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Effects of Access On Capacity and Flow

Final Report

By

John C. Powers

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ACKNOWLEDGEMENTS

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ABSTRACT

The presence of entering and exiting vehicles has effects beyond those due to increased mainline volumes. The relationships of speed and flow on the main roadway are negatively impacted and the effects, particularly in the rightmost lane, can be substantial. The presence of shoulders and the spacing of access points are the most important factors in how entering and exiting vehicles affect mainline flows. Shoulders act effectively as a surrogate for the acceleration and deceleration functions of well designed ramps.

A policy of controlling access along multilane divided highways because of the potential negative impacts of access on mainline flow is supported. Shoulders are recommended along the right hand side of any facility where access is largely uncontrolled. The 1985 Highway Capacity Manual provides procedures for evaluating the impacts of access on mainline flows. About 1% of capacity is lost in the right lane for each 2% volume increase due to accessing vehicles.

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I. SUMMARY AND CONCLUSIONS

Many primary arterials in N.J. are multilane divided highways. Common to these are substantial amounts of access between at grade intersections controlled by traffic signals. Where highway design includes signalized intersections the capacity of those intersections will limit the roadway's thoroughput. While the speed and capacity limiting effects of traffic signals are well documented, the incremental effects of allowing access, most often in the form of driveways, have not. The following conclusions about the effects of access on capacity and flow are drawn from field observations on unsignalized highways and modelling performed as part of this study.

A. CAPACITY

Whether or not signals are present, capacity losses due to accessing vehicles seems to be limited to about 1% of right lane capacity for each 2% increase in right lane volume that is due to accessing vehicles. The capacity of primary arterials which have freeway like cross sections and driveway access can be adequately estimated by using the freeway style analysis methods for multilane highways of the 1985 Highway Capacity Manual (HCM), reference 3. When shoulders are present on such multilane roads full freeway capacity can be attained, even when access between intersections is largely uncontrolled.

B. SPEED

Average speeds on multilane divided highways are about 10% lower than a similar freeway section for most uncongested traffic conditions because of the presence of access. The effect in specific situations can be estimated by the difference in results of Multilane and Freeway analyses using 1985 HCM procedures. In these analyses, estimates of speeds when volumes approach capacity and in congested flows will be unaffected. When intersections are signalized, the speeds of vehicles between intersections will be limited to about 45 mph, regardless of mainline design speed, unless the intersections are 2 or more miles apart.

Speeds in the vicinity of access points can be expected to be lower than the mainline average due to the conflicts of entering and exiting vehicles with mainline vehicles and the increased demand for the right most lane. These right lane conditions are worst when the distance between access points is less than 300 feet. Effects in specific situations can be estimated reasonably well with 1985 HCM weaving and merge/diverge analysis methods.

C. ACCOMMODATING ACCESS

The presence of shoulders and the spacing of access points are the most important factors in how entering and exiting vehicles affect mainline flows. Shoulders act effectively as a surrogate for the acceleration and deceleration functions of well designed ramps.

Since weaving analysis methods show that speeds in the right lane will be reduced by about 10 mph, locations where distances between access points are less than 300 feet are most problematic. Increases beyond 300 feet toward ramp standards (1000-1500 feet) will improve speeds further, but less dramatically.

According to HCM Merge/diverge analysis methods, demand for the right lane in the immediate vicinity of the access point can be reduced by 130 vehicles per hour when distances between access points is increased from 200 to 300 feet. Although less dramatic, further increases toward ramp standards provide additional improvements.

In summary, the presence of entering and exiting vehicles has effects beyond those due to increased mainline volumes. The relationships of speed and flow are negatively impacted and the direct effects on flow, particularly in the right most lane, can be substantial. Provision of shoulders can substantially ameliorate these negative effects.

D. EVALUATING IMPACTS

The 1985 Highway Capacity Manual provides valuable procedures for evaluating the impacts of access on mainline flows. The 1%/2% rule as described in section I.A. on page 1 provides an acceptable rule of thumb for estimating capacity loss due to the volume of accessing vehicles.

II. RECOMMENDATIONS

The conclusions of this study support a policy of controlling access along multilane divided highways because of the negative impacts of access on mainline flow. Shoulders are recommended along the right hand side of any facility where access is largely uncontrolled. In addition to other functions, shoulders will provide entering and exiting vehicles room to accelerate and decelerate. As a result, shoulders become an effective surrogate for ramp-like access designs.

Based on this study's review of HCM relationships, increasing the distance between access points is also an effective way to offset the impacts of access. Therefore, spacing between access points should be controlled. It is clear from the 1985 HCM that at least 300 feet should exist between access points. Longer separation distances and concentrated volumes at access points are preferable.

In summary, a roadway design which includes shoulders and considers distance between access points makes access more ramp-like. This clarifies the specific impacts of each access point, even when the actual design of the curb cut is not ramp-like at all.

III. INTRODUCTION

The N.J. DOT is developing policies which will determine how control of access to N. J.'s arterial routes will be integrated into functional and design standards. A primary factor in making policy decisions is how access control (or the lack thereof) affects both safety and quality of flow conditions for the vehicles travelling on the mainline.

There is much literature that establishes that the more restrictive the control policy, the lower the accident rate. However, available literature failed to identify information on how access control affects traffic flow.

The relationship between safety and the frequency of access locations is well described in a study conducted by P.R. Staffield.

As described on page 4 of reference 7, accident rates were about 1.5 per million vehicle miles (MVM) at sites with as few as 0 access points per mile. Rates increased steadily to about 3 per MVM where there were as many as 28 access points per mile. Other studies, such as those of P. C. Box, also discussed on page 4 in reference 7, show that accident rates where there is no access control are 2 to 3 times higher than the rates at sites with full access control. Also reported was that urban rates were about 70 % higher on average than rural rates.

It is clear then that safety improves with increased access control and, from a safety standpoint, access ought to be minimized or even eliminated. Unfortunately, eliminating existing access is often impossible and legislating an area to remain rural in nature is frequently impractical or undesirable, thus some compromise must be developed. Reference 8, "Guidelines For Medial and Marginal Access Control On Major Roadways," provides a major resource in this matter. Relying heavily on the issue of safety, this report proposes increasingly tighter control on access to the main road as through vehicle speed and flow increase.

In addition to safety it is important to consider the quality of flow on the highway when choosing reasonable ways to allow access. Unlike the safety issue, the traffic flow impacts of access have not been well investigated. NCHRP Report 93, reference 8, states on page 113 that "... data defining the relationship between level of service and driveway design characteristics are not available to the extent that specifications for driveway design, in terms of performance or desired operation, can be easily implemented." This lack of information is the major focus of this study.

IV. BACKGROUND

Upgrading the numerous primary arterials in N. J. is a major focus of current planning efforts since there are few opportunities to build new facilities. While incorporating higher levels of access control to take full advantage of capacity improvements is desirable, it is also problematic because of the typically poor levels of access control that currently exist. An accurate understanding of the value of access control is thus important in developing reasonable standards for improvements.

A report entitled "Access Management for Streets and Highways," (reference 7) and another entitled "Guidelines for Medial and Marginal Access Control on Major Roadways" (reference 8) compile numerous studies which point to reducing access as a major method of reducing accidents. According to the Federal Highway Administration (FHWA) report "Technical Guidelines for the Control of Direct Access to Arterial Highways," the most important improvements that can be made along existing highways are those that eliminate left turns. This is because some 70% of driveway accidents involve left turning vehicles (reference 11, page 27). Dividing the highway is an obvious choice in this regard. While divided highways reduce accidents as much as 35%, also according to the FHWA (reference 7, page 7), they also improve traffic flow. However, provisions must be made to allow U-turns for those desiring to go to the left by use of jughandles, or other means. Since many N. J. arterials are in fact now median divided multilane facilities with jughandles, major steps in reducing the problems of access have been substantially accomplished by eliminating crossing movements.

Less obvious are standards for further improving flow on divided roads with frequent access. The multilane chapter of the 1985 HCM is the primary source of help in estimating flows and capacity on such highways. It does not directly address the effects of varied levels of access or of access design nor do ITE or AASHTO publications deal with such factors.

This study, then, was an attempt to learn more about how entering and exiting vehicles affect capacity and traffic flow. With this knowledge, design standards for improving existing highways can concentrate on the severest flow inhibiting aspects of the access design. At the same time, designers and planners will have a better understanding of the capacity and flow impacts of existing and future access needs. Developing standards to limit access can be done in a manner that is reasonable in consideration of the substantial amount of access that may exist or develope along any given route.

V. STUDY PROCEDURES

While the effects of entering and exiting vehicles on mainline speeds and capacity are primary concerns, other measures selected for study were conflicts, the use of shoulders, and lane specific entering and exiting rates. Potential study sites were screened using cross section information from the State Highways Straight Line Diagrams Book. Only highways with median dividers and controlled access at intersections or interchanges were considered to eliminate left turns and simplify the study.

With mainline capacity as a major concern, peak flow volumes were also considered. Finding locations not subject to interruptions to flow, such as are caused by traffic signals, was essential. The quantity of access points and the volume of entering and exiting vehicles was the final factor in selecting a study site and was based on site visits.

Review of the major arterials in N.J. made it apparent that traffic signals at .5 mile intervals were common where access and volumes are substantial. While mainline volumes also tend to be greatest at these locations, few sites exist without the influence of traffic signals. In fact, only a six lane section of Route 3 fitting the preferred study site description was found. This section of Route 3 was also the subject of previous efforts to model peak period traffic flows.

This section of Route 3 has shoulders, and it was decided to find a similar location without shoulders that could be used to evaluate their importance. On site inspections lead to a decision that only the Route 1 section in front of two major shopping malls provided substantial access activity in combination with mainline volume. Like Route 3, this section is three lanes in each direction. Unlike Route 3, there is no shoulder in one direction. With signals present on Route 1, investigating mainline capacity implications was limited to the Route 3 study section. Thus the Route 1 signals, only .8 miles apart, were a major limitation. However, no site had the desirable two miles between intersections and, based on an inventory of N. J. routes, .8 miles was the longest distance available.

The selection of only two study sites, neither a four lane section, does not mean that the problems related to a relatively high degree of access do not exist at numerous locations. Rather, it means these conditions rarely exist without other complicating factors. As mentioned, most problematic are the traffic signals.

With only two field study sites, the analysis was augmented using the Highway Capacity Manual methods. Traffic conditions at the study sites were videotaped to provide a record of conditions and data was extracted from this tape to augment field observations. Both peak and off peak direction traffic conditions were observed.

VI. REVIEW OF DATA

Results of the study site data collection are presented in the following section as supplemented by Figures 1 through 8. Tables 1 and 2 of Appendix A contain the details. Hours of observation on-site extended from 3:30 PM to 7:30 PM. During this period several 15 minute breaks in the data collection were needed to accommodate the observers who collected the several types of data simultaneously. As a result, peak period totals for the roadway and driveway volume data, reported in hourly rates, vary from the totals reported for conflicts and lane maneuvers which did not require conversion to hourly rates for analysis.

A. Roadway Volumes

Figure 1 illustrates the volumes observed at both study sites. Each site provided two sets of volume related information as this data was collected for each direction of travel. Route 1 volumes peaked at 3250 vehicles per hour and Route 3 volumes, where no signals existed, peaked at just over 5000 vehicles per hour per hour.

B. Driveway Volumes

Figures 2 and 3 show the driveway volume data for Routes 1 and 3 respectively. The data is shown in terms of hourly rates. At Route 1, vehicles entered the roadway at a higher rate than they exited for the driveways studied. Entering and exiting combined, the hourly rates range from about 75 to 450 vehicles per hour. At Route 3, the combined rates range from about 25 to 250 vehicles per hour. Entering was more frequent here as well.

Figure 4 summarizes the combined access activity in terms of percent of hourly mainline flows. Driveway activity was generally between 2.5 and 5% of mainline volumes while the 20% which occurred at Route 1 in the southbound direction is a notable exception.

C. Conflicts

Each mainline vehicle that was observed to slow down or change lanes in the presence of a vehicle entering or leaving the road was considered conflicted with. Figure 5 shows the summary of all conflict data taken between 3:30 and 7:30 p.m. Taken on Route 1 only in the southbound direction and on Route 3 only in the westbound direction, entering and exiting conflicts are shown by conflict type. Mainline vehicles slowing outnumbered those changing lanes by about 4 to 1. In total, 783 mainline vehicles were observed in conflicts.

Figure 6 shows the rates that mainline vehicles were conflicted with by entering and exiting vehicles. On both roads, about half the entering vehicles caused conflicts with mainline vehicles, a rate of .5. Exiting rates were about .5 on Route 1 but lower, about .35, on Route 3.

D. Lane Access

Lane entering and exiting maneuvers were also observed. The diagram of Figure 7 summarizes the lane placement of vehicles immediately after entering or immediately before exiting. For example, a move into lane 3 was noted when a vehicle entering the road proceeded directly across the right lane and the center lane in order to enter the left lane in a single continuous maneuver.

On Route 1, entering vehicles travelled directly into the center (lane 2) and left (lane 3) lane about 10 percent of the time. Exiting vehicles left the road from these lanes only 1 % of the time. On Route 3, with full shoulders, vehicles entered lane 2 or 3 directly less than 1% of the time. Exiting vehicles left the road from lane 2 or 3 about 2% of the time. At Route 3, 68 % of both entering and exiting vehicles made use of the shoulders .

E. Speeds

Speed observations plotted against the existing v/c ratios are shown in Figure 8. The influence of the traffic signals on Route 1 can be clearly seen as the speeds are substantially lower than the speed limit despite volumes which are only about 40 to 60 % of capacity. Route 3 data is quite different with speeds averaging about 10 mph higher than on Route 1, despite the considerably higher v/c's.

Specifically, average speeds observed on Route 1 ranged from 28 to 34 mph during the four hours of mainline volumes which ranged from 1960 to 3140 vehicles per hour. The driver of the vehicle used for collecting speed data noted that the highest speed attained in the .8 mile study section was near 45 mph, considerably less than the 55 mph speed limit. On Route 3, average speeds as low as 36 and as high as 60 were observed in the presence of mainline volumes ranging from 3150 to 5000 vehicles per hour. The speed limit on Route 3 is 55 mph.

The data for Route 3 has been replotted in Figure 9. Also shown are the appropriate portions of the 70 mph design speed HCM curve for multilane highways (70 M) and a curve developed for NJ roads (Rt.3-1975). These curves are discussed in the following sections.

VII. DISCUSSION

Figures 9 through 16 have been created to aid in the following discussions. Tables 3 and 4 present the detailed data.

A. Speed-Flow Relationships

Figure 9 was generated to introduce the topic of multilane highway analysis techniques. Route 3 speeds appear to be fairly well predicted by the HCM type curves. In fact, a previous study of Route 3 (reference 1) validated the use of the simplified curve referred to as Rt.3-1975 based on the 1965 HCM and ignoring the presence of driveways.

Procedures adopted by the 1985 HCM build in alternative curves, in part to account for presence of access. In such circumstances the road is considered a multilane highway rather than a freeway. The curve of Figure 9 referred to as 70 M is the speed-flow curve developed for roads like Route 3 which have a 70 mph design speed and substantial amounts of access. This curve predicts that speeds will be about 10% lower than for a freeway of similar design.

B. Estimates of Capacity for Route 3

V/C ratios for the average speed observations on Rt. 3 were read from each of the curves discussed above. These were divided into the respective flow rate, adjusted for truck presence, to produce estimates of capacity as shown in Table 3. The range of observed flow rates, 1340 to 1775 pcphpl, reflects heavy demand but in every case, traffic was freely flowing.

Based on the range of capacities as derived above, the best fit occurs with the 70 Mph Design curve of the Multilane chapter of the HCM. Averaging the data of this analysis for observations of speed of 45 or less, the capacity of Route 3 is estimated to be about 1840 vehicles per hour per lane. Similarly, the Rt.3-1975 and HCM 70 Fwy curves produced capacity estimates of 1770 and 1720 pcphpl respectively.

For comparison, a capacity of 1800 pcphpl was estimated based on classic HCM methods using cross sectional characteristics. The geometrics based estimate of capacity becomes 1620 pcphpl when further adjusted by a factor of .9 according to the HCM method for a multilane facility. As can be seen, the freeway based capacity estimate of 1800 better predicts Route 3 conditions.

In summary, the presence of driveways clearly influences driving habits. This influence can be measured in terms of speeds that are lower than would be observed at similar volume to capacity ratios on a freeway. However , the above discussion makes it clear that a multilane highway may develop the capacity that a well designed cross section with limited access (a freeway) would produce. Route 3 is an example of this, in contrast to the capacity reduction of 10 % as estimated by the HCM.

The only other HCM factor for multilane highways is for undivided roads to account for the estimated 20 % capacity reduction which occurs when left turns are allowed. While left turns were not considered here, the single largest impact of access on multilane highways occurs as a result of left turning vehicles.

C. The 1% / 2% Rule

As a further example of the potentially minimal impact of driveways, Brian Bochner's so called "1%/2%" rule (reference 2) has also been examined. Derived from observing arterials, the 1%/2% rule states that capacity of a lane is reduced 1 percent for each 2 percent of lane volume that entering and exiting vehicles represent. Bochner also suggests the impact is lessened when the access to the mainline is well designed. Figure 10 illustrates the relationship suggested by this rule. Table 4 summarizes capacity calculations based on Route 3 data. The HCM calculations described above are presented here as well.

Based on the ramp volumes observed on Route 3, relatively small capacity reductions can be anticipated according to this rule. Because for a given number of accessing vehicles capacity reductions are inversely related to mainline volume, they are smallest when the mainline volumes are highest. Conversely, the rule estimates the greatest capacity loss per driveway vehicle when mainline volume is lowest. The range of estimated capacity loss on Route 3 is 1 to 5%.

The method is interesting because it introduces the volume of entering and exiting vehicles as a capacity factor, unaddressed in the Multilane Chapter of the HCM. In any event, range of predicted capacity reductions on multilane highways like Route 3 will clearly be minimal.

Estimated effects on Route 1 for observed flows will undoubtedly be higher, due primarily to the lower mainline flows. The severe impact of traffic signals (about 50% loss of capacity per lane) makes the concern moot, however. With the signals removed, the projected increases in mainline flow will work to reduce the percent of lane volume that the driveways represent. The capacity loss associated with access will then decline and have only relatively small significance in determining how traffic flows.

D. Conflicts With Mainline Vehicles

As reported previously, conflict rates were determined on each of the two roads studied. For the purposes of this analysis, a conflict was noted as having occurred each time a mainline vehicle visibly slowed down or changed lanes in the immediate vicinity of an entering or exiting vehicle.

A review of the specific study sections and typical driveway characteristics is presented in Appendix B. Overall, the driveways on both roads can be considered generally well designed. Parking areas are often setback from the road and angled or radiused curbs clearly direct entering and exiting vehicles to and from the highway. In the case of Route 3, a full shoulder exists on both sides of the travelled way.

The driveways exhibited conflict rates which averaged about 0.5 and ranged from 0.2 to 1.0 with one exception. This driveway had poorly defined curb cuts and no setback from the edge of the travelled way. It also had a conflict rate of 1.4, excessive by comparison to the other relatively well designed driveways. Since the design of this driveway is clearly not recommended, according to many references such as the ITE Guidelines (reference 6), the excessive rate for this location is not surprising.

Figures 11 and 12 show the conflict rates for the well designed access points plotted against entering and exiting volumes for each road. Regression analysis was performed to look for a linear "model" for conflicts for each road. The obvious scatter of the Route 3 data resulted in a poor linear fit. No line appears in Figure 11 for this reason. In comparison, there is a fairly good fit and downward trend observable in the Route 1 data, emphasized in Figure 12 by the line of best fit.

Thus, conflict rates at Route 3 appear to be independent of entering and exiting vehicle volumes while there is a fair degree of dependence on Route 1. As previously noted, the only major difference in cross section is the shoulder available on Route 3. The Figure 7 indicates, in fact, that about two-thirds of Route 3 entering and exiting vehicles use the shoulder for acceleration or deceleration. This is the apparent reason why there is no direct relationship between conflict rates and entering and exiting volumes and the differences in conflict rates among driveways are then a function of the differences in driveway design.

Breaking down conflict rates illustrates that, despite the shoulder at Route 3, movements onto the highway often produced higher conflict rates than did movements off. Figures 13 and 14 reflect this trend. Thus, while the value of a shoulder has been demonstrated, it appears limited in its ability to make up for the added distance entering vehicles need to accelerate to the higher mainline speeds of Route 3. Thus, even when shoulders are present, the need for minimum design standards for driveways is demonstrated.

E. Additional Modelling

Additional modelling efforts were performed to investigate merge/diverge and weaving activity in order to better understand the effects of varying the distance separating access points. These two analyses were selected because they consider the distance between ramps as well as volume and mainline demands when estimating capacity at the access vicinity. The application of these methods here is based on the theory that the best driveway would be likely to have impacts on traffic just a little worse than the worst ramp. The logic follows from the idea that a driveway can generally be considered to be a poorly designed and relatively low volume ramp. Thus the analysis technique of this study investigated trends near the limits of HCM procedures.

F. Merge/Diverge Performance

The HCM merge/diverge analysis method estimates demand for space in the right lane in the immediate vicinity of the ramp terminal. The method is needed because other capacity estimates are based on the average of all lanes and conditions in the right lane can be expected to be different than the roadway per-lane average. As a result, the lane will often have considerably different operating characteristics than the roadway section on average. Conflicts documented in this study, most common in the right lane in the vicinity of access points, are evidence of this effect.

The analysis itself is done by inspecting a series of point locations upstream of off-ramps and downstream of on-ramps for volume approaching 2000 vehicles per hour (vph), the theoretical merge/diverge capacity. Where demand approaches 2000 vph, disruptions to flow will occur despite average per lane capacity which is otherwise adequate.

HCM procedures show right lane performance is highly dependent on the distance between adjacent access points. As the distance from an access point increases, the volume in lane 1 (the right lane) decreases as more and more entering and exiting vehicles get in adjacent lanes to avoid potential conflicts with other accessing vehicles. According to the tables in the HCM, the rate of vehicles leaving the right lane changes most dramatically in the first 300 feet. Exiting concentrations are similarly change the most in the last 300 feet before exiting. As a result, increasing the distance between adjacent access points from 200 to 300 feet has the same impact on demand for the right lane as a reduction of 130 entering and exiting vehicles per hour.

Figure 15 illustrates HCM merge/diverge comparisons using lower than ramp volumes and Rt. 3-like mainline volumes. With constant access volume, increasing spacing from 100 to 300 feet reduces demand for the right lane from values of about 2000 vehicles per hour (capacity) to values below the average lane demand (1800). Such dramatic changes for such relatively small changes in spacing is the most notable result of the comparisons made. As noted, changes in lane one demand are less dramatic as the separation distance increases to 500 and 1000 feet. While it is not appropriate to expect driveway merges to act just like well designed ramps, a policy of minimum distances to reduce localized flow disruptions is clearly supported.

A factor of some concern is that the driveways studied involved volume rates so low as to be below the minimum values listed in the HCM chapter for ramp analysis. Low volumes may well produce impacts less than the minimum noted in the studies used to design the HCM method. One way of dealing with this problem is to analyze the volumes of several driveways collectively across a section of highway rather than inspecting each as a point specific location. Such a procedure would be similar to the following weaving section analysis.

G. Weaving Section Analyses

The value of a continuous shoulder has been demonstrated by the data on Route 3. As was seen, even though the driveways exist and conflicts occur as on Route 1, freeway-like flow in the section is still possible. The shoulder operates in a manner comparable to weaving sections. On freeways such sections are defined as the area between adjacent ramps which are within 4000 feet.

As in the merge/diverge analysis, site specific distances and volumes are important variables in the HCM analysis method. Also similar to the merge/diverge analysis, the procedure involves a check for conditions in the right lane which may be significantly worse than would be estimated based on average per lane conditions.

Figure 16 illustrates the results of applying HCM methods to several specific cases. Indicated again is that increasing the distance between access points from 100 to 300 feet improves conditions in the right lane dramatically. The estimates of speeds of weaving vehicles (Sw) and of non-weaving vehicles (Snw) each increase about 40%. Inspecting the HCM tables shows that this percentage is relatively constant for any pair of ramp and mainline volume conditions.

Because the Figure 16 comparison then is typical of many situations, once more the value of a shoulder is confirmed. Speed estimates are about 10 mph higher when distances are 300 feet or more, again as a result of the increased accel/decel space. At closer spacing, the speed of weaving vehicles is reduced and the differential declines. By comparison, substantial increases in the total access volume (combined on and off totals) works to reduce estimated weaving vehicle speeds only 3 mph.

When the distance between access points drops to 100 feet, weaving speeds drop quickly. This dramatic change in predicted conditions near 100 foot spacing between access is the most notable result of the exercise.

H. Summary of Modelling

The 1985 Highway Capacity Manual methods for analyzing ramps and sections where weaving is prevalent do not deal directly with driveway like access conditions. The tables and procedures appear to have value in predicting conditions that such access may create, considering the limitations of the procedures. Thus driveways appear to be treatable as ramps which have low volume and are often substandard in design.

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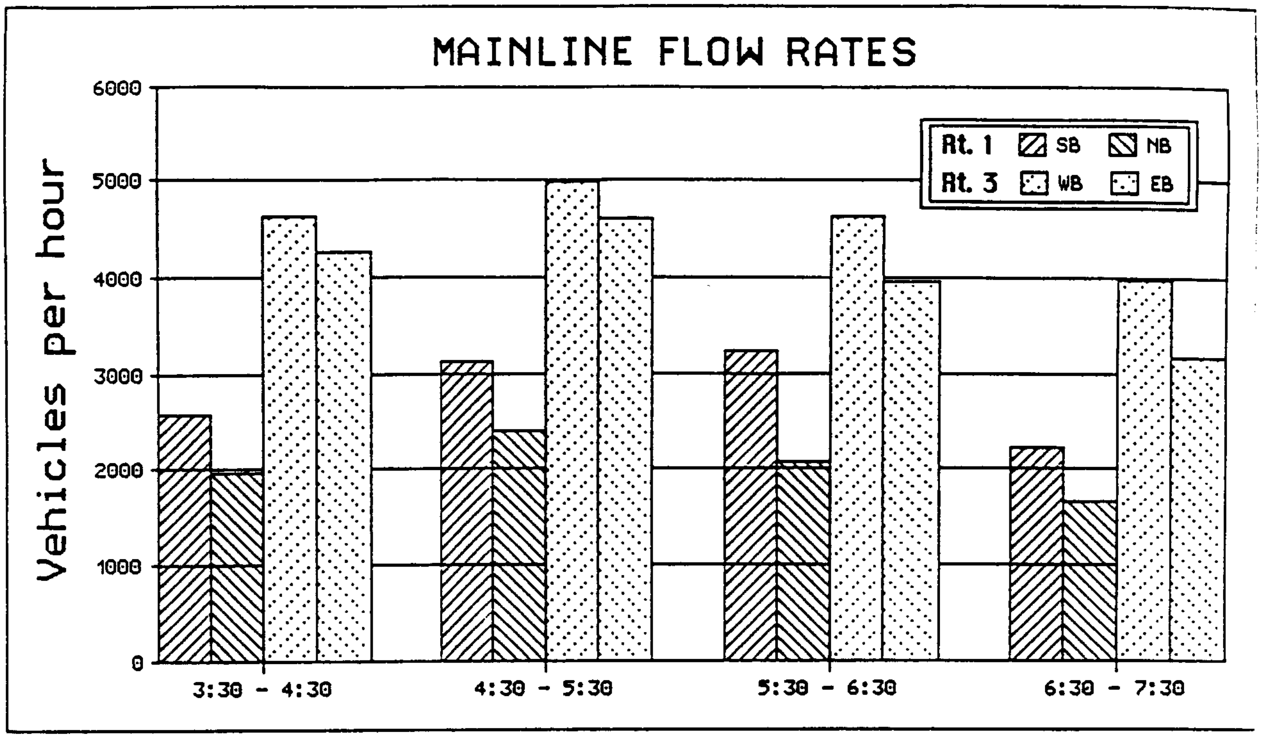
APPENDIX A

FIGURES AND TABLES


MAINLINE FLOW RATES
Vehicles per hour
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5000
4000
3000
2000
1000
0
Rt. 1 SB NB
Rt. 3 WB EB
3:30 - 4:30
4:30 - 5:30
5:30 - 6:30
6:30 - 7:30

FIGURE 1

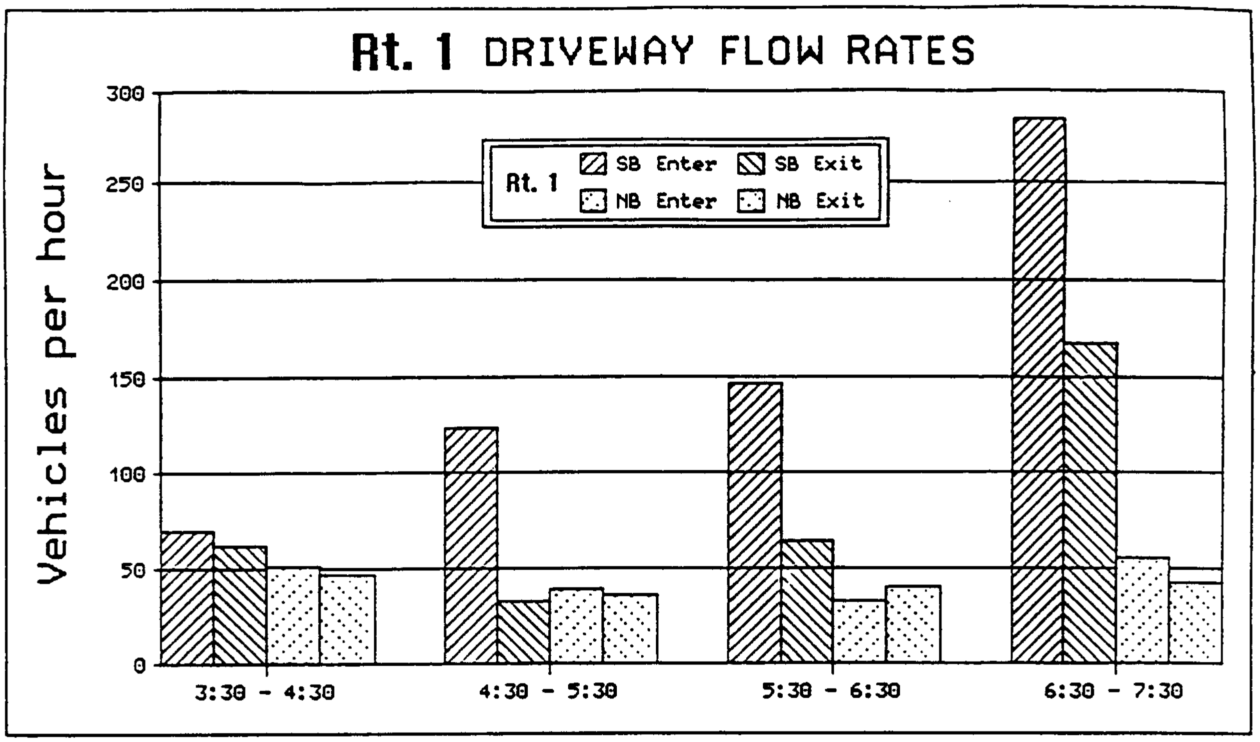


FIGURE 2

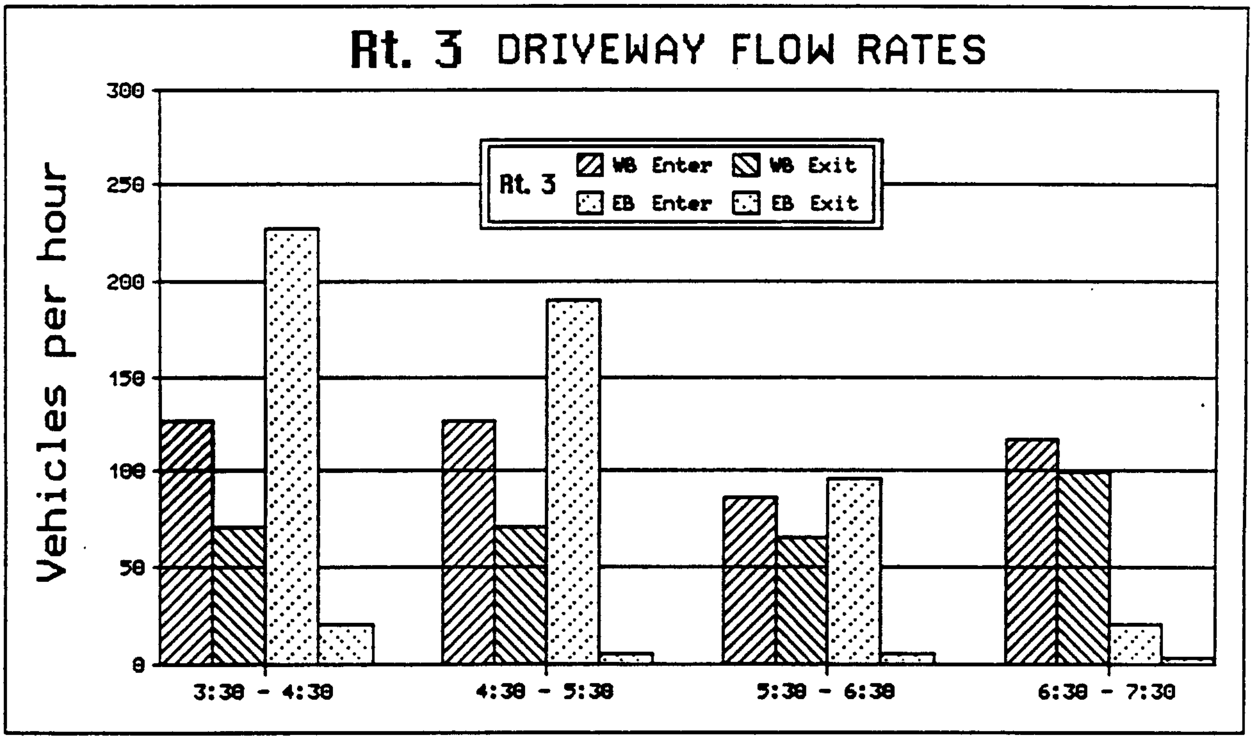


FIGURE 3

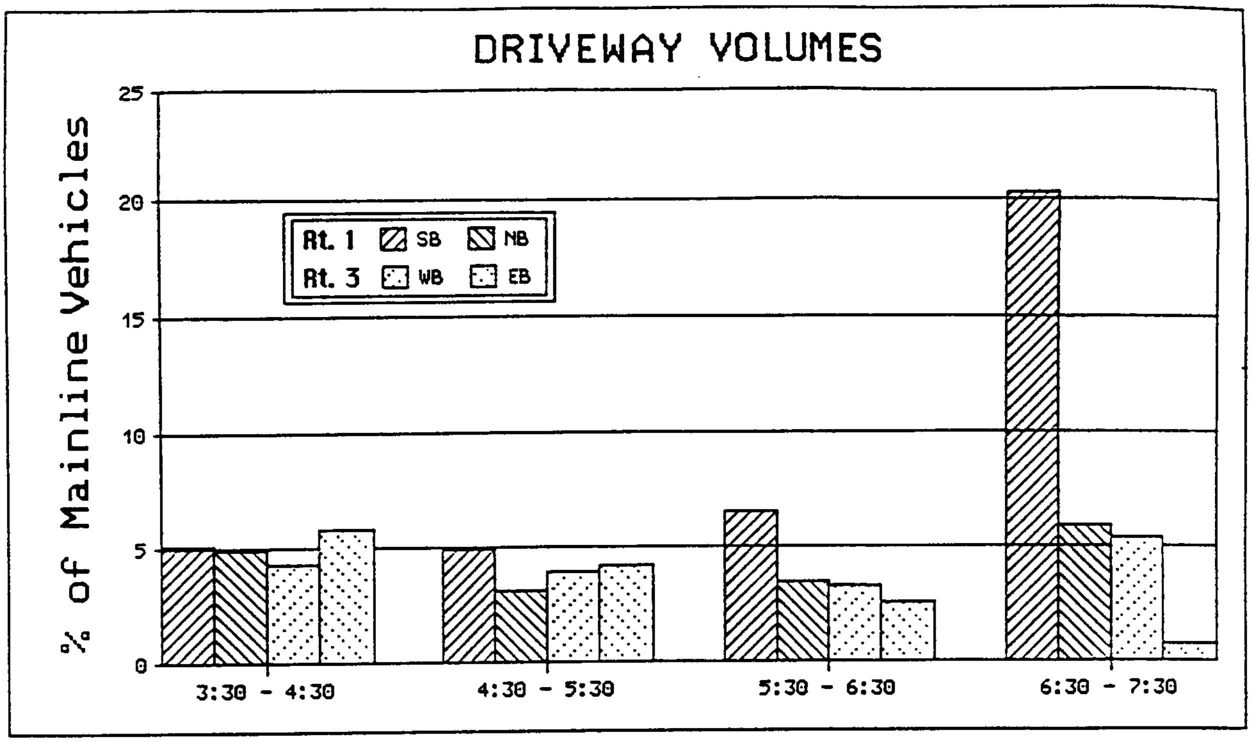

DRIVEWAY VOLUMES
25
20
15
10
5
0
% of Mainline Vehicles
Rt. 1 SB NB
Rt. 3 WB EB
3:30 - 4:30
4:30 - 5:30
5:30 - 6:30
6:30 - 7:30

FIGURE 4

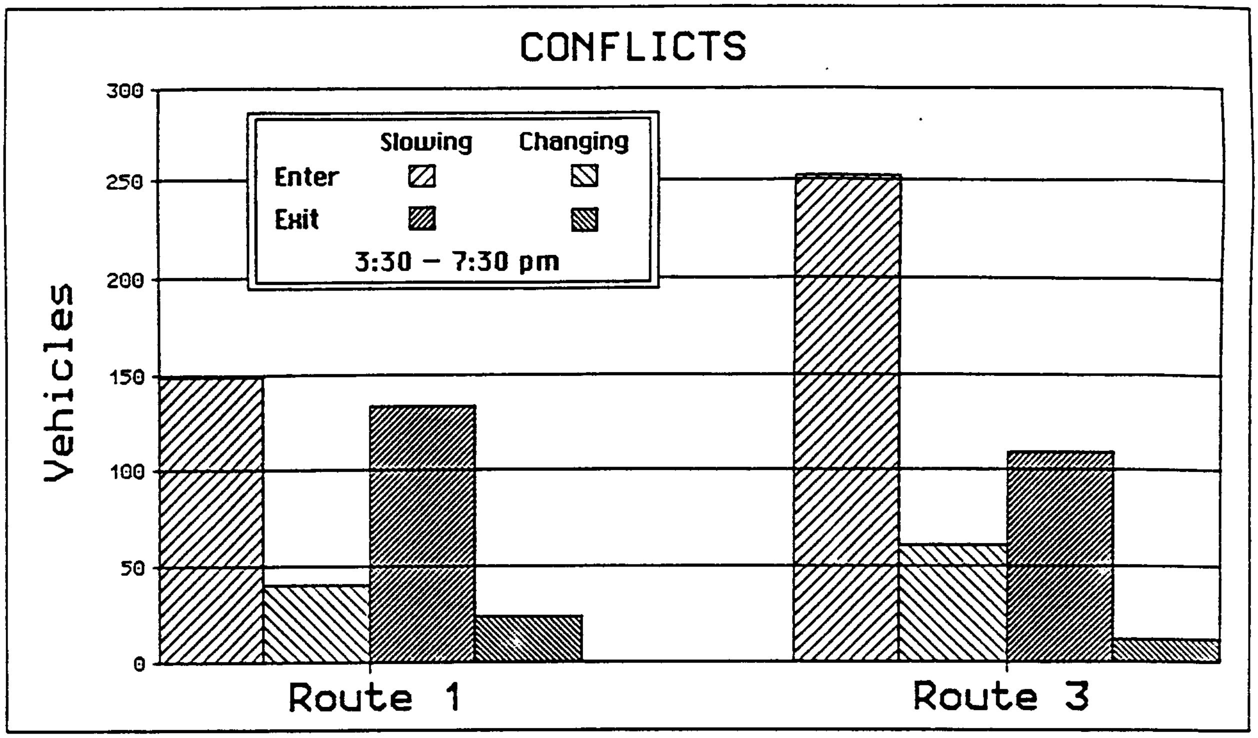


FIGURE 5

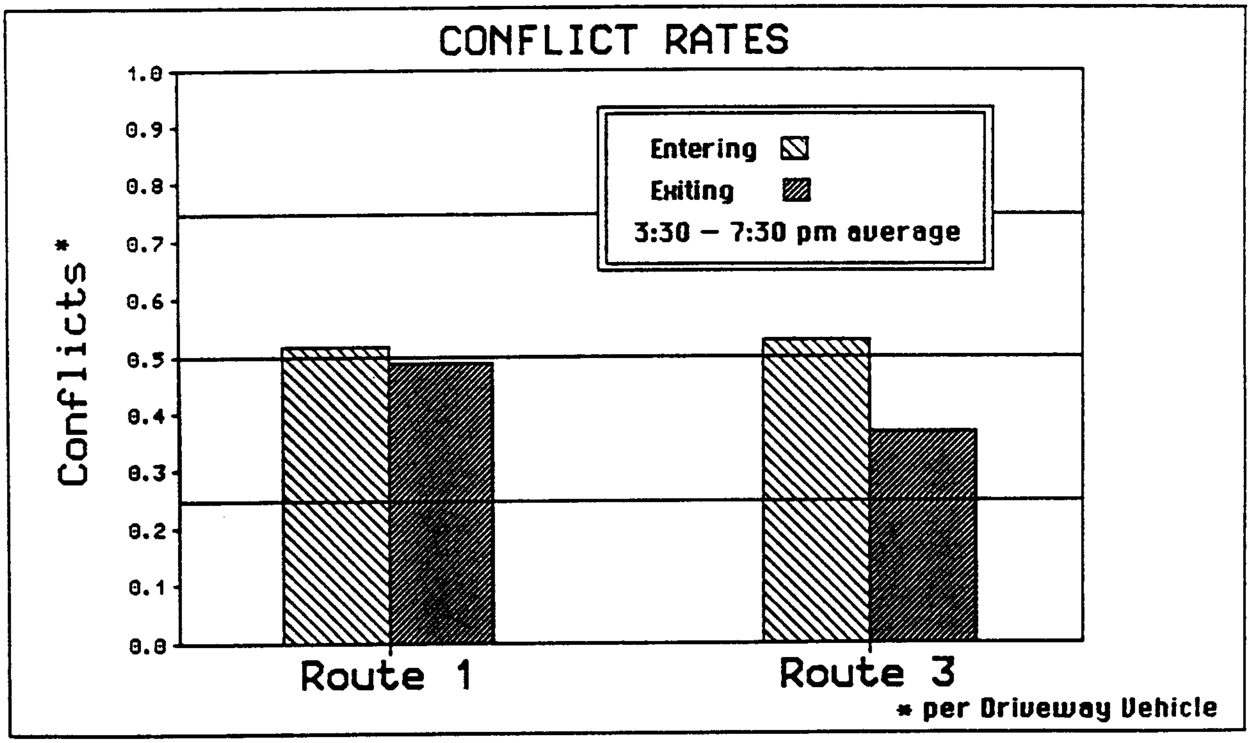
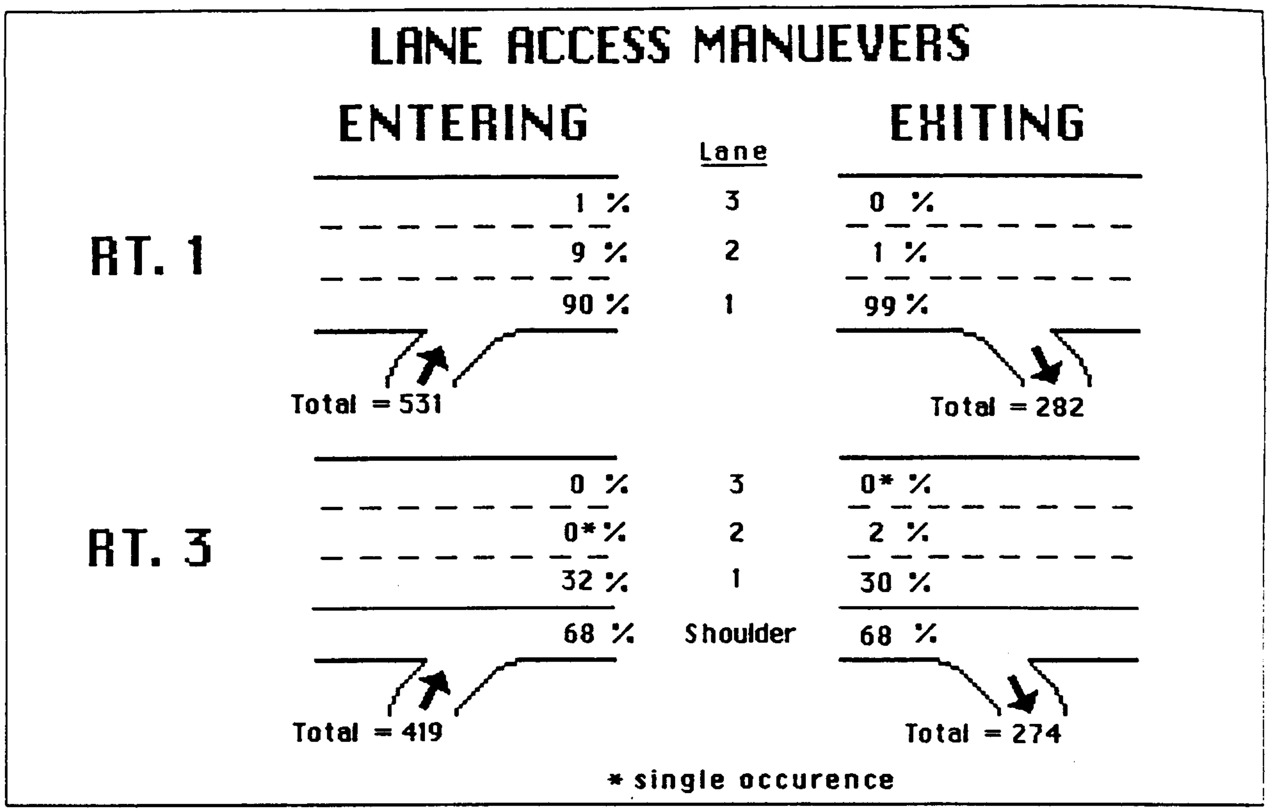


FIGURE 6


LANE ACCESS MANUEVERS
ENTERING
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Lane
RT. 1
1 %
3
0 %
9 %
2
1 %
90 %
1
99 %
Total = 531
Total = 282
RT. 3
0 %
3
0* %
0* %
2
2 %
32 %
1
30 %
68 %
Shoulder
68 %
Total = 419
Total = 274
* single occurence

FIGURE 7

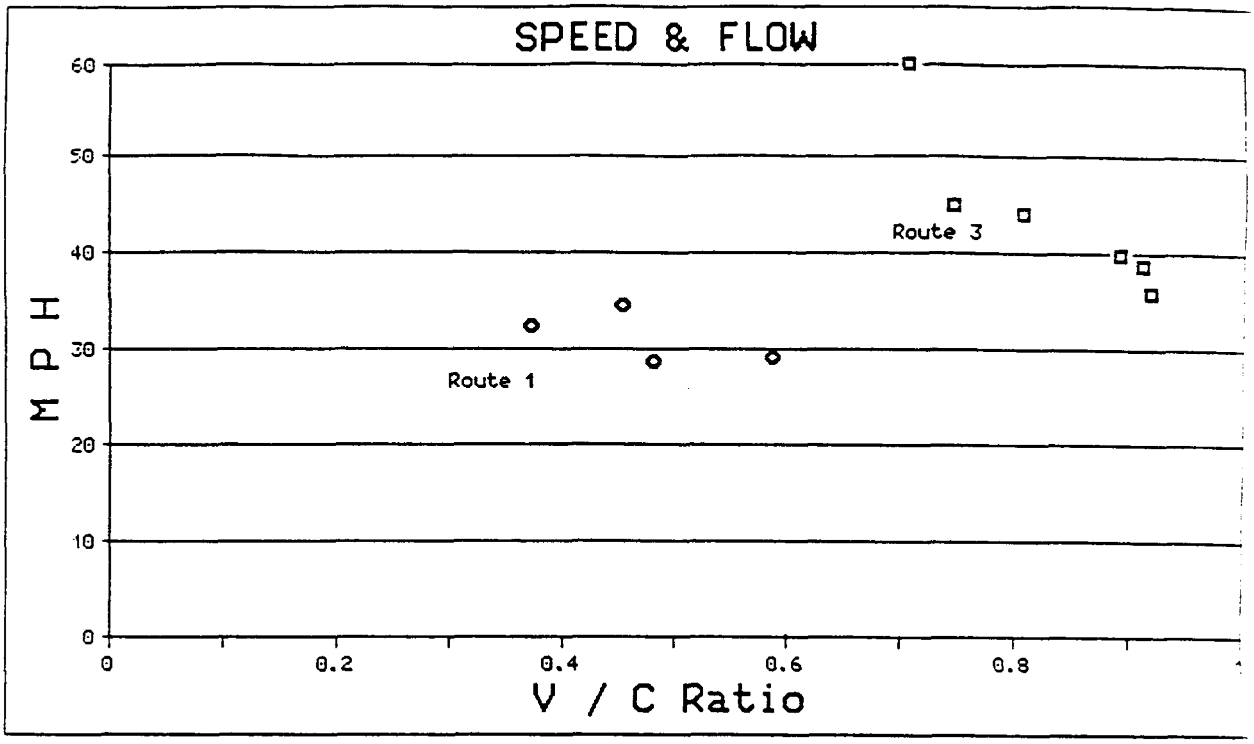


FIGURE 8

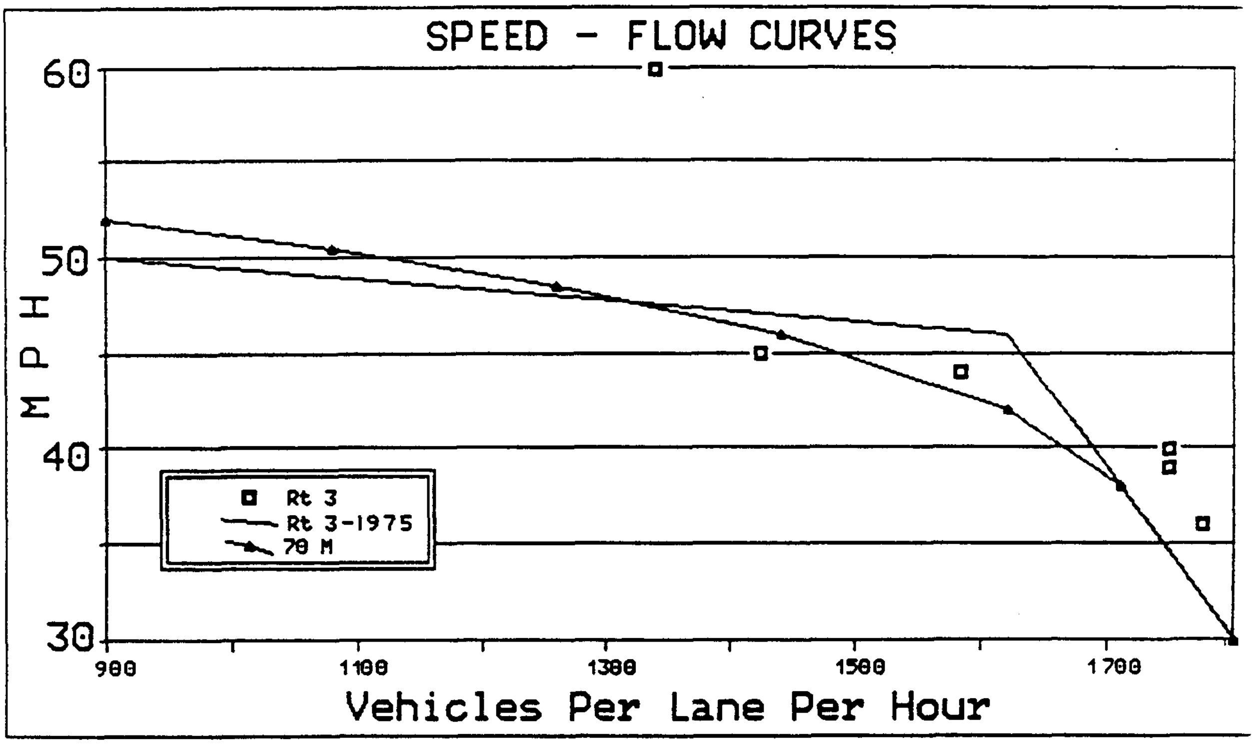
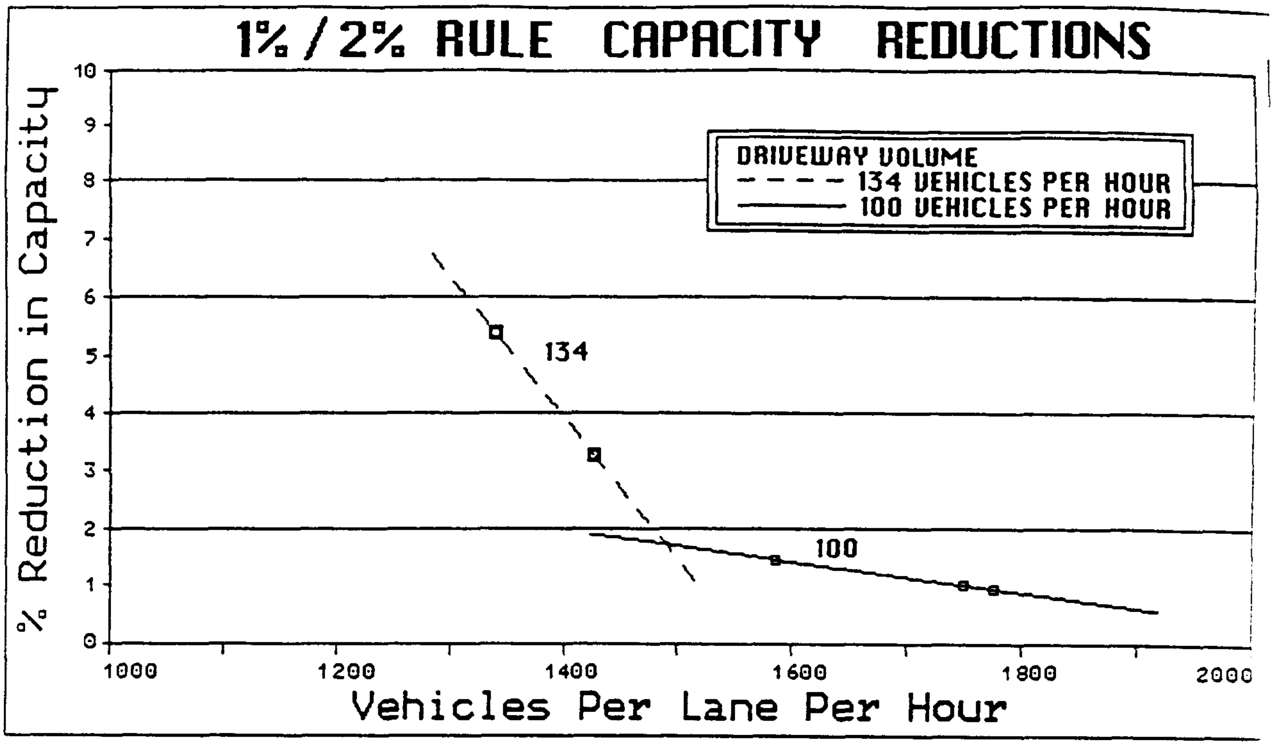


FIGURE 9



1%/2% RULE CAPACITY REDUCTIONS
% Reduction in Capacity
10
9
8
7
6
5
4
3
2
1
0
DRIVEWAY VOLUME
134 VEHICLES PER HOUR
100 VEHICLES PER HOUR
134
100
1000
1200
1400
1600
1800
2000
Vehicles Per Lane Per Hour

FIGURE 10

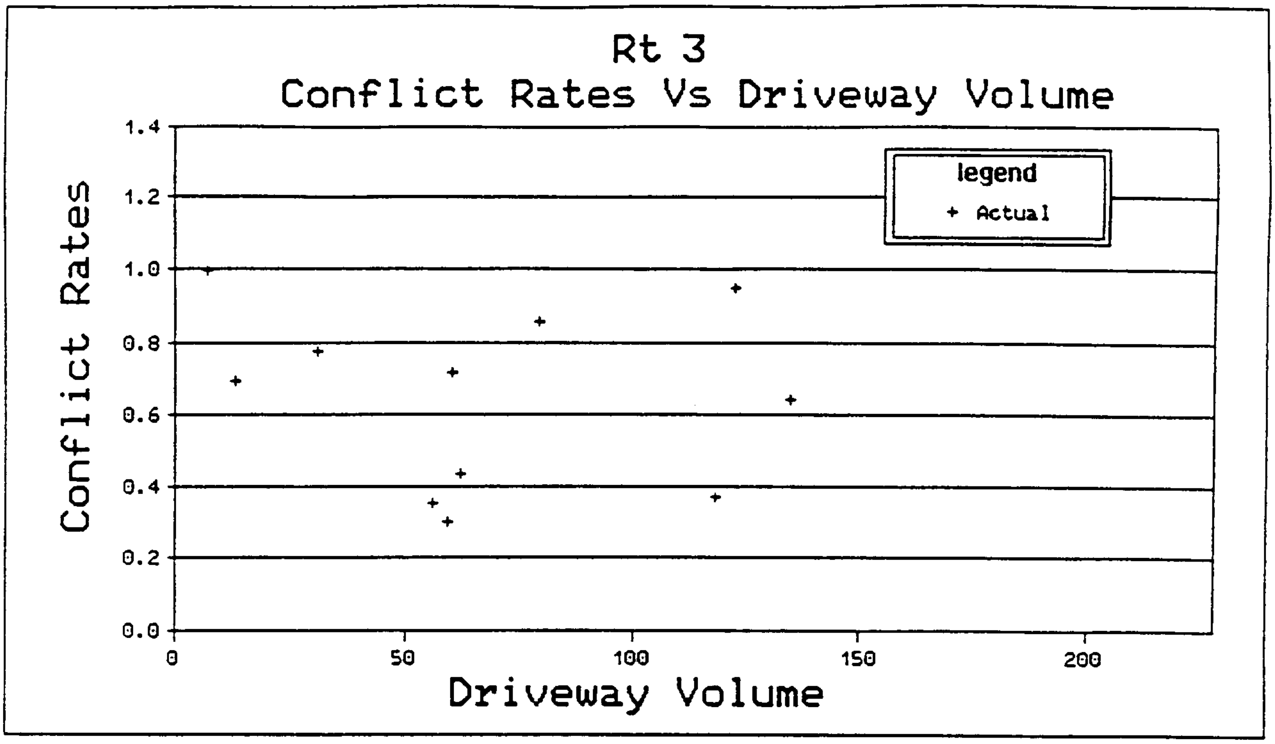


FIGURE 11

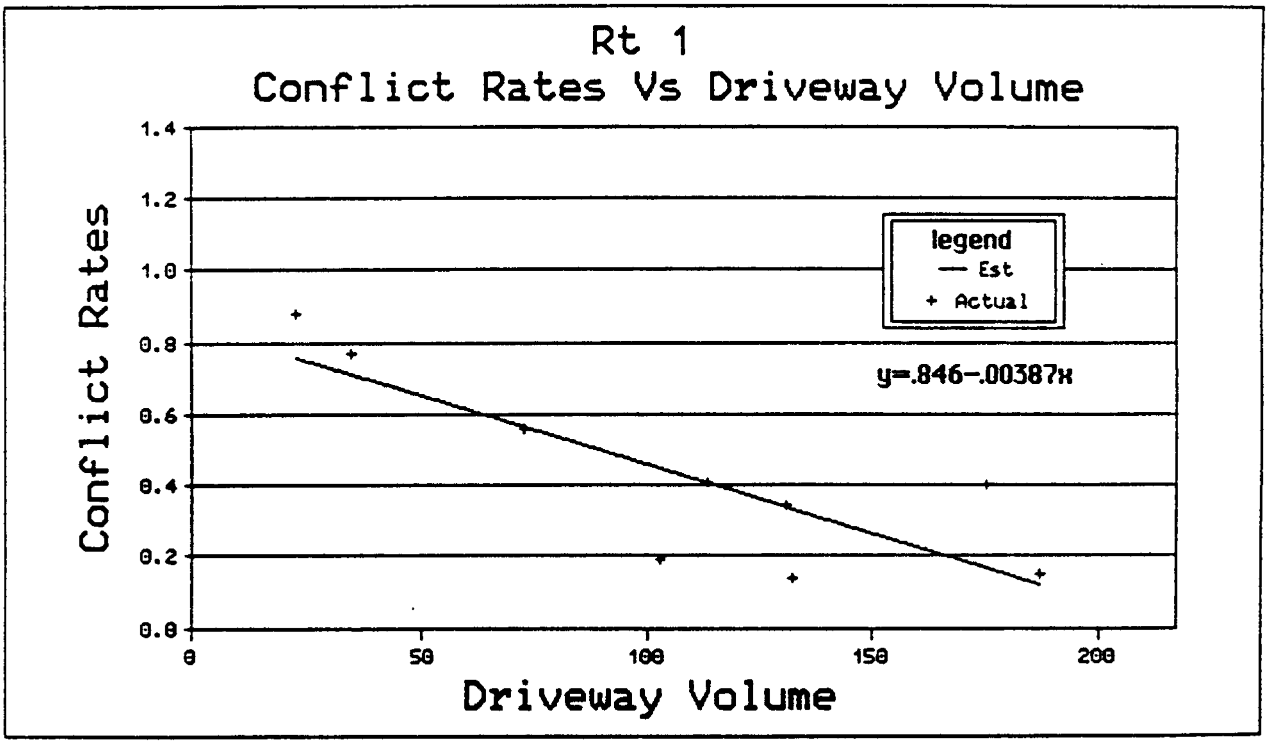


FIGURE 12

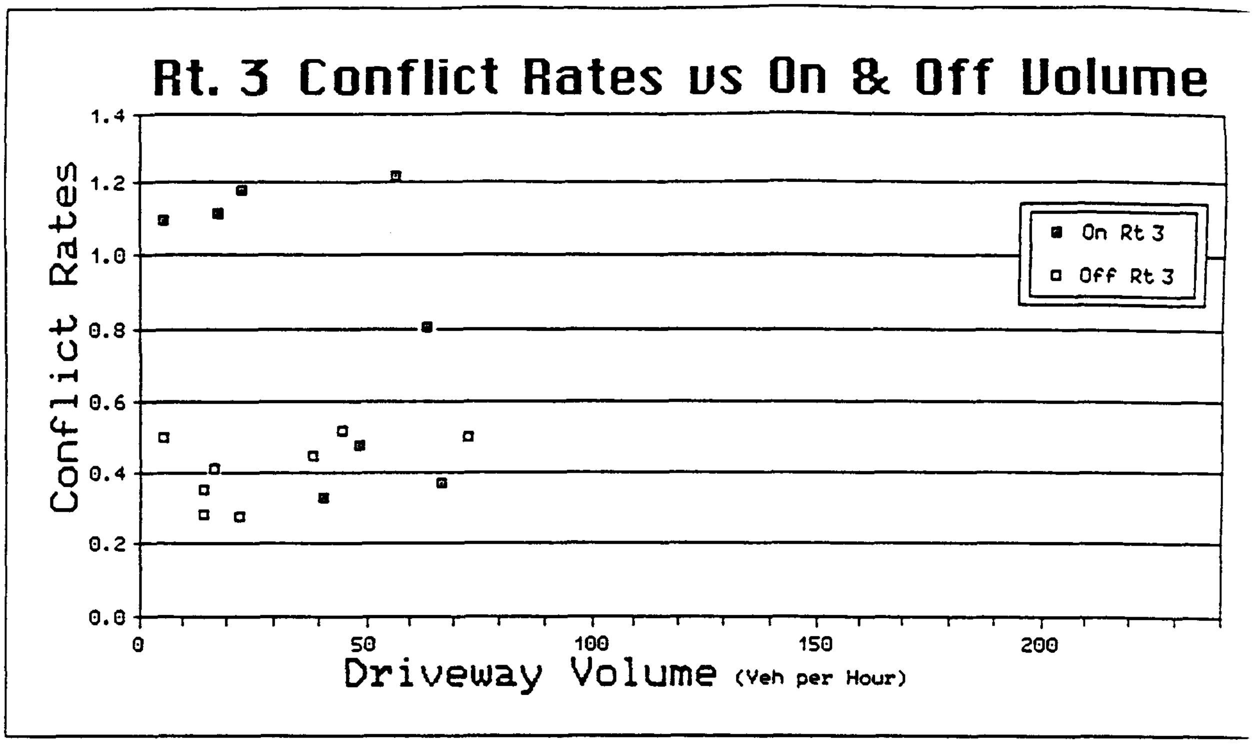


FIGURE 13

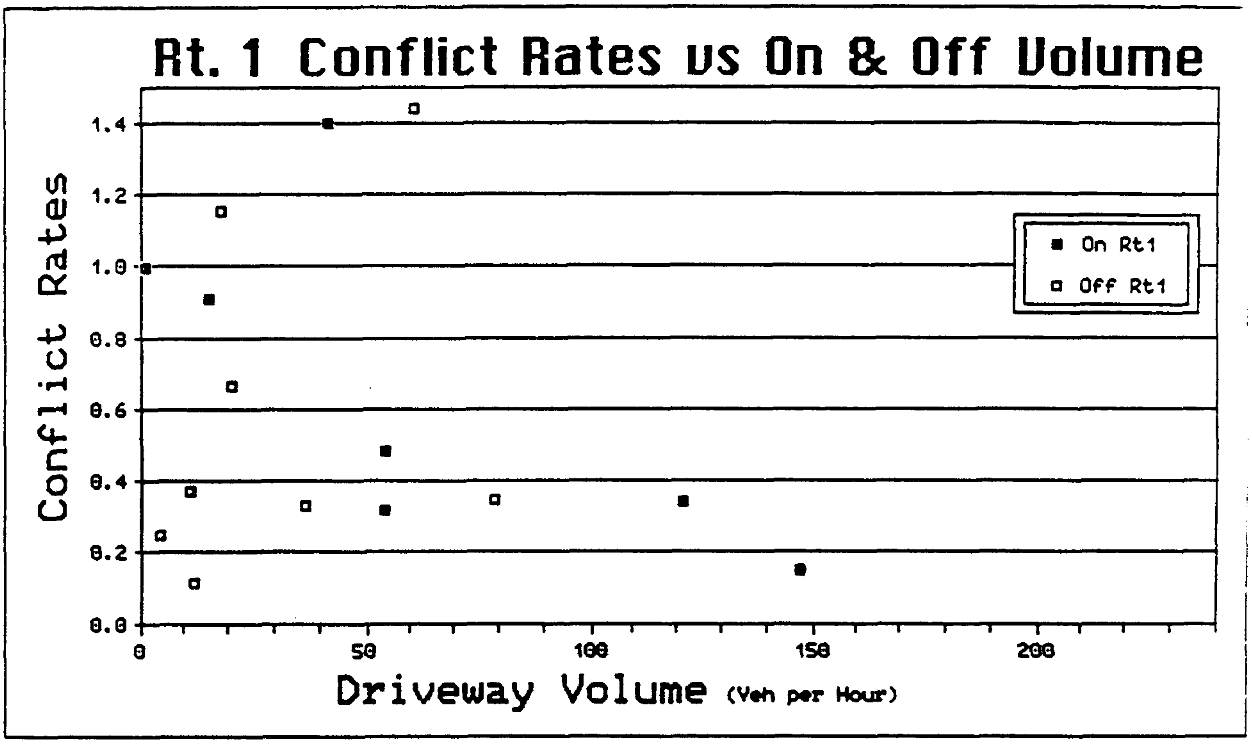


FIGURE 14

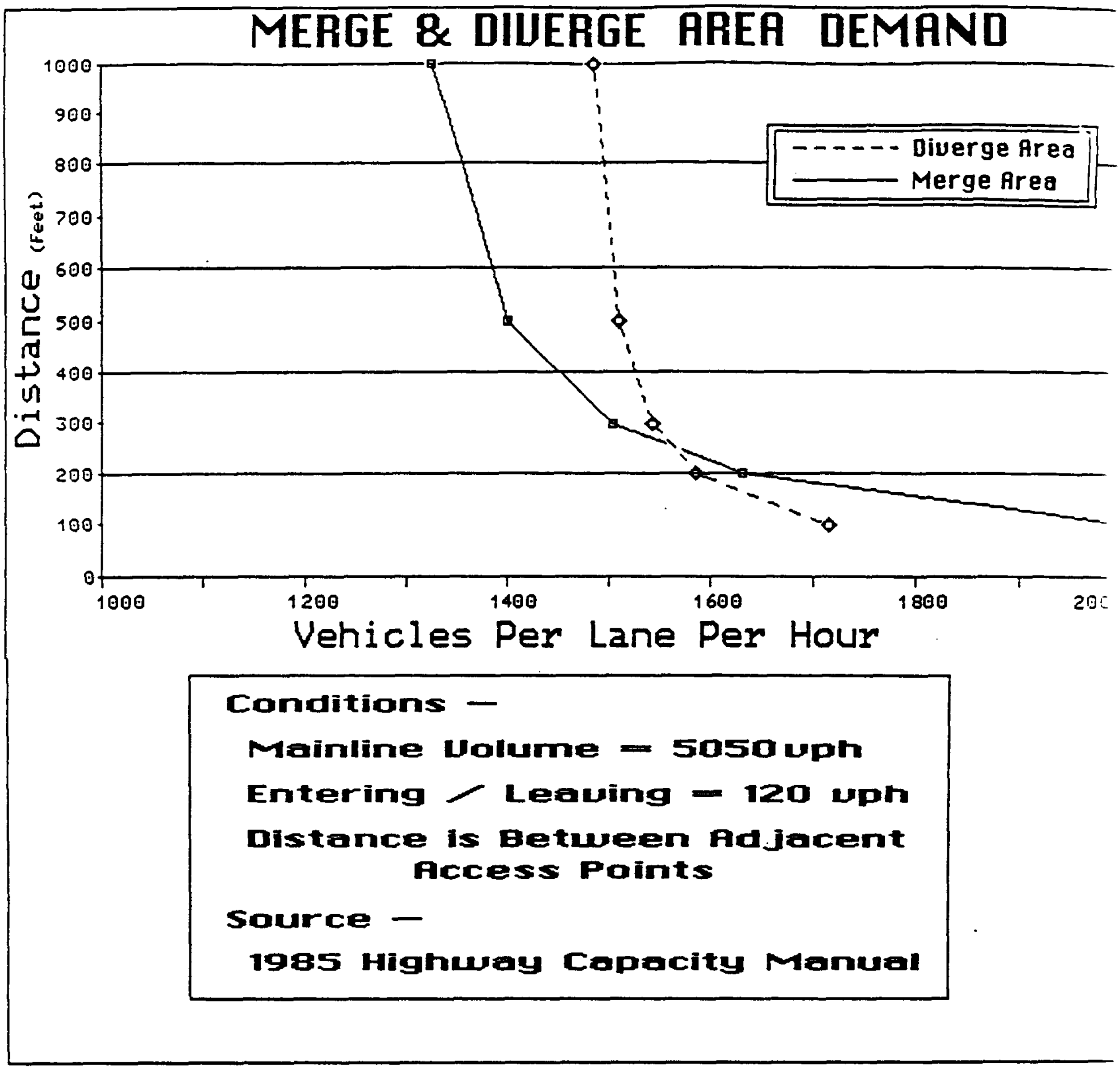

MERGE & DIVERGE AREA DEMAND
Distance (Feet)
1000
900
800
700
600
500
400
300
200
100
0
1000
1200
1400
1600
1800
20
Vehicles Per Lane Per Hour
Diverge Area
Merge Area
Conditions —
Mainline Volume = 5050 vph
Entering / Leaving = 120 vph
Distance is Between Adjacent Access Points
Source —
1985 Highway Capacity Manual

FIGURE 15

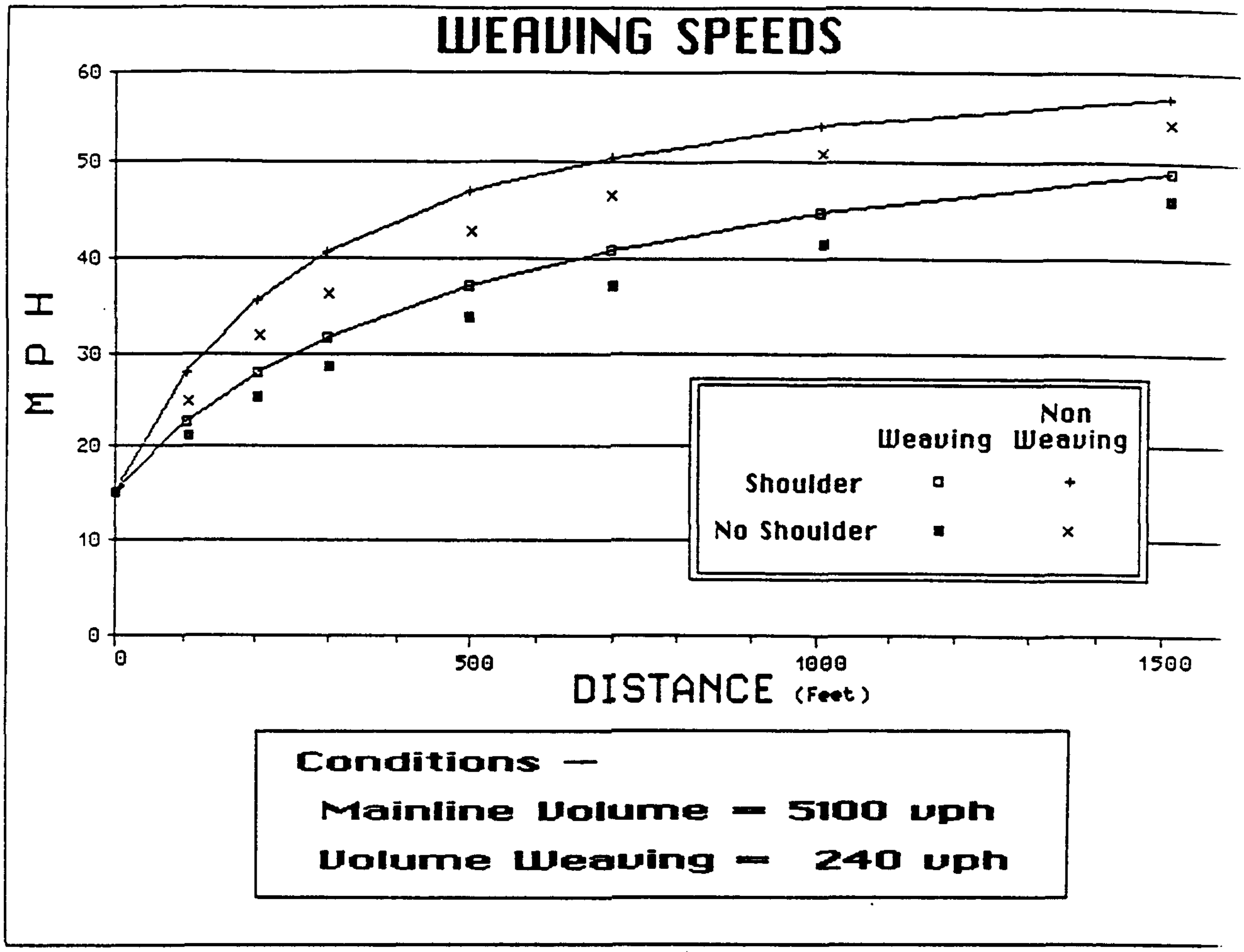

WEAVING SPEEDS
60
50
40
30
20
10
0
M P H
0
500
1000
1500
DISTANCE (Feet)
Non
Weaving Weaving
Shoulder
No Shoulder
Conditions —
Mainline Volume = 5100 vph
Volume Weaving = 240 vph

FIGURE 16

TABLE 1 RESULTS AT RT 1 MP 8.0

MAINLINE VEHICLES	RT 1 SB (Peak) Total vph	Trucks %	Speed mph	RT 1 NB (Off Peak) Volume vph	Trucks %	Speed mph
Hour (pm)						
3:30 - 4:30	2592	6.3	28	1960	6.6	32
4:30 - 5:30	3140	3.4	29	2415	3.8	34
5:30 - 6:30	3242	2.9		2081	2.8	
6:30 - 7:30	2229	4.2		1657	2.3	

DRIVEWAY LOCATIONS	RT 1 SB (Peak) Entering	Exiting	Total	RT 1 NB (Off Peak) Entering	Exiting	Total
	4	5	9	1	1	2

DRIVEWAY VEHICLES	(vph)	(vph)	%	(vph)	(vph)	%
Hour (pm)						
3:30 - 4:30	70	62	5.1	51	47	5.0
4:30 - 5:30	124	33	5.0	39	36	3.1
5:30 - 6:30	147	65	6.5	33	40	3.5
6:30 - 7:30	285	168	20.3	56	43	6.0
AVERAGES						
Section Total	157	66	8.0	45	42	4.3
Each	39	13	1.9	45	42	4.3

CONFLICT VOLUMES	ENTERING RT 1 SB (Peak) Slowing	Changing	Rate *	EXITING RT 1 SB (Peak) Slowing	Changing	Rate *
Hour (pm)						
3:30 - 5:30	64	21	0.65	28	7	0.33
5:30 - 7:30	86	19	0.40	106	17	0.61
3:30 - 7:30	150	40	0.52	134	24	0.49

DIRECT LANE ACCESS	**Entering Rt 1 (No Shoulder) Lane 1**	**Lane 2**	**Lane 3**	**Exiting Rt 1 (No Shoulder) Lane 1**	**Lane 2**	**Lane 3**
Hour (pm)						
3:30 - 5:30	**182**	**12**	**2**	**89**	**1**	**0**
5:30 - 7:30	**295**	**37**	**3**	**190**	**2**	**0**
3:30 - 7:30	**477**	**49**	**5**	**279**	**3**	**0**
Percent:	**90**	**9**	**1**	**99**	**1**	**0**

*** Rate = Mainline Vehicle Conflicts per Accessor Vehicle**

TABLE 2 RESULTS AT RT 3 MP 3.3

MAINLINE VEHICLES	RT 3 WB (Peak)			RT 3 EB (Off Peak)		
	Volume vph	Trucks %	Speed mph	Volume vph	Trucks %	Speed mph
Hour (pm)						
3:30 - 4:30	4633	5.9	42	4276	7.9	60
4:30 - 5:30	5016	4.3	37	4624	5.3	47
5:30 - 6:30	4636	4.1	45	3956	4.3	48
6:30 - 7:30	4006	3.2	60	3166	3.3	57

DRIVEWAY LOCATIONS	RT 3 WB (Peak)			RT 3 EB (Off Peak)		
	Entering	Exiting	Total	Entering	Exiting	Total
	4	4	8	3	3	6

DRIVEWAY VEHICLES	(vph)	(vph)	%	(vph)	(vph)	%
Hour (pm)						
3:30 - 4:30	128	71	4.3	228	21	5.8
4:30 - 5:30	128	71	4.0	190	5	4.2
5:30 - 6:30	87	66	3.3	96	5	2.6
6:30 - 7:30	117	100	5.4	21	3	0.8
AVERAGES						
Section Total	115	77	4.2	45	3	1.2
Each	29	19	1.0	15	1	0.4

CONFLICT VOLUMES	ENTERING RT 3 WB (Peak)			EXITING RT 3 WB (Peak)		
	Slowing	Changing	Rate	Slowing	Changing	Rate *
Hours (pm)						
3:30 - 5:30	161	37	0.55	56	7	0.38
5:30 - 7:30	92	24	0.51	53	5	0.37
3:30 - 7:30	253	61	0.53	109	12	0.37

DIRECT LANE ACCESS	**Entering Rt 3**			**Exiting Rt 3**		
	Shoulder	**Lane 1**	**Lane 2+3**	**Shoulder**	**Lane 1**	**Lane 2+3**
Hours (pm)						
3:30 - 5:30	**201**	**54**	**0**	**116**	**25**	**1**
5:30 - 7:30	**83**	**80**	**1**	**71**	**57**	**4**
3:30 - 7:30	**284**	**134**	**1**	**187**	**82**	**5**
Percent:	**68**	**32**	**0**	**68**	**30**	**2**

*** Rate = Mainline Vehicle Conflicts per Accessor Vehicle**

TABLE 3 RT 3 CAPACITY ESTIMATES - SPEED FLOW CURVE FIT

OBSERVED DATA				SPEED FLOW CURVE							
Total Volume (Veh/Hr)	Trucks %	Per Lane Volume (pcph)	Speed Mph	NJ #5 V/C	NJ #5 Capacity	HCM Freeway 70 V/C	HCM Freeway 70 Capacity	HCM Multilane 70 V/C	HCM Multilane 70 Capacity	HCM Multilane 60 V/C	HCM Multilane 60 Capacity
4466	6.4	1584	44	0.91	1741	0.945	1676	0.84	1886	0.6	2640
4930	6.4	1749	40	0.94	1860	0.97	1803	0.93	1880	0.78	2242
5100	4.4	1775	36	0.97	1830	0.985	1802	0.97	1830	0.89	1994
5040	4.1	1749	39	0.945	1851	0.975	1794	0.94	1861	0.8	2186
4120	3.7	1424	45	0.905	1574	0.94	1515	0.82	1737	0.58	2455
3910	2.7	1339	60	NA	NA	0.2	6693	0	NA	NA	NA
				AVERAGE	1771		1718		1839		2303
				MAXIMUM DIFFERENTIAL	89		85		47		335

TABLE 4 RT 3 CAPACITY ESTIMATES - CALCULATION OF CAPACITY

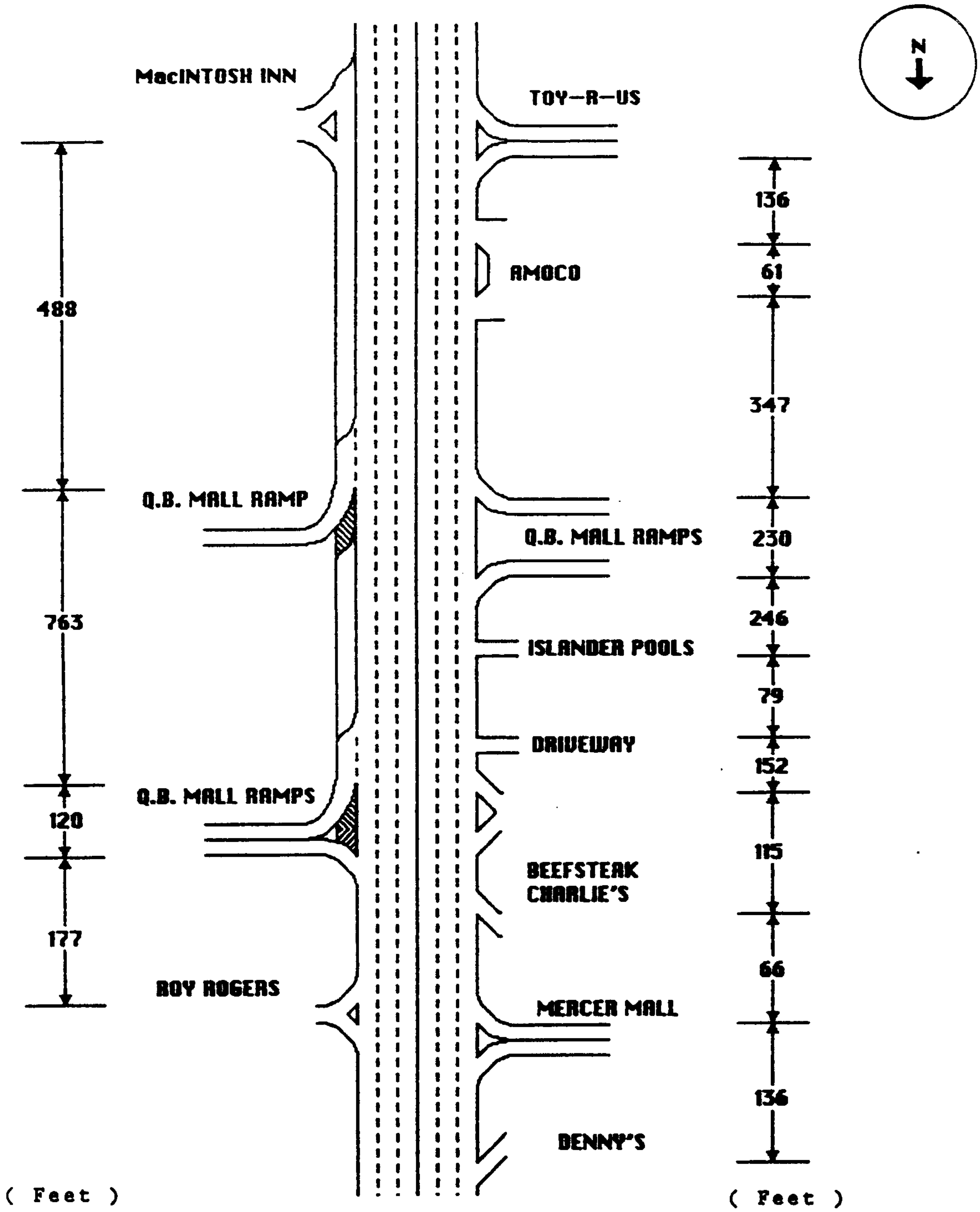
SECTION DATA			HCM CAPACITY		1% / 2% RULE CAPACITY				
Total Volume (Veh/Hr)	Trucks %	Per Lane Volume (pcph)	Per Lane Freeway 1800	Per Lane Multilane .9xFreeway	Ramp Volume (pcph)	Right Lane %	Capacity Reduction Total (pcph)	Capacity Reduction Per Lane (pcph)	Overall Impact %
4466	6.4	1584	1800	1620	100	8.68	78	25	1.45
4930	6.4	1749	1800	1620	100	6.08	55	18	1.01
5100	4.4	1775	1800	1620	100	5.80	52	17	0.97
5040	4.1	1749	1800	1620	100	6.07	55	18	1.01
4120	3.7	1424	1800	1620	134	19.98	180	60	3.33
3910	2.7	1339	1800	1620	134	32.32	291	97	5.39

KEY TO ABBREVIATIONS

HCM -Highway Capacity Manual
Veh/Hr -Vehicles per Hour
pcph -passenger cars per hour
NJ #5 -New Jersey DOT developed Speed Flow Curve #5
V/C -Volume to Capacity Ratio

APPENDIX B

STUDY SITE INVENTORY

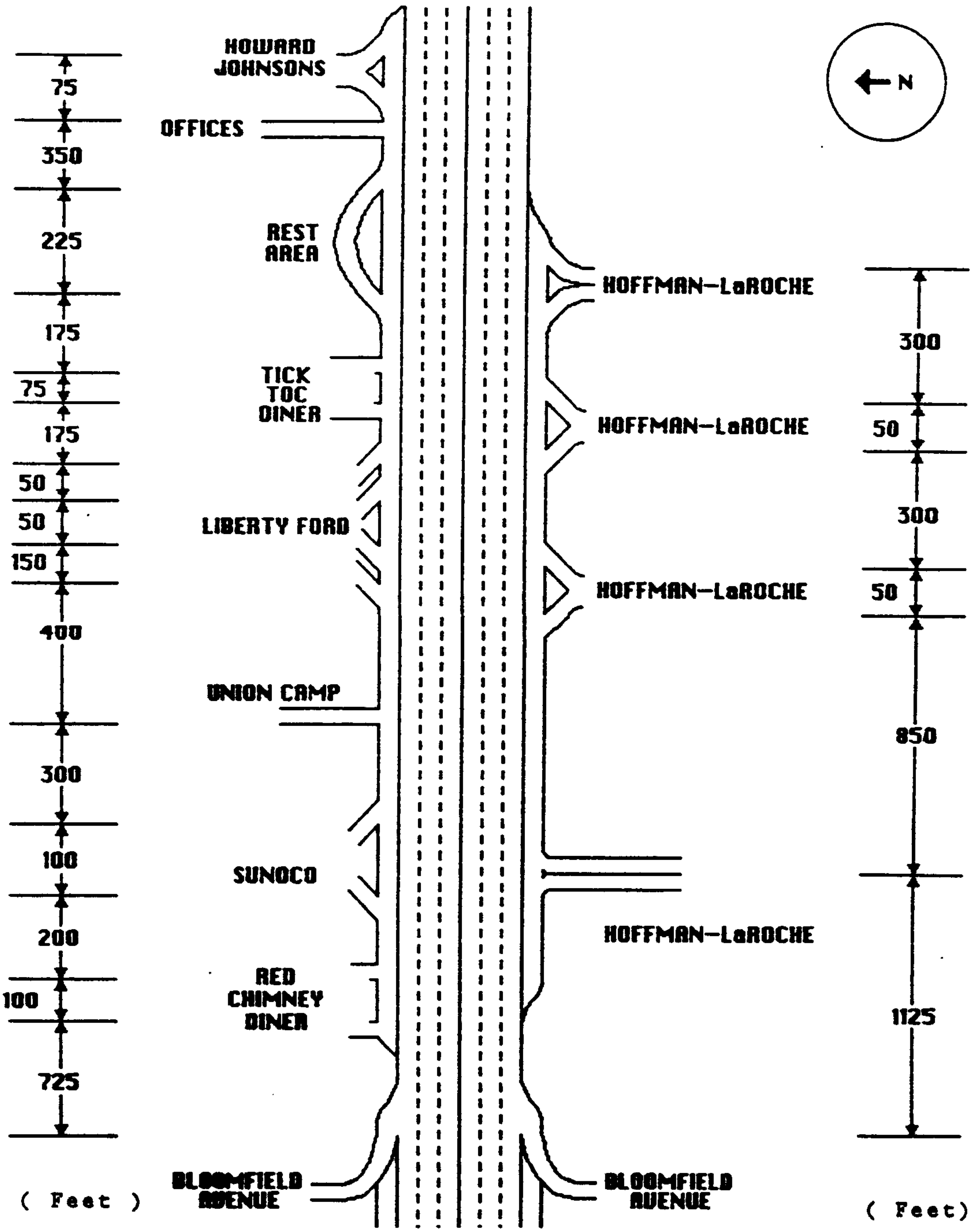

MacINTOSH INN
TOY—R—US
136
61
AMOCO
488
347
Q.B. MALL RAMP
Q.B. MALL RAMPS
230
763
246
ISLANDER POOLS
79
DRIVEWAY
152
Q.B. MALL RAMPS
120
115
BEEFSTEAK
CHARLIE'S
177
66
ROY ROGERS
MERCER MALL
136
DENNY'S
(Feet)
(Feet)
N

Route 1

ROUTE 1
QUAKER BRIDGE (QB) RD TO MOTOR VEHICLE (MV) AGENCY
INVENTORY OF ACCESS POINTS

	SEPARATION (Feet)	SOUTHBOUND (Down)		BASELINE (Feet)		NORTHBOUND (UP)	SEPARATION (Feet)	
	0	Q B Road		0		Q B Road		
		Gas		54		Q B Road	54	
	190	Mercer Mall		190		Gas	136	
	119			309				
	138	Colonial Diner		447		Diner	257	
	105			552				
	193	Chi-Chi's		745		Motel	298	
----	247	Denny's		992				
	136	Mercer Mall	R	1128	R			
	66		T	1194	T	Roy Rogers	449	---
								S
S	118	Beafsteak	1	1312	1			T
T		Charlie's		1371		Q B Mall Ramps	177	U
U	152		S	1464	N			D
D			O	1491	O		120	Y
Y	79	Private	U	1543	R			
			T		T			
	246	Islander Pools	H	1789	H			S
S			B		B			E
E	179	Q B M Ramps	O	1968	O			C
C	230		U	2198	U			T
T			N	2254	N	Q B Mall Ramps	763	I
I			D		D			O
O		Q B Mall Overpass				Q B Mall Overpass		N
N			v					---
	347	Amoco Gas		2545				
	61			2606				
	136	Toys-R-Us		2742		MacIntosh Inn	488	
---	82			2824			82	
	47	Red Lobster		2871				
				2916		Color Tile	174	
				2995			79	
	239			3110				
				3306				
	487	Junk Yard		3597				
	72			3669				
	141	Meineke		3810				
	44			3854				
	125	Motel		3979				
	67			4046				
	50	M V Jughandle		4096				
	119	Intersection		4215				

SUMMARY OF ACCESS	STUDY AREA SB	STUDY AREA NB
Average Separation (Feet)	130	330


HOWARD JOHNSONS
OFFICES
REST AREA
TICK TOC DINER
LIBERTY FORD
UNION CAMP
SUNOCO
RED CHIMNEY DINER
BLOOMFIELD AVENUE
HOFFMAN-LaROCHE
HOFFMAN-LaROCHE
HOFFMAN-LaROCHE
HOFFMAN-LaROCHE
BLOOMFIELD AVENUE
N
75
350
225
175
75
175
50
50
150
400
300
100
200
100
725
(Feet)
300
50
300
50
850
1125
(Feet)

Route 3

ROUTE 3
PASSAIC AVE TO BLOOMFIELD AVE
INVENTORY OF ACCESS POINTS

	SEPARATION (Feet)	WESTBOUND (Down)		BASELINE (Feet)		EASTBOUND (Up)	SEPARATION (Feet)	
		Passaic Ave		0				
	175			175		Passaic Ave	175	
---	675	Howard Johnson's		850				
	75	Offices		925				
	350	Rest Area		1275				
S				1325	^	Hoffman-LaRoche	1150	---
T	225			1500				S
U			R	1625	R		300	T
D	175	Tick Tock Diner	T	1675	T	Hoffman-LaRoche	50	U
Y	75			1750				D
			3		3			Y
	175	Liberty Ford		1925				
S	50		W	1975	E		300	S
E	50		E	2025	A	Hoffman-LaRoche	50	E
C	150		S	2175	S			C
T			T		T			T
I	400	Union Camp	B	2575	B			I
O			O		O			O
N	300	Sunoco	U	2875	U	Hoffman-LaRoche	850	N
	100		N	2975	N			---
	150		D	3125	D			
	50	Red Chimney	v	3175				
---	100			3275				
	725	Bloomfield Ave		4000			1125	
	200			4200		Bloomfield Ave		

SUMMARY OF ACCESS	STUDY AREA West	STUDY AREA East
Average Separation (Feet)	140	450