FINAL REPORT -

ARTERIAL TRAFFIC CALMING PROGRAM

September 1993

PEER REVIEW ANALYSIS

TRAFFIC CIRCLE PROGRAM

Portland, Oregon

KITTELSON & ASSOCIATES, INC.

October 1991

PEER REVIEW ANALYSIS

of the

TRAFFIC CIRCLE PROGRAM
PORTLAND, OREGON

Prepared for

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EXECUTIVE SUMMARY

Traffic circles have been an integral part of the City of Portland's Neighborhood Traffic Management Program (NTMP) for approximately five years. The NTMP has utilized traffic circles as a device to help meet the program objectives of better managing traffic on local streets. Specifically, traffic circles are used to reduce vehicle speeds and eliminate very fast vehicles on local residential streets. They are frequently chosen over other devices because they do not divert truly local traffic and do not restrict access to adjacent streets or land uses.

The City of Portland is just one of many cities throughout the United States and Europe employing traffic circles in this manner. Experience in these cities indicates that traffic circles are effective in reducing vehicle speeds and can reduce the number and severity of intersection accidents. However, the actual impact of these traffic circles and their potential effect on traffic speeds and intersection safety have not been previously evaluated in the City of Portland.

Several meetings were held with NTMP staff to define the role and scope of this peer review evaluation. The following tasks were conducted as part of this peer review for evaluating the effect of the NTMP traffic circles on vehicle speed and traffic safety:

1. Develop a method to evaluate how vehicles travel around traffic circles and determine if these speed profiles vary by any key traffic circle design elements.

2. Analyze changes in mid-block vehicle speed data that were collected before and after traffic circles were installed and determine if these changes differ by any key traffic circle design elements.

3. Analyze changes in the number and severity of accidents that occurred after the installation of traffic circles.

4. Observe traffic at each of the traffic circle sites under day time and night time conditions and assess their operational, visibility, and safety characteristics.

The results of this peer review study have clearly demonstrated that overall these traffic circles are successful at reducing the number of vehicles traveling at high speeds (30-35 mph) on residential streets. On many of these residential streets, 15 percent or more of the vehicles routinely exceeded 35 mph. After traffic circles were installed, vehicles rarely exceed 35 mph. The new larger circles (12 foot radius) appear to reduce vehicle speeds more than smaller traffic circle islands.

Moreover, this peer review analysis found that traffic circles have dramatically reduced, if not almost eliminated, reported accidents, especially multi-vehicle collisions. Overall, once traffic circle were installed the monthly rate of reported accidents decreased by 58 percent. For comparison, a special analysis of "control" intersections that are nearby the intersections that had traffic circles installed was conducted to verify that this reduction in accidents could not be attributed to other extraneous factors. This analysis found that during the same period that reported accidents dramatically decreased at intersections with traffic circles, reported accidents increased 6 percent at these nearby control intersection. It should be also noted that traffic volumes at intersections with traffic circles did not significantly change once the circle was installed.

Observations at the traffic circles installed by the NTMP found vehicles did not have any significant problems negotiating around the islands. However, their nighttime visibility can be improved. Several specific recommendations, including upgrading traffic circle delineators and signs, are detailed in this report. In addition, the City of Portland should establish a program of routinely inspecting these traffic circle intersections to assess their condition and operating characteristics during both daylight and nighttime conditions. Traffic circle intersections should also be inspected after an accident occurs in its vicinity.

INTRODUCTION

Traffic circles have been an integral part of the City of Portland's Neighborhood Traffic Management Program (NTMP) for approximately five years. The NTMP has utilized traffic circles as a device to help meet the program objectives of better managing traffic on local streets. Specifically, traffic circles are used to reduce vehicle speeds and eliminate very fast vehicles on local residential streets. They are frequently chosen over other devices because they do not divert truly local traffic and do not restrict access to adjacent streets or land uses. In addition, traffic circles are often installed at a series of two or more adjacent intersections with the intention that a corridor will be created in which drivers will maintain the slower speeds mandated by the traffic circles. In general, traffic circles are readily accepted by nearby residents and are perceived as being successful at reducing speeding along local streets. However, the actual impact of these traffic circles and their potential effect on traffic speeds and intersection safety have not been previously evaluated in the City of Portland.

The City of Portland is just one of many cities throughout the United States employing traffic circles in this manner. Seattle, Washington has had an aggressive program of installing traffic circles for residential traffic control for many years, installing circles at over 200 locations. (Ref. 1) Their experience indicates that traffic circles are very effective in reducing high vehicle speeds, but do not necessarily reduce traffic volumes. Moreover, Seattle experienced a dramatic reduction in the number and severity of accidents in the vicinity of these traffic circles. In addition, almost all traffic circle locations were readily accepted by the local community and citizens perceived that their neighborhood street was quieter and safer with the circle even though they did not accomplish their original goal which was to reduce traffic volumes. The NTMP traffic circle installation program is based largely on the Seattle program.

Traffic circles are commonly used in European countries, particularly Great Britain, as a traffic control measure at major intersections instead of four-way stop control or traffic signals. (Ref. 2) The experience of these countries is that traffic circles can be used very successfully in these circumstances and relatively high levels of service and capacities can be achieved. As in Seattle, dramatic reductions in accidents accompanied the installation of traffic circles.

Given the positive experience with traffic circles in Seattle and Europe, this study was initiated by the City of Portland to better understand how their NTMP program of installing traffic circle affects both speed and safety characteristics on neighborhood streets. Kittelson & Associates, Inc. (KAI) was retained by the City to assist in defining a technical approach for evaluating the effects of traffic circles on speed and safety characteristics. Further, KAI conducted a peer review of the NTMP traffic circle locations by analyzing speed data collected by the City, assessing the changes in accidents accompanying the installation of traffic circles, and conducting an overall safety review of the traffic circles locations under both day time and night time traffic conditions. This report details the findings and recommendations of this peer review.

UNDERSTANDING OF THE PROBLEM

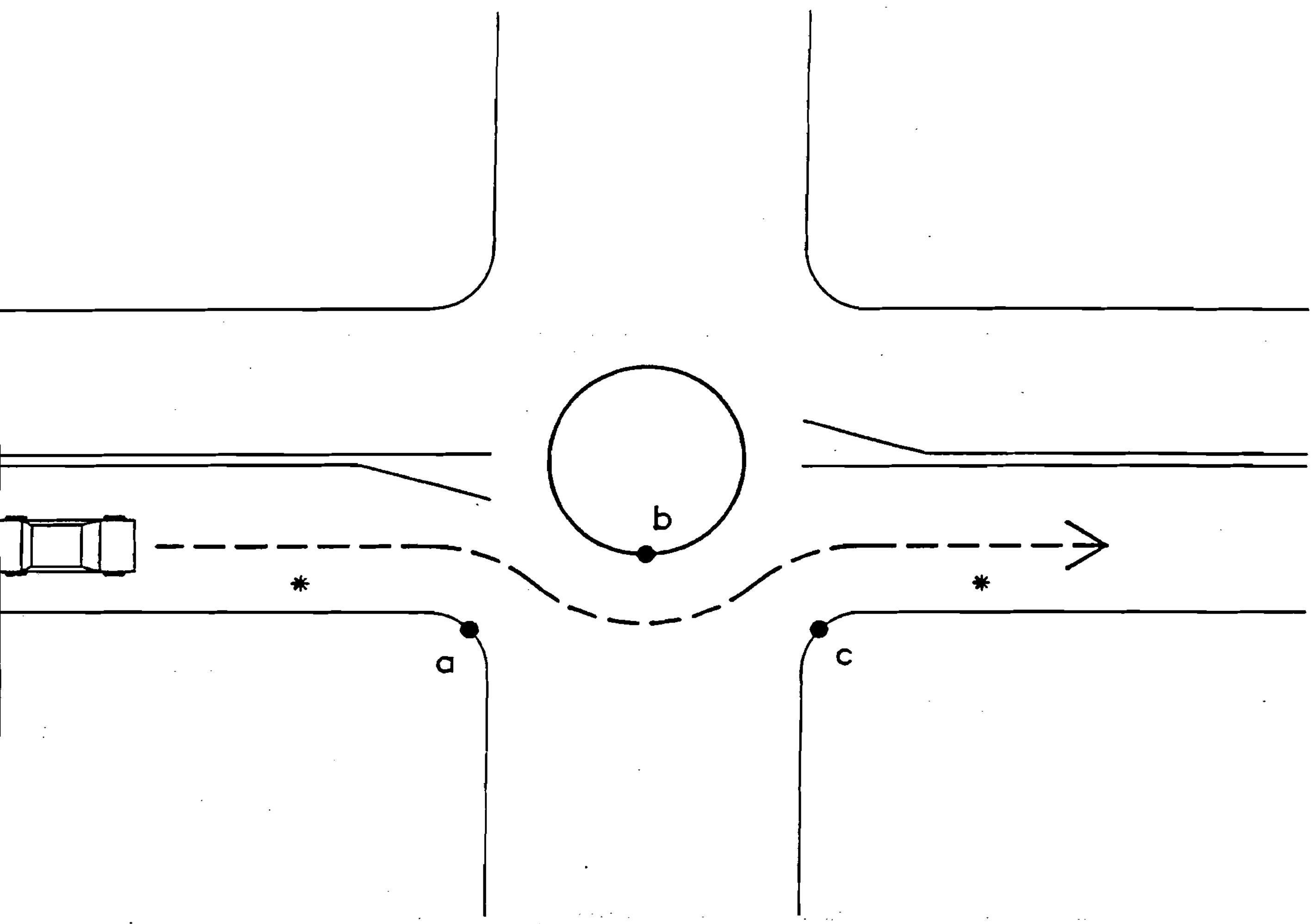
Traffic Circle Effects on Speed

Traffic circles are usually installed for the purpose of reducing speed. However, from a neighborhood perspective, speed is a broadly defined term that can have many connotations. For example, residents are probably not as concerned about the speed of all vehicles, but focus on those vehicles traveling above a certain threshold speed. Additionally, they are probably more concerned about vehicle speeds along their street, including mid-block speed characteristics, than simply a single spot speed at the specific location where the traffic circle may be installed. By their design, traffic circles affect speed by forcing a through vehicle to change its travel path to go around the circular island (See Figure 1). As drivers go around this island, they will slow their speed to limit lateral acceleration and side forces that he experiences. (Lateral acceleration equals (velocity*velocity)/path radius.) Traffic circle design (i.e. island radius), therefore, can play a significant role in how speeds are affected.

However, because there is a wide range of vehicles that a traffic circle must accommodate, it may be possible for astute drivers to reduce their lateral acceleration by adjusting their vehicle path to be as straight as possible as they travel around the circle. This can be done by moving the vehicle to the right, particularly on wide streets with parking, but no parked vehicle present. Also, many high performance sports cars are designed to accommodate small sharp turns and have better suspension systems to limit the lateral acceleration forces the driver experiences.

It is our hypothesis that traffic circles will affect the speeds of most vehicles. Traffic circles should at least limit the number of vehicles traveling at ***relatively high*** speeds, while having little or no effect on lower speed vehicles. As a result, traffic circles should also reduce the range of speeds as well as the variance in vehicle speeds. The effectiveness of a traffic circle in lowering speeds should diminish as a vehicle's distance from the circle increases. However, if a street contains a series of traffic circles, drivers will have little incentive to increase their speeds significantly higher than the speed needed to comfortably negotiate around the circle. If drivers choose to ignore this, they will accelerate as they travel away from the first traffic circle, only to have to significantly decelerate to negotiate around the next circle.

Other site specific or extraneous factors could influence the effectiveness of traffic circles in reducing speeds. For example, vehicle speeds could vary significantly by the time of day. Vehicles during peak commuting hours may be very reluctant to reduce their speeds because of the perceived urgency of their trip. Also, these drivers would typically travel the street daily and are likely to accumulate a great deal of experience negotiating the traffic circle. Drivers during other times of the day or those who are unfamiliar with the area may be more careful driving around a traffic circle and they may tend to significantly reduce their speeds. In addition, there are many environmental situations, such as poor weather, during which all drivers will limit their speeds. Consequently, in these situations traffic circles will have little impact vehicle speeds.



* Path is significantly affected by presence of parked vehicle at these locations.

Note: Points a, b, & c, in relation to roadway centerline, define the vehicle movement around a traffic circle.

TYPICAL VEHICLE PATH THROUGH TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW

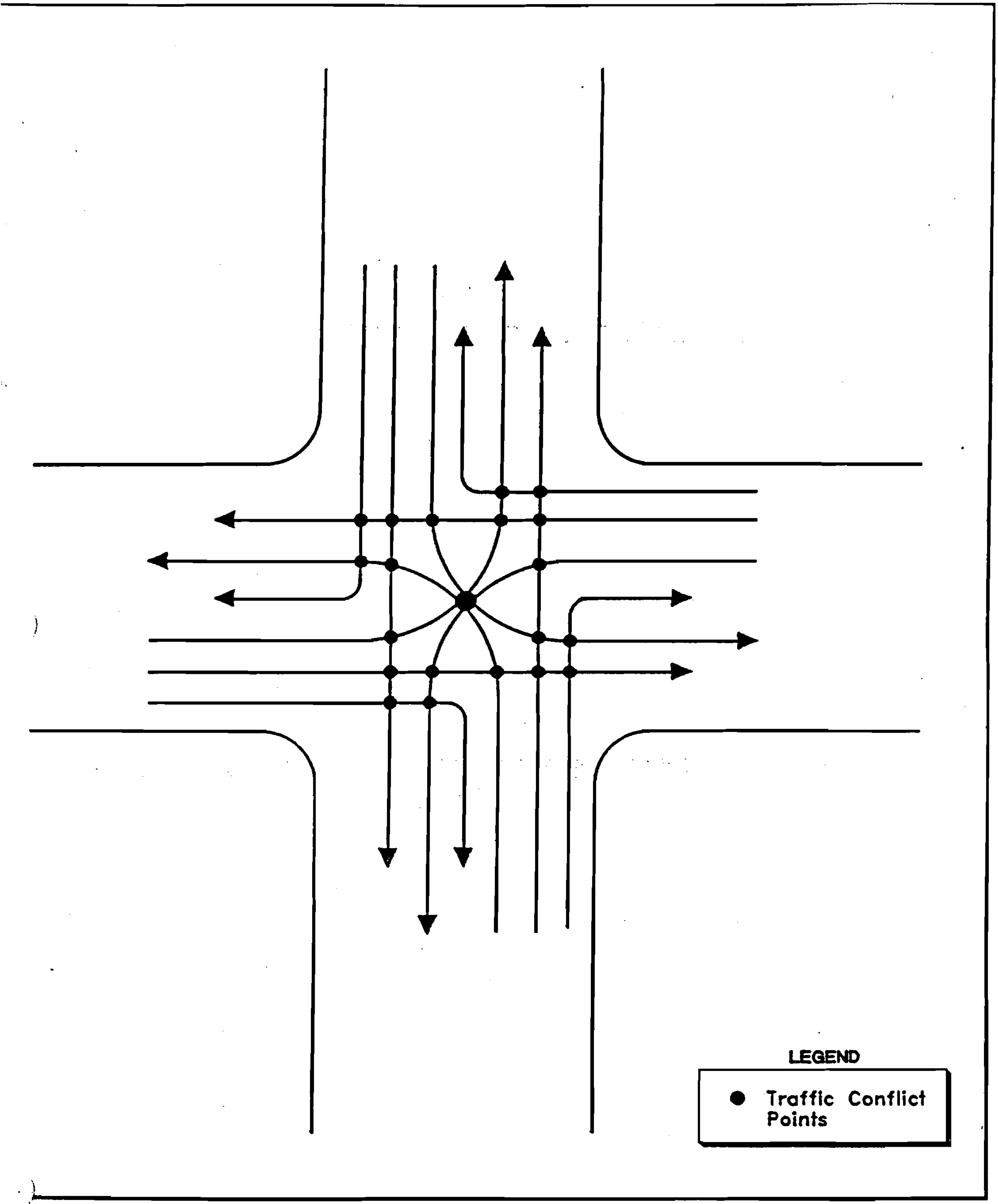
October 1991

Figure 1

Traffic Circle Effects on Safety

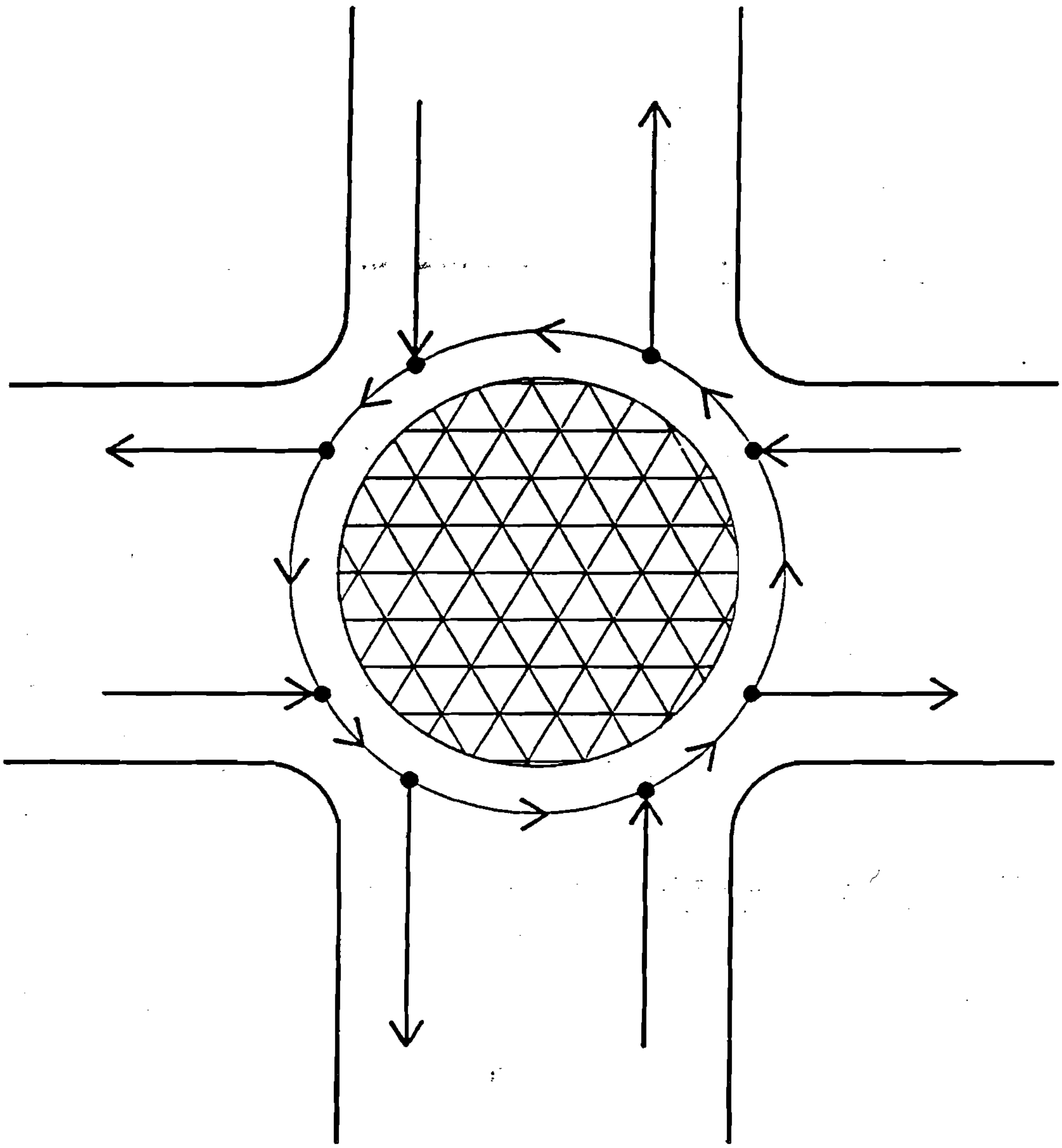
As detailed earlier, a review of the existing literature reveals that traffic circles have dramatically reduced the number of accidents and their severity. The basic principle may lie in the fact that a traffic circle reduces the number of vehicle conflict points at an intersection. As shown in Figure 2a, a typical four way intersection has at least 21 conflicting traffic movements. In contrast, Figure 2b shows that there are only 8 conflicting traffic flows with a traffic circle. In addition, with a typical 4-legged intersection, there may be some problems with minor street traffic not giving the right-of-way to main street traffic. Although minor street traffic should yield to main street vehicles, they may try to cut in front of main street vehicles or misjudge gaps in main street traffic. With a traffic circle, the special nature of this island may elicit additional caution on the part of minor street traffic. Also, because of the curved route of main street traffic around the traffic circle, minor street traffic will stop further back from the intersection and has to carefully consider their decision to proceed.

Thus, based on above, traffic circles appear to address many of the hazards that may lead to multiple vehicle crashes. However, by their very nature, a traffic circle may represent a fixed object hazard and measures should be taken to make the circle island visible and "forgiving" if it is struck by a vehicle. The tradeoff in installing traffic circles may be a reduction in multiple vehicle crashes that may often result in injuries against an increase single vehicle fixed object crashes that may not be so severe. To address any safety problems that traffic circles may represent the City of Portland has taken several actions. First, they install advance traffic circle warning signs that also typically include a travel speed. In addition, for each approach, standard "three arrow" regulatory traffic circle signs are installed on the circle itself. To improve the traffic circle's conspicuity, reflective markers are placed along the circumference of the circle island and vegetation is planted in the middle of the island. This vegetation varies from low shrubbery to 6-8 foot trees.



TRAFFIC CONFLICT POINTS AT TYPICAL 4-LEG INTERSECTION

TRAFFIC CIRCLE PEER REVIEW	Figure 2A
October 1991	



LEGEND

● Traffic Conflict Points

TRAFFIC CONFLICT POINTS
AT A TYPICAL TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure 2B
October 1991	

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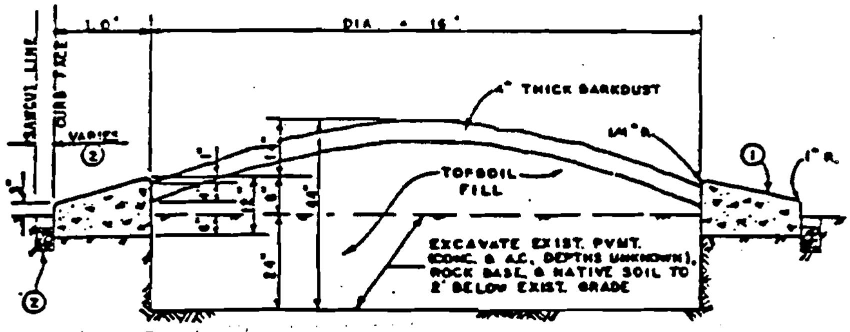
It should also be noted that, as shown in Figure 3, two general types of traffic circle islands were constructed. The older type is a simple raised circular island. The new typ of island consists of a slightly larger circular outer island "lip" with an additional concentric ring/curb. This new design also makes the middle of the island higher than the older design. The City's experience with these older islands indicated that some drivers were not turning sharp enough and their vehicle's tires would rub against the island. The purpose of this newer design is to make the island more conspicuous and make it more difficult for an errant vehicle to mount the traffic circle island. Instead, the larger initial curb/lip of the newer design should help drivers recognize the outer edge of the circle. Furthermore, if the curb of the traffic circle is struck by a vehicle, the newer design should be better at redirecting the vehicle along its path and way from the center of the island.

Like speed characteristics, there may be other site specific or environmental factors that play a role in determining how traffic circles affect safety and accidents.

OLDER SMALLER DIAMETER DESIGN



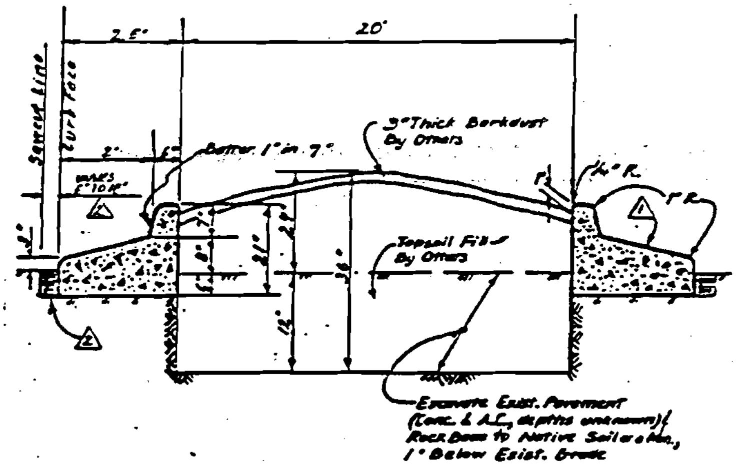
① CURB TO BE CONSTRUCTED OF 4000 LB., 2"- 4" SLUMP CONCRETE.

② SAWCUT EXISTING PAVEMENT (DEPTH UNKNOWN) AS CLOSE TO NEW CURB LINE AS PRACTICAL. PAVE SPACE BETWEEN SAWCUT & NEW CURBING WITH 3" CL. "C" ASPHALT CONC. PVMT., ON A 6" AGGREGATE BASE (1'-0).

TYPICAL SECTION & CURB DETAIL

(NOT TO SCALE)

NEWEST LARGER DIAMETER DESIGN



⚠1 Curb to be Constructed of 3000 LB., 2"-4" Slump Concrete. See Concrete Island Curb Finish Detail, Sheet 5 of 7

⚠2 Sawcut Existing Pavement (Depth Unknown) as Close to New Curb Line as Practical. Pave Space Between Sawcut and New Curbing with 6" Cl. "C" Asphalt Conc. Pvmt.

TYPICAL ISLAND SECTION

NOT TO SCALE

COMPARISON OF TRAFFIC CIRCLE DESIGNS

TRAFFIC CIRCLE PEER REVIEW	Figure 3
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OLDNEW

PEER REVIEW METHODOLOGY

Several meetings were held with NTMP staff to define the role and scope of this peer review evaluation. The following tasks were conducted as part of this peer review for evaluating the effect of the NTMP traffic circles on vehicle speed and traffic safety:

1. Develop a method to evaluate how vehicles travel around traffic circles and determine if these speed profiles vary by any key traffic circle design elements.

2. Analyze changes in mid-block vehicle speed data that were collected before and after traffic circles were installed and determine if these changes differ by any key traffic circle design elements.

3. Analyze changes in the number and severity of accidents that occurred after the installation of traffic circles.

4. Observe traffic at each of the traffic circle sites under day time and night time conditions and assess their operational, visibility, and safety characteristics.

The City of Portland provided KAI with the specific design characteristics and installation dates for all of the traffic circles.

Speed Profile Study

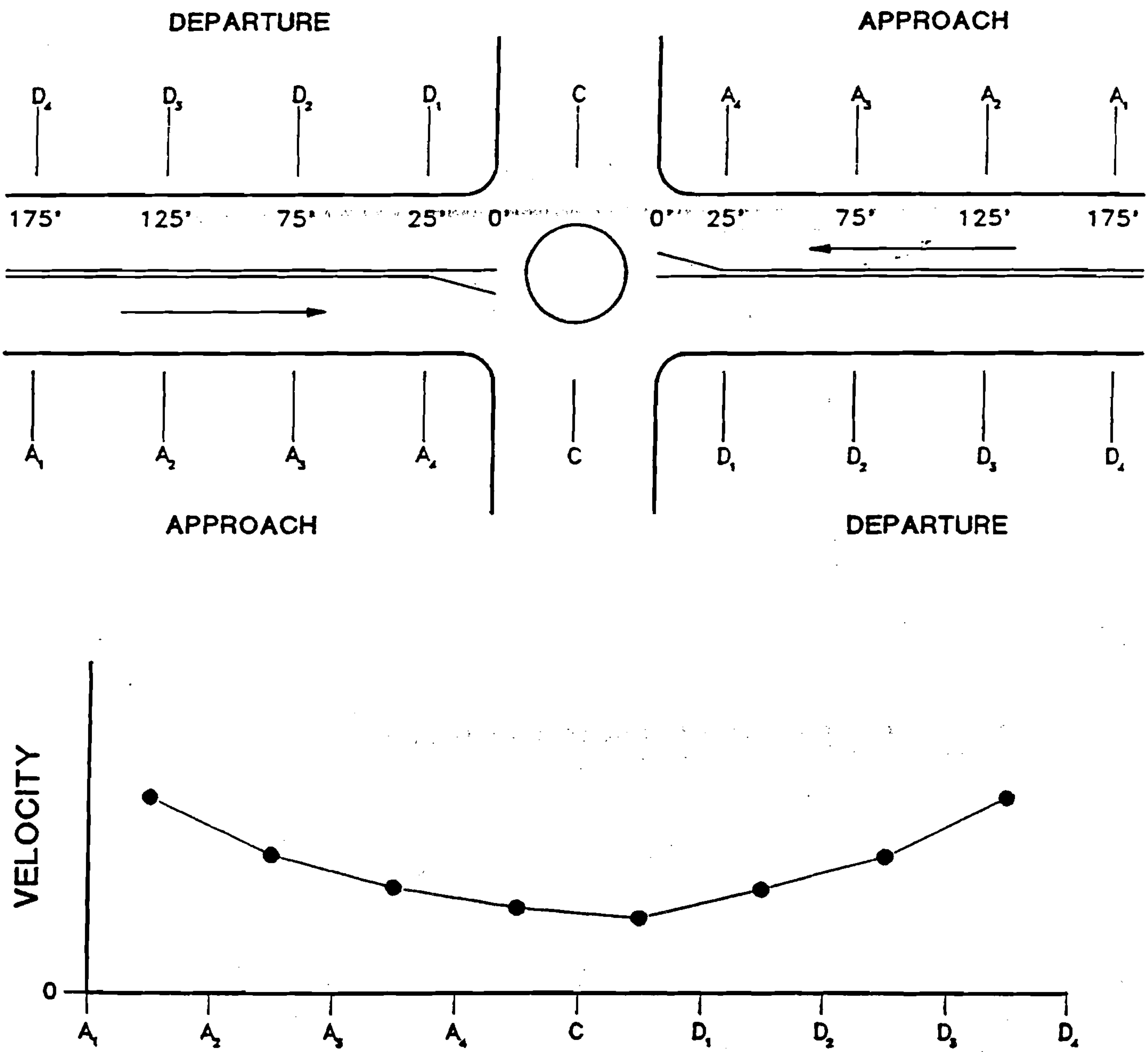
Traffic circles have an effect on vehicle movement over distance that is not constant. A vehicle negotiating a traffic circle is in a continual and dynamic process of either decelerating or accelerating. For this reason, it is appropriate that speed characteristics be evaluated in terms of a speed profile. Speed profile data provide a graphical depiction of speed characteristic for vehicles approaching and departing traffic circles (See Figure 4). This speed profile data will allow for evaluation of a circle's effect on vehicle speed over a range of locations along the roadway in relation to the circle itself. The traffic observation and data reduction for this task were performed by City of Portland staff at 16 different intersections shown in Table 1.

As shown on Figure 4, the speed profile data was collected by dividing the approach and departure to a traffic circle into eight segments of approximately 50 feet in length. By way of a series of flash boxes or mirrors set up at the nine points defining the eight segments, data collection personnel used a lap top computer to record the time it took a vehicle to traverse each segment.

Angled mirror "flash" boxes were used to indicate that a vehicle had passed a specific point. The primary component of a flash box is a reflecting device (i.e., a mirror). As a vehicle passes the device, it creates a flashing image on the mirror that can be seen for some distance. These devices and procedures have been used for many years to conduct simple speed studies. Tests were conducted with City of Portland staff to confirm the validity of this method.

Table 1: Intersections Where Speed Profile Data Were Collected.

Main Street	Side Street	Circle Radius (ft)	Direction	Approaching			Departing		
				Date	Start Time	# of Vehicles Observed	Date	Start Time	# of Vehicles Observed
NE 21st Ave	Brazee St	14	SB	5/9/91	7:51am	99	5/8/91	1:00pm	93
NE 21st Ave	Thompson St	12.5	SB	5/13/91	12:40pm	100	4/25/91	8:07am	99
NE 24th Ave	Thompson St	12	SB	4/23/91	7:51am	42	5/21/91	8:55am	65
NE 24th Ave	Tillamook St	12	NB	5/30/91	8:36am	63	6/21/91	8:19am	100
Clinton St	SE 23rd Ave	10	WB	6/17/91	7:58am	98	6/11/91	8:32am	100
Clinton St	SE 31st Ave	11	WB	6/12/91	7:52am	57	6/18/91	7:44am	100
Clinton St	SE 45th Ave	8	WB	7/3/91	8:41am	92	7/1/91	8:35am	50
Clinton St	SE 47th Ave	11	EB	7/5/91	8:02am	100	6/26/91	8:53am	100
SE 30th St	Caruthers St	7.5	SB	7/10/91	9:06am	61	7/8/91	8:04am	99
Harrison St	SE 37th Ave	12	EB	6/10/91	8:42am	60	6/19/91	8:07am	59
Lincoln St	SE 43rd Ave	7	EB	6/7/91	11:10am	98	6/6/91	7:53am	76
Lincoln St	SE 51st Ave	11	EB	5/14/91	7:31am	76	5/1/91	1:34pm	66
Lincoln St	SE 55th Ave	6.5	WB	6/13/91	9:32am	97	6/12/91	12:51pm	99
Lincoln St	SE 58th Ave	6	EB	6/4/91	8:31am	100	7/11/91	8:56am	100



SAMPLE TRAFFIC CIRCLE SPEED PROFILE CHARACTERISTICS

TRAFFIC CIRCLE PEER REVIEW	Figure 4
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398FIG3

This data collection method did have some limitations. First, to set up the flash boxes and verify its operation took considerable time. As a result, most of the vehicles that were observed were during the late a.m. peak to mid-day hours. The drivers of these vehicles would typically not be pressed for time as peak hour commuters would be. Second, the data was limited to isolated vehicles. If any other vehicles were in the area of the flash boxes, it was difficult to distinguish which flashes were caused by the subject vehicles versus the flashes caused by the second vehicle. The data collectors estimated that they could only collect speed profiles for 50 percent of the vehicles that traveled through a traffic circle. Finally, it should be realized that only one side (either the approach or departing) side of the traffic circle could be observed at a given time. Thus, the vehicles that defined the speed profile for the approach direction were not necessarily the same vehicles that defined the departure speed profile. This should have little effect on the results of these speed studies because these observation were typically taken on consecutive days and at approximately the same time so that to a large extent the same vehicles were observed.

One characteristic that may play a significant role in vehicle movement through a traffic circle is the presence of parked vehicles within the traffic circle maneuvering area. Most of the streets involved in this study were wide enough to permit on-street parking. If a parked vehicle was present, it would force an approach vehicle to travel in the center of its lane and then travel a circular path around the circle. To accomplish this, a vehicle would be forced to slow down to the design speed of the traffic circle. However, if a parked vehicle was not present, an approaching vehicle could move to the right of the street and attempt to travel a less curved, if not straight, path around the circle. If this was the case, a vehicle may not have to slow down much to negotiate through the traffic circle. A similar situation occurs when there is a vehicle parked on the far side (departure side) of the traffic circle. If a parked vehicle is on the far side of the circle, the through vehicle is forced to travel a complete circular path around the traffic circle. If there was not a parked vehicle on the far side, a through vehicle can travel away from the traffic circle in a straight path and start its acceleration. The presence of parked vehicles was noted during this data collection, but it was difficult to segregate this phenomena from the data.

Mid-Block Speed Study

As part of the NTMP, midblock speed data are sometimes collected to identify if, in fact, a speeding problem exists on a particular street. In addition, if the mid-block speeds were initially taken, these measurement are collected at or near the same location again after the traffic circle is installed. Table 2a shows the intersections for which this data was available. KAI's peer review examined changes in vehicle speeds between these two measurements. In some cases, the "after" speed measurements were taken specifically for this peer review evaluation. Table 2b shows which intersections were involved in this special study. Mid-block speed data are not available for all the intersections where traffic circles were installed, but almost all the corridors are represented in this data. As mentioned previously, traffic circles were often installed as a series, but the corridor was identified as a high speed corridor by observing speeds at only one location. This data were collected by mechanical devices via tubes that were typically placed 100-250 feet from an intersection. These data were summarized into speed categories (e.g. 29-32 mph, 33-36 mph, 37-40 mph, etc.) and by hour.

From this data KAI was able to compute several measures including the average speed, the distribution of vehicles exceeding a particular speed, and a percentile speed which few vehicles exceed. As discussed earlier, traffic circles should have little effect on slower vehicles because they can maintain this lower speed regardless of the installation of the traffic circle. Consequently, a change in the average speed along a street actually reflects a reduction in the number of relatively fast vehicles. As a result, although the average speed will be reduced, this measure does not communicate the nature of changes in vehicle speeds that occur after a traffic circle is installed. The main focus of this analysis was the change in the distribution of vehicle speeds, in particular the 85th percentile speed of vehicles along the street by time of day (a.m. peak, mid-day, p.m. peak, and night time). Figure 5 shows ~~a hypothetical cumulative~~ distribution of vehicle speeds that are likely to occur with and without a traffic circle. For a given speed (x axis), the lines in this figure show the percent of vehicles that were traveling at this velocity or slower (y axis). After the circle is installed, the distribution of vehicle speeds should shift to lower values (to the left on Figure 5). In addition, the variability in vehicle speeds, which is indicated by the length of the lines in Figure 5, will decrease. To simplify comparisons of changes in the distribution of vehicle speed that occurred with the installation of traffic circles, differences in the 85th percentile speed (speed which only 15 percent of drivers exceed) will be examined in detail. This percentile measures the higher portion of the vehicle speed distribution and has traditionally been used by traffic engineers to set speed limits and/or represent the unusual driver.

Finally, as a byproduct of this data collection, KAI was also able to estimate average daily traffic (ADT) volumes, although these volumes can vary significantly by day of week and time of year. These ADT volumes were compared to determine if traffic may have diverted once a traffic circle was installed.

Table 2a: Intersections Where Mid-Block Speed Data Were Available Both Before and After Traffic Circles Were Installed.

Main Street	Side Street	Circle Radius	Direction	Installation Date
Raleigh St	NW 27th Ave	12	E-W	9/88
Multnomah St	Imperial Ave	16	E-W	10/87
NE 37th Ave	Thompson St	7	N-S	10/87
Holman St	NE 41st Ave	9	E-W	10/88
Lincoln St	SE 58th Ave	6	E-W	6/90
NE 47th Ave	Brazee St	12	N-S	9/90
NE 37th Ave	Brazee St	9	N-S	10/87
NE 24th Ave	Tillamook St	12	N-S	10/89
NE 24th Ave	Thompson St	12	N-S	10/89
NE 21st Ave	Brazee St	14	N-S	10/89
NE 21st Ave	Thompson St	12.5	N-S	10/89
NE 24th Ave	Brazee St	12	N-S	10/89

Table 2b: Intersections Where Mid-Block Speed Data Were Available Only After Traffic Circles Were Installed.

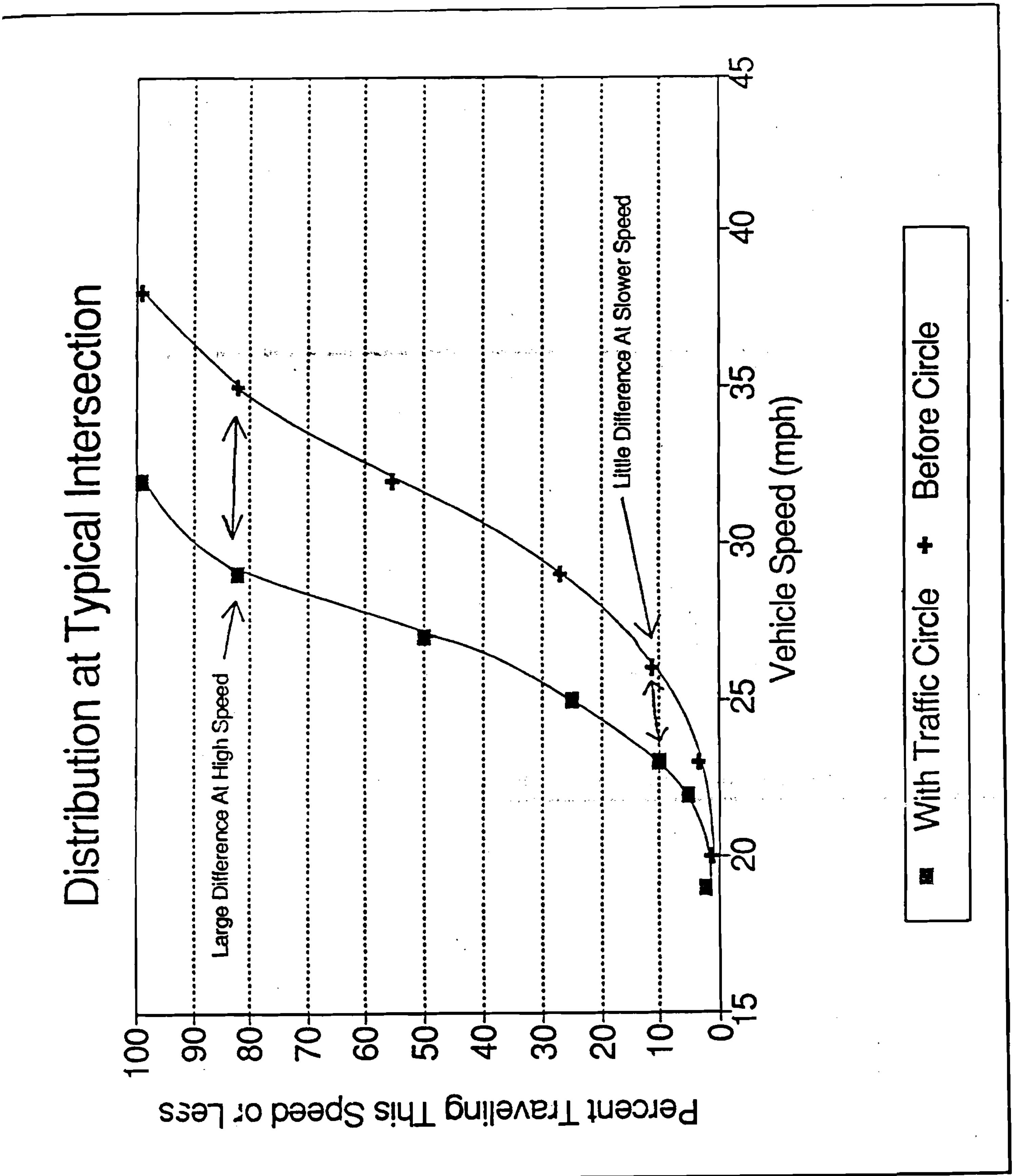
Main Street	Side Street	Circle Radius	Direction	Installation Date
NW 25th Ave	Northrup St	--[1]	N-S	--
NW 25th Ave	Overton St	10	N-S	9/88
NW 25th Ave	Quimby St	11.5	N-S	9/88
Lincoln St	SE 48th Ave	--[2]	E-W	--
Lincoln St	SE 54th Ave	--[3]	E-W	--
Lincoln St	SE 58th Ave	6	E-W	6/90
Clinton St	SE 43rd Ave	--[4]	E-W	--
Clinton St	SE 47th Ave	11	E-W	6/90

[1] - Between traffic circles at 25th Ave/Marshall St (12' radius) and 25th Ave/Overton St.

[2] - Between traffic circles at Lincoln St/43rd Ave (7' radius) and Lincoln St/51st Ave (11' radius).

[3] - Between traffic circles at Lincoln St/51st Ave and Lincoln St/55th Ave (6.5' radius).

[4] - Near traffic circle at Clinton St/45th Ave (8' radius).



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS AT TYPICAL INTERSECTION WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure 5
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398FIG5

Accident Trends

Since most traffic circles in the City of Portland have been constructed within the last four years, the City's recently computerized database of reported accidents from the Oregon Department of Motor Vehicles was used to assess the effect of traffic circles. Specific information on reported accidents was obtained for a three year period before circle construction and for the full time period since construction. At some locations, the City of Portland conducted a preliminary test of neighborhood acceptance of traffic circles by constructing a temporary island with barrels. The few accidents that may have occurred during this period were not part of this peer review evaluation. These accident summaries contained the accident type, location, time of day, and severity, as well as several other characteristics. Because any one intersection will not have a large number of accidents, the intersections were grouped into corridors such as along N.E. 21st Avenue or along S.E. Lincoln Street.

It should be noted that this analysis is confined to only reported accidents, typically $400 or more property damage or an injury. However, there may be a number of accidents that go unreported either because they do not meet these criteria or because the persons involved chose not to comply with Oregon law. KAI cannot estimate the number of accidents that go unreported. However, KAI's analysis did attempt to control or account for fluctuations in accident trends or other extraneous events that may have occurred in the vicinity of these traffic circles which would include changes in how or if people report accidents. This was done by also assessing accident trends at comparable intersections that were located near the ones where traffic circles were installed, but these "control" intersections remained unchanged during the entire study period. Most of these control intersections were just prior to or adjacent to the intersection with a traffic circle. Consequently, if there were significant factors that affected the accident trends in the corridors with traffic circles, then these same factors would affect these control locations.

For example, if a nearby construction project forced traffic into a corridor with traffic circles, there is a chance that accidents might increase due to these additional vehicles. However, these additional vehicles would also travel through the control intersections and they will also experience this increased accident risk. By analyzing the change in accidents at the locations with traffic circles as well as at these nearby control locations, KAI's analysis will then account for the effect of extraneous factors that might influence accident trends such as changes in patterns of the under reporting, unusual weather, etc. However, there is no way that this analysis can account completely account for all unreported accidents that may have occurred before or after traffic circles were installed.

Intersection Observations

KAI engineers visited each of the traffic circles and observed traffic operations under both daytime and nighttime conditions. Most the corridors with several traffic circles were actually observed for several hours. During these visits, general assessments were made of regarding the traffic operation might be influenced by the circle's location, design (e.g. radius), visibility, and safety characteristics. After an initial set of observations, several of the problematic circles were revisited at night with an illumination engineer from the firm of R&W Engineering, Inc. to take specific light measurements and discuss potential improvements to circle visibility. A final set of nighttime visits to several of these problematic circles was made with KAI engineers, the illumination engineer, and City staff to review the findings and recommendations made from the earlier visits. It should be noted that during all of these visits the primary focus was the perception and visibility of traffic circles for main street traffic. Some observations were made from the side street, but this was not done on a systematic basis because most of these streets are lightly traveled and are stop controlled at the traffic circle.

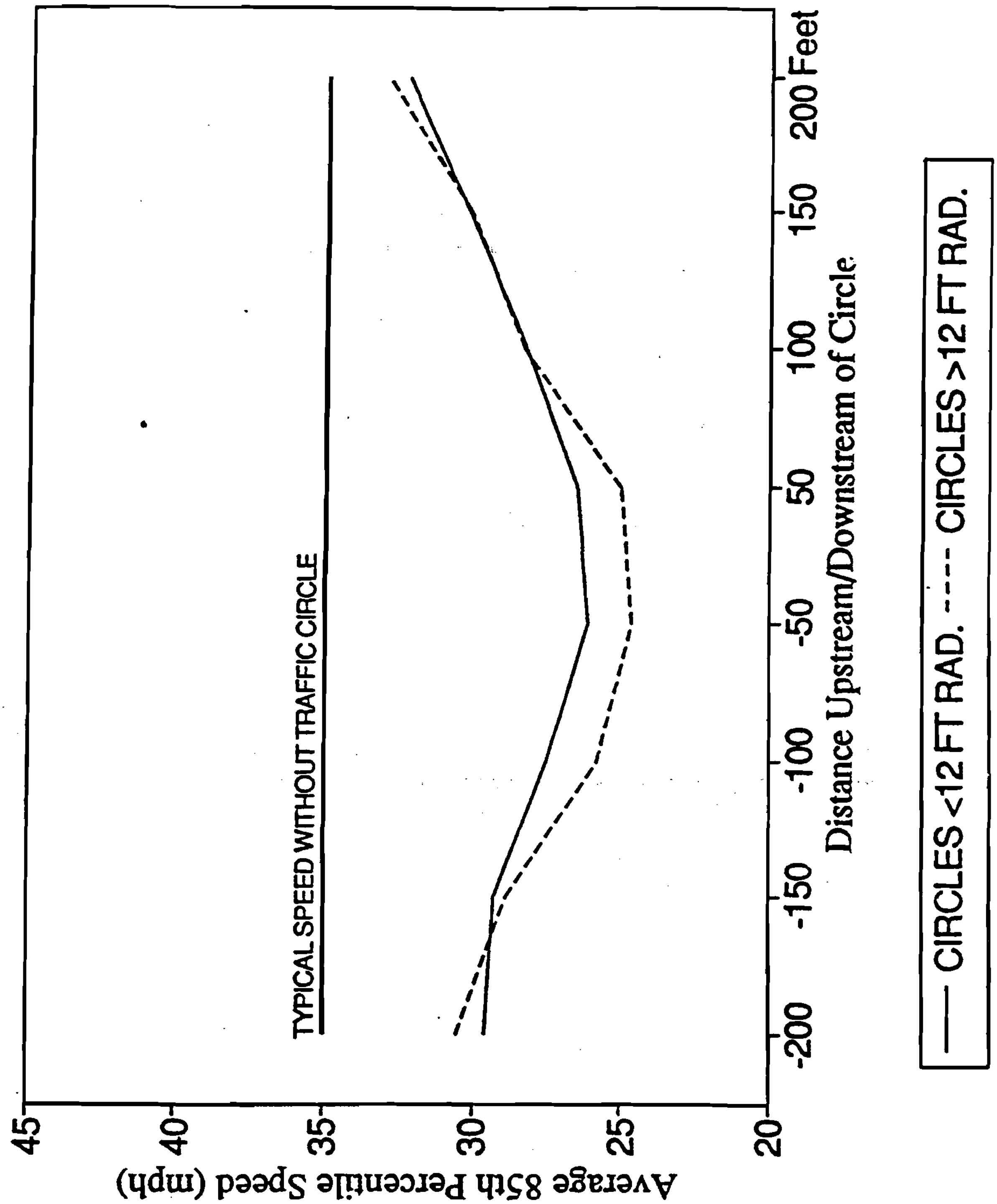
RESULTS AND FINDINGS

This section presents the results and findings for each of the tasks that were performed for this peer review. Each of these tasks are further categorized by issues that were addressed or individual task components.

Effect on Vehicle Speeds

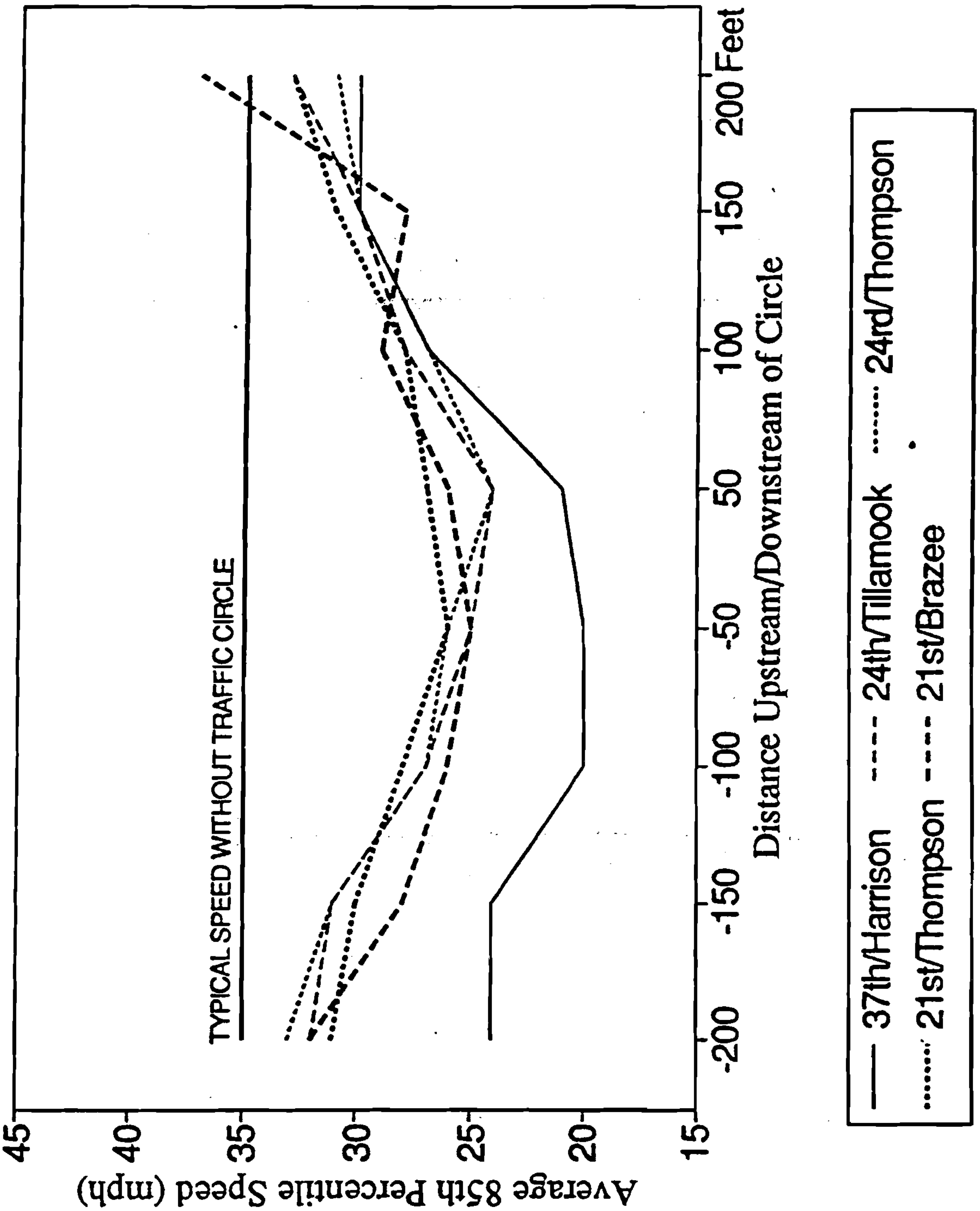
As detailed earlier, two sets of vehicle speed data were obtained by the City of Portland for this peer review effort. The first set of speed data is individual vehicle speed profiles collected for vehicles traveling around a specific traffic circle. The second data set consists of midblock speeds that were collected at a group of intersections both before and after traffic circles were installed. Traffic circles will limit the speeds vehicles can travel and thus will primarily affect faster vehicles. To evaluate the effect of installing these circles the key measures of effectiveness analyzed were the effect of traffic circles on the distribution of vehicle speeds, in particular reductions in the number of relatively fast vehicles. A detailed analysis of changes in the 85th percentile speed values was also performed. This percentile is the speed at which only 15 percent of drivers will exceed and has traditionally been used by traffic engineers to set speed limits and/or represent the unusual driver. Additional analyses were conducted to determine if specific intersection or traffic circle characteristics influenced these results.

Traffic Circle Speed Profiles: Figure 6 presents the results of the speed profile data categorized by traffic circle radius. Without the traffic circles, the 85th percentile speeds would be about 35 mph as shown on this figure. The trend lines in this figure show that at the extreme upstream and downstream points the average 85th percentile speeds appear to be similar regardless of traffic circle size. However, as vehicles go through the traffic circle the 85th percentile speed was approximately 3 mph lower at wider circles. This indicates that the larger radius circles force vehicles to travel at lower speeds, but that this effect dissipates once the vehicle is 200 feet or more away from the traffic circle. Figure 7 presents the individual traffic circle speed profiles where the circle radius was approximately 12 feet. Most of these speed profiles are very similar. Figures 8 and 9 present the speed profiles for smaller traffic circles. In contrast to the results in Figure 7, these profiles vary substantially. About half of these traffic circles had significantly lower 85th percentile speeds along their approach (below 30 mph) than at the larger traffic circles. Based on these profiles, it appears that larger traffic circles are more effective at consistently reducing the 85th percentile speed. Since the width of the vehicle path around a traffic circle is about the same regardless of the size of the circle, the larger the radius the slower vehicles will have to travel around the circle. By traveling slower around the circle, drivers limit their lateral acceleration.



OVERALL SPEED PROFILES BY SIZE OF TRAFFIC CIRCLE

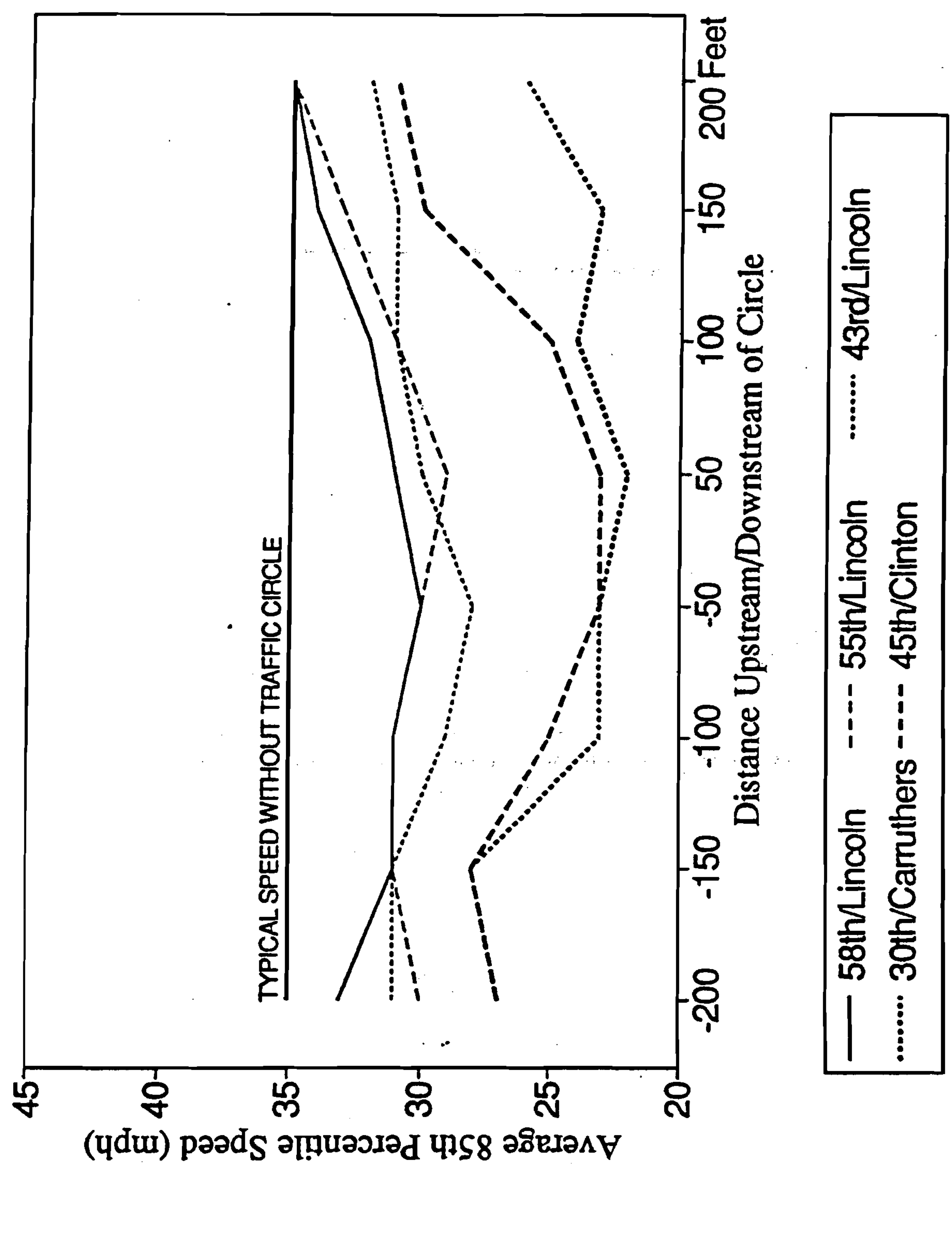
TRAFFIC CIRCLE PEER REVIEW	Figure 6
October 1991	



SPEED PROFILES AT TRAFFIC CIRCLES BY SIZE (GREATER THAN 12 FT RADIUS)

TRAFFIC CIRCLE PEER REVIEW	Figure 7
October 1991	

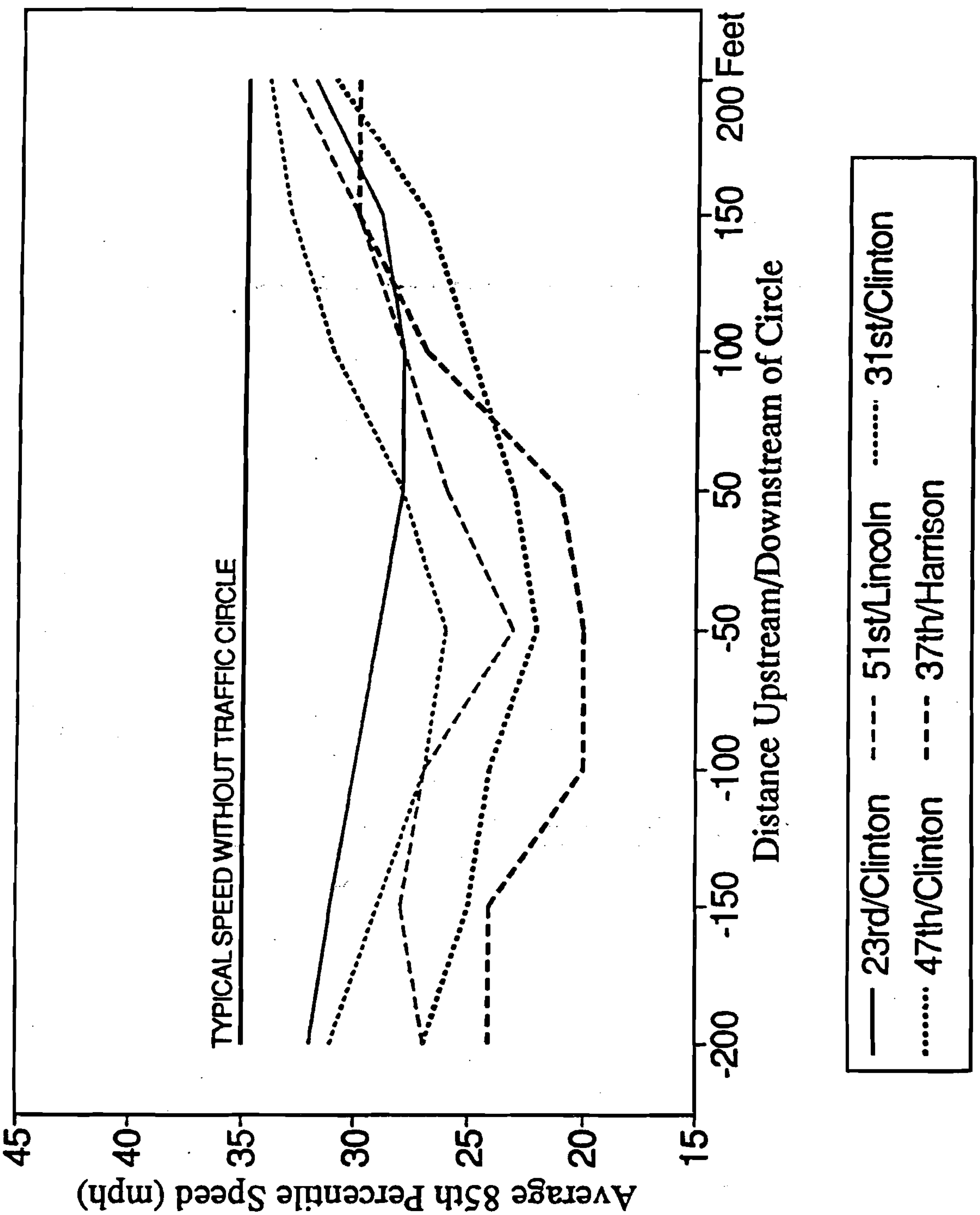
SPROF1



SPEED PROFILES AT TRAFFIC CIRCLES BY SIZE (LESS THAN 12 FT RADIUS - #1)

TRAFFIC CIRCLE PEER REVIEW	Figure 8	
October 1991		

SPROF2



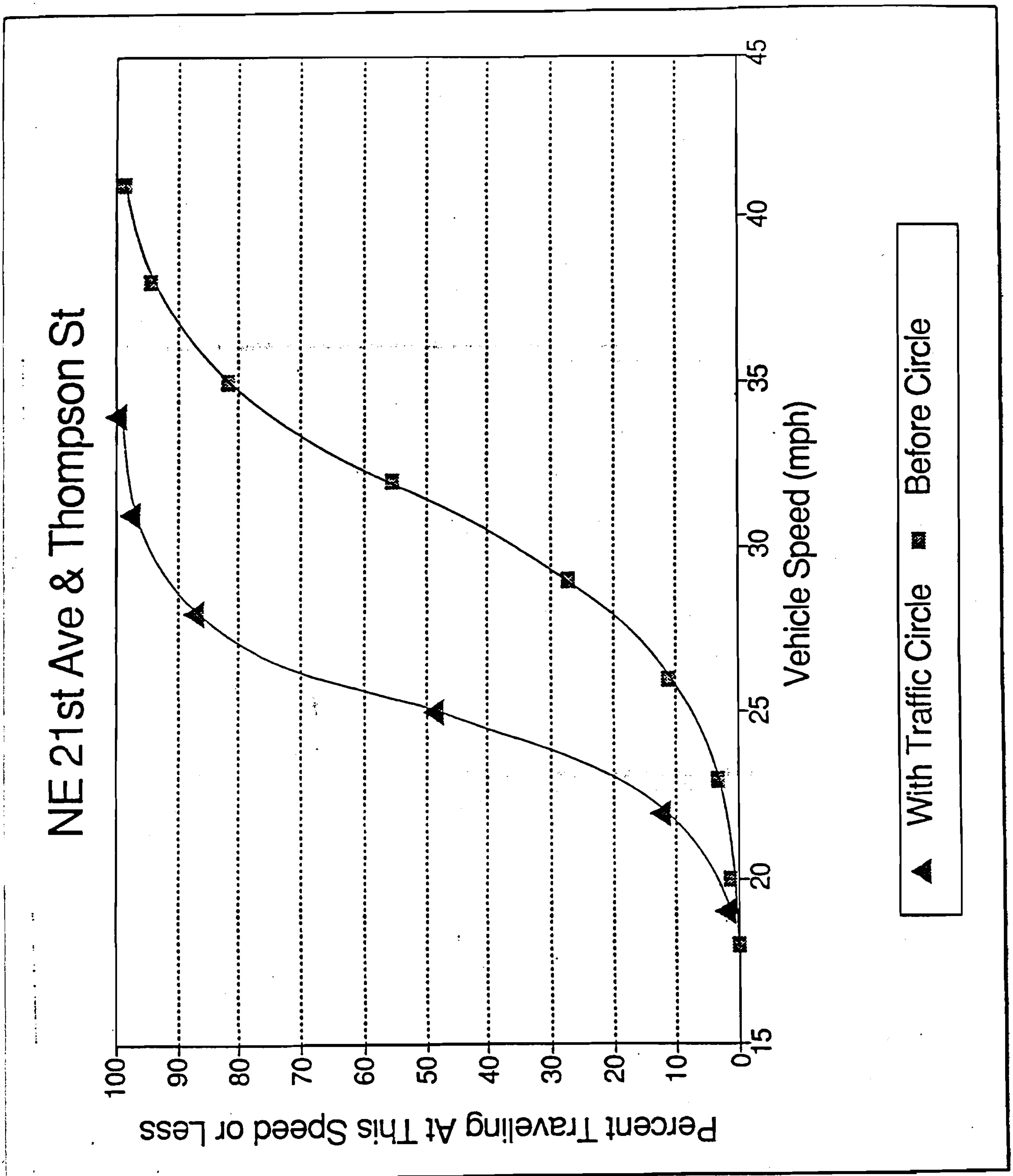
SPEED PROFILES AT TRAFFIC CIRCLES
BY SIZE (LESS THAN 12 FT RADIUS - #2)

TRAFFIC CIRCLE PEER REVIEW	Figure 9
October 1991	

SPROF2A

Mid-Block Vehicle Speeds: Figure 10 shows the change in the cumulative distribution of mid-block vehicle speeds with and without a traffic circle along the NE 21st Avenue corridor. This plot was chosen as being representative of the general results of this analysis. One of these comparisons were made for each of the traffic circle corridors studied and are included in Appendix A. The results in this figure clearly show that after the circle was installed the distribution of mid-block vehicle speeds shifted significantly to the left indicating that speeds have been reduced. For example, without the traffic circle about 60 percent of vehicles were traveling 33 mph or less along this corridor. After the traffic circle was installed, 60 percent of the vehicle were traveling at 28 miles or less. Notably, the difference in the two distributions at the lower speeds, such as 25 mph, is less than at higher speeds, such as 35 mph. This is consistent with our assumption that traffic circles will have a larger impact on faster vehicles. Finally, it should be noted that, as indicated by the length and slope of the lines in this figure as well as those included in Appendix A, the majority of vehicle speeds occur in a much smaller range after a traffic circle is installed. Vehicles traveling along this corridor have more uniform speeds after the circle is installed. From analysis of specific data at study intersections, the variance in mid-block speeds decreased at least 20 percent after a traffic circle was installed. A reduction in the variability of vehicle speeds is generally considered by traffic engineers as beneficial for traffic operations and safety.

Another way to view this same result is shown in Figure 11. The bars in this figure show the percent of vehicles traveling in a specific range of speeds with and without traffic circles. These comparisons can also directly answer the question of what percentage of vehicles are traveling at a particular speed and how the traffic circle has changed the pattern of mid-block speeds. Again, the results shown in Figure 11 are along the NE 21st Avenue corridor and the graphs for the other corridors are in Appendix A. The trends of the bars in Figure 11 show that without a traffic circle, over 50 percent of vehicles were traveling 31-35 mph and an additional 4 percent were traveling at higher speeds.



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. 21ST AVE. & THOMPSON ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure 10
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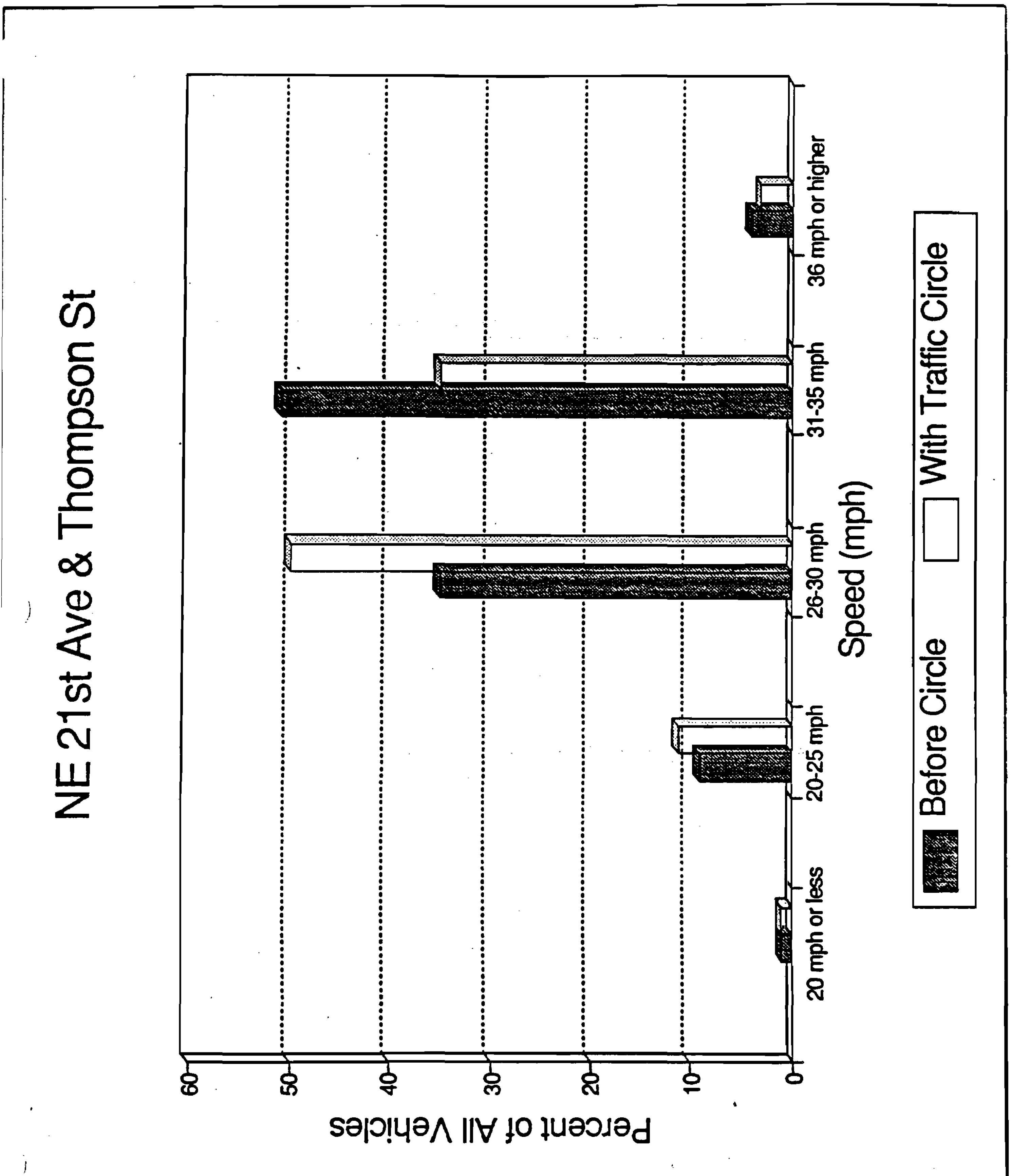
398FIG9



OVERALL DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. 21ST AVE. & THOMPSON ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure 11
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In contrast, with a traffic circle, only 35 percent of vehicles were traveling 31-35 mph and only 3 percent were traveling higher than this. Notably, there was only a small change in the percent of vehicles traveling 21-25 mph. Thus, most of the shift in vehicle speeds were drivers reducing their speeds from 31-35 mph to 26-30 mph. This same trend was true along the other corridors as shown on the figures in Appendix A. These figures demonstrate that traffic circles are effective in reducing the number of vehicles traveling above 30 mph by at least 50 percent. At about half of the study intersections, the number of vehicles traveling 26-30 mph were also reduced. These finding suggest that traffic circles can be effective at reducing vehicle speeds, even as low as 26-25 mph. Thus, if the "speeding problem" along a corridor is vehicles traveling at 20-25 mph, then traffic circles should not be installed because they will probably not reduce vehicle speeds below this level.

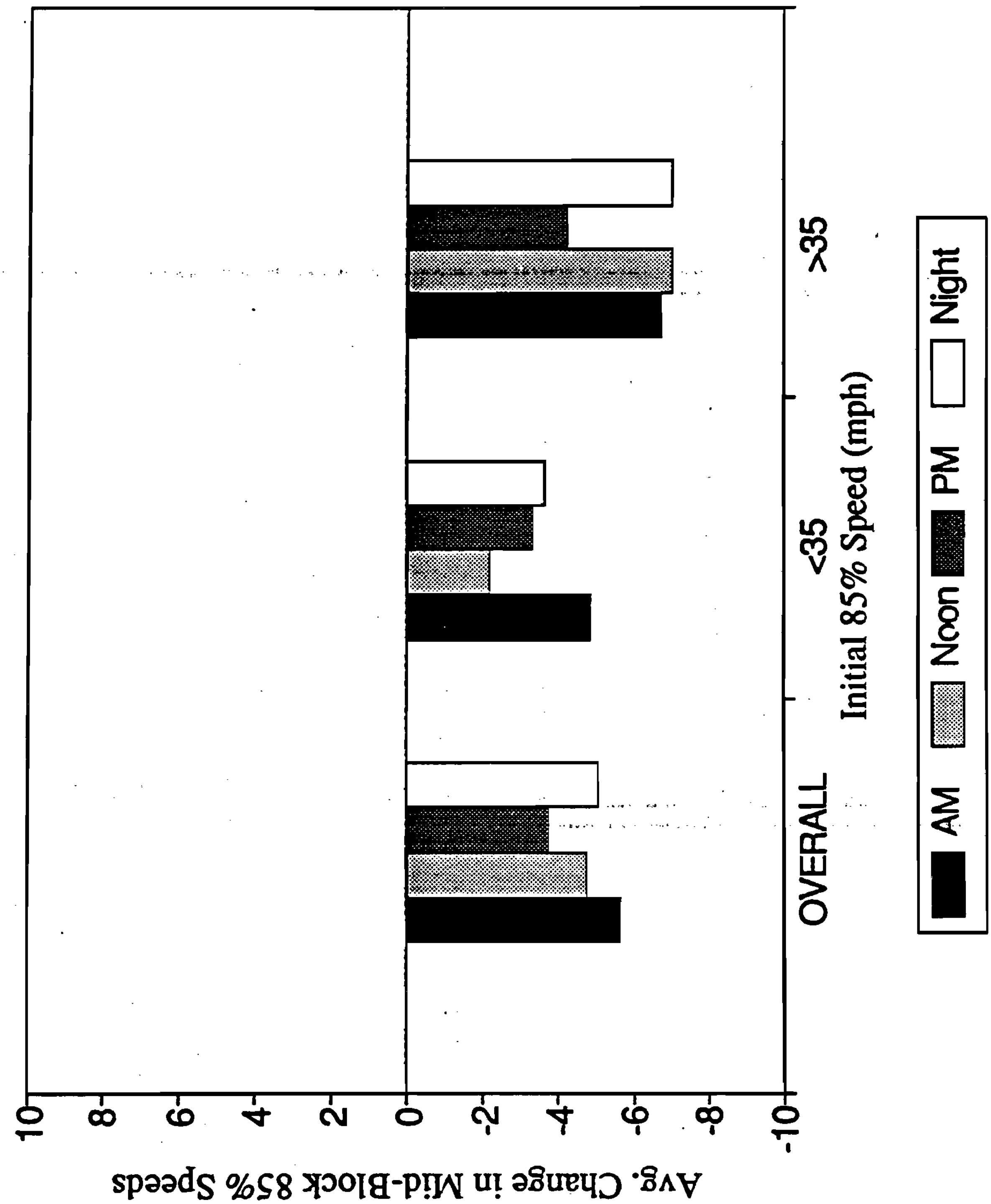
To further analyze changes in mid-block speeds by specific intersection characteristics, changes in the 85th percentile speeds were evaluated in detail. This value indicates the speed which is exceeded by only 15 percent of vehicles. The trends already noted will be directly reflected in this analysis of 85th percentile speeds. By limiting this analysis to a single measure, the analysis is simplified and other factors such as traffic circle design can be examined.

An initial analysis of changes in mid-block 85th percentile speeds before and after traffic circles were installed revealed that vehicle speeds and volumes vary significantly throughout the day. Consequently, it may not always be appropriate to summarize this measure for an entire day. For example, it may be that once a traffic circle is installed at a particular intersection, mid-block speeds decrease slightly (1-2 mph) during the mid-day, p.m. peak and night periods, but during the a.m. peak period speeds decrease dramatically (10 mph). If these changes are combined into a single daily measure, it is possible that this value could indicate that the traffic circle had little effect (2-3 mph).

Since the traffic during the a.m. peak period is typically only 10 percent of the daily traffic volume, the large decrease during the a.m. peak hour could be masked by the smaller decreases that occurred during most of the day. To account for this situation, 85th percentile speeds were calculated for the a.m. peak, mid-day (noon), p.m. peak and night time (after 9 p.m.) periods. In addition, these percentiles were computed for both directions of traffic (east/west or north/south). Thus, for each location studied, eight 85th percentile mid-block speed measures were computed.

Figure 12 presents the results of the mid-block speed analysis for all locations studied categorized by their 85th percentile vehicle speed prior to installing the traffic circle. These results demonstrate that speed reduction at traffic circles does vary by time of day. Overall, the change in 85th percentile speed ranged from 4-6 mph, with the largest speed reductions occurring during the a.m. peak period. The results in this figure also show that intersections with higher initial 85th percentile speeds experienced larger reductions in faster vehicles. Similarly, Figure 13 shows that greater reductions in 85th percentile speeds occurred at the larger diameter traffic circles. These findings are consistent with the speed profile results. It should be noted that although the street blocks in the vicinity of most of these traffic circles are only 200-300 feet long so that the "mid-block" speeds are really only 100-150 feet away from the intersection. Appendix A contains similar graphs for each traffic circle location studied by direction of travel and time of day. The results in these figures show that in almost all circumstances 85th percentile speeds did decrease, particularly during the night time.

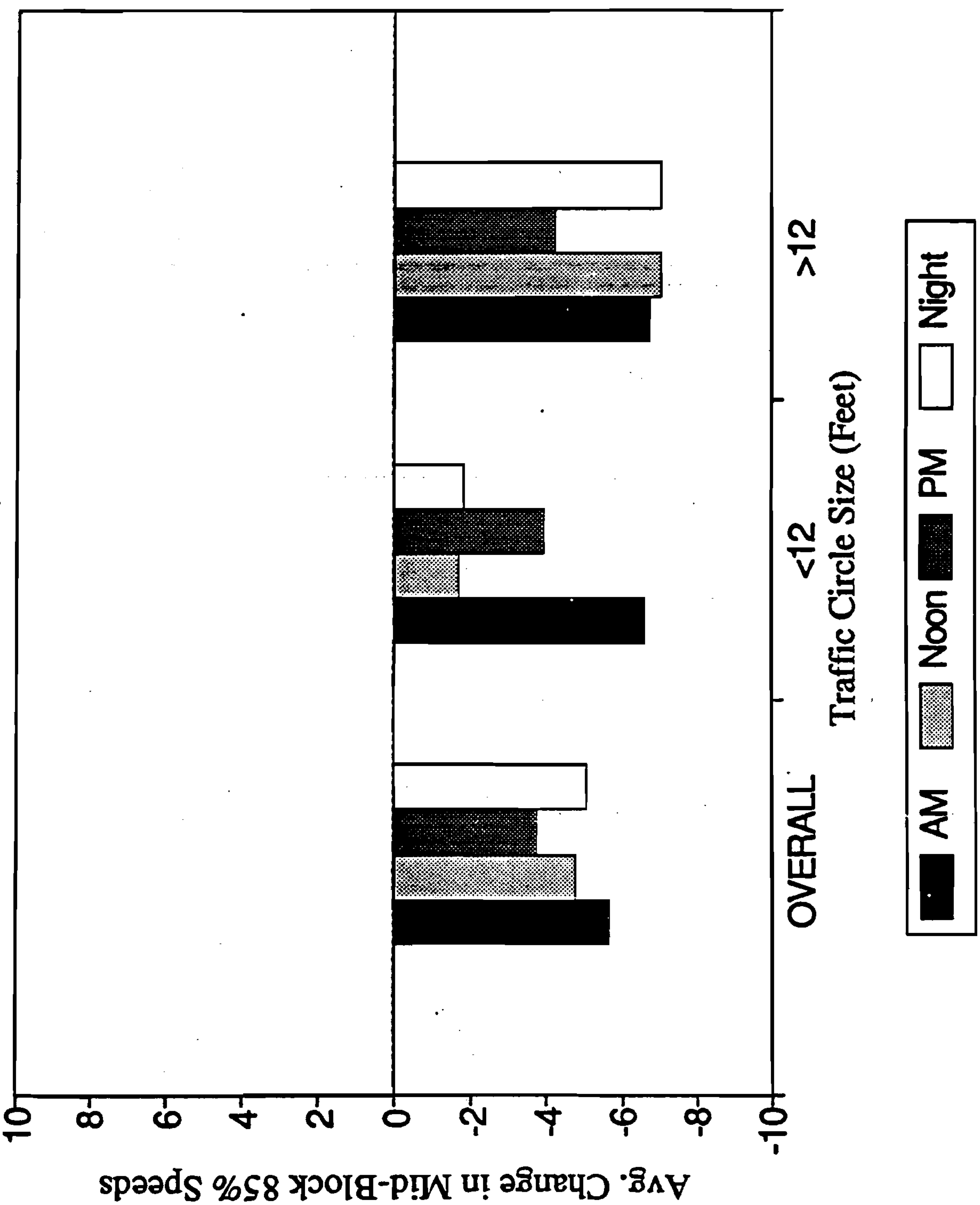
The implication of all these findings is that once a traffic circle is installed, the number of vehicles traveling at faster speeds, typically 35 mph or higher, were drastically reduced. In fact, for most locations only a 2-5 percent of vehicles, were observed traveling at speeds greater than 35 mph after the installation of a traffic circle, compared to 15 or 20 percent prior to the circle being installed.



CHANGE IN 85TH PERCENTILE SPEED
BY INITIAL 85TH PERCENTILE SPEED

TRAFFIC CIRCLE PEER REVIEW	Figure 12
October 1991	

39885TH1



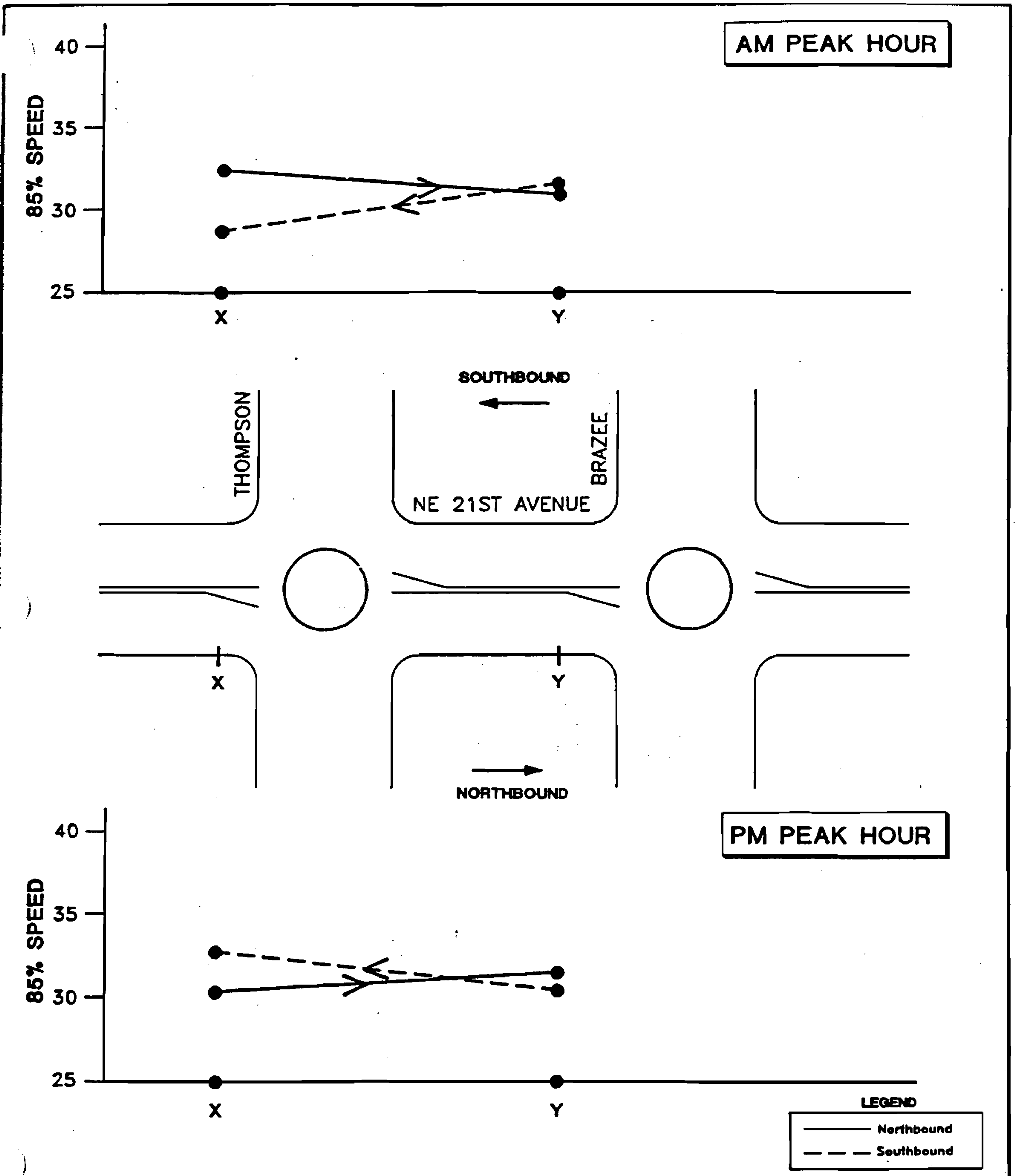
CHANGE IN 85TH PERCENTILE SPEED
BY SIZE OF TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure	
October 1991	13	

398851TH

Vehicle Speeds Along a Corridor: An additional analysis was conducted with the mid-block speed data to determine how vehicle speeds vary as they travel through a series of traffic circles. Intuitively, one might expect that as a vehicle travels through a series of intersections with traffic circles that drivers will reduce their speeds through the corridor to adapt to the speed mandated by the circles. Figure 14 presents the results of this analysis for one of the corridors, along N.E. 21st Avenue. The top graph shows that as vehicles traveled northbound through the traffic circles during the a.m. peak hour, the 85th percentile speed of vehicles approaching the second circle (at location y) was lower at the first circle (at location x). However, during the p.m. peak period this trend did not occur. In contrast, during the p.m. peak period the 85th percentile speed at the approach to the second circle (location y) was slightly higher than at the first circle (location x). The results for other corridors are in Appendix B and they also show mixed results. Since this data was collected for only a few situations it is difficult to interpret these results. However, in all of the circumstances, it should be kept in mind that the 85th percentile approach speeds at all of these locations are significantly lower than speeds before the circles were installed.

Recommendations: The City of Portland should continue its progressive program of installing traffic circles to reduce vehicle speeds along residential streets. The analyses of vehicle speeds clearly show that traffic circles are effective in reducing the number of vehicles traveling a higher speeds (35 mph or higher). Prior to the installation of traffic circles, at least 15-20 percent of vehicles traveled at high speeds on these residential streets. With traffic circles, very few vehicles traveled at these high speeds. At some locations, the number of vehicles traveling 26-30 mph were also reduced. Based on these findings, traffic circles should be used to address "speeding" on residential streets where many vehicles are exceeding 25-30 mph. The newer larger diameter traffic circle designs were most effective in reducing speeds and should continue to be the design of choice.



N.E. 21ST AVENUE
CORRIDOR SPEED PROFILE

TRAFFIC CIRCLE PEER REVIEW	Figure 14
October 1991	

Effect on Traffic Safety

Reported Accidents: Table 3 presents the number and rate of reported accidents that occurred prior to and after the installation of traffic circles along the major street corridors in this study. In addition, this table also shows the number and rate of reported accidents that occurred at nearby control intersections that remained unchanged throughout the comparison periods. The overall reductions in monthly accident rates are shown in Figure 15. These results clearly show that the installation of traffic circles have almost eliminated reported accidents. Overall, the average monthly rate of reported accidents at these major corridors where traffic circles were installed was 0.38 accidents per month prior to the traffic circle compared to 0.16 per month after the circles were installed, a 58 percent reduction. In contrast, the average rate of reported accidents at control intersections was 0.31 accidents per month during the before period compared to 0.33 accidents during the period after the traffic circles were installed, a 6 percent increase. The largest reduction in reported accidents occurred along the N.E. 37th Avenue corridor where the intersection with circles experienced an 84 percent reduction in their reported accident rate while the accident rate at the control intersections increased 21 percent.

Table 3: Comparison of Changes in the Monthly Rate of Reported Accidents

Area of Portland (Installed)		Intersections With Circles: Single Vehicle PDO*	Single Vehicle Injury*	Multi-Vehicle PDO*	Multi-Vehicle Injury*	Total Rate*	Total Change	Change in Monthly Accident Rates at Nearby Control Intersections (See Report)
NW Portland	Before**	0.000	0.000	0.083	0.028	0.111	-64%	+53%
	After (9/88-12/90)	0.000	0.036	0.000	0.000	0.036		
SE 13th, 14th & 15th	Before	0.000	0.000	0.500	0.167	0.667	-81%	+23%
	After (1/89-12/90)	0.000	0.000	0.083	0.042	0.125		
SE Clinton St.	Before	0.000	0.000	0.306	0.167	0.473	-70%	-55%
	After (6/90-12/90)	0.000	0.141	0.000	0.000	0.141		

* Average number of reported accidents per month.

** Before accident data contains the number of crashes that were reported 3 years prior to the test period or the circle was actually installed. The after period contains the number of crashes that were reported since the circle was installed as indicated by the dates shown.

Table 3. (Continued) Comparison of Changes in Monthly Rate of Reported Accidents.

Area of Portland (Installed)		Intersections With Circles: Single Vehicle PDO*	Single Vehicle Injury*	Multi-Vehicle PDO*	Multi-Vehicle Injury*	Total Rate*	Total Change	Change in Monthly Accident Rates at Nearby Control Intersections (See Report)
NE 21st & 24th Street	Before**	0.000	0.000	0.528	0.083	0.611	-41%	+58%
	After (11/89-12/90)	0.071	0.071	0.071	0.143	0.356		
SE Lincoln St.	Before	0.028	0.028	0.222	0.250	0.528	-21%	-53%
	After (5/90-12/90)	0.125	0.125	0.000	0.125	0.375		
NE 37th St.	Before	0.028	0.000	0.139	0.028	0.195	-81%	+21%
	After (10/88-12-90	0.000	0.000	0.028	0.000	0.028		
NE Holman St.	Before	0.000	0.000	0.056	0.000	0.056	-36%	+200%
	After (10/88-12/90)	0.037	0.037	0.000	0.000	0.074		

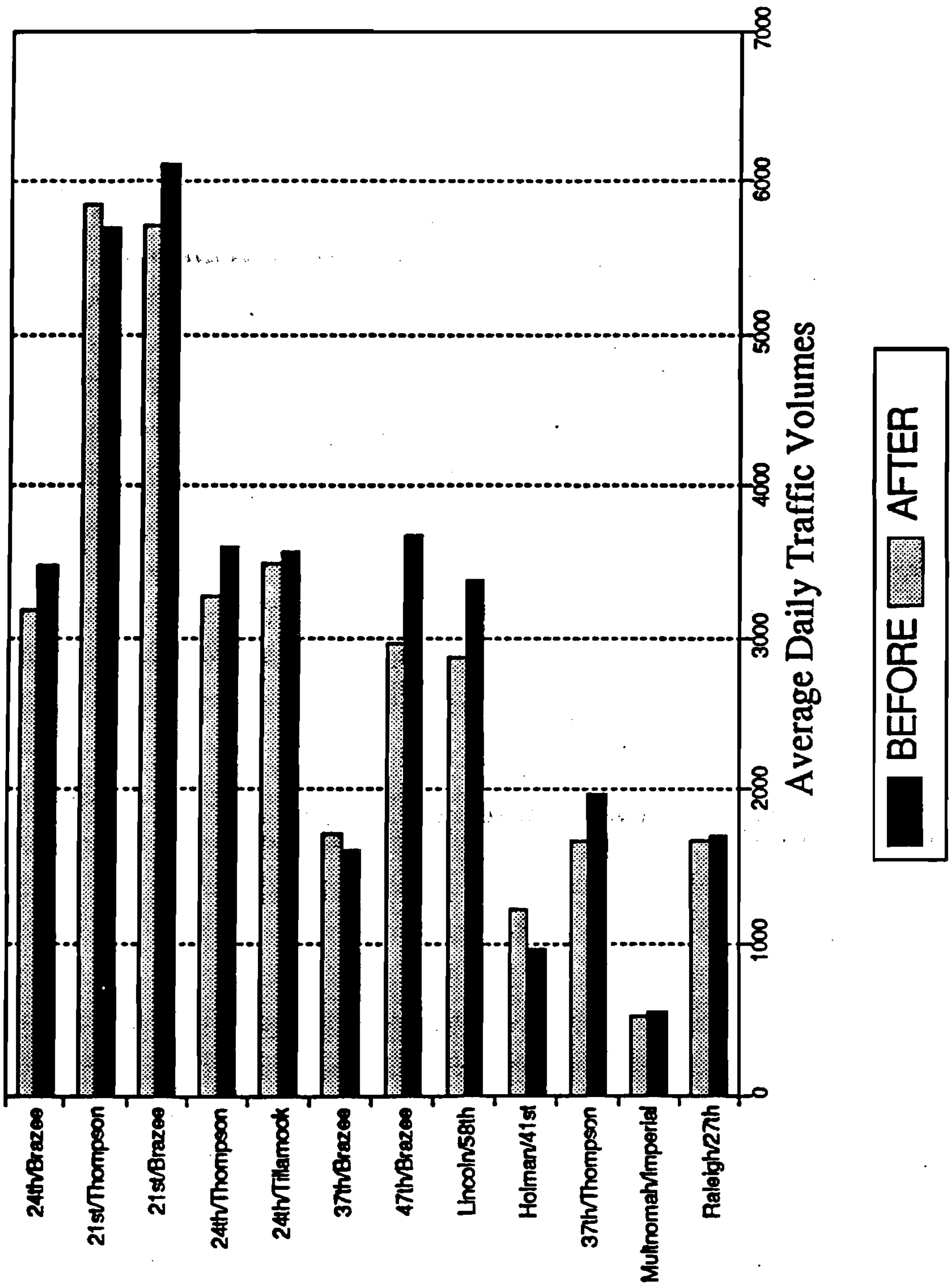
* Average number of reported accidents per month.

* Before accident data contains the number of crashes that were reported 3 years prior to the test period or the circle was actually installed. The after period contains the number of crashes that were reported since the circle was installed as indicated by the dates shown.

To examine the possible influence of other factors, Figure 16 shows the average daily traffic volumes along the main street at some of the intersections before and after the periods traffic circles were installed. Although there are minor differences in these ADT volumes, they have not change dramatically at these locations. The only exception to this is along S.E Clinton Street and S.E. Lincoln Street where traffic diverters were also installed in conjunction with the traffic circles.

Given the results detailed above, the reduction in reported accidents that accompanied the installation of traffic circles cannot be attributed to extraneous factors. Rather, these reductions reflect the better traffic flow and safety characteristics of traffic circles which is consistent with the findings from Seattle and the European experience.

Table 3 also presents these accident trends by type of accident and severity. Examining these data, as well as the detailed accident summaries, indicates that traffic circles primarily reduce multiple vehicle crashes. Most of these were right angle or turning accidents where one vehicle was moving into the path of another. These types of collisions might also be attributed to drivers misjudging available gaps in traffic. As noted earlier, traffic circles simplify the number of conflict points at an intersection, primarily right angle and opposing left turn traffic flow conflicts. By their design, traffic circles reduce vehicle speeds and may also influence drivers to use more caution, especially side street traffic.



AVERAGE DAILY TRAFFIC VOLUMES BEFORE AND AFTER TRAFFIC CIRCLE WAS INSTALLED

TRAFFIC CIRCLE PEER REVIEW	Figure 16
October 1991	

As a final note, the only drawback to the traffic circles was a small increase in single vehicle fixed object crashes; in some of these cases, the traffic circle was struck. There has also been evidence of a few unreported crashes occurring where a vehicle struck a traffic circle island, typically late at night. In at least one instance, the neighbors observed that the driver had been drinking alcohol. These single vehicle and unreported crashes tend to be low-damage events, and the vehicle can often be driven away. In contrast, multiple vehicle crashes, in particular angle collisions such as those that were occurring at the study intersections, often resulted in an injury and/or extensive damage to the vehicles. These multiple vehicle crashes also typically occurred during day time hours where they can disrupt traffic along residential streets. Consequently, even though traffic circles are an object in the roadway, their dramatic effect of reducing multiple vehicle crashes more than compensates for their small potential to increase single vehicle crashes. Also, as detailed later, this peer review study recommends several improvements to the night time visibility of the traffic circle islands that may help address any potential safety problem that these island represent.

Recommendation: Based on the substantial reduction in accidents at these intersections, the City of Portland should consider installing traffic circles as an accident countermeasure at unsignalized intersections that consistently have a higher number of reported right angle accidents than other nearby comparable intersections.

Traffic Circle Design: As noted in the main report, there are two general traffic circle designs. The older design is similar to a typical traffic island. The newer design is a larger diameter circle with a curb/lip as an outer ring. The City staff as well as our field observations found that many of older smaller island typically had many tire marks indicating that drivers had trouble identifying where the actual edge of the island is. Also, there were a couple of crashes during which a vehicle went straight across the traffic island. In contrast, the newer larger islands tended to have few tire marks. Because of their larger size, they are also more conspicuous particularly during the day time. Although there are only a few accidents that have occurred where these new circles have been struck, the outer lip/curb should be more effective in redirecting vehicles along their path.

> **Recommendation:** Based on this limited accident experience and the results of the speed analyses, the City of Portland should continue its use of the newer larger diameter traffic design with the outer curb rather than the smaller older design.

Other Safety Issues: In general, KAI did not observe any unsafe driving situations while at the different traffic circle locations. However, there are at least three issues that were of some concern. First, all the street corners, especially the far side curb corner, should be kept free of unnecessary objects that could be a hazard if struck by a vehicle. Although, few accidents involved errant vehicles running up on these curb corners, there was evidence from tire marks that many of these far side curbs have been struck. This may be difficult to achieve at all locations, but any cost-effective opportunity to remove or relocate fixed objects from these corners should be explored. Second, although there is a policy of limiting the distance from the traffic circle that on-street parking can occur, KAI observed local residents disobeying the parking regulations. Also, at some intersections, it appeared that vehicles going around the circle came too close to a properly parked vehicle such that the restricted no parking area should be increased. The City should review their policy regarding on-street parking policy in the vicinity of traffic circles and confirm by actual observation that the no-parking area is sufficient. Finally, although KAI did limited observations from the minor streets, there was concern that all these minor side streets should have adequate sight distance which is free of trees, parked cars, and other obstructions.

Recommendation: As part of the City's periodic inspection of all traffic circle intersections, they should review the overall safety of their traffic operations including how vehicles go around the circles and if parked vehicles or fixed objects on the street curbs might constitute a significant hazard. In addition, an evaluation of sight distance for drivers on the minor street should be performed. Adjustments to the parking restrictions or removal/modification of objects that obstruct adequate sight distance should be made as appropriate.

Traffic Circle Visibility

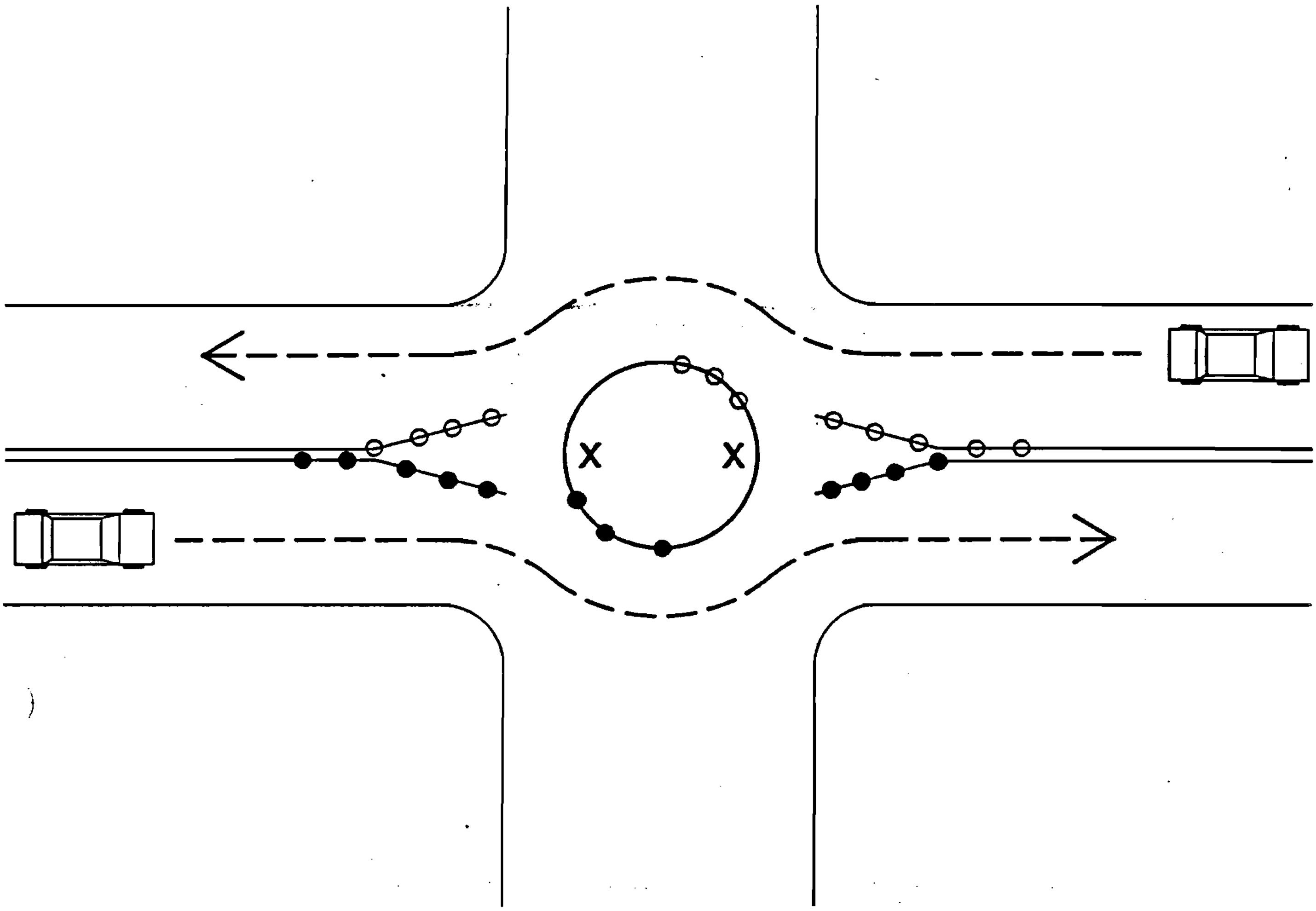
Two key issues were considered in our peer review: the long-range and short-range visibility needs of an approaching driver. As drivers enter a section of roadway with a traffic circle they need long range guidance to alert them that a circle is ahead and the distance they will traverse before encountering it. As they get closer, drivers need to perceive how their path will be altered and what adjustments to their driving behavior and vehicle speed will be required. As drivers go through the traffic circle, they need to have specific short-range guidance on what path they should follow to enter, negotiate, and leave the traffic circle.

During daylight hours the traffic circles are very conspicuous. However, some problems in traffic circle visibility occurred during nighttime hours, and there are several aspects of their signing and delineation that could be improved.

Signs: In some areas with mature vegetation, a driver's view of advance warning signs for traffic circles was blocked by tree branches. Although somewhat visible at during the daytime, these signs were often difficult to see at night. In addition, some of the three arrow circle signs placed on the traffic circle island were found to mounted too high and did not have high-grade reflective sheeting. As a result, the headlights of an approaching vehicle did not always adequately illuminate the sign's surface. A few signs were also found to have suffered from vandalism; in some cases, additional arrows or words were drawn or painted on these signs.

Delineators: Currently, most circles have multi-sided delineators placed along the roadway centerline approaching the traffic circle island as well as the along the island itself. The pattern of delineators on the circle island starts at the center of the rim and goes around the side of the island following the path of an approaching main street vehicle. The purpose of these delineators is to provide an approaching driver with long-range positive guidance during the nighttime about the location of the circle and specific short range guidance as to the path that he must travel to negotiate around the circle as well as the physical dimensions of the circle. However, these delineators are visible only about 100 to 150 feet away. In contrast, some of the traffic circles have been updated with retro-reflective "cat eye" delineators that dramatically improve the visibility of a traffic circle. An approaching driver should be able to see these retro-reflective delineators 400-500 feet away. In addition to the type of marker, the pattern should be revised, as shown in Figure 17, to provide a single clear pattern that defines the traffic circle and the path the approaching vehicle will follow. If there are too many delineators that go completely around the circle, then these delineators will not provide the specific guidance and information that drivers need. Furthermore, these delineators should be retro-reflective in the direction of traffic only. At least one of the circles had too many two-way retro-reflective delineators. This configuration was very confusing and gave the impression of an awkwardly shaped traffic circle. Finally, in examining existing delineators at the traffic circles, some were found to be covered with paint or tar from roadway and lane marking maintenance activities.

Lighting: Appendix D contains a copy of the lighting engineers report. Overall, the illumination provided at traffic circle intersections by the single adjacent street light was adequate for driver needs. As a general guideline, the lighting engineer recommended that the traffic circle intersection should have an average of 0.2 footcandles of illumination, which is in accordance with City of Portland standards and IES recommendations for local residential streets. The illumination engineer also suggested that it would be a good practice to maintain a minimum level of at least 0.1 footcandles. This level of illumination can be verified with standard ASTM measuring equipment.



○ ● Delineation locations. All delineations should be retroreflective in approach direction only.

X Possible location for additional markings such as directional arrow.

RECOMMENDED DELINEATOR PATTERN FOR TYPICAL TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure 17	K
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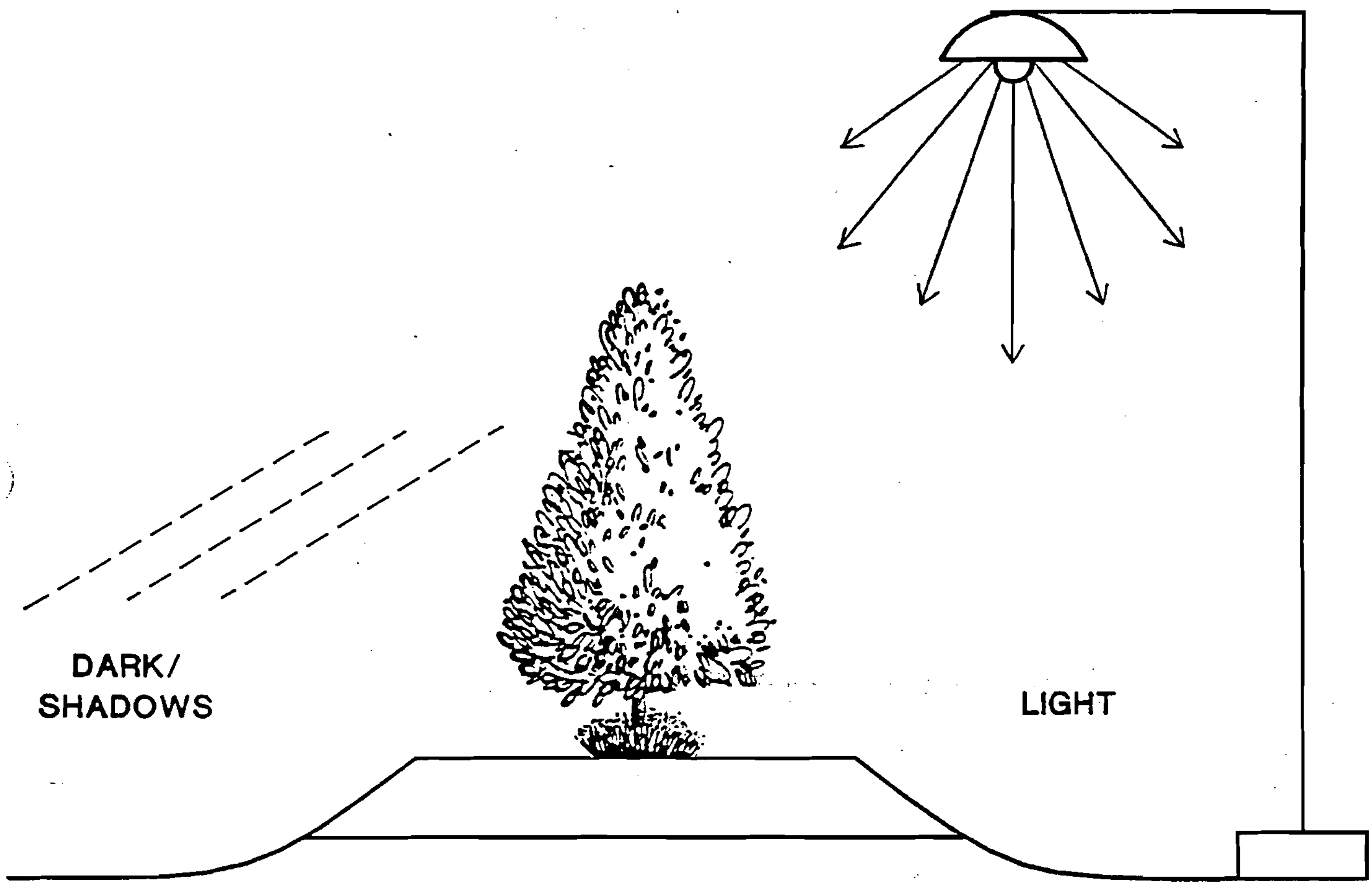
All the traffic circles have at least one street light. Typically, these lights are "cut off" lamp fixtures. This type of fixture is designed to minimize glare and to spread light along the street. The range of this light is restricted and much of the light is concentrated in the vicinity surrounding the fixture. It is used in residential areas to reduce the amount of light that intrudes on nearby homes. A few of the traffic circles have a drop glass lamp fixture which scatters light over a wider angle than the cut-off light. Our night time observations with the illumination engineer and City of Portland staff found that, in almost all cases, the one light fixture of either type should provide sufficient light at a traffic circle location. However, the placement of this fixture and the planting of tall dense vegetation and trees in the middle of a traffic circle island can degrade visibility. At a few intersections the street light was placed too far back or on the side street, and combined with the use of the cut off fixture, caused the circle to be insufficiently illuminated. Also, at a few circles, particularly along the N.E. 21st and 24th Avenue corridors, relatively tall dense trees were planted in the middle of the traffic circle island. As shown in Figure 18, these trees can actually block light from reaching the opposite side of the circle, or at the least cause shadow patterns, that make it difficult for approaching drivers to see the far-side curb or pedestrians that may be in this area of the intersection. Finally, again along streets with mature vegetation, tree branches can block a light fixture such that the darkest part of the intersection will actually be directly under the lamp itself.

Other Issues: Although the standard lighting, signing, and upgraded delineators should be adequate to address both long-range and short-range visibility needs of a typical driver, there may be ways to further enhance the visibility of the traffic circle island and/or the path drivers need to follow. For example one of the City's staff thought that it would be useful to place additional delineation on the circle, either along its rim or on its side. One idea was to stripe the rim of the circle. Another idea was to place a retro-reflective arrow on the side of the circle (see Figure 13). These further enhancements might be considered



EFFECT OF TALL VEGETATION
ON STREET LIGHT PATTERNS

TRAFFIC CIRCLE PEER REVIEW	Figure 18
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if correctable accidents persist after the traffic circles have been upgraded with retro-reflective delineators.

Recommendations:

1) As noted above, the delineators used along the centerline of the roadway and rim of the traffic circle should be upgraded to one-way retro-reflective delineators as outlined in Figure 17.

2) A systematic review of the night time visibility of each traffic circle should be conducted to assess the adequacy of the lighting, signing, and potential effect of vegetation with particular focus on the issues noted in this section. This review should be performed from the perspective of both a main street and side street driver. Furthermore, this inspection and assessment should be conducted at least on a yearly basis and after roadway maintenance or an accident has occurred in the vicinity of a traffic circle intersection.

3) If night time accidents persist at a particular traffic circle location, the City may want to consider testing other visibility enhancements mentioned in this section.

Pedestrian Safety

Although KAI personnel saw few pedestrians during any of their day or nighttime observations, pedestrian safety was one of the issues that was of great concern, particularly pedestrians crossing the street from left to right on the far side of the traffic circle. The problem is that a traffic circle diverts a driver's attention to the right side as he negotiates around the island. Furthermore, depending on the amount and height of any vegetation, a traffic circle can also block an approaching driver's view of the far left corner of the intersection. During the night, pedestrians on the opposite side of at least one of the traffic circles along NE 21st Avenue could not be seen at a few of the traffic circle intersections because of limited illumination due to nearby trees or tall vegetation in the traffic circle that block the light from the street lamp. Another pedestrian concern is the fact that main street vehicles going around a traffic circle will be forced toward the crosswalk for pedestrians crossing the minor street. Although not directly conflicting, the main street vehicle and minor street pedestrian will be much closer than if the circle was not at the intersection.

With all this said, the accident trends do not indicate that pedestrian safety is a problem. Few, if any, pedestrian accidents have occurred at traffic circle locations. However, if a street has a large number of pedestrians or pedestrian is a major concern, then an appropriate mitigation might be to move the pedestrian cross walk away from the traffic circle intersection, maybe even as far as mid-block. Once away from the traffic circle, approaching motorists should have little problem seeing pedestrians. Of course, if the crosswalk is moved to midblock appropriate striping, signing and lighting should be provided.

Recommendations:

1) As noted previously and in this section on pedestrian safety, dense and/or tall vegetation planted in the middle of the traffic circle can obstruct a driver's view of the circle and nearby pedestrians. As part of their periodic review, the City should review the types of trees and shrubs that are planted in traffic circle islands and eliminate or significantly trim back plantings that obscure a driver's vision. In addition, an arborist should be consulted to identify appropriate types of trees and shrubs to plant in islands that are less dense and need little maintenance.

2) If pedestrian traffic is of concern at a particular traffic circle intersection, the City should consider moving the pedestrian crosswalks away from the intersection.

SUMMARY AND CONCLUSIONS

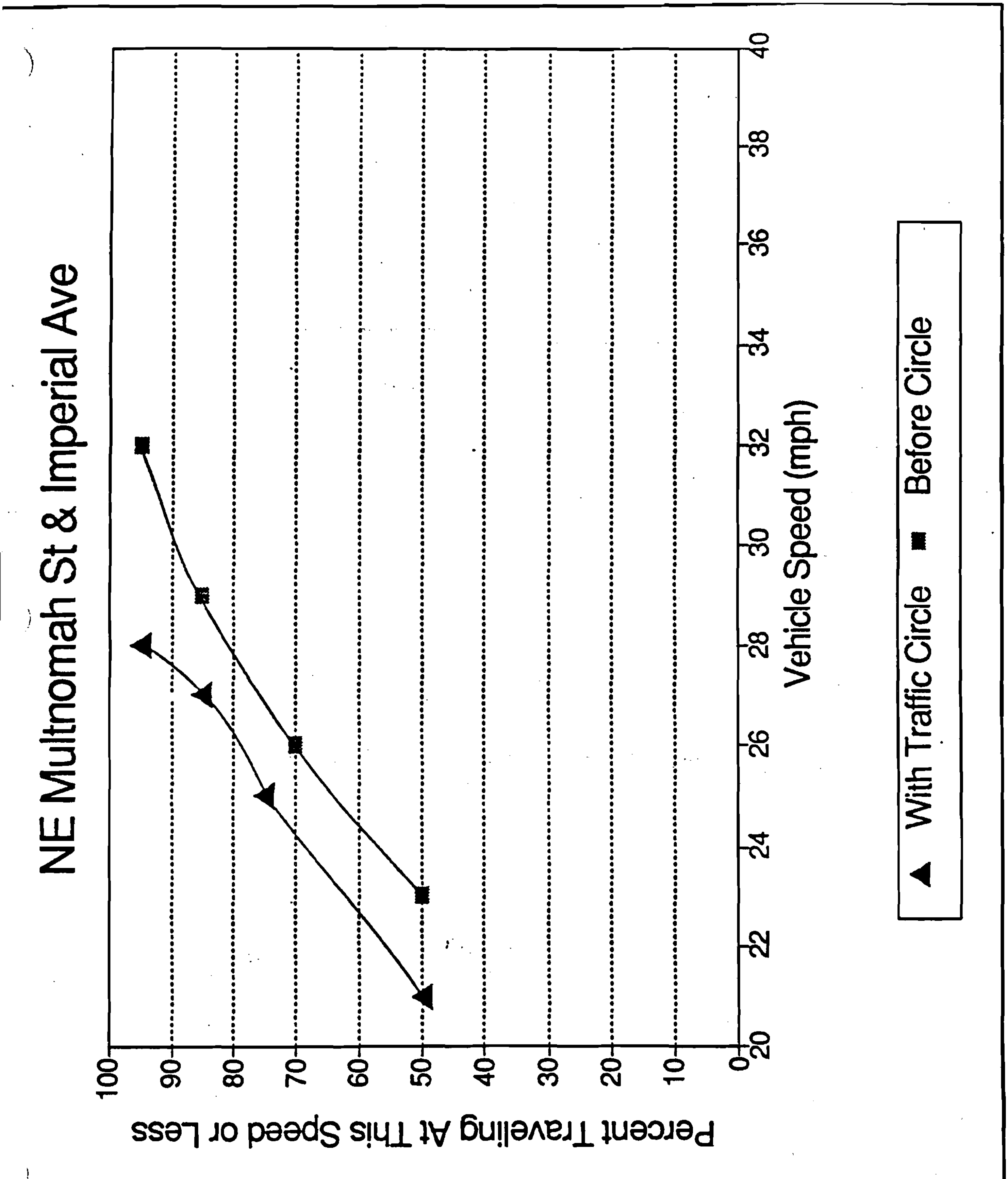
The primary objective of this peer review study was to objectively assess the traffic circles that have been installed by the City of Portland's Neighborhood Traffic Management Program (NTMP). The results of this study have clearly demonstrated that overall these traffic circles are successful at reducing the number of vehicles traveling at high speeds (30-35 mph) on residential streets. On many of these residential streets, 15 percent or more of the vehicles routinely exceeded 35 mph. After traffic circles were installed, vehicles rarely exceed 35 mph. The new larger circles (12 foot radius) appear to reduce vehicle speeds more than smaller traffic circle islands. Moreover, this peer review analysis found that traffic circles have dramatically reduced, if not almost eliminated, reported accidents, especially multi-vehicle collisions. Overall, once traffic circle were installed the monthly rate of reported accidents decreased by 58 percent. Observations at the traffic circles installed by the NTMP found that their nighttime visibility can be improved. Several specific recommendations, including upgrading traffic circle delineators and signs, are detailed in this report.

REFERENCES

1. Von Borstel, E. W., *Traffic Circles: Seattle's Experience*, ITE Journal
2. Brilon, W. (editor), *Intersections Without Traffic Signals II.* Springer Verlag, 1988

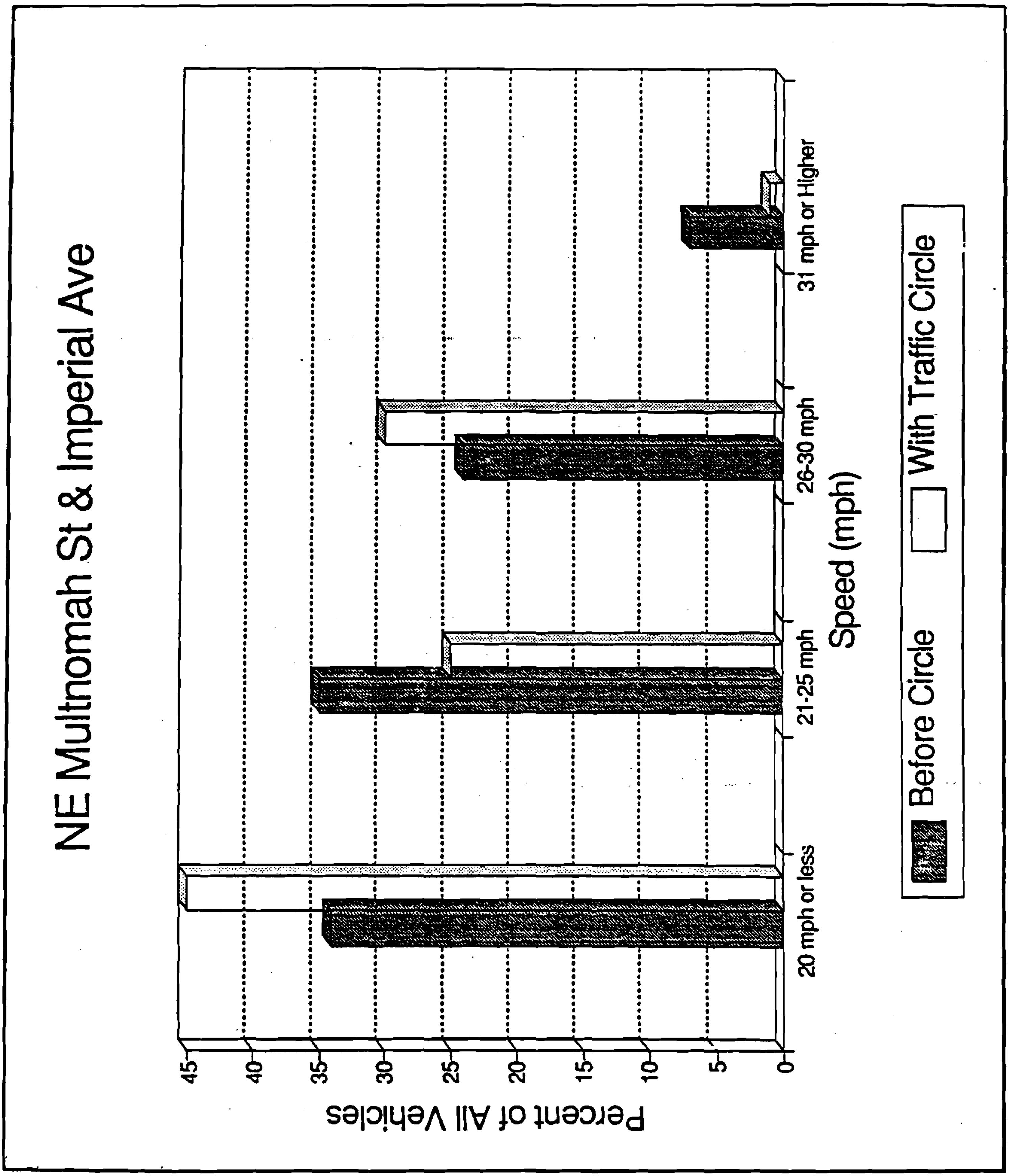
APPENDIX A: Results of Mid-Block Speed Analysis

This appendix contains the results of the analysis of the mid-block 85th percentile speeds for each intersection where a traffic circle was installed.



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. MULTNOMAH ST. & IMPERIAL AVE. WITH AND WITHOUT THE TRAFFIC CIRCLE

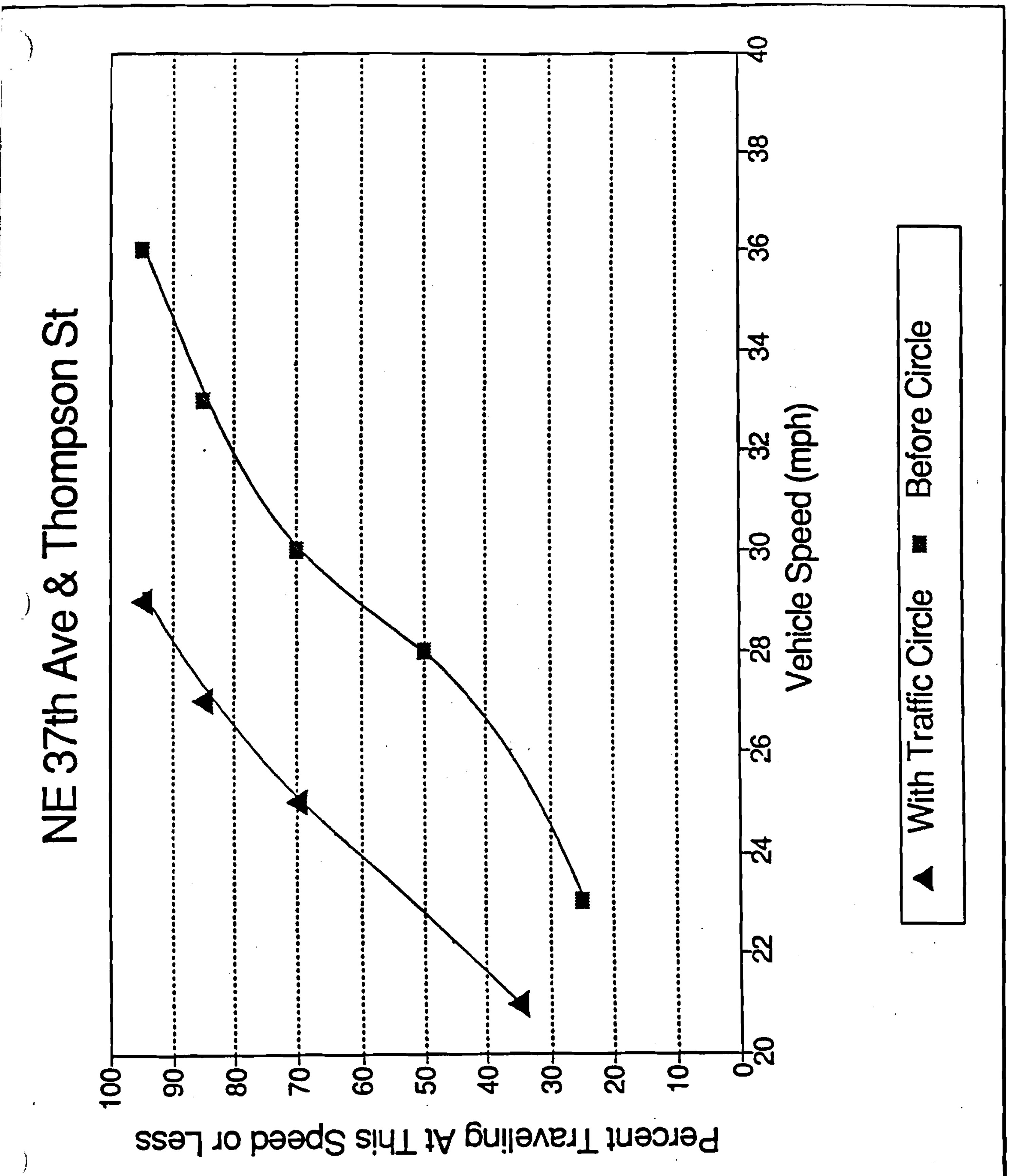
TRAFFIC CIRCLE PEER REVIEW	Figure A1	
October 1991		



OVERALL DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. MULTNOMAH ST. & IMPERIAL AVE. WITH AND WITHOUT THE TRAFFIC CIRCLE

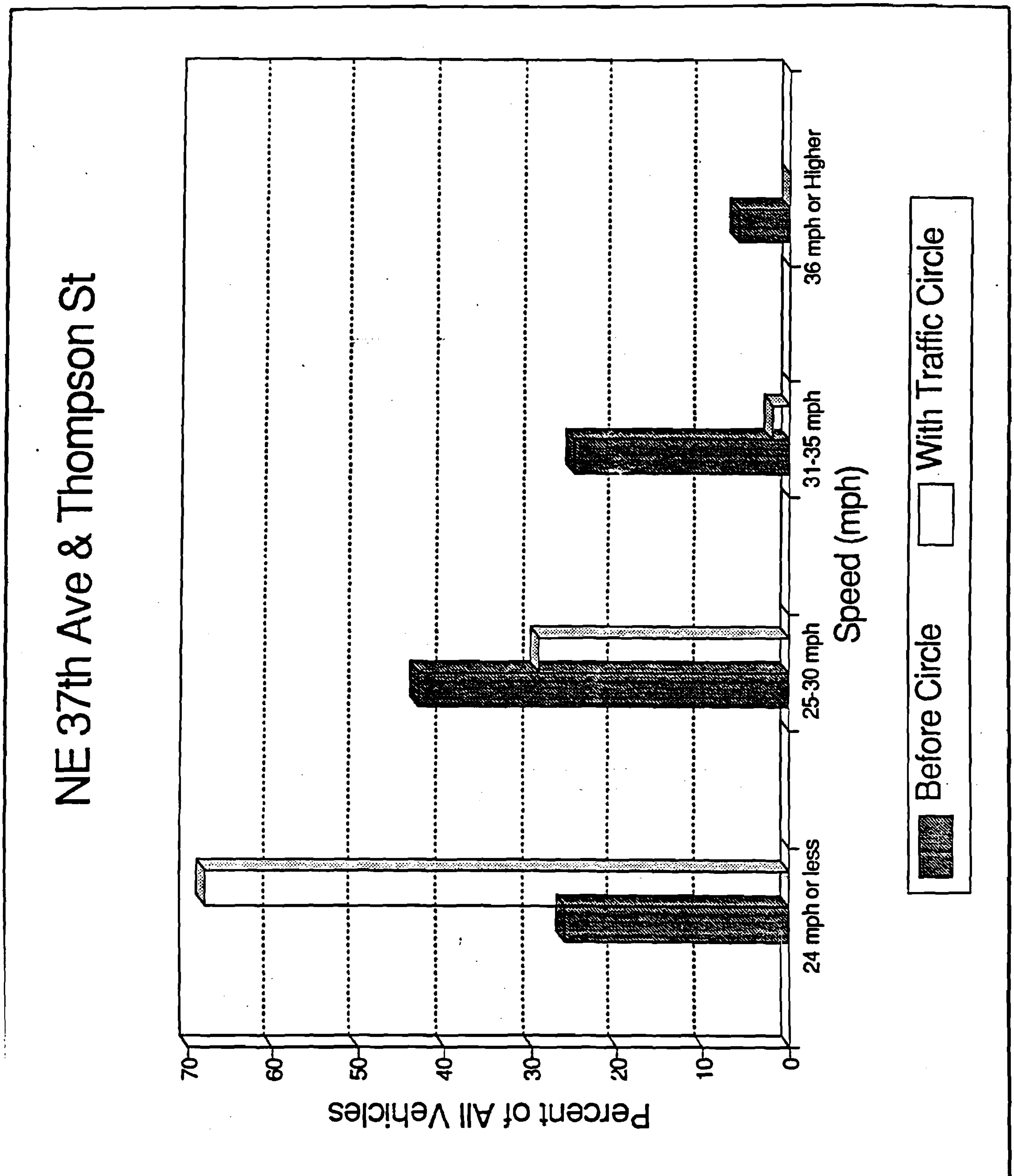
TRAFFIC CIRCLE PEER REVIEW	Figure A2
October 1991	

398FIGA2



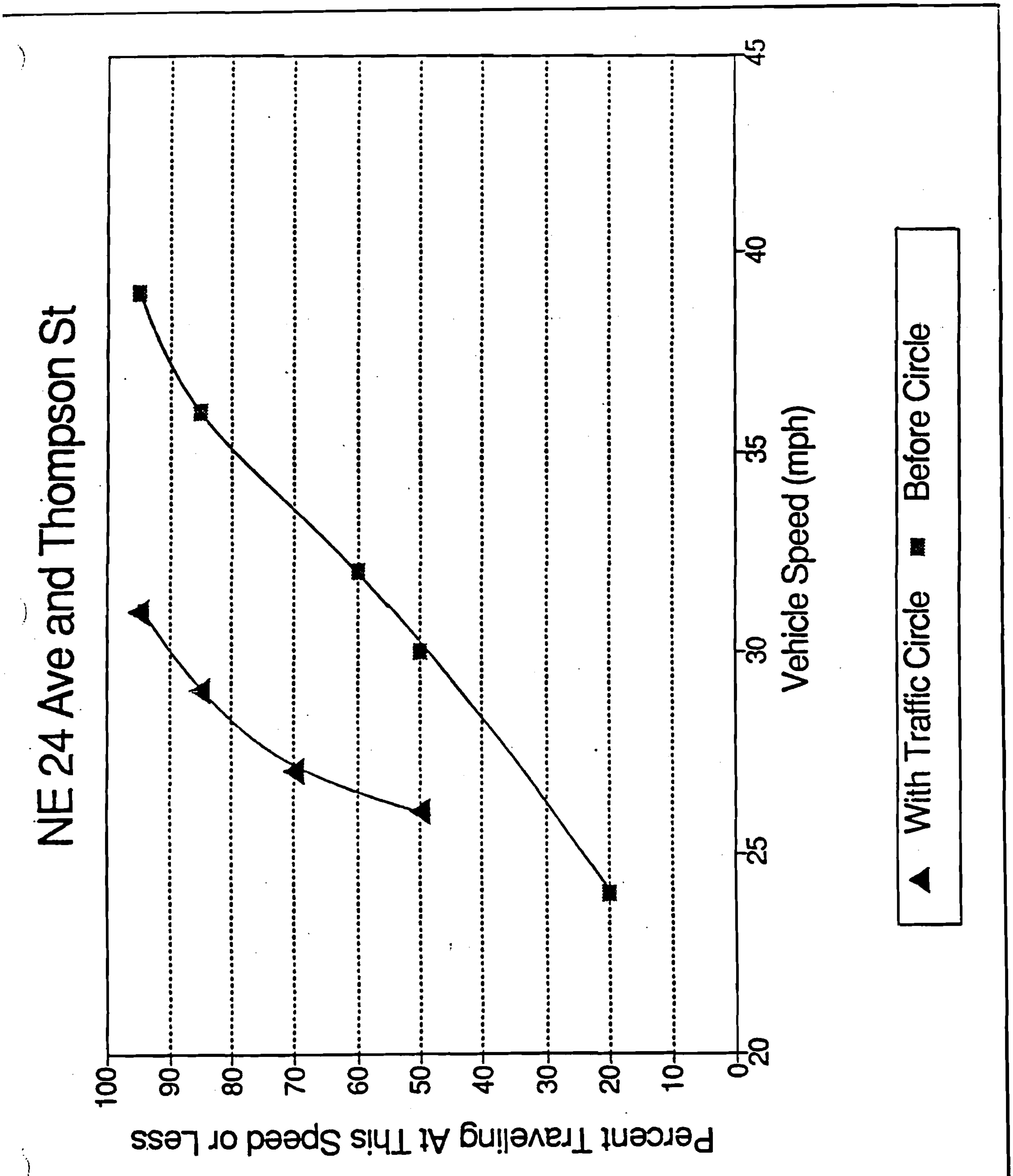
CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS
NEAR 37TH AVE. & THOMPSON ST.
WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A3
October 1991	



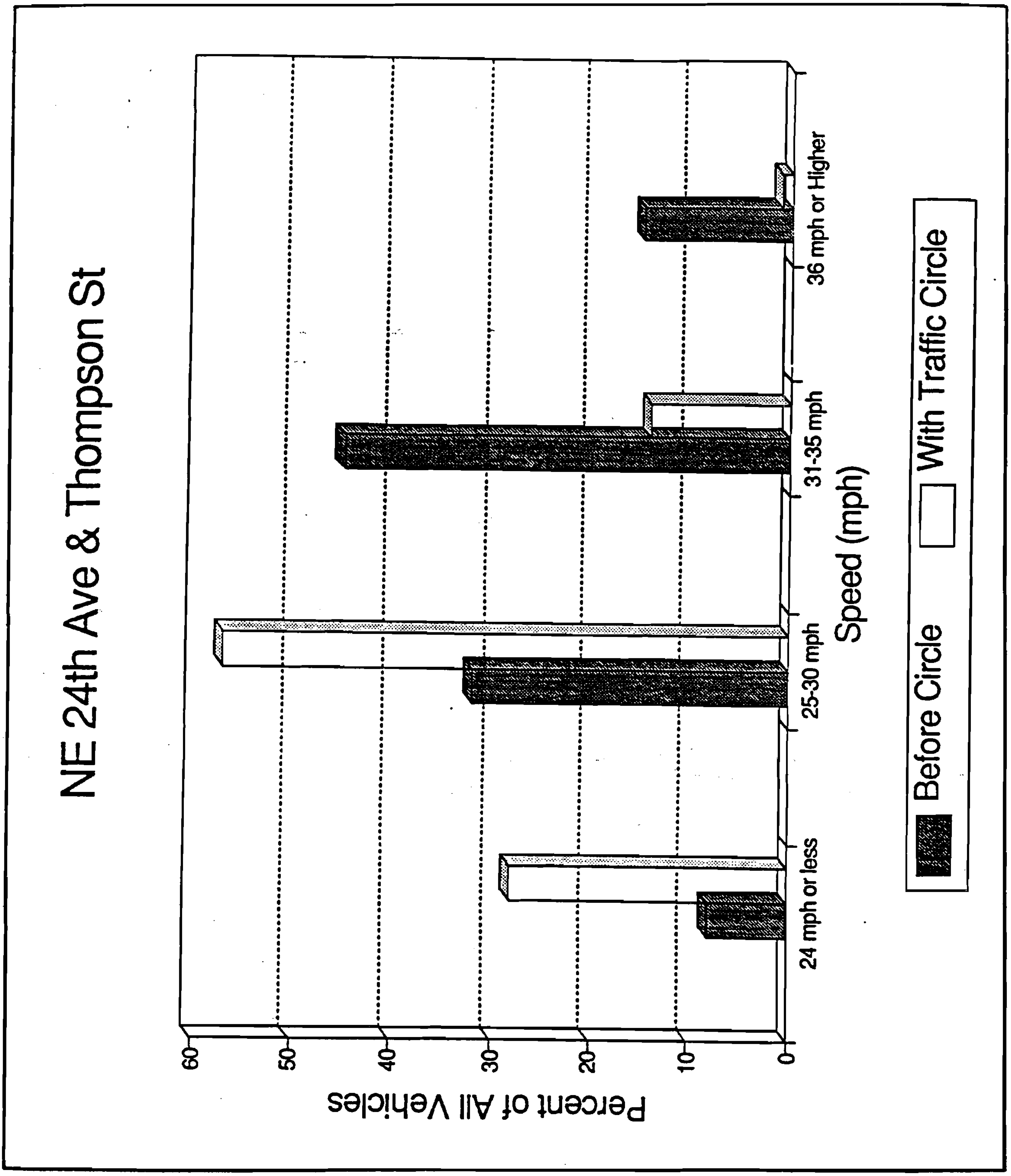
OVERALL DISTRIBUTION OF VEHICLE SPEEDS
NEAR N.E. 37TH AVE. & THOMPSON ST.
WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure
October 1991	A4



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. 24TH AVE. & THOMPSON ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

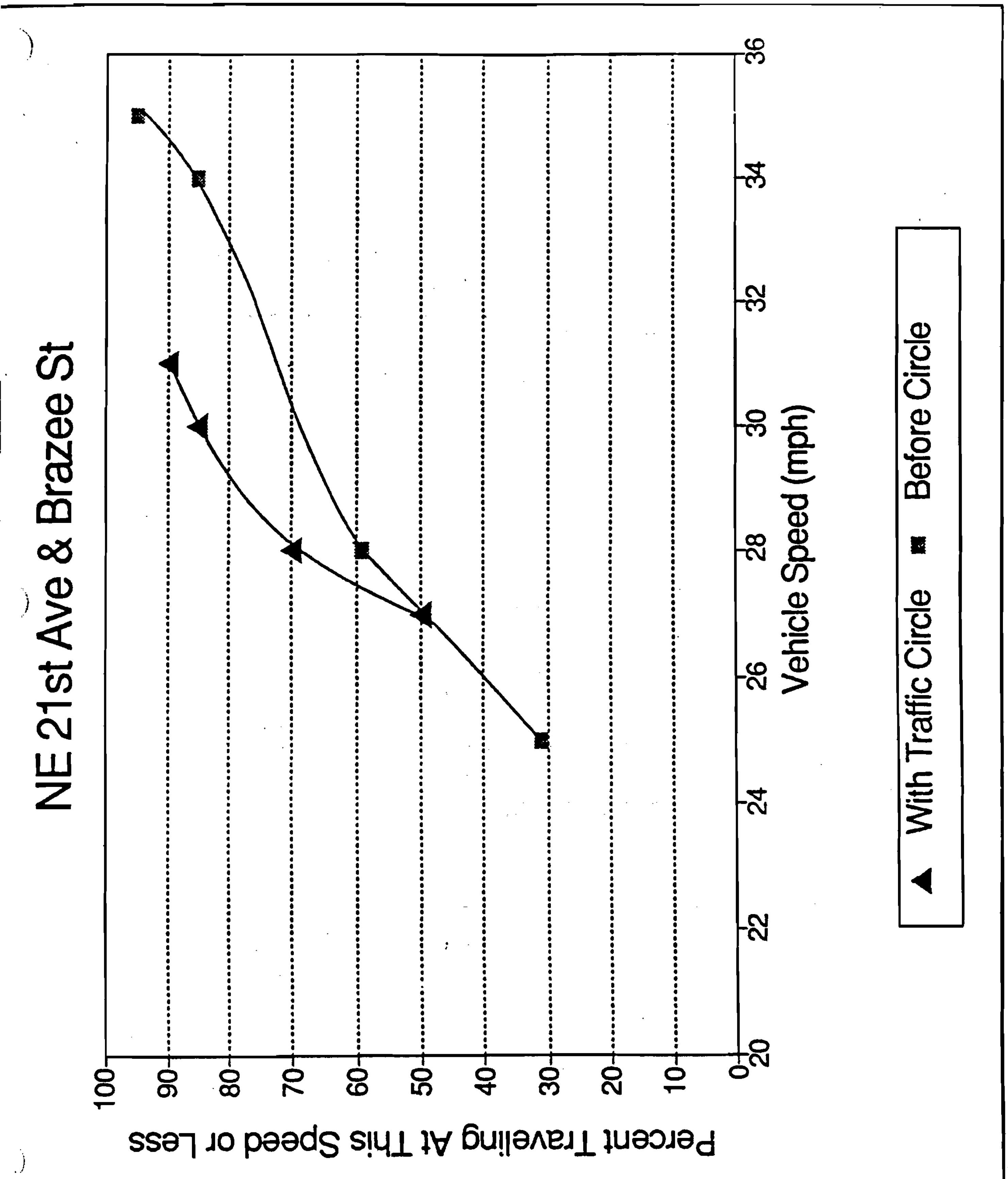
TRAFFIC CIRCLE PEER REVIEW	Figure A5
October 1991	



OVERALL DISTRIBUTION OF VEHICLE SPEEDS
NEAR N.E. 24TH AVE. & THOMPSON ST.
WITH AND WITHOUT THE TRAFFIC CIRCLE

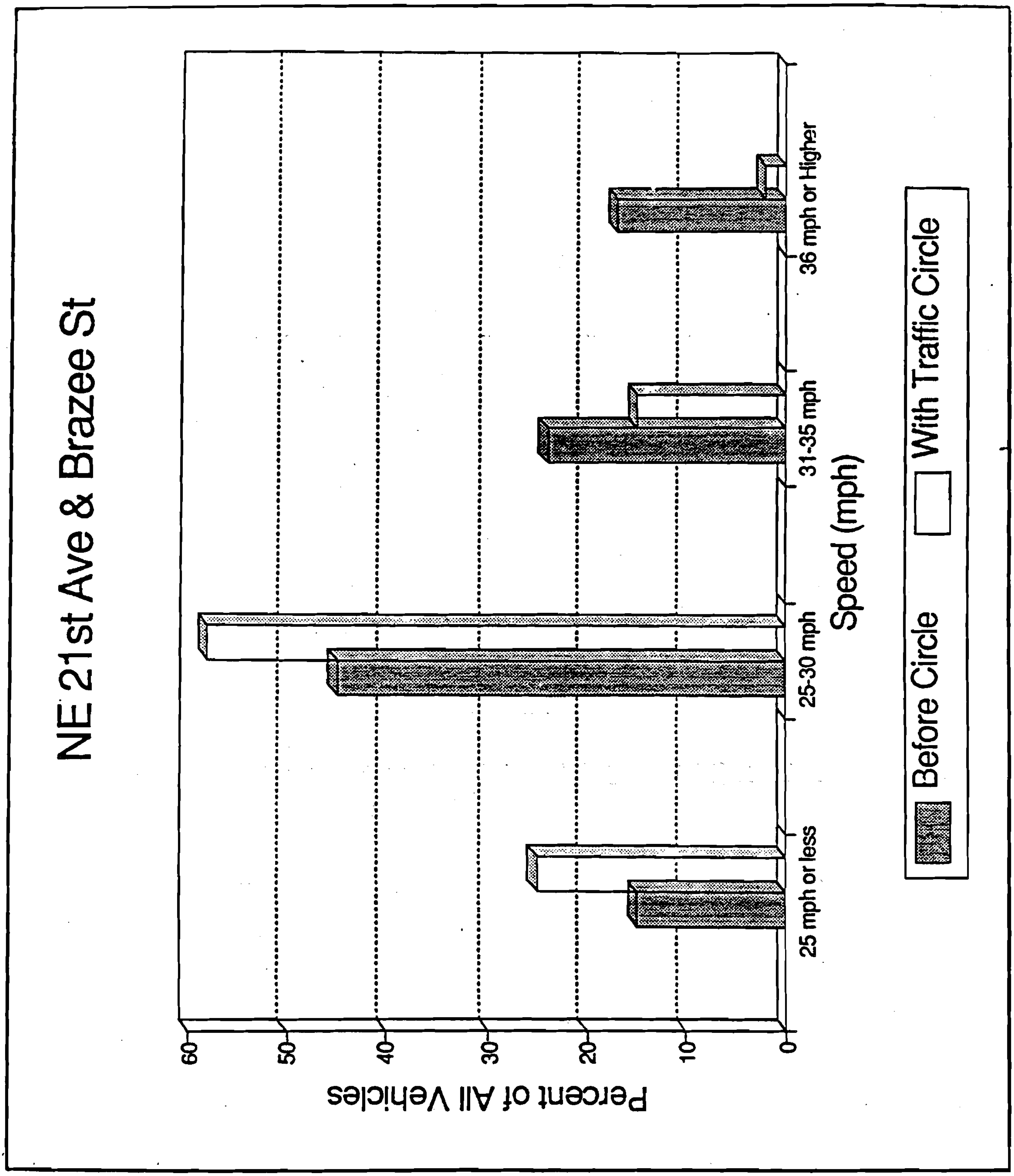
TRAFFIC CIRCLE PEER REVIEW	Figure A6
October 1991	

398FIGA6



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS NEAR 21ST AVE. & BRAZEE ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

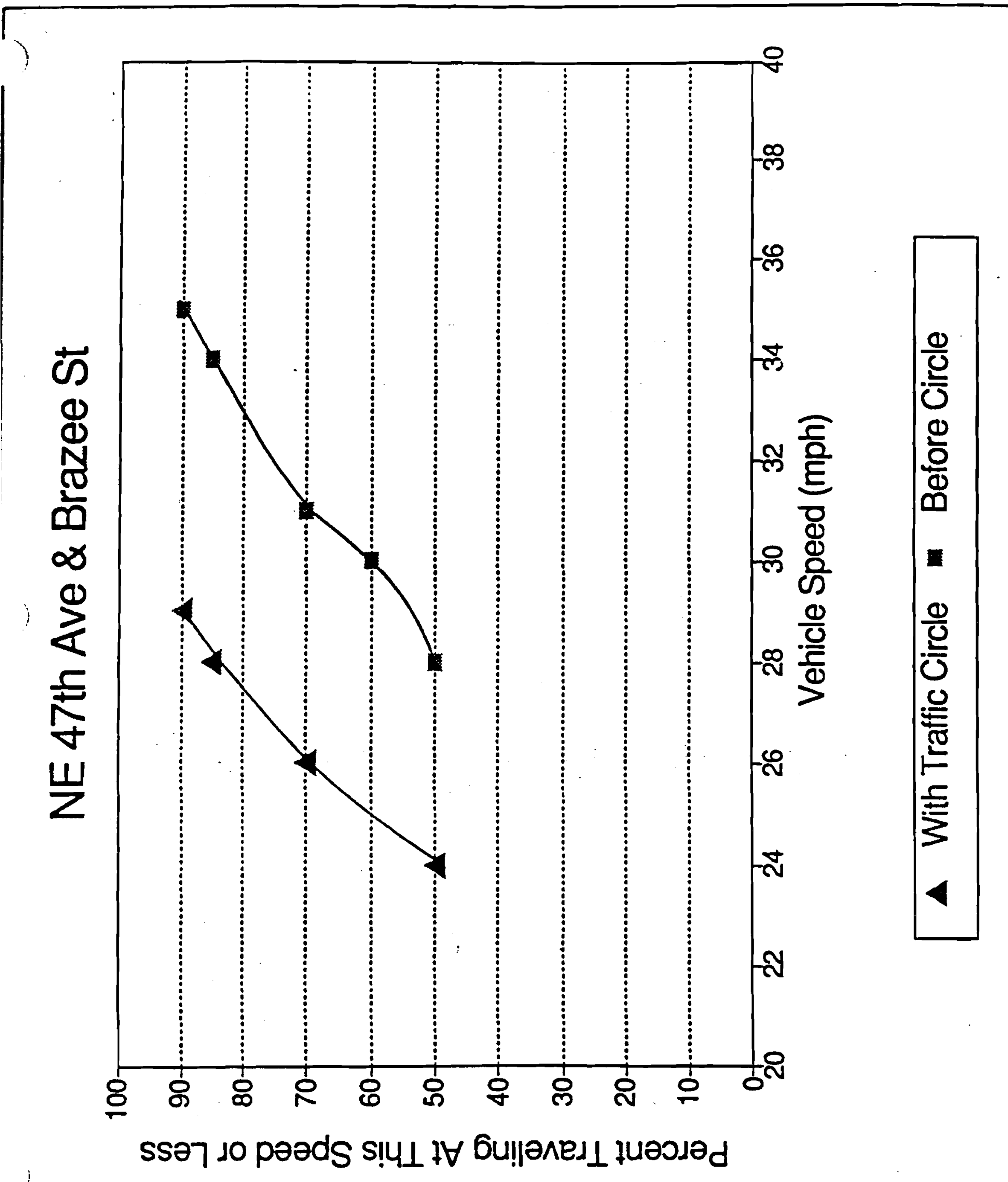
TRAFFIC CIRCLE PEER REVIEW	Figure A7
October 1991	



OVERALL DISTRIBUTION OF VEHICLE SPEEDS NEAR N.E. 21ST AVE. & BRAZEE ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

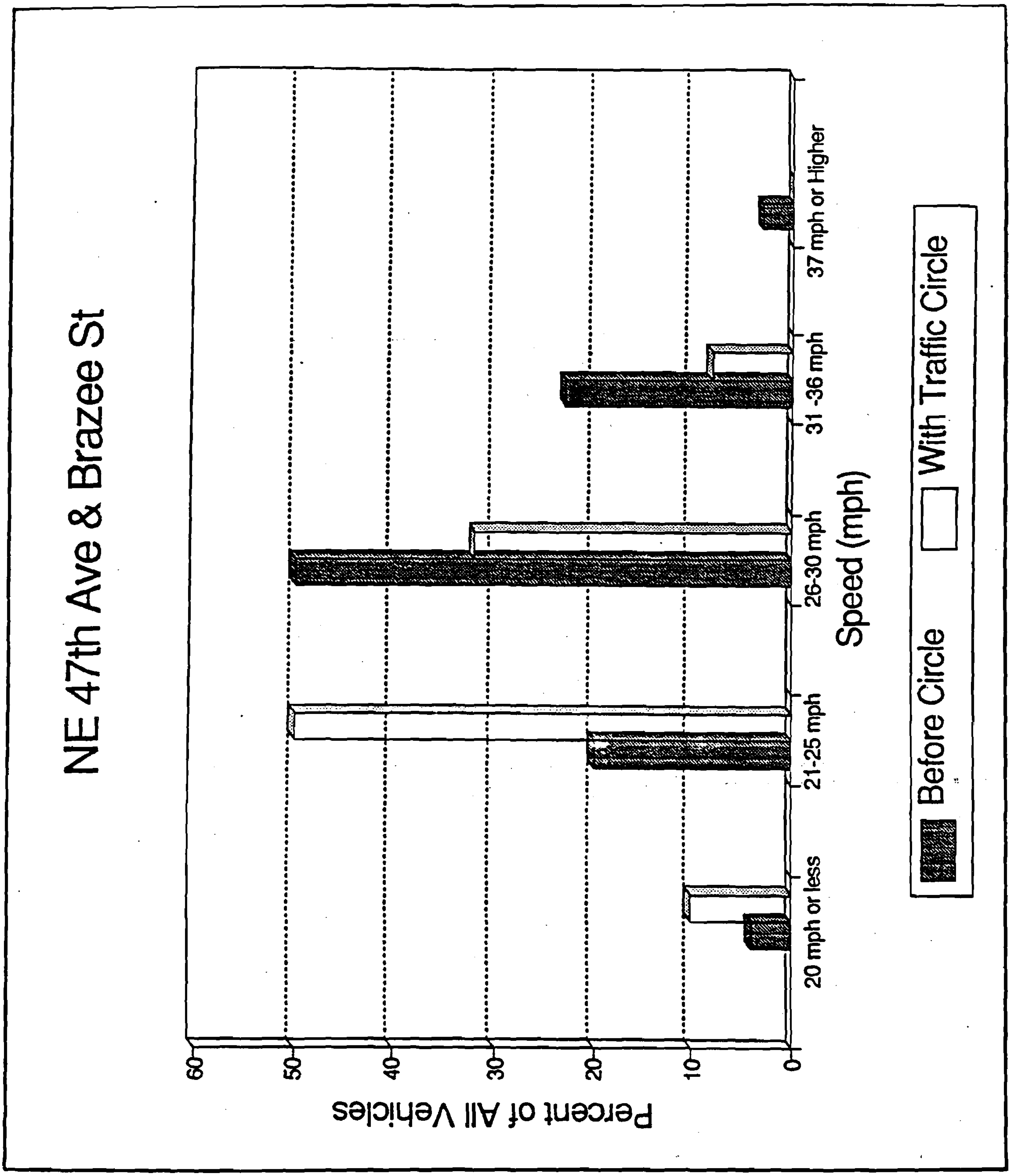
TRAFFIC CIRCLE PEER REVIEW	Figure A8
October 1991	

398FIGA8



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS
NEAR 47TH AVE. & BRAZEE ST.
WITH AND WITHOUT THE TRAFFIC CIRCLE

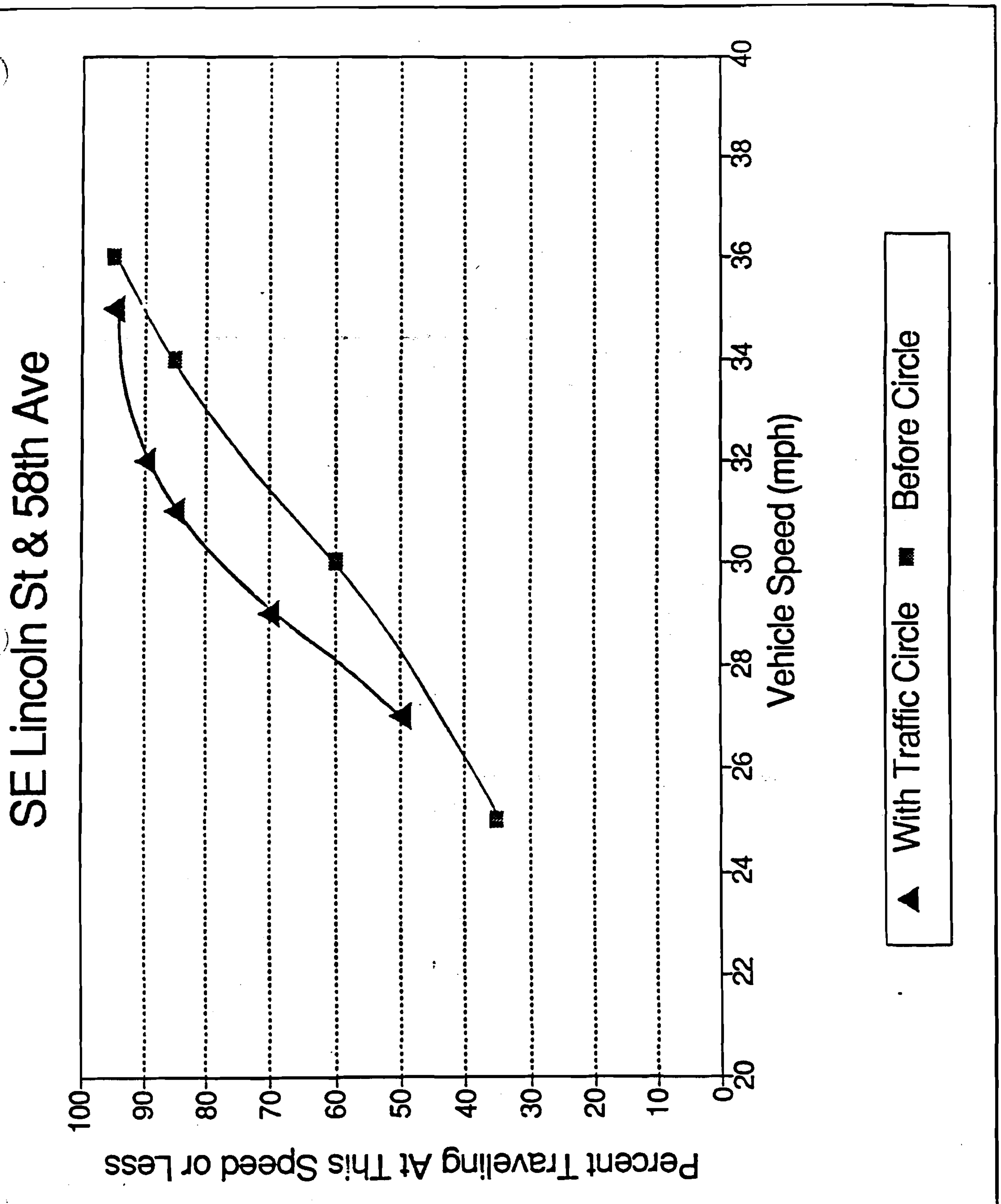
TRAFFIC CIRCLE PEER REVIEW	Figure A9
October 1991	



OVERALL DISTRIBUTION OF VEHICLE SPEEDS NEAR 47TH AVE. & BRAZEE ST. WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A10
October 1991	

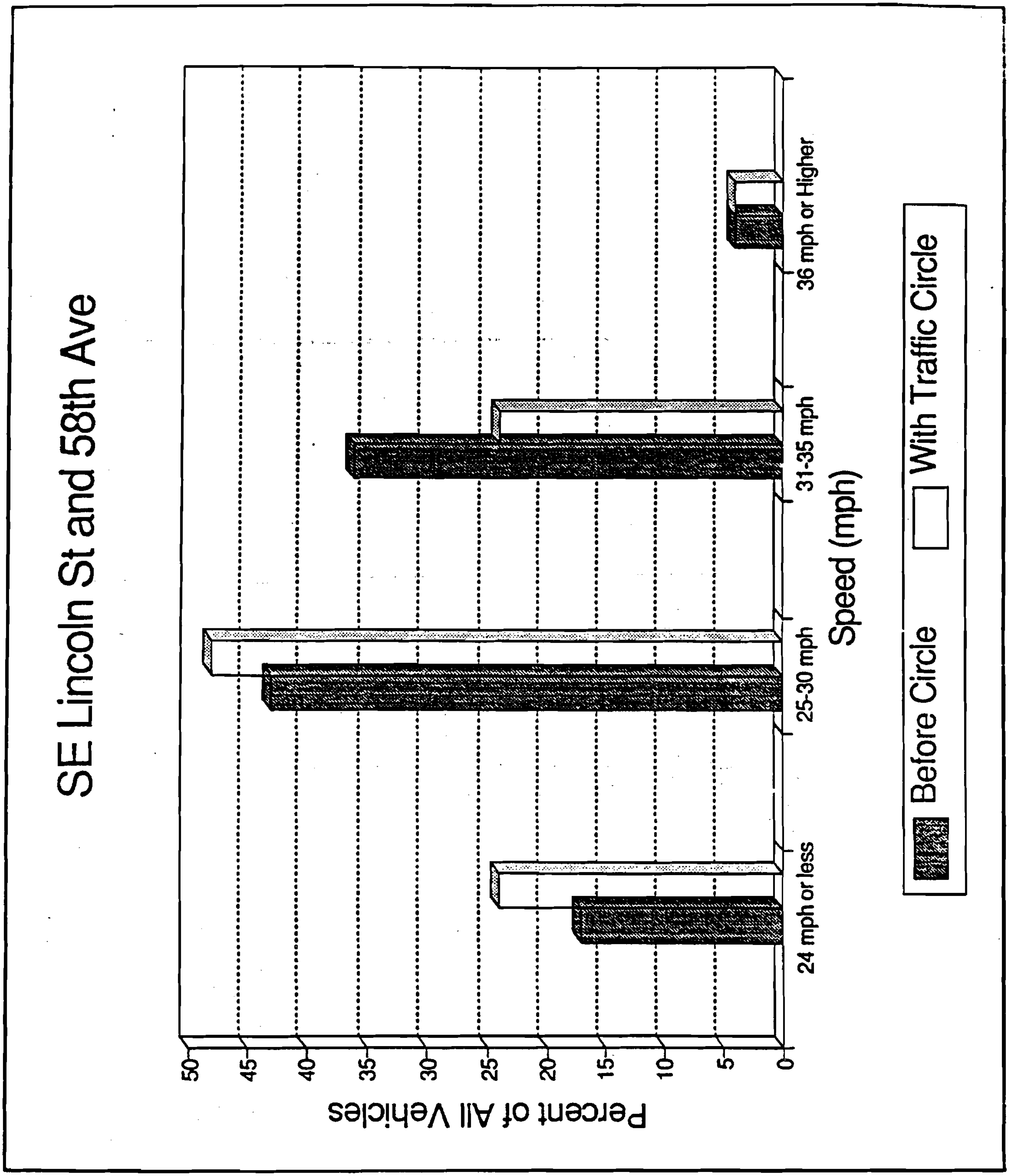
39BFGA10



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS
NEAR S.E. LINCOLN ST. & 58TH AVE.
WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A11
October 1991	

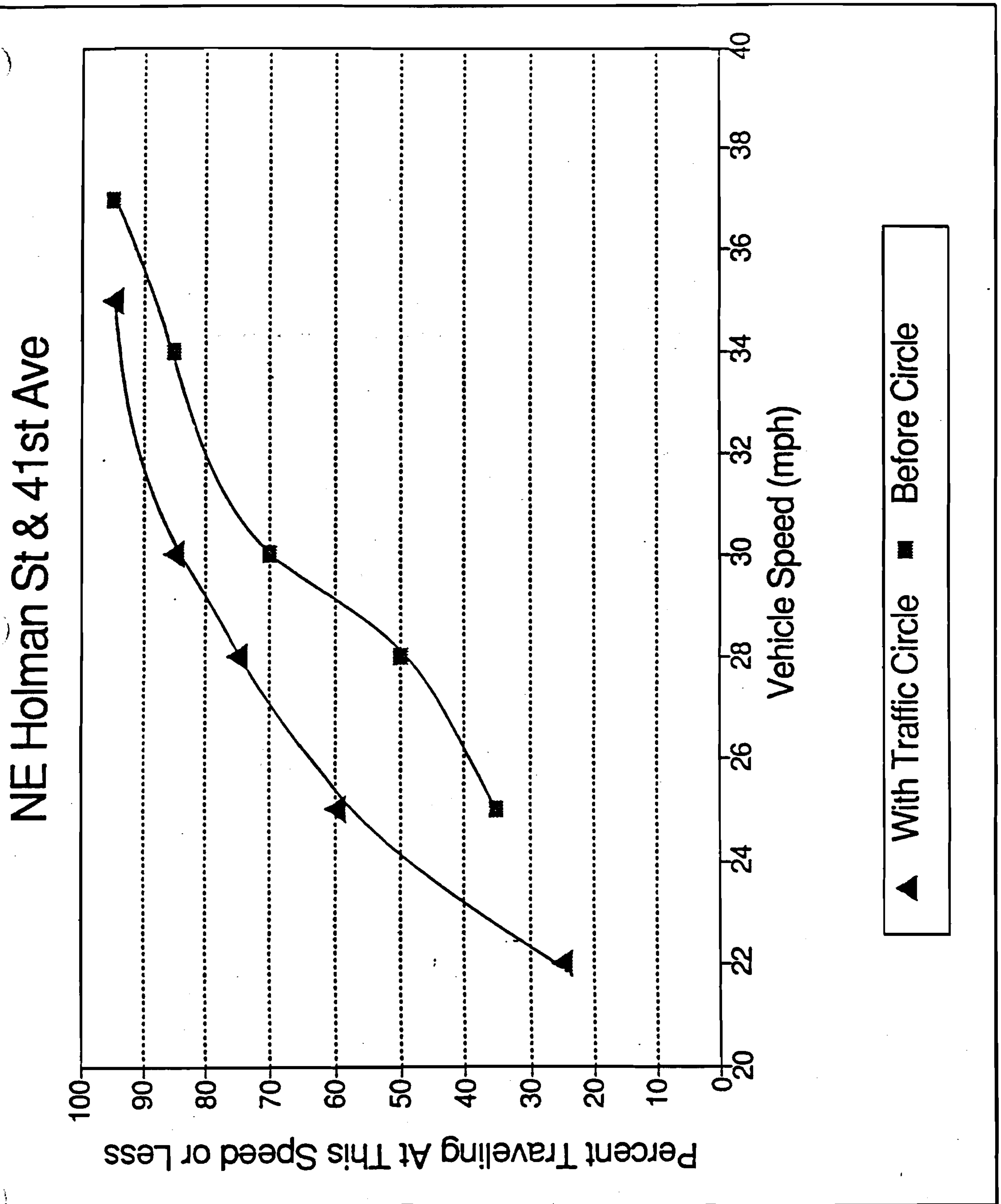
398FCA11



OVERALL DISTRIBUTION OF VEHICLE SPEEDS NEAR S.E. LINCOLN ST. & 58TH AVE. WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A12
October 1991	

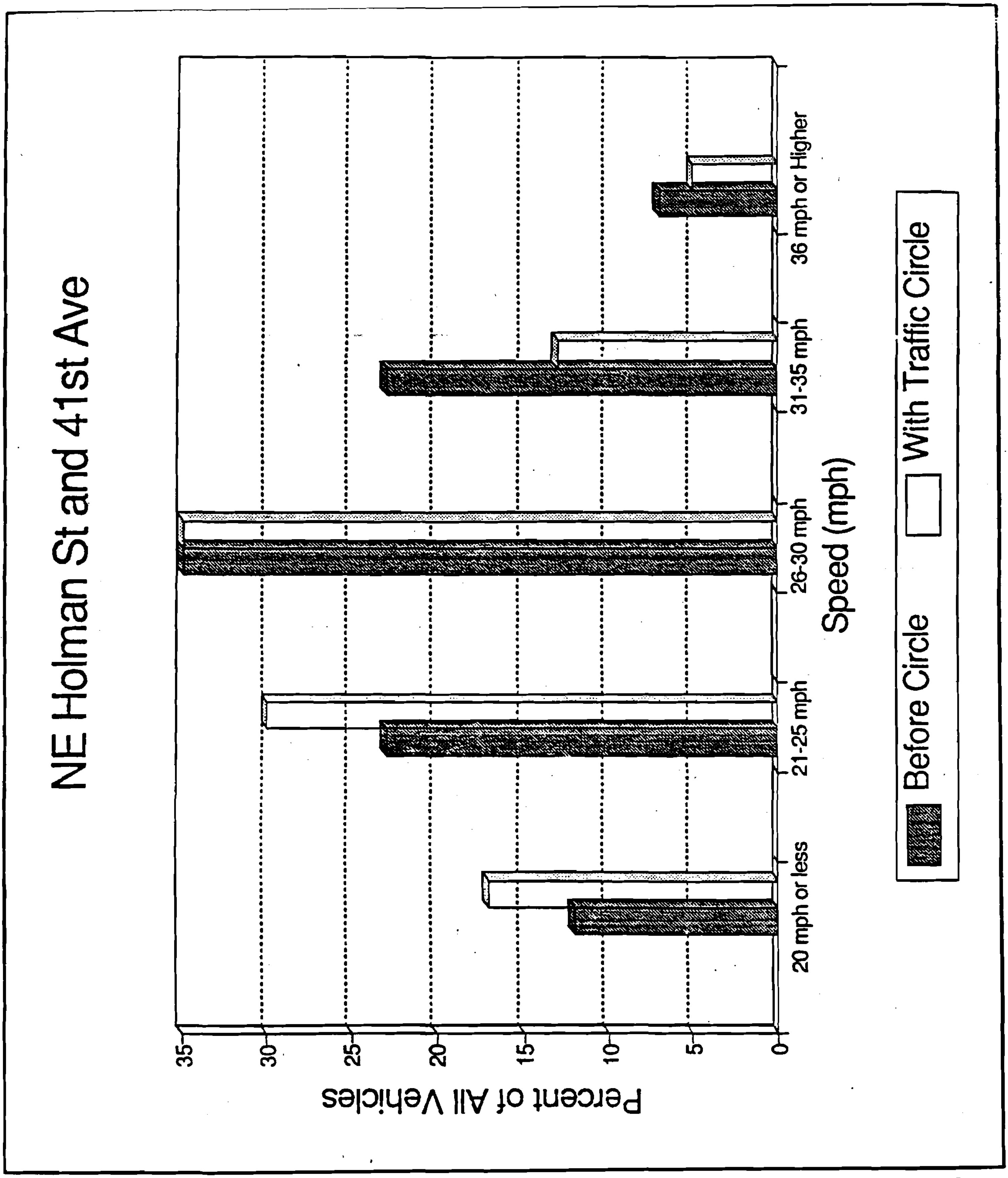
398FGA12



CUMULATIVE DISTRIBUTION OF VEHICLE SPEEDS
NEAR HOLMAN ST. & 41ST AVE.
WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A13
October 1991	

398FGA13



OVERALL DISTRIBUTION OF VEHICLE SPEEDS
NEAR N.E. HOLMAN ST. & 41ST AVE.
WITH AND WITHOUT THE TRAFFIC CIRCLE

TRAFFIC CIRCLE PEER REVIEW	Figure A14
October 1991	

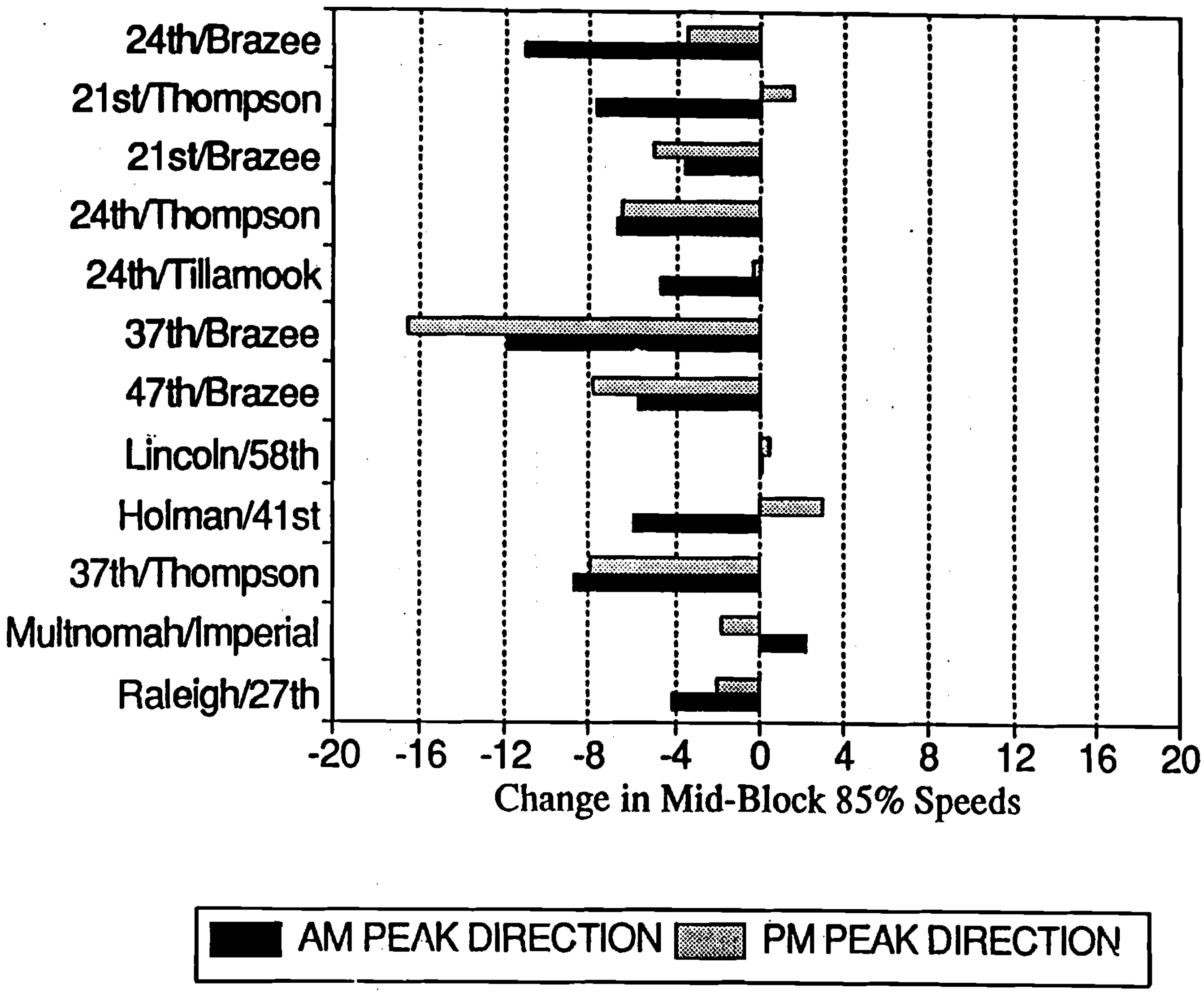
398FGA14

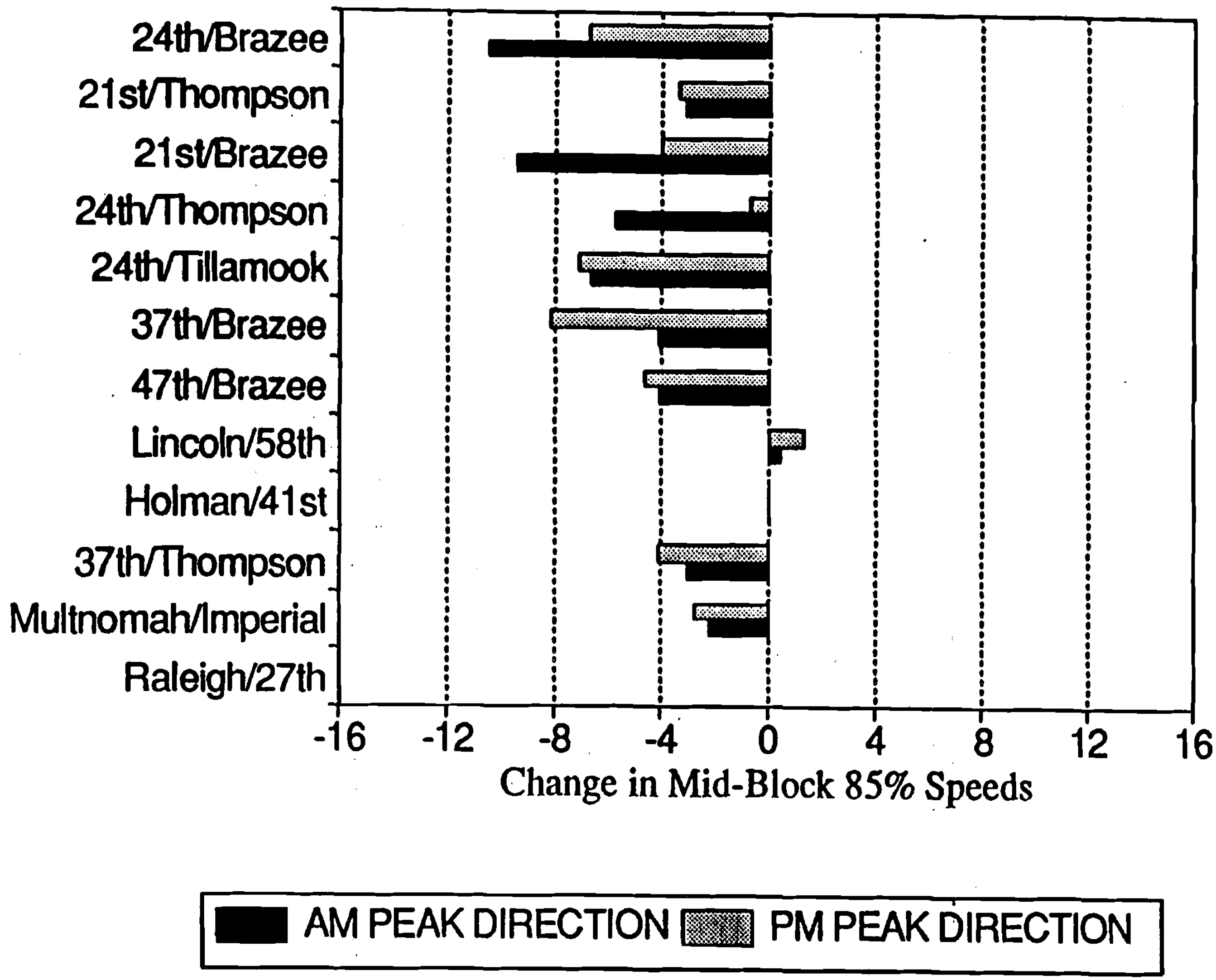
CHANGE IN 85TH PERCENTILE SPEED DURING A.M. PEAK HOUR

TRAFFIC CIRCLE PEER REVIEW

October 1991

Figure A-15



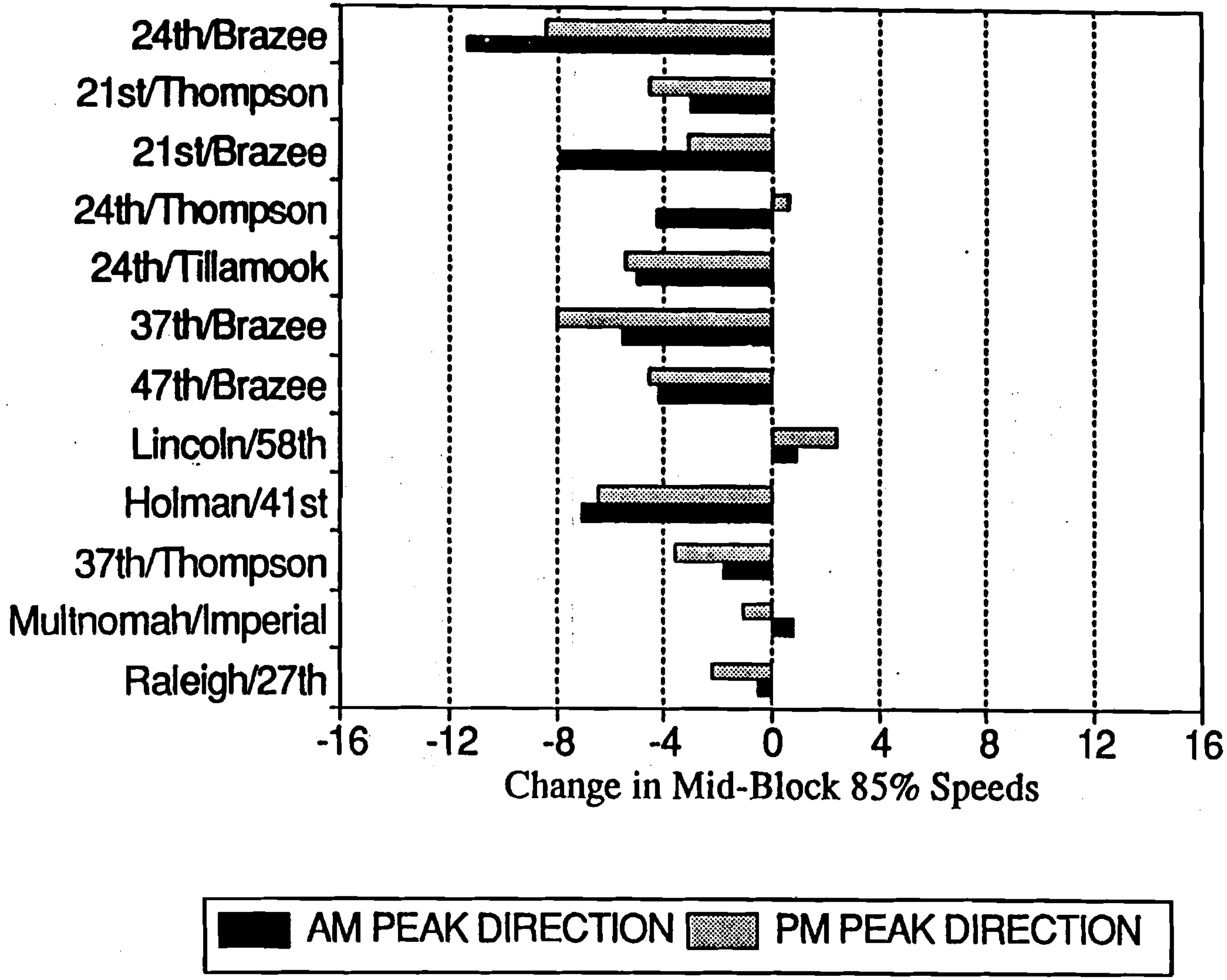


CHANGE IN 85TH PERCENTILE SPEED
DURING MID-DAY HOURS

TRAFFIC CIRCLE
PEER REVIEW
October 1991

Figure
A-16

398A2

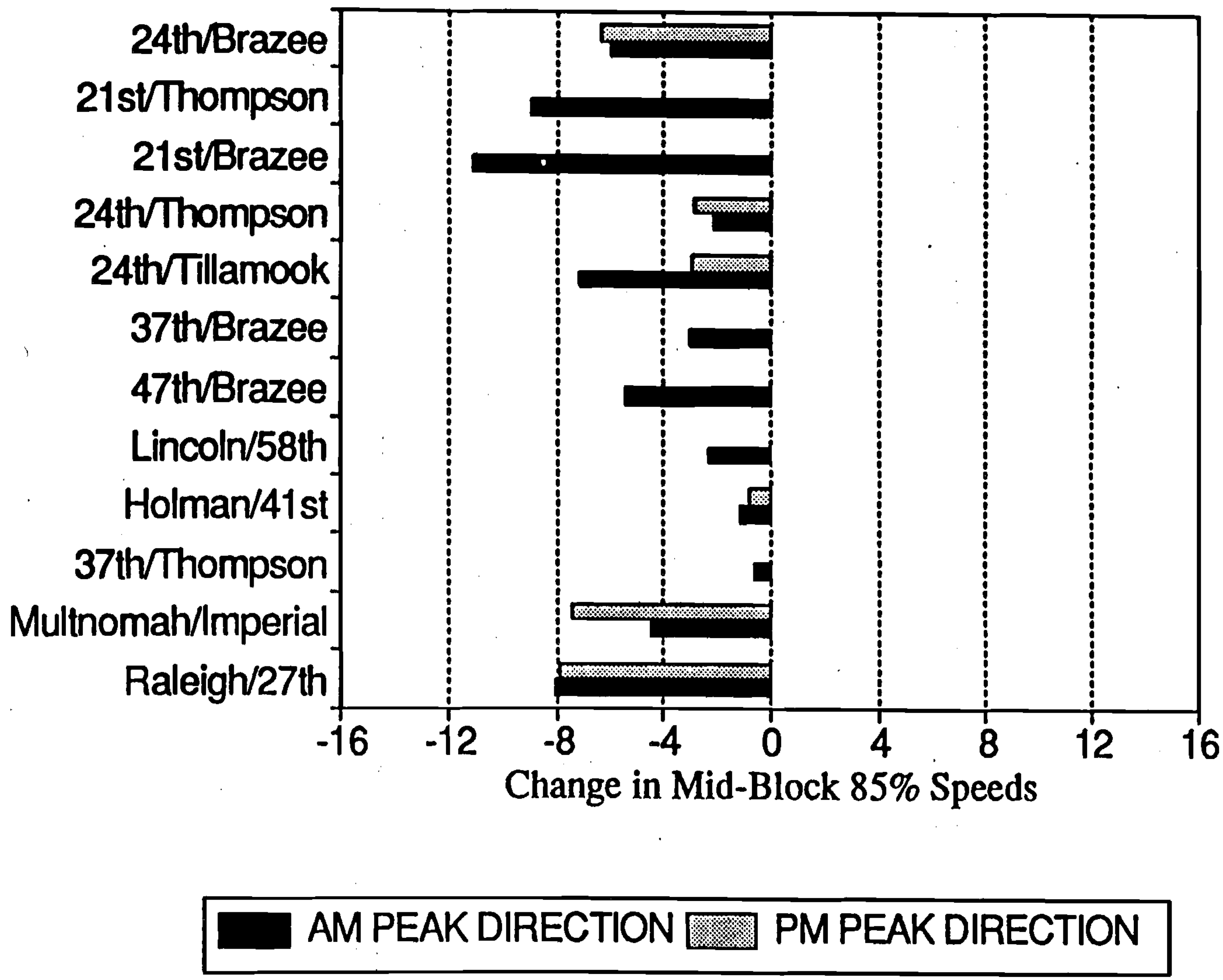


CHANGE IN 85TH PERCENTILE SPEED DURING P.M. PEAK HOUR

TRAFFIC CIRCLE PEER REVIEW

October 1991

Figure A-17



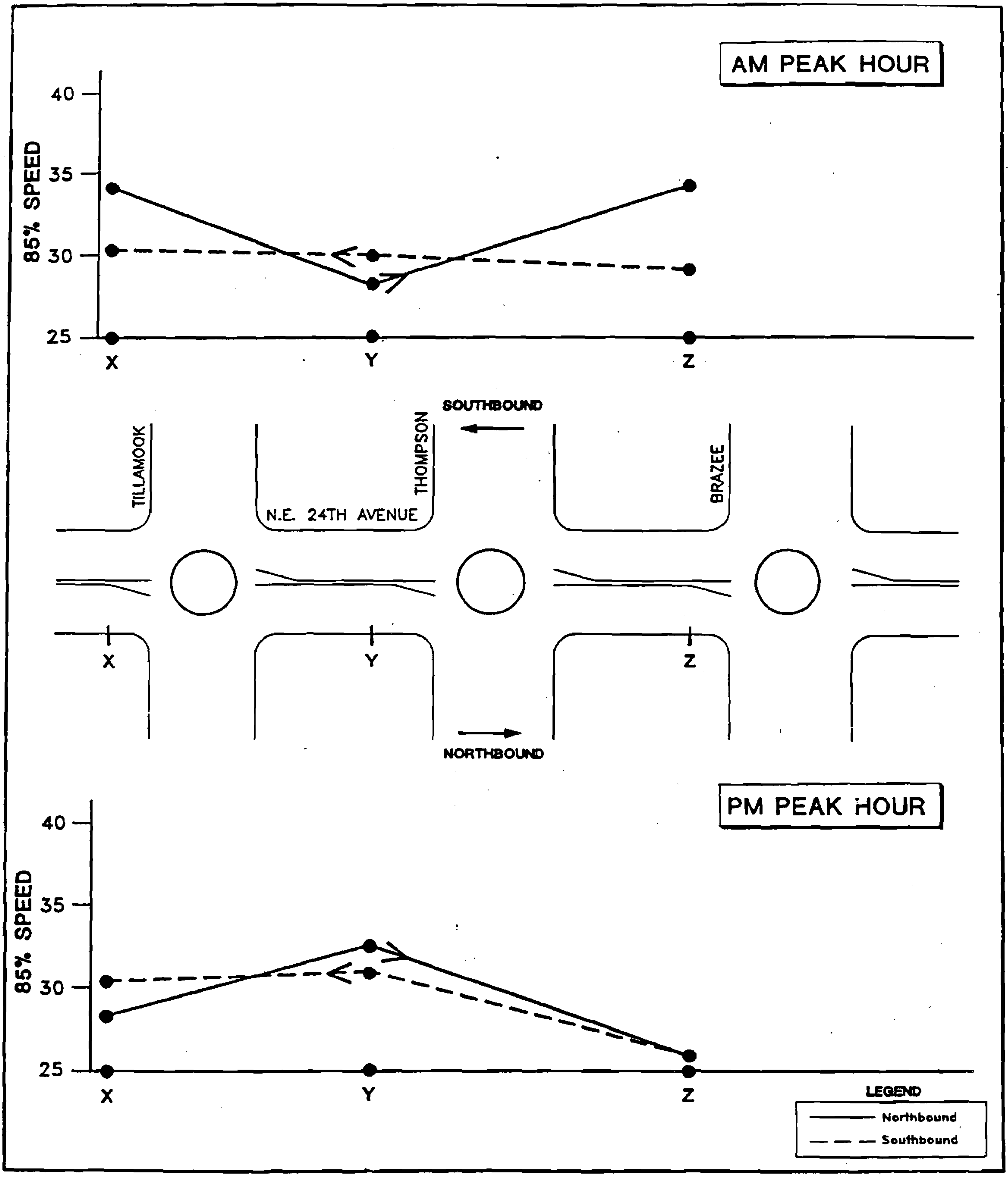
CHANGE IN 85TH PERCENTILE SPEED
DURING NIGHT HOURS

TRAFFIC CIRCLE
PEER REVIEW
October 1991

figure
A-18

APPENDIX B: Results of Corridor Speed Analysis

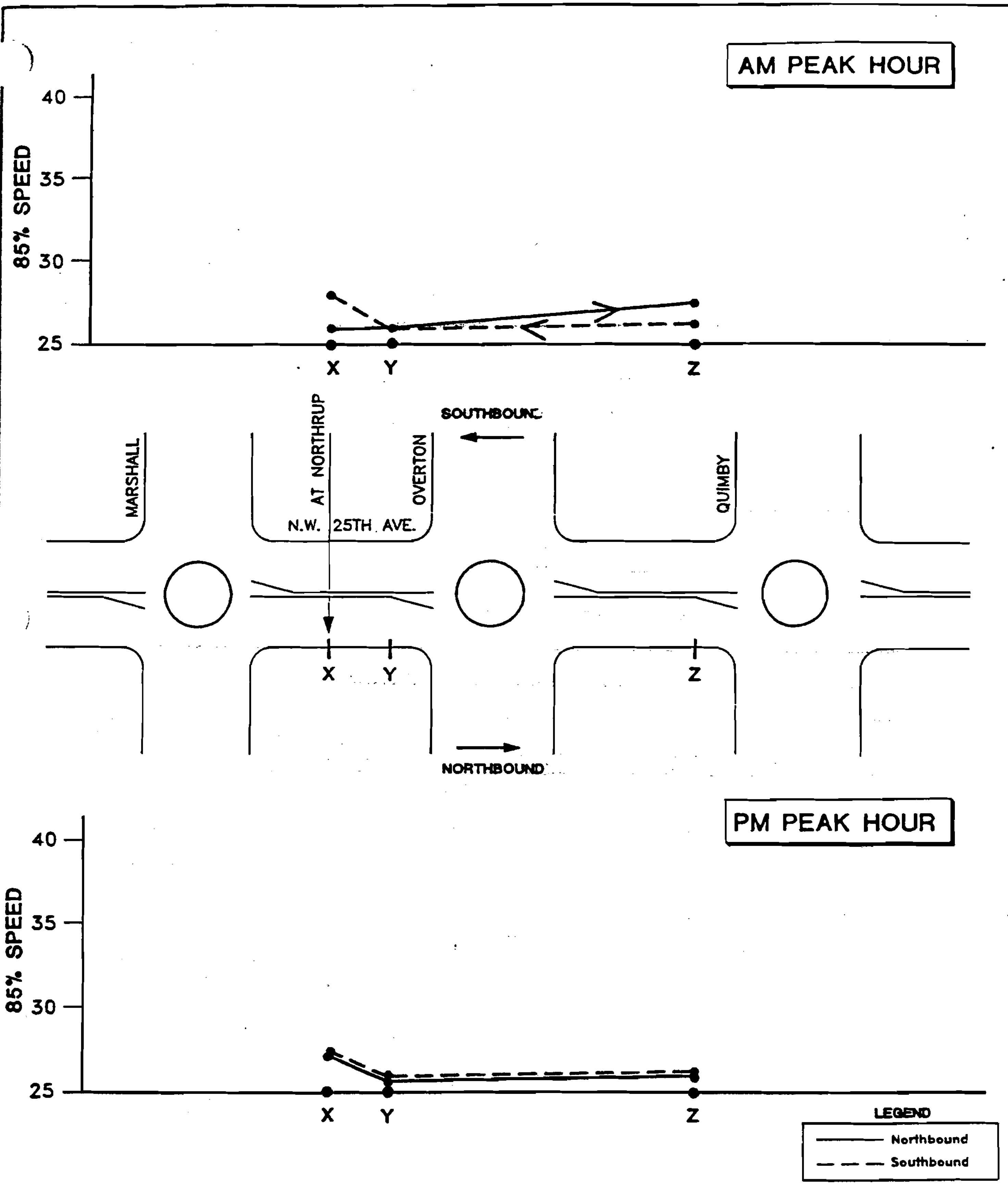
This appendix contains the results of the corridor speed profile analysis for several of the traffic circle corridors where mid-block speed data was available.



N.E. 24TH AVENUE CORRIDOR SPEED PROFILE

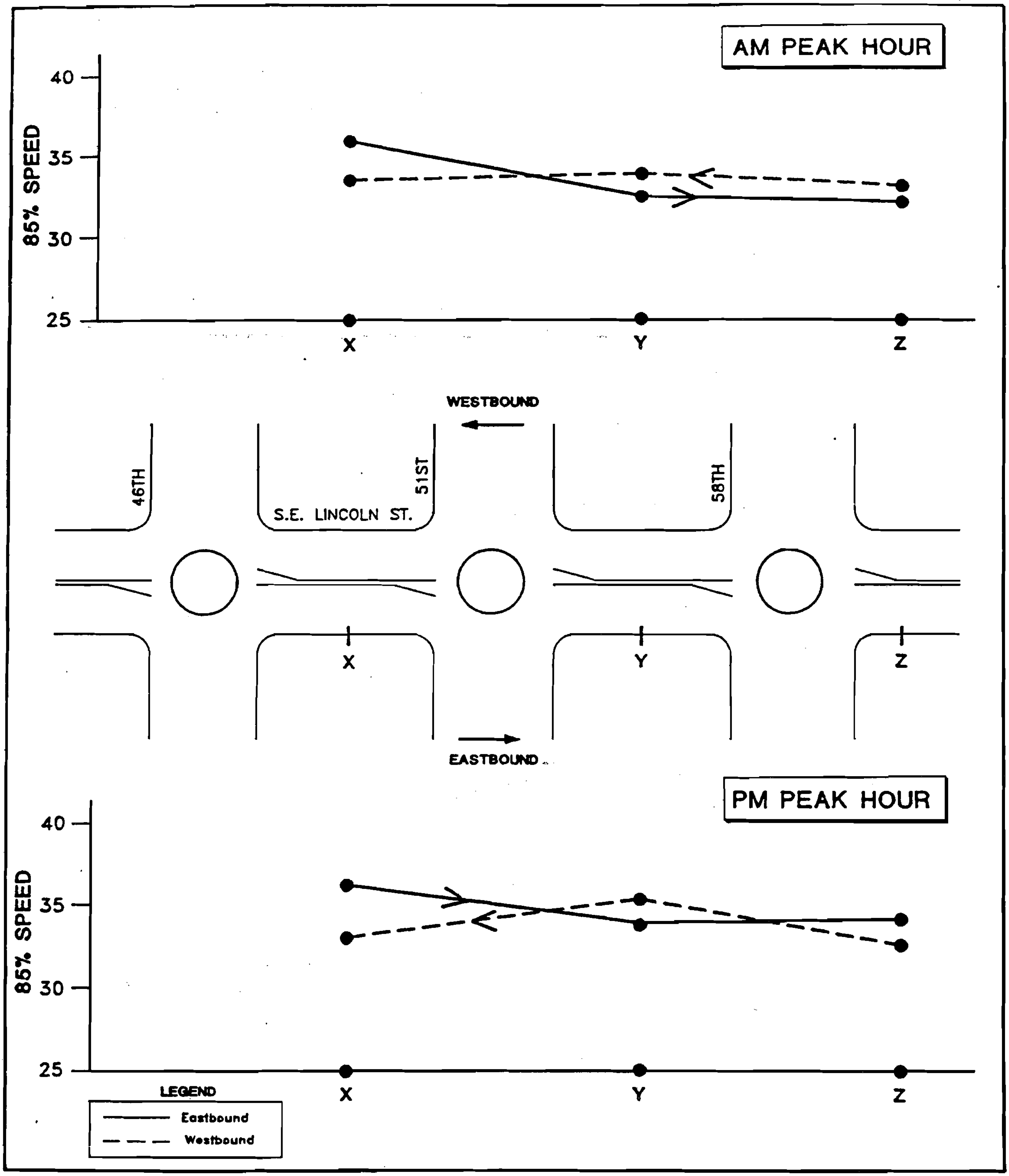
TRAFFIC CIRCLE PEER REVIEW	Figure	
October 1991	B1	

398JAN3



N.W. 25TH AVENUE CORRIDOR SPEED PROFILE

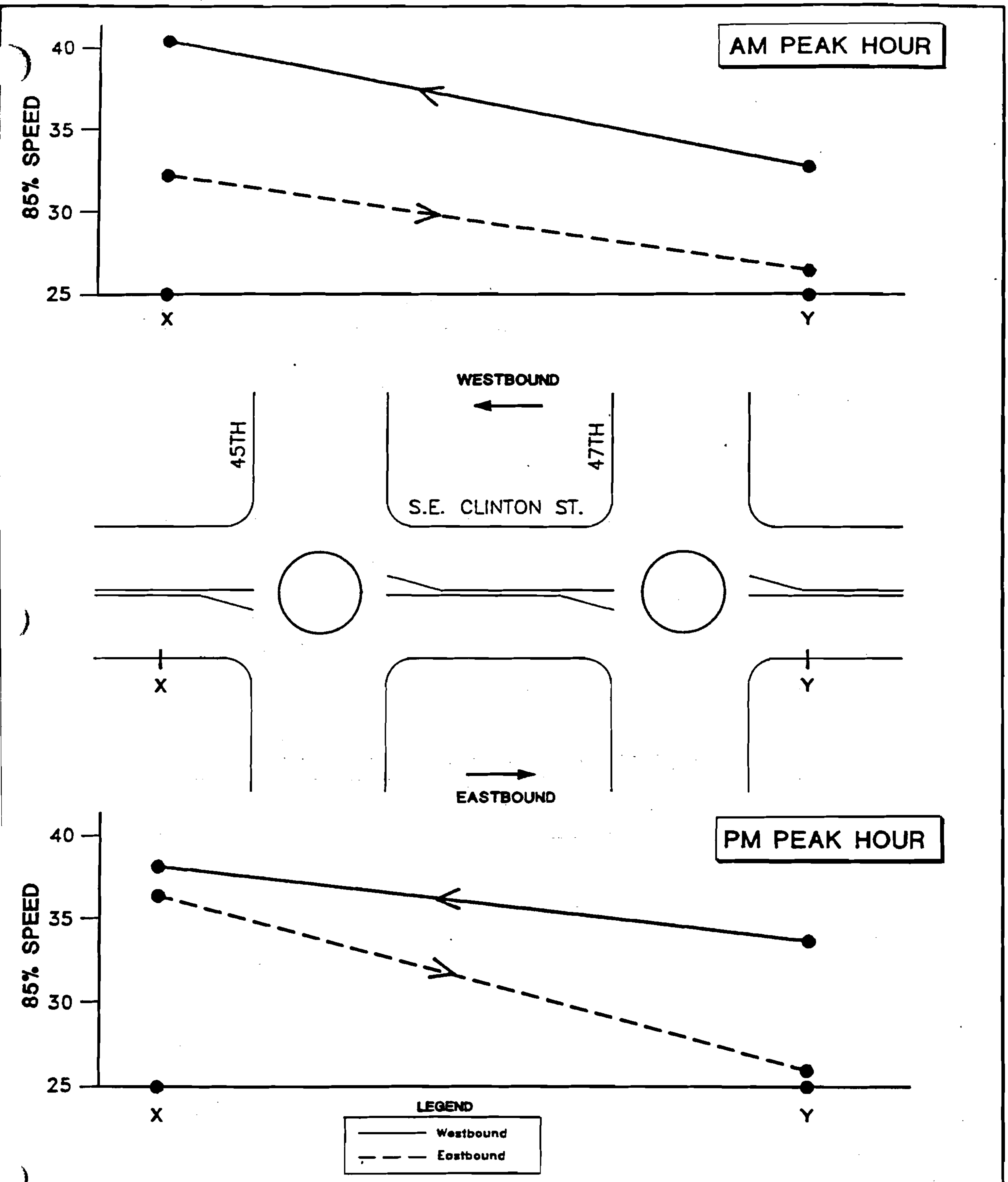
TRAFFIC CIRCLE PEER REVIEW	Figure B 2
October 1991	



S.E. LINCOLN STREET
CORRIDOR SPEED PROFILE

TRAFFIC CIRCLE PEER REVIEW	Figure B 3
October 1991	

398JAN4



S.E. CLINTON ST. (E. OF 39TH)
CORRIDOR SPEED PROFILE

TRAFFIC CIRCLE PEER REVIEW	Figure B4
October 1991	

APPENDIX C: Analysis of Reported Accident at Study and Control Intersections

This appendix contains the results of the analysis of reported accidents at intersections where traffic circles were installed as well as nearby "control" intersections. A few of the isolated traffic circles, such as along Fremont Avenue did not have any reported accidents either before or after the traffic circle was installed.

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles in ***Northwest Portland***

Intersections with Traffic Circles

Accidents Before Installation (7/85- 7/88)= 0.11 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	3	1	0	0

Accidents After Installation (9/88- 12/90)= 0.04 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	1
Multiple Vehicle	0	0	0	0

Nearby Control Intersections

Accidents (7/85- 7/88) = 0.19 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	0	0
Multiple Vehicle	4	0	0	2

Accidents (9/88- 12/90)= 0.29 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	5	2	1	0

Results: Accidents at intersections with traffic circles were *reduced by 64 percent*, even though accidents at the control intersections increased 53 percent.

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along *SE 13th, 14th & 15th Street*

Intersections with Traffic Circles

Accidents Before Installation (8/85- 8/88)= 0.67 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	14	6	4	0

Accidents After Installation (1/89- 12/90)= 0.13 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	2	1	0	0

Control Intersections

Accidents (8/85- 8/88) = 0.47 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	7	5	4	1

Accidents (1/89- 12/90)= 0.58 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	1	0
Multiple Vehicle	6	3	2	1

Results: Accidents at intersections with traffic circles were *reduced by 81 percent*, even though accidents at the control intersections increased 23 percent.

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along *SE Clinton Street*

Intersections with Traffic Circles

Accidents Before Installation (8/85- 8/88)= 0.47 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	10	5	1	1

Accidents After Installation (6/90- 12/90)= 0.14 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	1	0	0
Multiple Vehicle	0	0	0	0

Nearby Control Intersections

Accidents (8/85- 8/88)= 0.31 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	1
Multiple Vehicle	4	4	1	1

Accidents (6/90- 12/90)= 0.14 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	0	0
Multiple Vehicle	0	0	0	0

Results: Accidents at intersections with traffic circles *were reduced by 70 percent*, compared to a 55 percent reduction at the control intersections

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along ***NE Multnomah Street/53rd***

Intersections with Traffic Circles

Accidents Before Installation (7/84- 7/87)= 0.11 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	2	0	0	2

Accidents After Installation (10/88- 12/90)= 0.04 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	1	0	0	0

Too few crashes for a meaningful comparsion with a control group.

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along *NE 21st & 24th Street*

Intersections with Traffic Circles

Accidents Before Installation (9/85- 9/88)= 0.61 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	8	11	1	2

Accidents After Installation (11/89- 12/90)= 0.36 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	0	1
Multiple Vehicle	1	1	0	1

Control Intersections

Accidents (9/85- 9/88)= 0.50 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	3	0	1	0
Multiple Vehicle	12	6	1	1

Accidents (11/89- 12/90)=0.79 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	0	0
Multiple Vehicle	7	3	0	0

Results: Accidents at intersections with traffic circles *were reduced by 41 percent*, compared to a 58 percent increase at the control intersections

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along *NE 37th Street*

Intersections with Traffic Circles

Accidents Before Installation (8/85- 8/88)= 0.19 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	0	0
Multiple Vehicle	5	1	0	0

Accidents After Installation (0/88- 12/90)= 0.03 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	1	0	0	0

Control Intersections

Accidents (8/85- 8/88)= 0.14 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	4	0	1	0

Accidents (1/88- 12/90)= 0.17 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	1	0
Multiple Vehicle	2	1	0	1

Results: Accidents at intersections with traffic circles ***were reduced by 81 percent***, compared to a 21 percent increase at the control intersections

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along *NE Holman Street*

Intersections with Traffic Circles

Accidents Before Installation (8/85- 8/88)= 0.11 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	2	1	0	1
Accidents After Installation (10/88- 12/90)= 0.07 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	0	1	0
Multiple Vehicle	0	0	0	0

Control Intersections

Accidents (8/85- 8/88)= 0.00 per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	0	0	0	0
Accidents (10/88- 12/90)= 0.07 per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	0	2	0	0

Results: Accidents at intersections with traffic circles *were reduced by 36 percent*, compared to a 200 percent increase at the control intersections

Comparison of Changes in Reported Accidents with the Installation of Traffic Circles along ***SE Lincoln Street***

Intersections with Traffic Circles

Accidents Before Installation (8/85- 8/88)= 0.53 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	1	1	0	0
Multiple Vehicle	6	4	2	5
Accidents After Installation (5/90- 12/90)= 0.38 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	1	1
Multiple Vehicle	0	1	0	0

Control Intersections

Accidents (8/85- 8/88)= 0.53 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	10	7	1	1
Accidents (5/90- 12/90)= 0.25 acc. per month				
Type of Accident	Day		Night	
	PDO	Injury	PDO	Injury
Single Vehicle	0	0	0	0
Multiple Vehicle	2	0	0	0

Results: Accidents at intersections with traffic circles ***were reduced by 21 percent***, compared to a 53 percent reduction at the control intersections

APPENDIX D: Report from Illumination Engineer

This appendix contains a copy of the report produced by the illumination engineer retained for this project. After traffic engineers with Kittelson and Associates, Inc. performed an initial night time review of all the traffic circles, they went back to several of the problem sites as well as some good sites with an illumination engineer. This report reflects the findings during this observation. A final night time meeting was held with City of Portland staff, the illumination engineer and the project engineer from Kittelson and Associates to review the findings in this report and discuss other traffic circle night time visibility issues.

engineering, inc.

6415 S.W. Canyon Court • Suite 100 • Portland, Oregon 97221
(503) 297-5676 FAX: (503) 297-8376

September 23, 1991 290.01

MEMORANDUM

TO:	Howard Stein, Kittelson & Associates
FROM:	Gregg H. Scholz, P.E.
SUBJECT:	Night Survey Lighting Analysis of Traffic Circles Northeast Portland
DATE:	July 31, 1991
TIME:	10:00 p.m. - 11:38 p.m.
CONDITIONS:	Partly cloudy/1/2 moon, dry pavement

Description

The traffic circles are approximately 12 - 15 feet in diameter located in the center of a four-way intersection. Circles are formed concrete curbs approximately 6-9 inches high with shrubs and a couple of trees, approximately 15 feet tall. Each intersection has a PGE pole with light approximately 30 feet high - 250 watt high pressure sodium. Streets are lined with full-grown trees, approximately 50-60 feet tall. Analysis of various traffic circles was made by approaching them from several directions.

Data

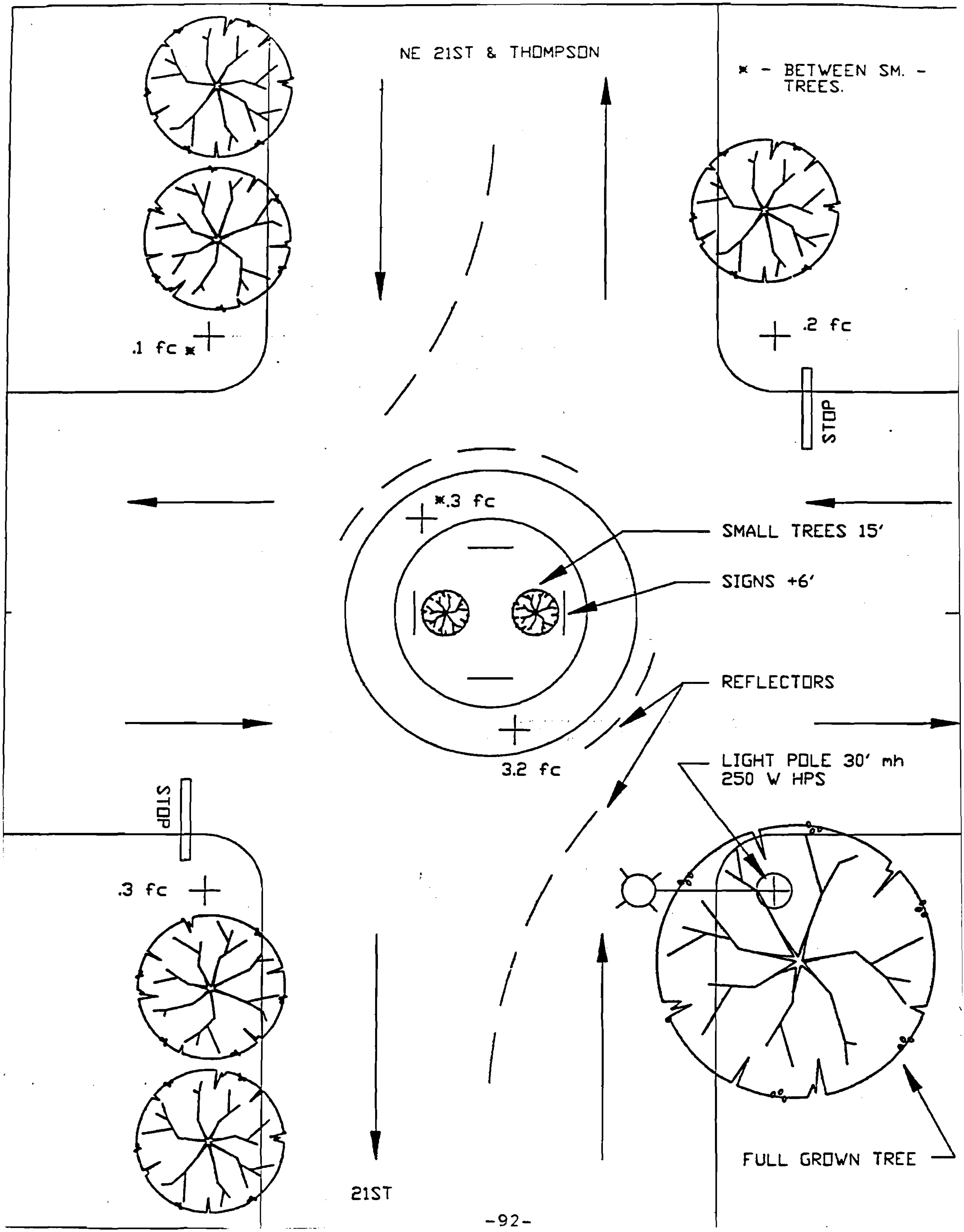
Footcandle readings were randomly taken at several points around the circles (see Sketch A). Readings indicate average values of approximately one footcandle on the side of the circle with a street light. Sides opposite the street light average approximately 0.2 footcandles. These values are in accordance with established City of Portland standards and IES recommendations of 0.2 footcandles.

When approaching the circle in a vehicle with street light on the approach side of the circle, the circle, traffic sign and reflectors are well defined by ambient light. When approaching the circle with street light in back of the circle, the circle appears as a dark object in the roadway. Traveling at the posted speed of 25 mph, the circle, sign and reflectors are defined by automobile headlights approximately 75 feet prior to the circle.

Conclusion

At the traffic circle intersection at 21st and Thompson, full-grown trees are obstructing the street light. These trees need to be pruned to improve light levels and visibility at night and to satisfy requirements established by City of Portland Bureau of Traffic Management Policy and Procedure Manual Paragraph STL-202.

The trees that were planted in the middle of the traffic circles, although they provide good definition of the circle, obstruct the street light and cause shadows behind the circle which diminish the definition of the circle. These trees should be replaced with shrubbery that will not hinder the lighting but will still provide good definition of the circle and allow pedestrian visibility.


NE 21ST & THOMPSON
* - BETWEEN SM. - TREES.
.1 fc *
.2 fc
STOP
*.3 fc
SMALL TREES 15'
SIGNS +6'
REFLECTORS
3.2 fc
LIGHT POLE 30' mh
250 W HPS
STOP
.3 fc
FULL GROWN TREE
21ST