure 14. Figure 15 also shows an apparent vertical alignment problem on SH-19 which also corresponds to the poor operating characteristics.

Figure 20 shows a good relationship between ADT and the need to widen a highway. The one point that looks out of place is for SH-289. It would appear from Figure 18 that the perception of users of SH-289 is for a more substantial improvement than just providing additional through lanes. SH-289 received the highest rating for constructing a divided highway or median. Figure 16 shows that motorists have a high perception of the need for shoulders when they are not present.

Overall, the results of the survey support the desire for highway improvements at modest traffic volumes. As ADT increase, the desire for capacity type improvements increases. However, ADT can not be considered as the single factor upon which to base decisions for prioritizing projects. Figure 21 shows motorists perceptions of how the various highways compare with others in the state. SH-49 was clearly perceived to have operational and safety problems similar to high ADT sites as was shown in Figure 14.
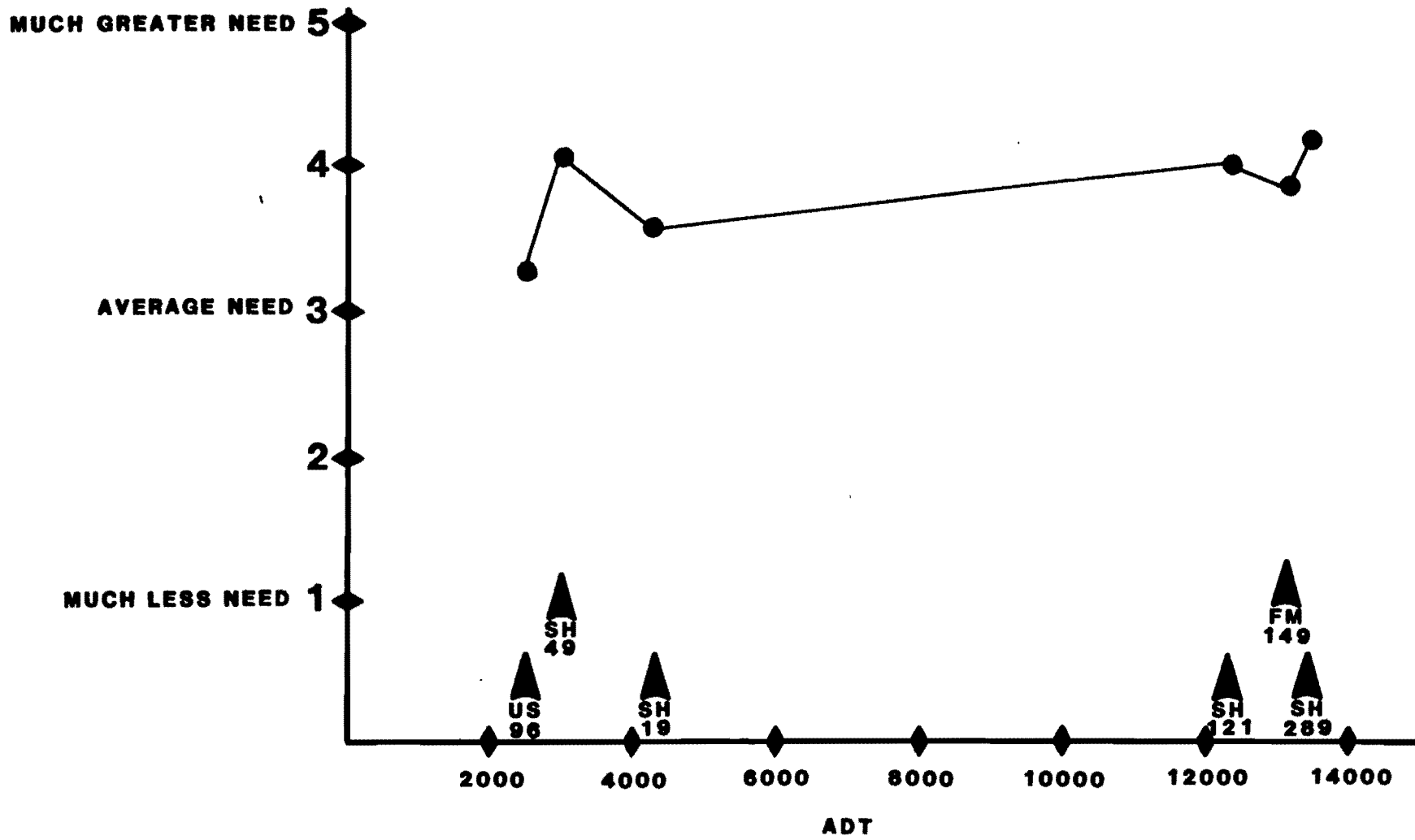
Figure 21. Need For Improvement When Compared To Other Texas Highways

VI. HOURLY TRAFFIC DISTRIBUTION

Speed estimates are based on hourly volumes. Since input data is provided as ADT, it is necessary to convert ADT to hourly volumes. Data from the nearly 200 permanent traffic recorder stations in Texas were analyzed for April 1982. The data was disaggregated in many ways, including hourly distribution by ADT and ADT per lane. However, it was concluded that too many inconsistencies resulted with the disaggregate data. A single distribution was selected for rural highways and a separate distribution for urban highways.

Table 3 presents the two distribution for rural and urban highways. It should be noted that the values in Table 3 differ from design values. Whereas design values are typically based on the 30th highest hour (or other design basis), the values in Table 3 represent average conditions over a year. This appears to be the appropriate basis for computing benefits.

Figure 21. Need For Improvement When Compared To Other Texas Highways

TABLE 3. HOURLY TRAFFIC DISTRIBUTION

TIME	URBAN PERCENT	RURAL PERCENT
Midnight to 1 A.M.	0.913	0.864
1 A.M. to 2 A.M.	0.500	0.485
2 A.M. to 3 A.M.	0.394	0.295
3 A.M. to 4 A.M.	0.298	0.105
4 A.M. to 5 A.M.	0.391	0.169
5 A.M. to 6 A.M.	1.768	0.485
6 A.M. to 7 A.M.	6.316	1.875
7 A.M. to 8 A.M.	7.683	6.783
8 A.M. to 9 A.M.	6.016	6.994
9 A.M. to 10 A.M.	5.122	5.393
10 A.M. to 11 A.M.	4.915	5.456
11 A.M. to Noon	5.114	5.941
Noon to 1 P.M.	5.124	6.236
1 P.M. to 2 P.M.	5.275	6.151
2 P.M. to 3 P.M.	5.710	6.214
3 P.M. to 4 P.M.	7.117	6.720
4 P.M. to 5 P.M.	7.870	7.478
5 P.M. to 6 P.M.	7.629	8.784
6 P.M. to 7 P.M.	5.695	6.552
7 P.M. to 8 P.M.	4.417	4.950
8 P.M. to 9 P.M.	3.187	3.623
10 P.M. to 11 P.M.	3.373	2.928
11 P.M. to Midnight	1.871	1.559

Source: State Department of Highways and Public Trans-
portation Permanent Count Stations, April 1982.

VII. RECOMMENDATIONS AND CONCLUSIONS

Table 4 shows the basic speed/volume relationships recommended as a result of this study and implemented in the computer program developed for Department use. In many cases, judgement was used in selecting values such that consistent results would be obtained. For example, although free flow speed data varied in the range of 57 to 62 mph, a single value of 60 mph was used in all cases. If existing conditions (e.g., poor geometrics or speed limits) are such that average free flow speed is less than 60 mph, this can be entered into the program through the speed limit parameter as discussed below.

The delay saving model as currently constructed allows for conditions where free-flow speeds are less than 55 mph. This could be the result of an actual speed limit, or geometric condition (e.g. poor horizontal or vertical alignment) that restrict speeds. The method to determine speed limiting geometrics would be to measure approximately 100 vehicle speeds using a moving radar over the entire roadway section under moderate to low volume conditions. The average speed, if determined to be less than 55 mph would be entered in the speed limit parameter of the model.

The speed/volume relationships developed are also presented in Figures 22, 23 and 24. The figures express average daily speed as a function of average daily traffic based on the previously specified relationships in Tables 3 and 4. Delay savings can be calculated from these figures as follows:

> Delay Savings (Vehicle - Hours) =
> (Length of Section (miles)) divided by
> (Speed After - Speed Before (mph)) times
> ADT (Vehicles per day)

47
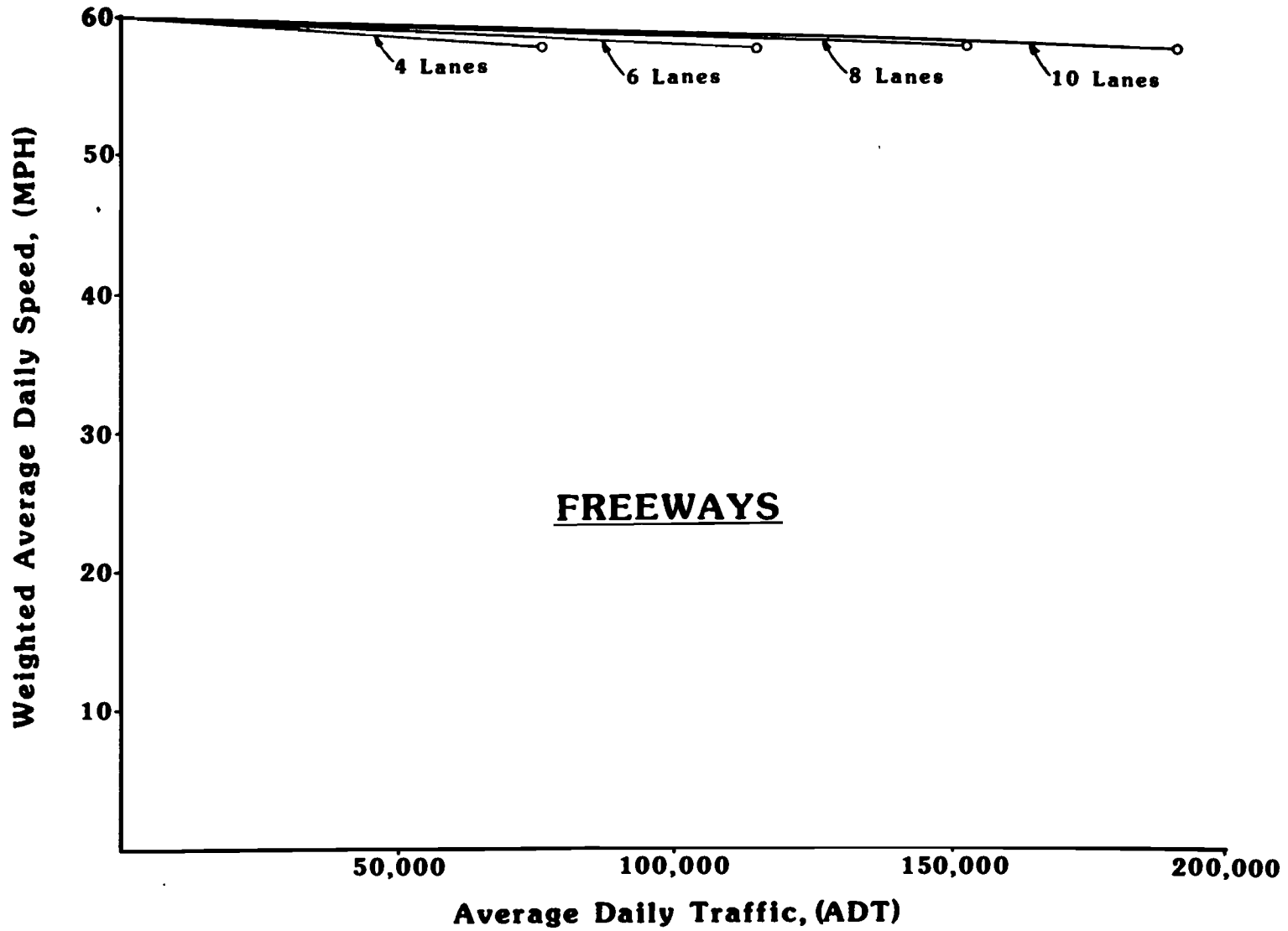
Figure 22. Average Speed Versus ADT for Freeways

Figure 22. Average Speed Versus ADT for Freeways
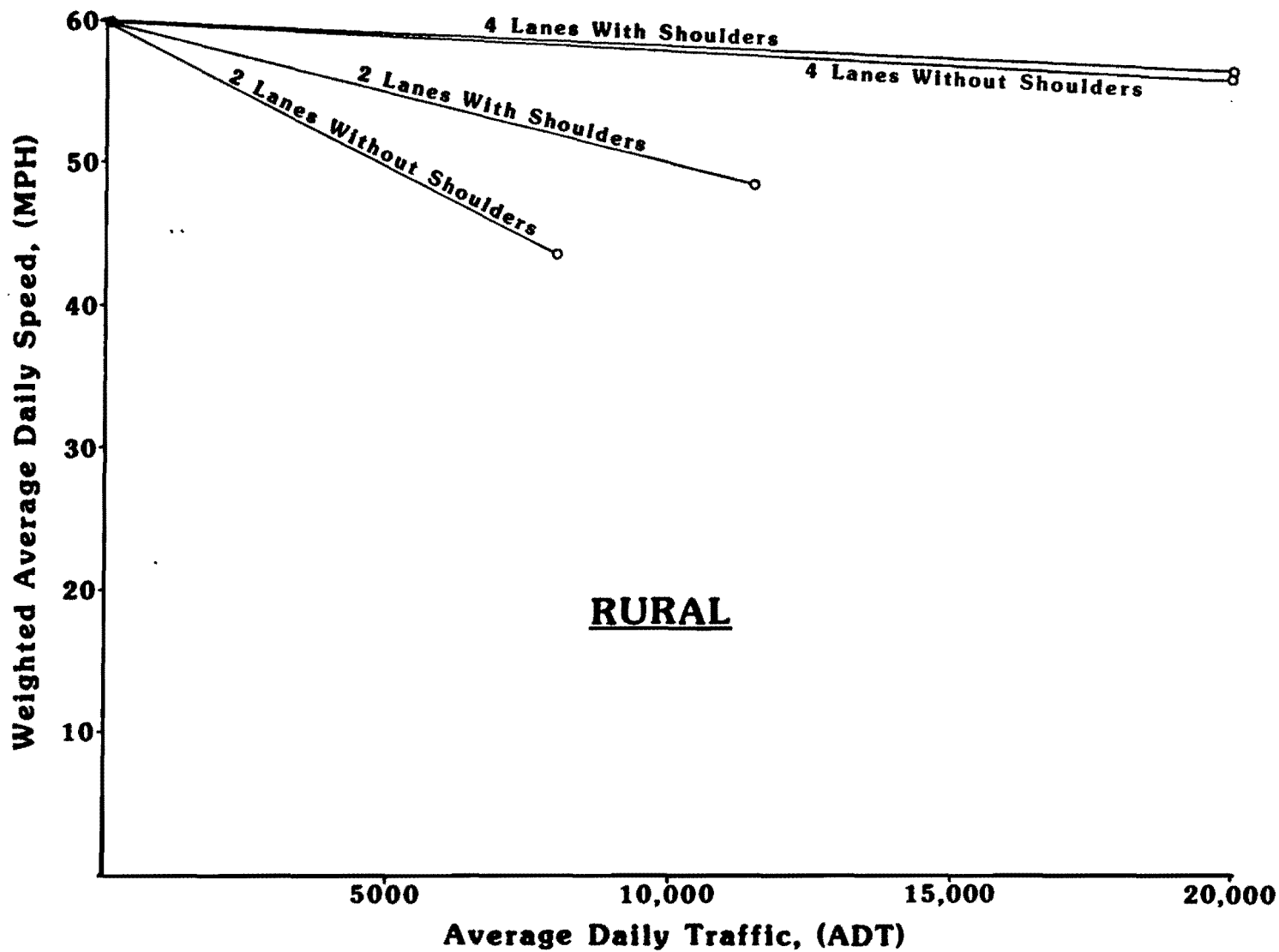
Figure 23. Average Speed Versus ADT for Rural Highways

Figure 24. Average Speed Versus ADT for Urban Streets

The chart axes and labels read:

- Y-axis: Weighted Average Daily Speed, (MPH) — marked 10, 20, 30, 40, 50, 60
- X-axis: Average Daily Traffic, (ADT) — marked 10,000, 20,000, 30,000, 40,000, 50,000

URBAN

Line labels:
- 6 Lanes With Shoulders, Without Turn Lane
- 6 Lanes With Shoulders, With Turn Lane
- 6 Lanes Without Shoulders, Without Turn Lane
- 6 Lanes Without Shoulders, With Turn Lane
- 4 Lanes Without Shoulders, Without Turn Lane
- 4 Lanes With Shoulders, Without Turn Lane
- 4 Lanes With Shoulders, With Turn Lane
- 4 Lanes Without Shoulders, With Turn Lane
- 2 Lanes With Shoulders, Without Turn Lane
- 2 Lanes Without Shoulders, Without Turn Lane

50

The preceding relation is valid only when volumes are below capacity. Manual analysis is not recommended for projects where volumes exceed capacity.

It should also be noted that these relationships for all highways are intended to represent average condition. Some projects could differ substantially. For those projects with poorer than average operating speeds, the previously described radar study should be performed at the site. The one roadway classification where care must be used to avoid including unwarranted projects is 2-lane rural roadways. A two-lane roadway in flat terrain and having unlimited sight distance <u>may</u> operate nearly as well as a four-lane highway. However, insufficient data exists to quantify the variables. It is, therefore, presumed that projects would <u>not</u> be proposed based on ADT alone, but also knowledge of the particular site. It is believed that this type of screening would be preferable to criteria based on an inadequate data base. The option also exists for a moving radar study to determine the actual operating characteristics of an individual site.

Figure 24. Average Speed Versus ADT for Urban Streets

TABLE 4. SPEED RELATIONSHIPS BY HIGHWAY TYPE

Location	Lanes	Shoulders	Turn Lanes	Intercept	Slope	Capacity*
Rural	2	No	No	60	.035	350
Rural	2	Yes	No	60	.017	500
Urban	2	No	No	60	.040	350
Urban	2	Yes	No	60	.020	500
Rural	4	No	No	60	.0035	1,000
Rural	4	Yes	No	60	.003	1,000
Urban	4	No	No	60	.015	500
Urban	4	Yes	No	60	.014	500
Urban	4	No	Yes	60	.012	650
Urban	4	Yes	Yes	60	.010	650
Freeways	4 or more	Yes	No	60	.002	1,500

*Per lane in vehicles per hour

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3. Highway Capacity Manual. U.S. Department of Commerce, Bureau of Public Roads, United States Government Printing Office, Washington, D.C., 1950.

4. Highway Capacity Manual 1965. Highway Research Board Special Report 87, National Academy of Sciences, Washington, D.C., 1965.

APPENDIX A

SURVEY FORMS

**STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION**
AUSTIN, TEXAS 78763

ENGINEER-DIRECTOR
MARK G. GOODE

IN REPLY REFER TO
FILE NO.

Dear Motorist,

The Texas State Department of Highways and Public
Transportation needs your help in determining needs and
priorities for roadway improvements. The survey is being
conducted for the Department by the Texas Transportation
Institute, The Texas A&M University System.

We have selected a local road and a small number of
area residents for survey purposes. Results will be used
to determine the quality of service being provided by this
road and other roads throughout Texas with similar traffic,
terrain, and roadway design characteristics. Your comple-
tion of the requested information is needed to insure success
of this study.

We are grateful for your participation in the survey.
Please complete the requested information as best you can
and return the survey form in the enclosed, postage-paid
envelope within one week.

Sincerely,

R. L. Lewis, Chief Engineer
of Highway Design

Encl.

A-1

ROAD USER SURVEY

The Texas Transportation Institute of Texas A&M University is conducting a road user survey for the Texas State Department of Highways and Public Transportation. The questionnaire is designed to be easy to complete and take no more that 5 minutes of your time. Your responses will be of great value to the study and will be held in strict confidence.

The survey concerns the two-lane portion of Texas 121 between Farm Road 3040 and Texas 26.

1. Are you familiar with the route being surveyed?   Yes _____   No _____

   Do you regularly use this road?   Yes _____   No _____

   If yes, what time of day usually do you use this road?   _____a.m.   _____p.m.

   _____ varies

   If yes, how many times per week do you use this road?   _____ times/week

2. How would you describe this road in terms of congestion or traffic delay?

   _____ Uncongested/No Delay   _____ Frequent Congestion or Delay

   _____ Occasional Congestion or Delay

3. What is the population of the city or metropolitan area where you live?

   _____ 500,000 or more   _____ 5,000 to 50,000   _____ Don't know

   _____ 50,000 to 500,000   _____ Less than 5,000 or rural area

4. How many years of driving experience do you have?   _____ Years

5. Please rate the following operational characteristics of the road.

	Much Worse Than Desired		Acceptable; Meets Expectations		Much Better Than Expected
a. Ability to pass other vehicles.	1	2	3	4	5
b. Congestion caused by crossing of turning traffic, signals, slow moving vehicles, or other interruptions	1	2	3	4	5
c. Ability to operate your vehicle at desired speed	1	2	3	4	5
d. Overall safety of the roadway	1	2	3	4	5
e. Overall driving comfort	1	2	3	4	5
f. List any other, and rate _____	1	2	3	4	5

(over)

6. In comparison to other Texas highways that you use, how would you rate the overall need for improvement needs along the route?

Much Less Need		Average Need		Much Greater Need
1	2	3	4	5

7. The following is a list of possible improvements to the road. Please circle the number that best explains the need for improvement.

Possible Improvements	Not Needed				Much Needed
a. Resurface road	1	2	3	4	5
b. Add surfaced shoulders	1	2	3	4	5
c. Provide left turn lanes at certain intersections	1	2	3	4	5
d. Widen narrow bridges	1	2	3	4	5
e. Realign road to reduce the sharpness of curves	1	2	3	4	5
f. Realign road to reduce steepness up and down hills	1	2	3	4	5
g. Install signals at certain intersections	1	2	3	4	5
h. Add climbing lanes up long, steep hills	1	2	3	4	5
i. Provide interchanges at certain intersections	1	2	3	4	5
j. Widen pavement to provide additional, continuous through lanes	1	2	3	4	5
k. Upgrade to provide roadways separated by a median divider	1	2	3	4	5
l. Upgrade to a freeway	1	2	3	4	5
m. List others and rate:					
_____	1	2	3	4	5
_____	1	2	3	4	5

APPENDIX B

SPEED/VOLUME CALCULATIONS

This study developed a simple method of calculating speed and volume using a moving radar unit. The technique adjusts the volume to account for the speed of the survey vehicle and also the speed of opposing traffic.

An appropriate study section would be one to two miles in length and have a uniform cross section. The technique is appropriate for conditions free of major interuptions such as traffic signals, a high volume intersection or driveway, or heavy congestion indicated by stop and go traffic.

The following equation can be used to calculate traffic volume from a moving vehicle over a roadway section of known length:

Volume = Number of oncoming vehicles (1 + ((distance of study section in feet)/travel time of the study vehicle in seconds)/1.47)/average speed of approaching traffic in MPH x (60/travel time of study vehicle in minutes).

The average speed of approaching traffic is determined from the speed observations of approaching vehicles.