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IMPROVED SIGNING FOR TRAFFIC CIRCLES

Final Report

By

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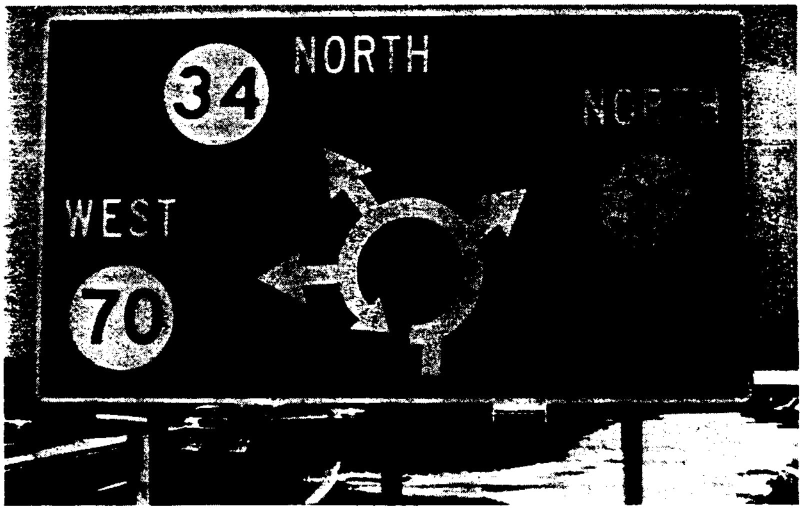
Principal Engineer



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16. Abstract
The objective of this project was to develop new guidance signing for traffic circles. The measure of effectiveness (M.O.E.) which seemed the most feasible for use in determining the effectiveness of the new guidance signing was the percentage of drivers who made the preferred maneuvers. The preferred maneuvers were determined on the basis of safety and efficiency. The percentage of vehicles who made the preferred maneuvers was measured for both before and after sign change conditions and compared to determine the effectiveness of the new signing.

Traffic studies were conducted at 5 circles; 3 of which were regular and 2, cut-through. Diagrammatic signs were tested at the 3 regular circles and 1 of the cut-through circles. A modified stack sign was tested at the other cut-through circle.

Diagrammatic signing was found more effective than conventional signing in reducing driver confusion at regular circles. Diagrammatic signing was also found more effective than conventional signing in reducing driver confusion at cut-through circles for left and right turning movements. No advantage could be shown for modified stack signing over conventional signing.

Diagrammatic signs were recommended for use at both regular and cut-through circles. Specifications and photos of the diagrammatic signs recommended are included in the report.

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Traffic Circle, Signalized Intersection, Traffic Parameters

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THE CONTENTS OF THIS REPORT REFLECT THE VIEWS OF THE AUTHOR WHO IS RESPONSIBLE FOR THE FACTS AND THE ACCURACY OF THE DATA PRESENTED HEREIN. THE CONTENTS DO NOT NECESSARILY REFLECT THE OFFICIAL VIEWS OR POLICIES OF THE NJ DEPARTMENT OF TRANSPORTATION OR THE FEDERAL HIGHWAY ADMINISTRATION. THIS REPORT DOES NOT CONSTITUTE A STANDARD, SPECIFICATION, OR REGULATION.

SUMMARY AND CONCLUSIONS

The objective of this project was to develop new guidance signing for traffic circles to lessen driver confusion and thereby improve safety and traffic flow. The measure of effectiveness (M.O.E.) which seemed the most feasible for use in determining the effectiveness of the new guidance signing was the percentage of drivers who made the preferred maneuvers. The preferred maneuver was determined on the basis of safety and efficiency. The percentage of vehicles making the preferred maneuver was measured for both before and after sign change conditions and compared to determine the effectiveness of the new signing.

Traffic studies were conducted at five circles; three of which were regular and two, cut-through. Diagrammatic signs were tested at the three regular circles and one of the cut-through circles. A modified stack sign was tested at the other cut-through circle. The specific conclusions reached from these investigations follow:

1.) Diagrammatic guidance signing was more effective than conventional signing in reducing driver confusion at regular circles. 70% of all morning and afternoon periods studied showed an increase in preferred maneuvers after sign installation.

2.) Diagrammatic guidance signing was more effective than conventional signing in reducing driver confusion for left and right turning movements at cut-through circles. Results for through movements were mixed. However overall results for all movements indicated an advantage for diagrammatic signing over conventional signing.

3.) Study results were inconclusive as to the increased effectiveness of modified-stack signing over conventional signing at cut-through circles.

IMPLEMENTATION STATEMENT

Based on the previous conclusions, the Division of Research and Demonstration makes the following implementation recommendations:

1.) Use of diagrammatic guidance signs at regular circles is recommended. These signs would be particularly effective at circles with a high-percentage of unfamiliar drivers.

2.) The diagrammatic sign should be located on the circle approach as the third sign in a progression after the circle warning sign and the standard junction sign.

3.) Use of diagrammatic guidance signs is recommended at cut-through circle intersections.

4.) The diagrammatic sign at cut-through circles should be located on the circle approach following the standard junction sign.

INTRODUCTION

In 1925, New Jersey became the first state to develop and construct traffic circles. Various other states and cities soon followed their lead. Today, some 70 of these are still in operation in this state, with an unknown number scattered across the country. Traffic circles worked well when used by the lower volume, lower speed traffic they were originally designed for, but with the growth of traffic over the years, they have become less effective. Improving circle effectiveness has often required major changes, such as cutting through the circle and signalizing the resulting intersections. However, in some instances improvement in traffic conditions at circles may also be gained by minor, less expensive changes, such as an improvement in the motorist information system.

Traffic circles, by their nature, create irregular traffic patterns, characterized by continuous vehicle weaving and lane changing, attended by a large variance in vehicle speeds. Because of this, circles represent a potential source of confusion to the driver. Improvement of guidance signing used at traffic circles would lessen confusion and allow the driver to concentrate more fully on driving tasks, thereby increasing safety at circles.

An HRIS search turned up 112 articles. However, most of the articles found concerned either the design of traffic circles or the calculation of capacity for traffic circles; neither of which was pertinent to this study. Only six articles were found that address the topic of either guidance signing at circles or measures of effectiveness useful for analyzing traffic flow at circles.

Two of the three articles concerning guidance signing described a study which compared two improved methods of signing (diagrammatic versus modified stack) with each other.(1,10) However, no comparison was made between the improved signing and conventional signing. The third article was an analysis of the effect of diagrammatic signing on traffic at one circle in Washington, DC.(4) This analysis used a driver survey rather than MOE's to determine sign effectiveness.

In regard to measures of effectiveness, two of the articles found were concerned mainly with vehicle paths through circles, which eventually became the major MOE used in this study. (15,16) The other one was a study of the use of traffic conflict techniques to assess the safety of road design elements. This article contained some information about the use of this technique at a mini-roundabout (small circle). Although several articles addressed some pertinent aspects, the fact remains that very little work has been done concerning guidance signing at traffic circles.

STUDY PROCEDURES

A. Measures of Effectiveness

Because of the unique characteristics of traffic circles, many of the usual traffic parameters used as measures of effectiveness (MOE's) are not useful, applicable or easily measured. Examples of this are conflicts and braking, which because of the traffic conditions are very frequent while being for the most part unrelated to driver confusion. For this reason, it was necessary to identify viable parameters in the early stages of this study for later use as MOE's.

Results from an initial period of observation of traffic circle operation indicated that MOE's based on deviations from preferred paths of travel, erratic maneuvers and a speed survey would be the most useful for determining change in the level of driver confusion at a circle. These parameters could be easily measured and a sufficient amount of individual movements obtained without an extended amount of data collection. An explanation of the specific parameters used follows. A fuller account of the development process which led to the MOE's can be found in Appendix A.

1. Paths of Travel

Specific parameters obtained from the overall classification of deviations from preferred paths of travel seemed to hold the most potential for use as MOE's. Since every vehicle exiting the circle could be classified either as deviating or non-deviating from a preferred path, a sufficient number of individual movements could be observed to provide an ample data base on which to draw conclusions.

In order to develop specific parameters in this area, it was first necessary to describe preferred paths of travel on a circle. The preferred path of travel was defined as that path which would minimize potential conflicts with other traffic streams. For example the preferred maneuver for exiting vehicles would be a "lane 2 exit." For traffic entering the circle, this maneuver would entail potential conflict with only one other traffic stream (circulating traffic exiting) whereas a "lane 1 exit" entails potential conflict with two other traffic streams. In the same way it can be shown that the preferred maneuver for vehicles continuing around (through) the circle would be a "lane 1 through." Figure 1 shows the typical preferred path of travel for exiting and thru maneuvers for both entering and circulating traffic.

In the case of cut-through circles, specific parameters obtained from the overall classification of deviations from preferred paths of travel also seemed to hold the most potential for use as MOE's. Cut-through circle describes a circle where the major road entering the circle has been continued through the circle central island producing two at-grade signalized intersections at the points where this road crosses the original circle. (See Figure 2) Since typically, the approaches to the two signalized intersections at cut-through circles are striped as normal, at-grade inter-

FIGURE 1

PREFERRED PATHS OF TRAVEL

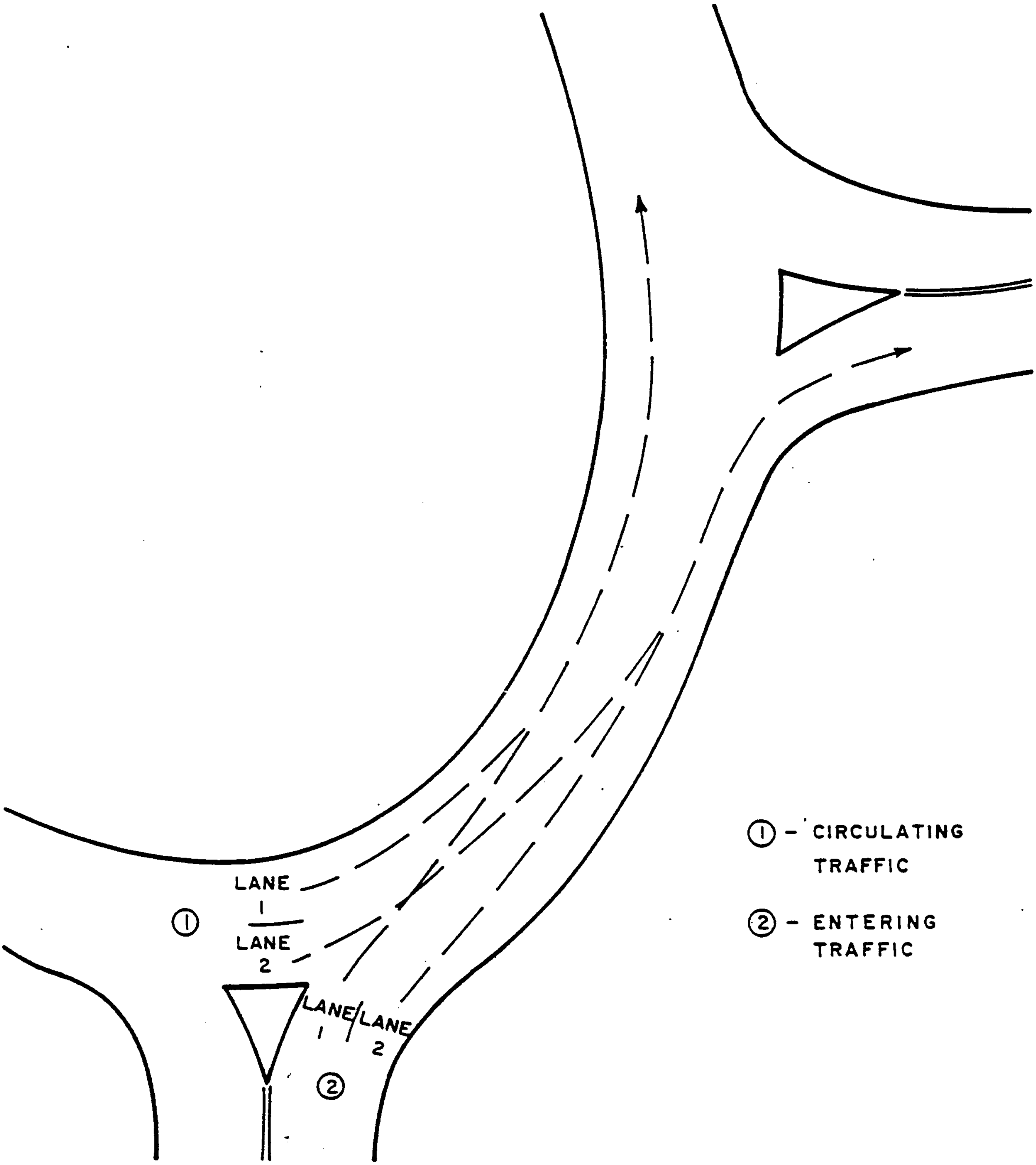
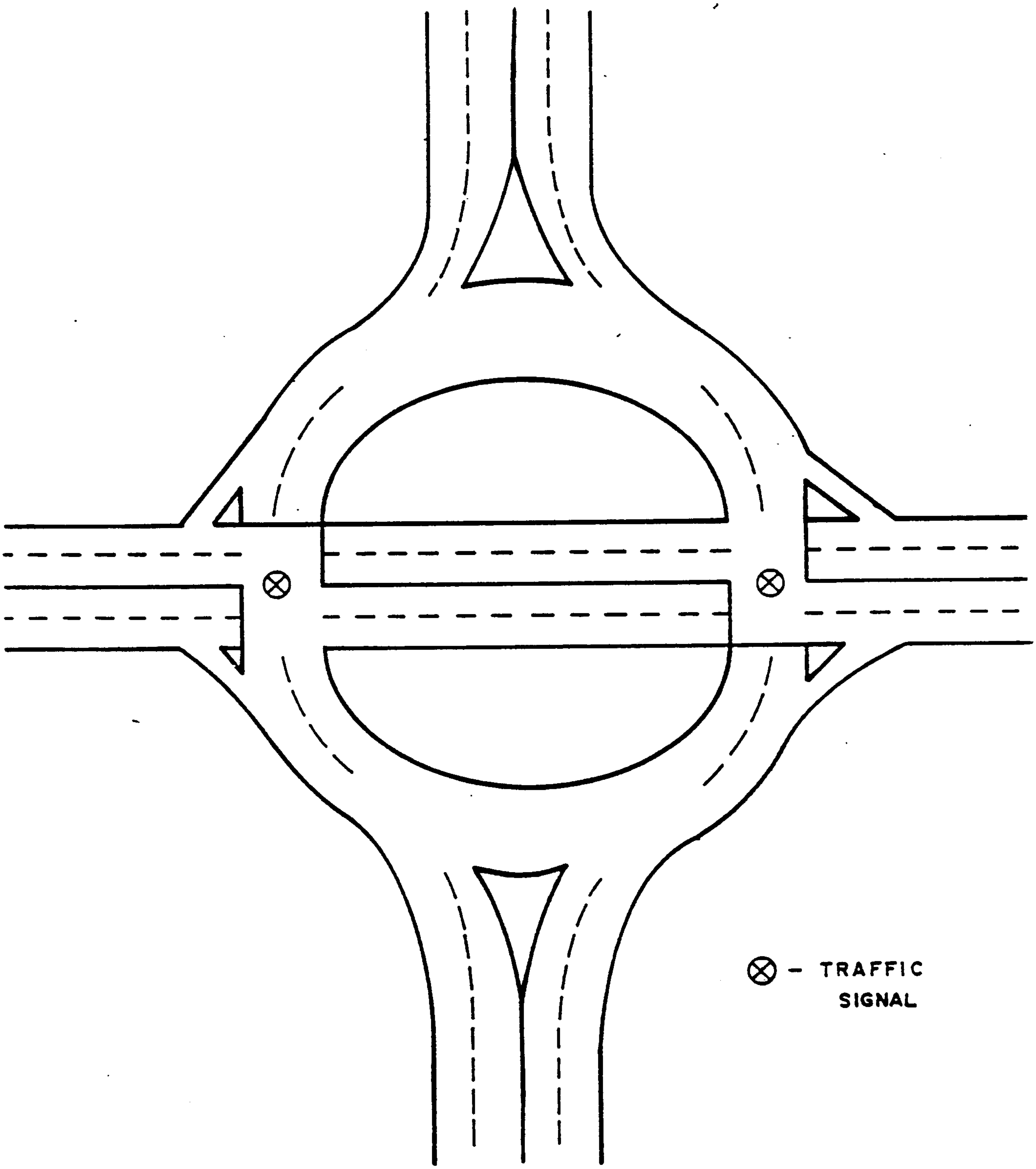


FIGURE 2

TYPICAL CUT-THROUGH CIRCLE DESIGN

IN NEW JERSEY



sections, the specific parameters can be defined in terms of lane use at these intersections. This allows observation of the traffic lanes on the approach to be used in determining percentage of preferred maneuvers. Again as with preferred maneuvers at regular circles, the preferred maneuvers were defined as those maneuvers which minimize potential conflicts with other traffic streams. The preferred maneuvers chosen for each type of movement were: for right turns, a right turn through the slot rather than at the intersection; for through movements, a right lane rather than left lane through, and for left turns a left turn at the intersection rather than around the circle.The chosen preferred maneuvers would have the benefit of allowing the left lane for left turns while freeing up the right lane for through movements. A left turn at the intersection rather than around the circle was chosen because it is a simplier maneuver to make and left turns around the circle cause problems at the opposite intersection since the left turning motorist must cross two lanes of opposing traffic to complete his move. Figure 3 depicts what the preferred movements at a typical cut-through circle intersection would look like.

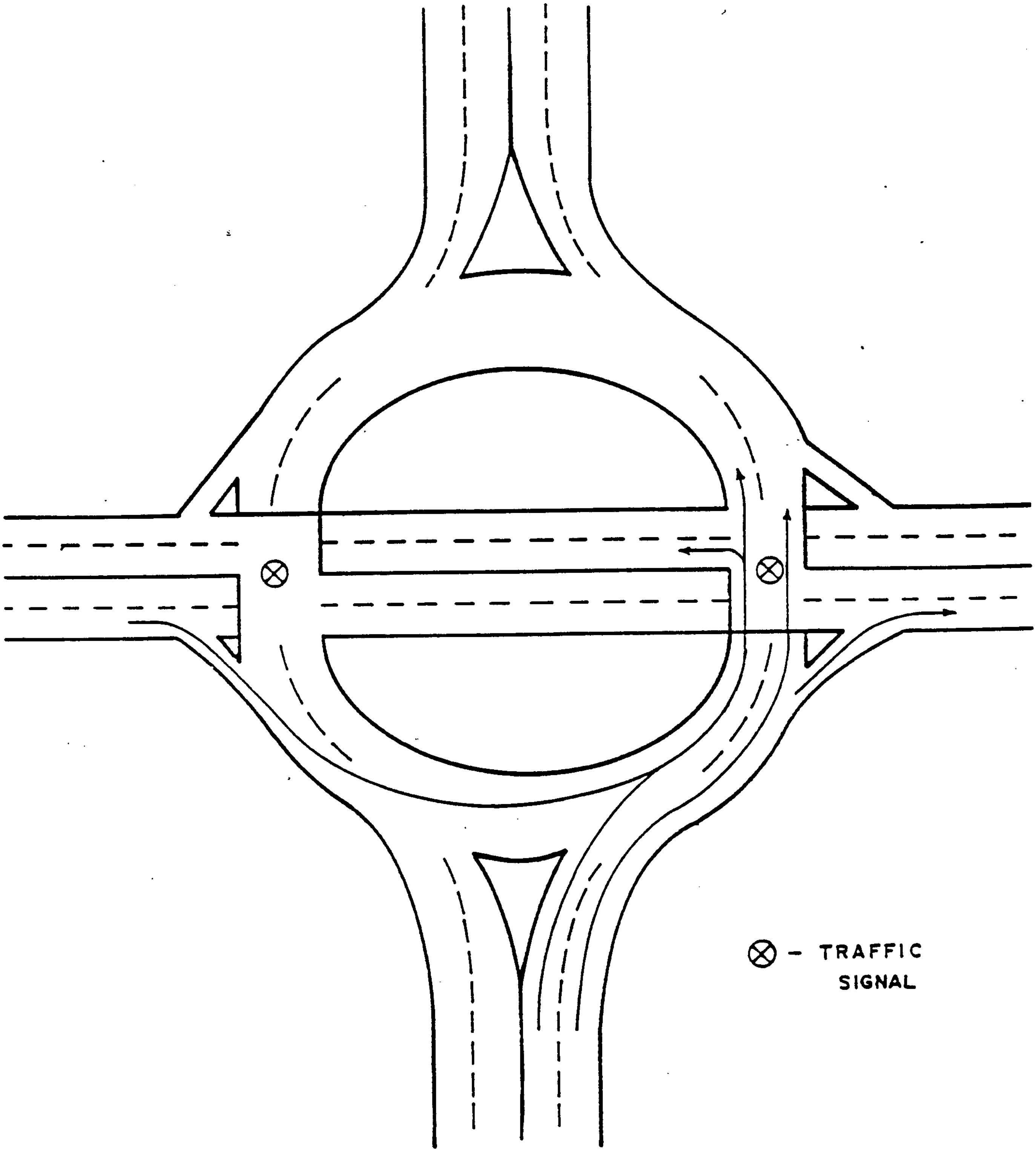
In the case of both regular and cut-through circles comparisons can be made between the before and after percentages of preferred maneuvers to determine the effect of the new signing.

2. Erratic Maneuvers

Erratic maneuvers which occur at circles and could be used for MOE's include vehicles backing up on a leg of the circle after having exited the circle, vehicles stopping in front of physical gores to read guide signs, vehicles U-turning on the circle approaches, either in the roadway or through adjacent properties, and vehicles making sudden exiting moves.

FIGURE 3

PREFERRED LANE MOVEMENTS



The erratic maneuvers found at regular circles, are also found at cut-through circles. In addition to these, however, other types of erratic maneuvers can also be seen. Abrupt lane change maneuvers both on the approach and in the intersection itself are examples of these erratic maneuvers. However, at both regular and cut-through circles, these types of erratic maneuvers are still fairly rare occurrences.

3. Spot Speed Survey

One of the more potentially hazardous characteristics of the irregular traffic patterns at traffic circles is the variance in speeds of vehicles on the circle itself. While most of this variance is due to a motorists natural caution when faced with irregular patterns, some of this can also be attributed to driver confusion since the unfamiliar driver must proceed more slowly and cautiously in order to deal with traffic while still attempting to find his exit off the circle.

By taking a spot speed survey of the traffic on the circle, the effect, if any, of the improved guidance signing on speed variance can be seen. A decrease in speed variance would provide potentially safer conditions at traffic circles.

The geometry of a cut-through circle however makes a spot speed survey of little use as an MOE at cut-throughs. Since the intersections are typically signalized, the speeds of vehicles are controlled, while vehicle speeds on the cut-through road are unaffected by either circle geometry or maneuvers. For this reason, spot speed surveys were not utilized as MOEs at cut-through circles.

B. Site Selection

A guideline consisting of four criteria was set up for the purpose of determining test sites for guidance signing. The four criteria were:

1. The traffic circle should be expected to have a significant number of unfamiliar drivers.
2. The approaches to the circle should be state highways, if possible.
3. The circle should have high weaving volumes.
4. There should be some evidence of driver confusion which is susceptible to correction by improved guidance signing.

Also considered in the selection process was the possibility of reconstruction work on the circles in the near future. During this selection process, contact was kept with the Bureau of Traffic Engineering to obtain their input and concurrence with the sites finally selected.

Using these guidelines, five circles were selected as test sites --three of which are regular circles and two cut-through circles. The three regular circles are Lakehurst (NJ 70 & NJ 37), Brielle (NJ 34, NJ 35 & NJ 70), and Freehold (US 9 and NJ 33). The two cut-through circles are Marlton (NJ 70 & NJ 73) and Livingston (NJ 10 & Eisenhower Parkway). The physical layouts for the selected circles can be seen in Appendix C.

The first two circles, Brielle and Lakehurst, are located on major routes leading to New Jersey shore resort areas. These circles, particularly during the summer months, experience heavy recreational traffic headed to and from the New Jersey shore. It was assumed that a good percentage of this traffic is composed of drivers who are unfamiliar with these circles.

The third of the regular circles, Freehold, has Freehold Raceway located just off the circle on one of its legs. This could account for a fair volume of drivers who are expected to be unfamiliar with this circle traveling through the circle.

In the cases of both the Brielle and Lakehurst circles, all of the approaches to the circles are state highways, while at Freehold, four out of the five are state highways.

The Marlton circle is a good representative of the typical cut-through design presently in use. The Livingston Circle, although exhibiting a typical cut-through design, is a five-legged circle. However, since other circle cut-throughs anticipated in the future include several circles which have more than four legs, it was decided to include Livingston circle as a test site.

At both of these cut-through circles, as at all three of the regular circles chosen, driver confusion was apparent from on-site observations.

The basic sign design settled upon for use at regular circles was a diagrammatic sign similar to those used at traffic circles in the United Kingdom. Modifications however, were needed to conform with United States usage and standards. Signs used at the three regular circles can be seen in Figures 4 a, b, and c. Final design specifications for these signs are listed in Appendix B, along with an account of the development process which led to the final design.

In the case of the cut-through circles two different designs were tested diagrammatic and modified stack. There were several reasons for this decision; the most important being a size limitation imposed by limited R.O.W. The size of sign required for use of the diagrammatic concept at the Livingston Circle would have violated this limitation. As this situation could arise at other cut-through circles as well, it was decided to test a modified stack design at this location. The modified stack design would retain the use of diagramatic arrows while reducing size of sign required for the message. If the modified stack design tested out as effective at this location, it would represent a viable alternative method for locations where diagrammatic was not feasible.

Examples of the two designs used at cut-through circles can be seen in Figures 5 a and b. Final design specifications for these signs are also listed in Appendix B.

FIGURE 4 - DIAGRAMMATIC SIGNS AT REGULAR CIRCLES

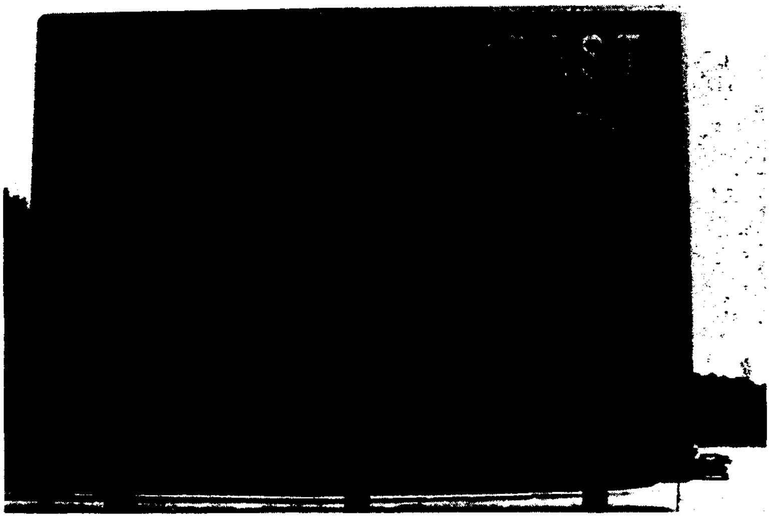


FIGURE 4a - DIAGRAMMATIC SIGN (LAKEHURST CIRCLE)

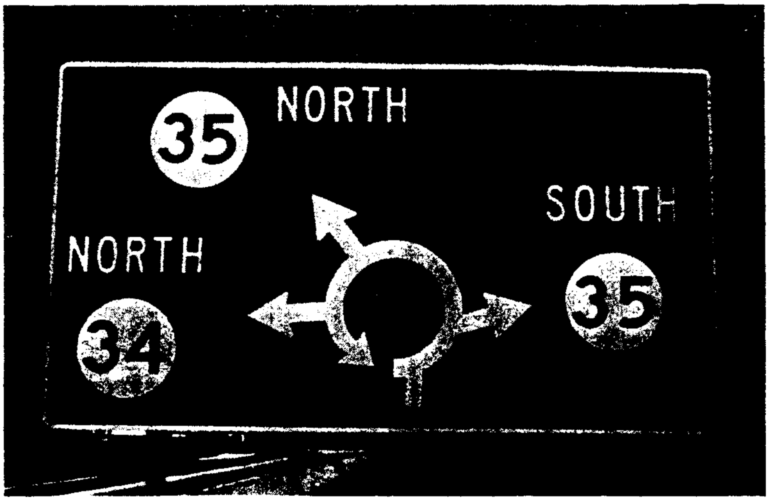


FIGURE 4b - DIAGRAMMATIC SIGN (BRIELLE CIRCLE)

FIGURE 4 - DIAGRAMMATIC SIGNS AT REGULAR CIRCLES (CONT.)

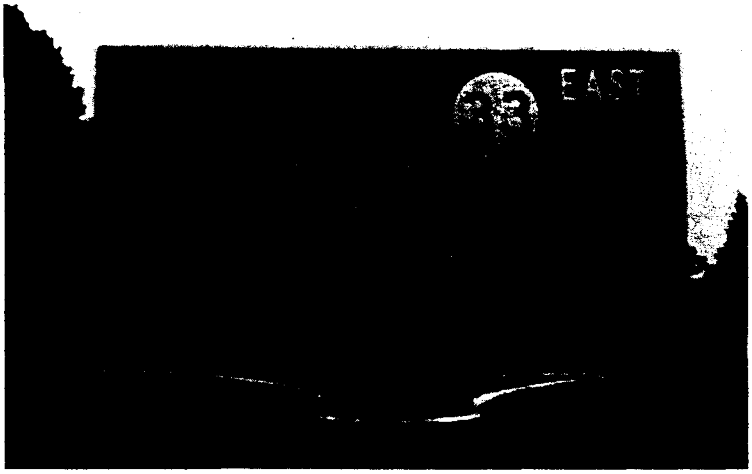


FIGURE 4c - DIAGRAMMATIC SIGN (FREEHOLD CIRCLE)

FIGURE 5 - SIGNS AT CUT-THROUGH CIRCLE

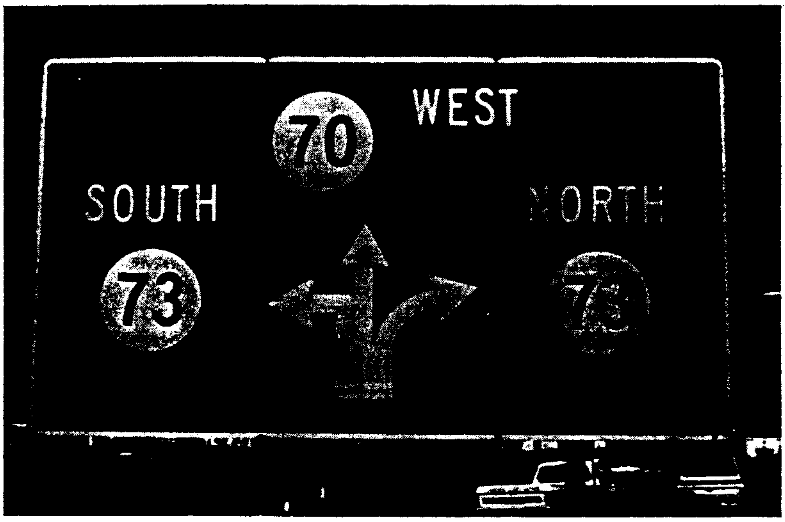


FIGURE 5a - DIAGRAMMATIC SIGN (MARLTON CIRCLE)

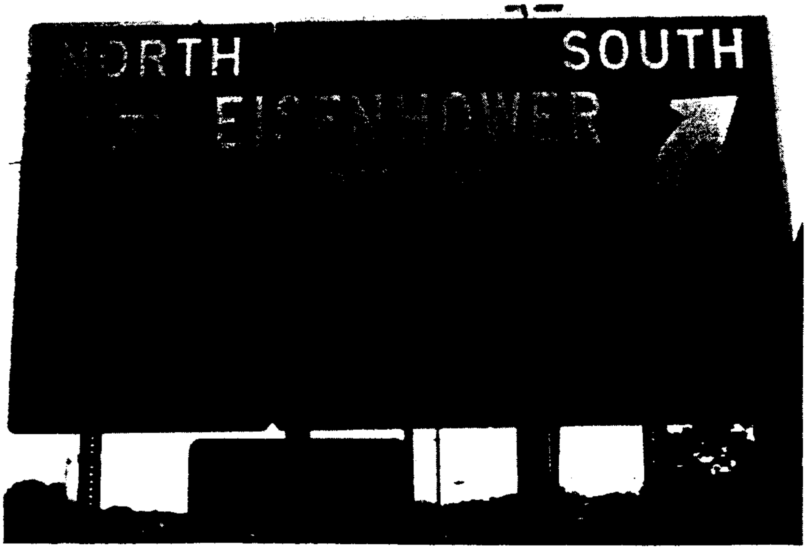


FIGURE 5b - MODIFIED STACK SIGN (LIVINGSTON CIRCLE)

Following completion of before installation traffic studies, the diagrammatic guidance signs were installed at the three selected traffic circles. Two of the circles (Brielle and Freehold) had signs installed on two approaches while, one, the Lakehurst circle, had only one approach signed.

The new signs were located on the circle approach a minimum of 250 feet from the circle, and acted as the third sign in a progression, which included a circle warning sign and a standard road junction sign.

In regard to the two cut-through circles, the modified stack sign with diagrammatic arrows was used at the Livingston Circle while at the Marlton Circle two diagrammatic signs were used.

Again as with the regular circles, the new signs were located on the circle approach a minimum of 250 ft. from the intersection. However, since it is not New Jersey Department of Transportation policy to install circle warning signs for cut-through circles, the signs acted in this case as the second sign in the progression following the standard road junction sign.

C. Data Collection

Traffic studies were used to document traffic conditions both preceding and following sign installation. These studies consisted of videotaping the selected weaving areas to record preferred maneuver percentages; a spot speed survey, using counter and tubes to record before and after speed data and manual counts. (In the case of cut-through circles a speed survey was determined not to be relevant because of queuing from the traffic signal at the intersection). Data was collected for three days at each circle during both the before and after periods.

The manuever data collected was divided into morning and afternoon periods. The morning period ran from 10:30 - 12:00, and the afternoon period from 1:00 - 2:30. The 12 - 1 period was excluded from the study for reason of the high incidence of lunch trips associated with this hour.

A minimum of a month was allowed to ellapse between installation of the signs and the after condition studies to allow drivers to familiarize themselves with the new signing. The after condition studies were conducted on the same day of the week and as close as possible to the same day of the year as the before studies with which they were to be compared.

The videotapes taken during the traffic studies were subsequently analyzed to obtain the percentages of "preferred" maneuvers.

RESULTS

A. Regular Circles

1) Speed Survey

The results of the comparison of the spot speed survey on the study circles before and after sign installation can be seen in Table 1 below.

TABLE 1

SPEED SURVEY COMPARISON

CIRCLE	TYPE OF STUDY	VOLUME	AVERAGE SPEED	STANDARD DEVIATION	VARIANCE
BRIELLE	BEFORE	10228	25.93	4.131	17.07
	AFTER	11165	26.90	4.186	17.52
FREEHOLD	BEFORE	14765	29.90	5.673	32.18
	AFTER	13094	30.63	5.679	32.25
LAKEHURST	BEFORE	10436	38.08	6.237	38.90
	AFTER	10743	37.96	6.759	45.68

Because of the large sample sizes all differences between the before and after conditions are statistically significant. However, it is evident from Table 1 that no real difference in average speed,

speed variance or standard deviation exists. Thus for all intents and purposes results from the spot speed surveys showed that traffic speeds remained essentially the same for both the before and after traffic conditions.

2) Paths of Travel

Erratic maneuvers and paths of travel used by vehicles at the selected circle sites were obtained both through use of the videotape and by manual observation. Erratic maneuvers such as vehicles stopping on the circle or vehicles traveling around the circle twice were of too infrequent occurrence both before and after installation to be useful in measuring the effectiveness of the new guidance signing. Therefore, analysis of paths of travel of vehicles through the circle was used as the major measure of effectiveness.

As described previously (see Figure I) the "preferred" maneuver for a vehicle exiting the circle would be a lane 2 exit. The preferred maneuver for a vehicle continuing around (or through) the circle would be a lane 1 through. Using both videotape and manual observation, the percentage of vehicles making the preferred maneuvers to total exiting or thru vehicles was obtained for both the before and after conditions.

The total vehicle flow was also divided into two streams, entering traffic and circulating traffic. The entering traffic stream consisted of vehicles entering the circle from an approach. The circulating traffic stream consisted of vehicles already on the circle passing through the selected weaving areas. (In the case of the Lakehurst circle the two flows were combined into one - entering - for the purpose of analysis since observation of traffic patterns at this circle indicated that very little circulating traffic passed through the weaving area chosen).

Tables 2 & 3 show the change between the before and after conditions in percentage of vehicles making the preferred maneuvers for the entering and circulating traffic streams. Also included in these tables is the statistical significance (p-value) of each change as determined through use of the Z-test.

As can be seen from Table 2 in the case of the entering traffic flows 17 out of the 32 periods studied showed a statistically significant increase at $p < 0.1$ in preferred maneuvers while only 5 showed a statistically significant decrease at $p < 0.1$. Overall 23 out of 32 periods studied showed some improvement. (Because of a camera malfunction, analysis of entering traffic data from the videotape for Day 1 of the before study at the Freehold circle was not possible and therefore, Day 1 was not included in Table 2).

In the case of the circulating traffic (Table 3) 9 out of 24 periods studied showed a statistically significant increase at $p < 0.1$ in percentage of preferred maneuvers while only 3 showed a significant decrease. Overall, for the circulating traffic, 16 out of the 24 periods studied showed an increase while only 8 decreased.

Individually, all 3 surveyed circles mirrored the overall positive trend with periods showing a significant increase in percentage of preferred maneuvers outnumbering those with a significant decrease at each circle.

For all morning and afternoon periods combined, 70% of the periods studied showed an increase in percentage of preferred maneuvers with 46% showing a significant increase. This overall

TABLE 2

CHANGE BETWEEN BEFORE + AFTER PREFERRED
MANEUVERS PERCENTAGES

ENTERING TRAFFIC

CIRCLE	DAY	MANEUVERS	MORNING PERCENT CHANGE IMPROVEMENT	MORNING PERCENT CHANGE DEGRADATION	MORNING SIGNIFICANCE	AFTERNOON PERCENT CHANGE IMPROVEMENT	AFTERNOON PERCENT CHANGE DEGRADATION	AFTERNOON SIGNIFICANCE
BRIELLE	1	thru maneuvers	+ 6.63		p = 0.004		- 0.56	p = 0.421
		exit maneuvers	+ 0.56		p = 0.375	+ 0.91		p = 0.352
	2	thru maneuvers	+ 8.41		p < 0.001	+ 6.84		p = 0.003
		exit maneuvers		- 5.18	p < 0.001		- 2.28	p = 0.079
	3	thru maneuvers		- 1.78	p = 0.251	+ 12.12		p < 0.001
		exit maneuvers	+ 3.11		p = 0.039	+ 3.49		p = 0.022
FREEHOLD	2	thru maneuvers		- 4.35	p = 0.049	+ 15.39		p < 0.001
		exit maneuvers	+ 5.87		p < 0.001	+ 2.26		p = 0.081
	3	thru maneuvers	+ 4.83		p = 0.023	+ 9.42		p < 0.001
		exit maneuvers	+ 3.67		p = 0.015	+ 0.61		p = 0.348
LAKEHURST	1	thru maneuvers	+ 4.15		p = 0.063		- 2.36	p = 0.272
		exit maneuvers	+ 0.30		p = 0.382	+ 0.40		p = 0.396
	2	thru maneuvers		- 4.62	p = 0.067	+ 4.75		p = 0.052
		exit maneuvers	+ 3.26		p = 0.001	+ 1.35		p = 0.106
	3	thru maneuvers	+ 6.85		p = 0.006	+ 8.18		p = 0.007
		exit maneuvers		- 0.44	p = 0.319		- 2.05	p = 0.014

TABLE 3

CHANGE BETWEEN BEFORE + AFTER PREFERRED
MANEUVERS PERCENTAGES

CIRCULATING TRAFFIC			MORNING			AFTERNOON		
			PERCENT CHANGE			PERCENT CHANGE		
CIRCLE	DAY	MANEUVERS	IMPROVEMENT	DEGRADATION	SIGNIFICANCE	IMPROVEMENT	DEGRADATION	SIGNIFICANCE
BRIELLE	1	thru maneuvers	+ 1.29		p = 0.331	+ 2.96		p = 0.159
		exit maneuvers	+ 15.96		p < 0.001	+ 1.21		p = 0.341
	2	thru maneuvers	+ 4.93		p = 0.043		- 0.48	p = 0.444
		exit maneuvers	+ 26.61		p < 0.001	+ 22.70		p < 0.001
	3	thru maneuvers	+ 1.40		p = 0.338	+ 2.84		p = 0.172
		exit maneuvers	+ 20.00		p < 0.001	+ 18.04		p < 0.001
FREEHOLD	1	thru maneuvers		- 1.30	p = 0.382		- 0.64	p = 0.425
		exit maneuvers		- 5.05	p = 0.087		- 5.84	p = 0.030
	2	thru maneuvers	+ 3.55		p = 0.160	+ 6.78		p = 0.024
		exit maneuvers	+ 4.89		p = 0.081	+ 3.07		p = 0.172
	3	thru maneuvers	+ 7.45		p = 0.013		- 1.70	p = 0.304
		exit maneuvers		- 1.45	p = 0.330		- 4.04	p = 0.088

increase in percentage of preferred maneuvers at the surveyed circles indicates a lessening of driver confusion and thus more orderly traffic flow occurring after sign installation at the 3 circles.

Aside from the new guidance signing no other changes were made at the study sites, and, as indicated by the speed profiles, traffic flow characteristics at the circles remained the same. Therefore, the findings of this study indicate a definite advantage for diagrammatic signing over conventional signing for decreasing driver confusion at regular circles.

B. Cut Through Circles

As was the case with regular circles, erratic maneuvers and paths of travel used by vehicles at the selected cut-through circle sites were obtained both through use of the videotape and by manual observation. Again as with regular circles, erratic maneuvers were too infrequent an occurrence to be used in testing the effectiveness of the new guidance signing and lane maneuvers were used as the major measure of effectiveness.

Three types of lane maneuvers were compared. Table 4 below shows the preferred maneuvers for left turning, thru, and right turning movements at the intersection.

Table 4
Preferred Maneuvers for Cut-through Circles

Movements	Preferred Maneuver	Percent of Total
Left Turns	Direct Lefts	Total Lefts
Right Turns	Slot Rights	Total Rights
Throughs	Right Lane Throughs	Total Throughs

Analysis of the results of comparison of the before and after preferred maneuver percentages follows.

1) Livingston Circle

Table 5 shows the changes between the before and after conditions in percentage of vehicles making the preferred maneuvers at the Livingston Circle. Also included in this table is the statistical significance (p-value) of each change as determined through use of the z - test.

As can be seen from Table 5, the only movement which showed any discernible trend in preferred maneuvers was through movements where all 6 periods showed an increase. Three of these were significant at $p<0.1$.

Results for left and right turn movements were inconclusive. For left turn movements, while 2 of the periods studied showed a significant increase at $p<0.1$, 2 others showed a significant decrease. Overall 4 periods showed a decrease in preferred maneuvers with only 2 showing an increase.

Right turn movement results were equally inconclusive. Two periods had no right turn movements at the intersection at all. The other 4 periods only had one. Therefore, although 2 of these 4 showed a significant increase at $p<0.1$, these results should be viewed with caution.

Although in regard to through movements there was a definite positive trend in preferred maneuvers, the overall results were mixed and inconclusive.

TABLE 5

CHANGE BETWEEN BEFORE + AFTER PREFERRED MANEUVERS PERCENTAGES

			MORNING			AFTERNOON		
			PERCENT CHANGE			PERCENT CHANGE		
CIRCLE	DAY	MOVEMENTS	IMPROVEMENT	DEGRADATION	SIGNIFICANCE	IMPROVEMENT	DEGRADATION	SIGNIFICANCE
LIVINGSTON	1	LEFT TURNS	+ 3.86		p = 0.116		- 2.64	p = 0.125
		THROUGHS	+ 2.89		p = 0.100	+ 1.81		p = 0.167
		RIGHT TURNS	0.00		----	+ 0.41		p = 0.149
	2	LEFT TURNS		- 5.36	p = 0.066		- 1.19	p = 0.317
		THROUGHS	+ 1.71		p = 0.234	+ 1.57		p = 0.196
		RIGHT TURNS		- 0.28	p = 0.410	+ 0.65		p = 0.125
	3	LEFT TURNS	+ 5.91		p = 0.052		- 0.76	p = 0.383
		THROUGHS	+ 12.85		p < 0.001	+ 18.57		p < 0.001
		RIGHT TURNS		- 0.08	p = 0.472	0.00		----

Therefore no advantage in decreased driver confusion for modified-stacked signing over conventional signing could be confirmed.

2) Marlton Circle

At the Marlton Circle, two approaches (Rt. 70 EB & WB) were studied. Table 6 shows the change between before and after conditions in percentage of vehicles making the preferred maneuvers for both the WB & EB intersections.

Results for both left and right turn movements showed a definite increase in percentage of preferred maneuvers after installation. In the case of left turn movements, 11 out of 12 periods studied over the two intersections showed an increase. Six of these periods showed a significant increase at $p<0.1$.

Again as with the Livingston Circle, results for right turn movements at the 70 WB intersection should be viewed with caution since only 1 of the 6 periods studied had right turn movements at the intersection. However, the 70 EB intersection in contrast had a high proportion of right turns being made at the intersection. (Before installation percentages of right turns at the intersection ranged from 46 to 55%). In this case, 5 out of 6 periods studied showed an increase in percentage of the preferred maneuver. Four of these showed significant increases at $p<0.1$.

Only in the case of through movements were the results mixed. In this case, 7 out of 12 periods studied showed a decrease in percentage of the preferred maneuver. Two of these showed significant decreases at $p<0.1$.

Overall, although the results for the through movement were inconclusive, results for the other two movements studied indicated a definite advantage for the diagrammatic sign over conventional signing in decreasing driver confusion at a cut-through circle.

TABLE 6

CHANGE BETWEEN BEFORE + AFTER PREFERRED MANEUVERS PERCENTAGES

			MORNING			AFTERNOON		
			PERCENT CHANGE			PERCENT CHANGE		
CIRCLE	DAY	MOVEMENTS	IMPROVEMENT	DEGRADATION	SIGNIFICANCE	IMPROVEMENT	DEGRADATION	SIGNIFICANCE
MARLTON (RT. 70 WB)	1	LEFT TURNS	+ 13.93		p = 0.002	+ 3.82		p = 0.219
		THROUGHS	+ 0.34		p = 0.432	+ 1.82		p = 0.180
		RIGHT TURNS	0.00		----	+ 0.01		p = 0.494
	2	LEFT TURNS	+ 11.31		p = 0.011	+ 14.29		p = 0.003
		THROUGHS		- 1.05	p = 0.291		- 0.47	p = 0.406
		RIGHT TURNS	0.00		----	0.00		----
	3	LEFT TURNS	+ 15.47		p < 0.001	+ 21.03		p < 0.001
		THROUGHS	+ 2.34		p = 0.104	+ 0.08		p = 0.483
		RIGHT TURNS	0.00		----	0.00		----
MARLTON (RT. 70 EB)	1	LEFT TURNS	+ 2.44		p = 0.171	+ 0.24		p = 0.460
		THROUGHS		- 0.42	p = 0.426		- 2.94	p = 0.084
		RIGHT TURNS	+ 13.55		p < 0.001	+ 10.59		p < 0.001
	2	LEFT TURNS		- 1.16	p = 0.316	+ 6.45		p = 0.003
		THROUGHS		- 1.17	p = 0.297	+ 2.62		p = 0.108
		RIGHT TURNS	+ 12.79		p < 0.001	+ 5.73		p = 0.031
	3	LEFT TURNS	+ 0.11		p = 0.484	+ 1.66		p = 0.215
		THROUGHS		- 4.39	p = 0.023		- 0.67	p = 0.365
		RIGHT TURNS		- 0.42	p = 0.447	+ 6.54		p = 0.107

Discussion and Suggested Research

The results of this study indicate that use of diagrammatic guidance signs at traffic circles, both regular and cut-through, can serve as an inexpensive interim step which would reduce driver confusion at traffic circles while awaiting the more expensive solutions of circle signalization or elimination. It should be noted, however, that these signs, while still effective, will not have as great an effect at circles with a high percentage of commuter traffic or during periods of heavy congestion. It should also be noted that there was a significant amount of unsolicited driver comment on these signs received during the study period from NJDOT employees who traveled through the circles. These comments were almost universally favorable. However since no attempt was made to survey public opinion of these signs, this information was not included as a factor in this report's analysis of sign effectiveness.

Another technique that could be useful for reducing motorist confusion at traffic circles is the use of pavement markings at circle entrances and splitter islands. Future research should be made into this approach as another means of increasing traffic flow and safety at circles.

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APPENDIX A

Development of Measures of Effectiveness

A. Problem Definition

As a first step toward improvement of guidance signing it was necessary to study traffic patterns at circles in order to better clarify the situation and define driver problems. Part of this effort entailed a survey of the number and locations of existing traffic circles in New Jersey. Site visits were made to each circle identified in this survey. These visits were used to obtain some idea of the drivers' ease in negotiating the various circles. Circles, at which evidence of driver problems as shown by stopping or slowing vehicles and abrupt exiting manuevers was apparent, were targeted for more detailed observation and study.

Observation of traffic flow and driver performance at the targeted circles was used to identify driver confusion problems as well as to define the worst areas for driver confusion at circles. From these observations, certain insights were obtained into circle operations.

1. The irregular traffic patterns existing at traffic circles, along with the fact that most guidance signing is on the circle itself, creates an information overload. The driver appears to be too preoccupied negotiating the circle to allow much time for seeking guidance information.
2. Present advanced signing consisting of a "CIRCLE" warning sign and a junction marker does not seem to fill the guidance needs of the unfamiliar driver.
3. Heavy traffic flows into a circle from entering roads tend to take precedence over circulating traffic.
4. As a corallary to No. 3, circulating traffic tends to use the splitter islands at the approach roads as a safe haven from behind which exiting or through maneuvers can be made.

5. Traffic operations at cu-through circles differ from those at regular circles. Thus, regular and cut-through circles would require different handling both in MOE's used and sign configurations tested.

6. Such obviously improper moves as vehicles going around the circle more than once and stops on the circle occur too rarely to be of use as potential MOE's in studying changes without collecting large amounts of data.

7. At periods of heavy traffic flow through the circle, erratic maneuvers appear more traffic related than driver confusion related.

The results of these observations were used in the next part of this study to develop measures of effectiveness (MOE's) useful at circles.

B. <u>Development of Measures of Effectiveness</u>

Because of the unique characteristics of traffic circles, many of the usual traffic parameters used as measures of effectiveness (MOE's) are not useful, applicable or easily measured. Examples of this are conflicts and braking, which because of the traffic conditions are very frequent while being for the most part unrelated to driver confusion. For this reason, it was necessary to identify viable parameters in the early stages of this study for later use as MOE's.

As noted, observations made at various circles have shown that some parameters thought to have potential did not occur sufficiently enough to be useful. These include vehicles going around the circle more than once and stopped vehicles on the circle. Although these occurrences were noted they represented too small a data base form which to draw any definite conclusions.

Taking into account the results of the initial period of observation of traffic circle operation, it was felt that MOE's based on deviations from preferred paths of travel, erratic maneuvers and speed profile would be the most useful for showing any change in the level of driver confusion at a circle. These parameters could be easily measured and a sufficient amount of individual movements obtained without an extended amount of data collection. Because of the differences between traffic operations at a regular circle and those at a cut-through circle, different specific parameters had to be collected at each. These differences, both between the operation of the regular circle vis-a-vis the cut-through circle and between the different specific parameters collected, are explained in the following sections.

1. Regular Circles

a. Erratic Maneuvers

NJDOT normally does not place extensive painted gores or lane lines on a traffic circle, so the most common erratic maneuvers such as encroachments or gore crossings are of little use in this study. However, other types of erratic maneuvers which occur more frequently at circles than at standard intersections can be used in their place. These types of erratic maneuvers include vehicles backing up on a leg of the circle after having exited the circle, vehicles stopping in front of physical gores to read guide signs, vehicles U-turning on the circle approaches, either in the roadway or through adjacent properties, and vehicles making sudden exiting moves. However, these maneuvers, although more frequent at circles than at other types of intersections, are still fairly rare occurrences.

b. Paths of Travel

Specific parameters obtained from the overall classification of deviations from preferred paths of travel seemed to hold the most potential for use as MOE's. Since every vehicle exiting the circle could be classified either as deviating or non-deviating from a preferred path, a sufficient number of individual movements could be observed to provide an ample data base on which to draw conclusions.

In order to develop specific parameters in this area it was first necessary to describe preferred paths of travel on a circle. The preferred path of travel was defined as that which would minimize potential conflicts with other traffic streams. For example, the preferred maneuver for exiting vehicles would be a "lane 2 exit." For traffic entering the circle this maneuver would entail potential conflict with only one other traffic stream (circulating traffic exiting) whereas a "lane 1 exit" entails potential conflict with two other traffic streams. In the same way it can be shown that the preferred maneuver for vehicles continuing around (through) the circle would be a "lane 1 through." Figure 1 shows the preferred paths of travel for exiting and thru maneuvers for both entering and circulating traffic.

c. Spot Speed Survey

One of the more potentially hazardous characteristics of the irregular traffic patterns at traffic circles is the variance in speeds of vehicles on the circle itself. While most of this variance is due to a motorists natural caution when faced with irregular patterns, some of this can also be attributed to driver confusion since the unfamiliar driver must proceed more slowly and cautiously inorder to deal with traffic while still attempting to find his exit off the circle.

By taking a spot speed survey of the traffic on the circle, the effect, if any, of the improved guidance signing on speed variance can be seen. A decrease in speed variance would provide potentially safer conditions at traffic circles.

2. Cut-Through Circles

a. Erratic Maneuvers

Cut-through circle describes a circle where the major road entering the circle has been continued through the circle central island producing two at grade signalized intersections at the points where the road crosses the original circle. (see Figure 2). Cut-through circles exhibit different traffic patterns than regular circles. Traffic patterns at cut-through circles, particularly at the two at-grade signalized intersections, are much closer to those at typical non-circle intersections than to those at regular circles. In fact, drivers on the road that is cut-through often will not even realize that they are passing through a circle. Only drivers who approach on the cross road or who are making turns off the main (cut-through) road experience any of the conditions exisitng at regular circles.

At the two signalized intersections and on the parts of the circle still remaining in use, erratic maneuvers found at regular circles, such as vehicles backing up on an approach, are still evident. In addition to these however, other types of erratic maneuvers can also be seen. Abrupt lane change maneuvers both on the approach and in the intersection itself are examples of erratic maneuvers caused by driver confusion. Again, as at regular circles, these types of erratic maneuvers are still fairly rare occurrences.

b. Paths of Travel

As in the case of regular circles, specific parameters obtained from the overall classification of deviations from preferred paths of travel seemed to hold the most potential for use as MOE's. However, in the case of cut-through circles, these specific parameters can be defined in terms of lane use at a signalized intersection. Typically, the approaches to the two signalized intersections at cut-through circles are striped as normal, at-grade intersections. This allows observation of the traffic lanes on the approach to be used in determining percentage of preferred maneuvers. Comparison can then be made between the before and after percentages to determine the effect of the new signing. Again as with preferred maneuvers at regular circles, the preferred maneuvers were defined as those maneuvers which minimize potential conflicts with other traffic streams. The preferred maneuvers chosen for each type of movement were: For right turns, a right turn through the slot rather than at the intersection; for through movements, a right lane rather than left lane through, and for left turns a left turn at the intersection rather than around the circle. The chosen preferred maneuvers would have the benefit of allowing the left lane for left turns while freeing up the right lane for through movements. A left turn at the intersection rather than around the circle was chosen because it is a simplier maneuver to make and left turns around the circle cause problems at the opposite intersection since the left turning motorist must cross two lanes of opposing traffic to complete his move. Figure 3 depicts what the preferred movements at a typical cut-through circle intersection would look like.

c. Spot Speed Survey

The geometry of a cut-through circle makes a spot speed survey of little use as an MOE at cut-throughs. Since the intersections are typically signalized, the speeds of vehicles are controlled, while vehicle speeds on the cut-through road are unaffected by either circle geometry or maneuvers. For this reason, spot speed surveys were not utilized as MOEs at cut-through circles.

APPENDIX B

Development of Final Design and specifications for diagrammatic signs used at circles

SIGN DESIGN AND INSTALLATION

Initially two major criteria were set for design of the new guidance signing installed at both regular and cut-through circles. These were:

1) That the signs be capable of being installed within the limited R.O.W. afforded by urban arterials. Since R.O.W. limitations necessitated that the signs be mounted on U-posts rather than break-away posts, maximum sign size was limited.

2) That the signs conform to MUTCD Standards as used by the New Jersey Department of Transportation.

Two additional criteria were added. One criteria concerned sign installation, and the other concerned sign message. In regard to sign installation, a decision was made to locate the signs on the circle approaches rather than on the circle itself. This would allow the motorist time to assimilate the sign message before entering the circle.

In regard to sign message, a decision was made to use only route numbers or names rather than destinations on the signs because of sign size limits. Destinational information would be supplied by existing signing on the circle.

The basic design settled upon for use at regular circles was a diagrammatic sign similar to those used at traffic circles in the United Kingdom. Modifications however, were needed to conform with United States usage and standards. Signs used at the three regular circles can be seen in Figures 4 a, b, and c. Final design specifications for these signs are listed following the text.

In the case of the cut-through circles two different designs were tested, diagrammatic and modified stack. There were several reasons for this decision; the most important being the size limitation criteria mentioned earlier. The size of sign required for use of the diagrammatic concept at the Livingston Circle would have violated this criteria. As this situation could arise at other cut-through circles as well, it was decided to test a modified stack design at this location. The modified stack design would retain the use of diagramatic arrows while reducing size of sign required for the message. If the modified stack design tested out as effective at this location, it would represent a viable alternative method for locations where diagrammatic was not feasible.

Examples of the two designs used at cut-through circles can be seen in Figures 5 a and b. Final design specifications for these signs are listed following this text.

Before any signs were actually installed at circles in the field, a pilot study was conducted in which selected NJDOT personnel were asked to drive past a demonstration sign located on an unopened section of road and then fill out a survey form regarding their reaction to the sign and their ease in interpreting sign message. Results from this survey were useful in determining modifications which were incorporated into the final design.

Pilot studies were also conducted at each circle selected as a study site in order to collect preliminary traffic maneuver data. This data was subsequently used in the selection of weaving areas to be monitored for a more extensive study of traffic conditions prevailing within each circle.

Before sign installation, data collection was initiated to document the traffic conditions in the selected weaving areas. Following completion of the "before" installation traffic studies, diagrammatic guidance signs for traffic circles were installed at the three selected traffic circles. Two of the circles (Brielle and Freehold) had signs installed on two approaches while, one, the Lakehurst circle, had only one approach signed.

The new signs were located on the circle approach a minimum of 250 feet from the circle, and acted as the third sign in a progression, which included a circle warning sign and a standard road junction sign.

In the case of cut-through circles traffic maneuver data collection took place at one or both of the two signalized intersections created where the major route "cut-through" the circle. Lane specific intersection data was taken on the minor route intersection approach only since drivers on the major "cut-through route did not perceive the intersection as a circle and were not exposed to weaving conditions.

Results of preliminary pilot studies were used to select the two study sites and to determine if one or both of the signalized intersections made by the "cut-through" route should be studied. At the Marlton circle, maneuver data was collected at both intersections while at the Livingston Circle data was collected at only one intersection.

"Before" sign installation data collection was initiated to document traffic conditions at the selected intersections. Following completion of the "before" installation traffic studies guidance signs for traffic circles were installed at the two selected cut-through circles. One circle (Marlton) had signs installed on two approaches while the other (Livingston) had only one approach signed.

As stated previously in the Site Selection section of this report, a modified stack sign with diagrammatic arrows (Figure 5b) was used at the Livingston Circle while at the Marlton Circle two full diagrammatic signs (Figure 5a) were used.

Again as with the regular circles, the new signs were located on the circle approach a minimum of 250 ft. from the intersection. However, since it is not New Jersey Department of Transportation policy to install circle warning signs for cut-through circles, the signs acted in this case as the second sign in the progression following the standard road junction sign.

DESIGN SPECIFICATIONS FOR REGULAR CIRCLE GUIDANCE SIGNS

Final design specifications for the guidance signs which were installed at three regular traffic circles are listed below:

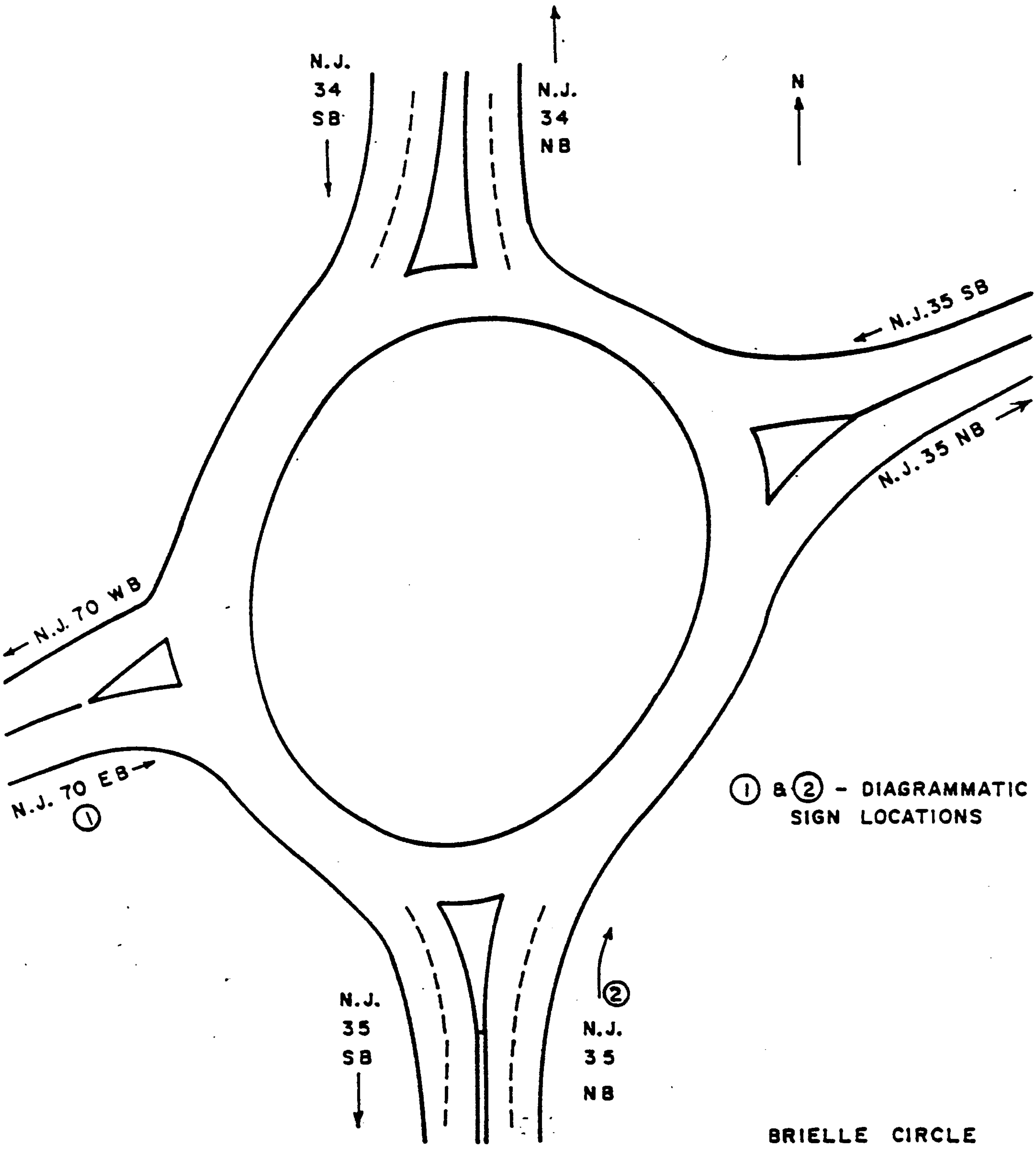
1. The dimensions of the signs to be installed at the Brielle and Freehold circles are 5' high by 9' wide. Those of the sign to be installed at the Lakehurst circle are 5' high by 7' wide.
2. The background for all signs are NJDOT's standard green and the diagram, arrows and borders are fabricated from Scotch-lite reflective tape.
3. All U.S., state and county route shields are 18" square, as per NJDOT standard shields
4. All cardinal direction words use 6" letters, as per NJDOT standards.
5. The circle diagram has an outside diameter of 22 inches and in inside diameter of 16 inches.
6. The width of the diagram and stems of the arrows is 3 inches. The width of the arrow heads are 8 inches. These are standard NJDOT arrows.
7. The distance between the circle diagram and the arrow head is 5 inches.
8. The shields and words are aligned both horizontally and vertically, as per NJDOT standards.

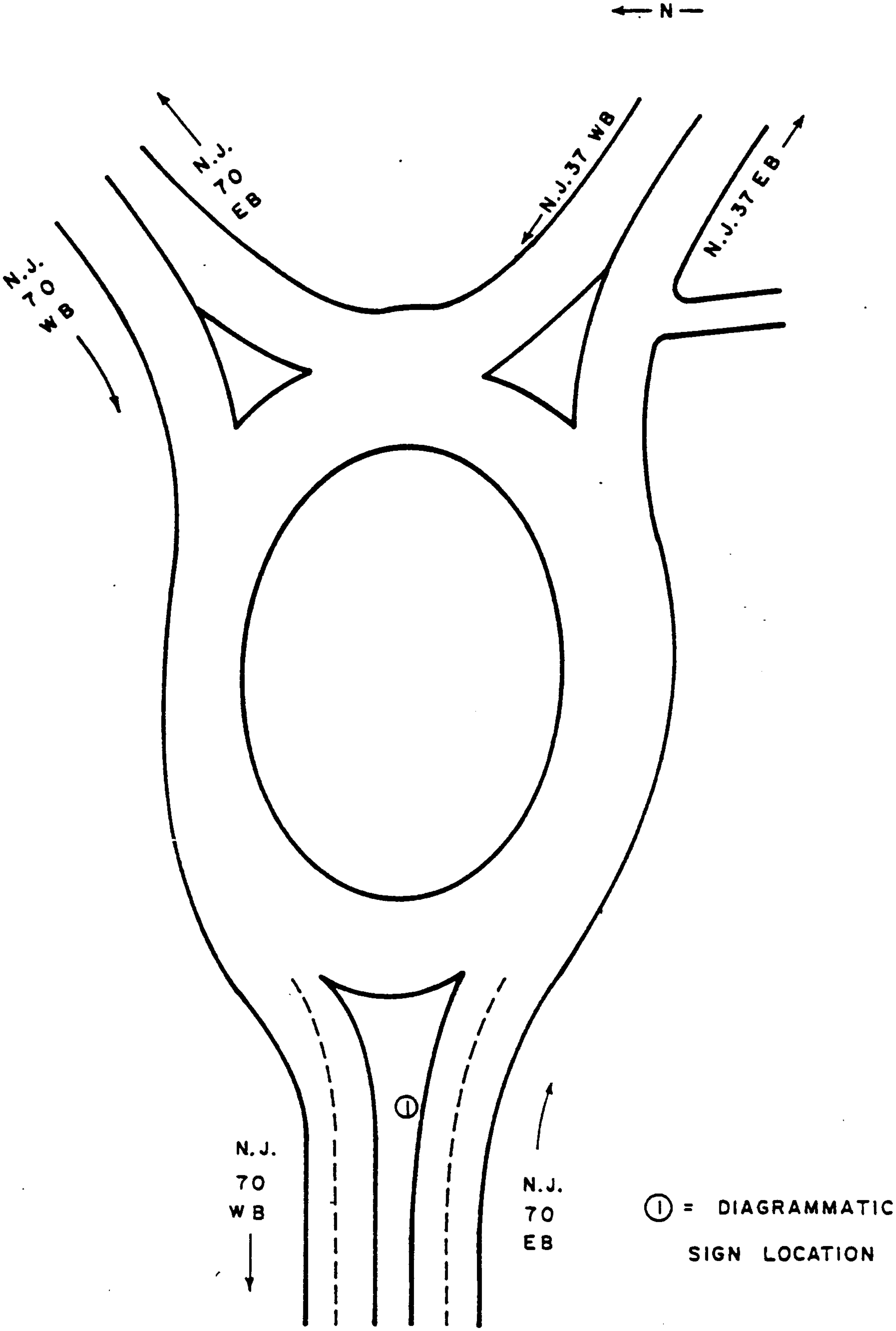
DESIGN SPECIFICATIONS FOR CUT-THROUGH CIRCLE GUIDANCE SIGNS

1. The dimensions of all signs are 5' high by 9' wide.
2. The background for all signs are NJDOT's standard green and the arrows and borders are fabricated from scotch-lite reflective tape.
3. All route shields are 18" square.
4. All words use 6" letters.
5. The width of the arrow heads is 8". The width of the arrow stems is 3".

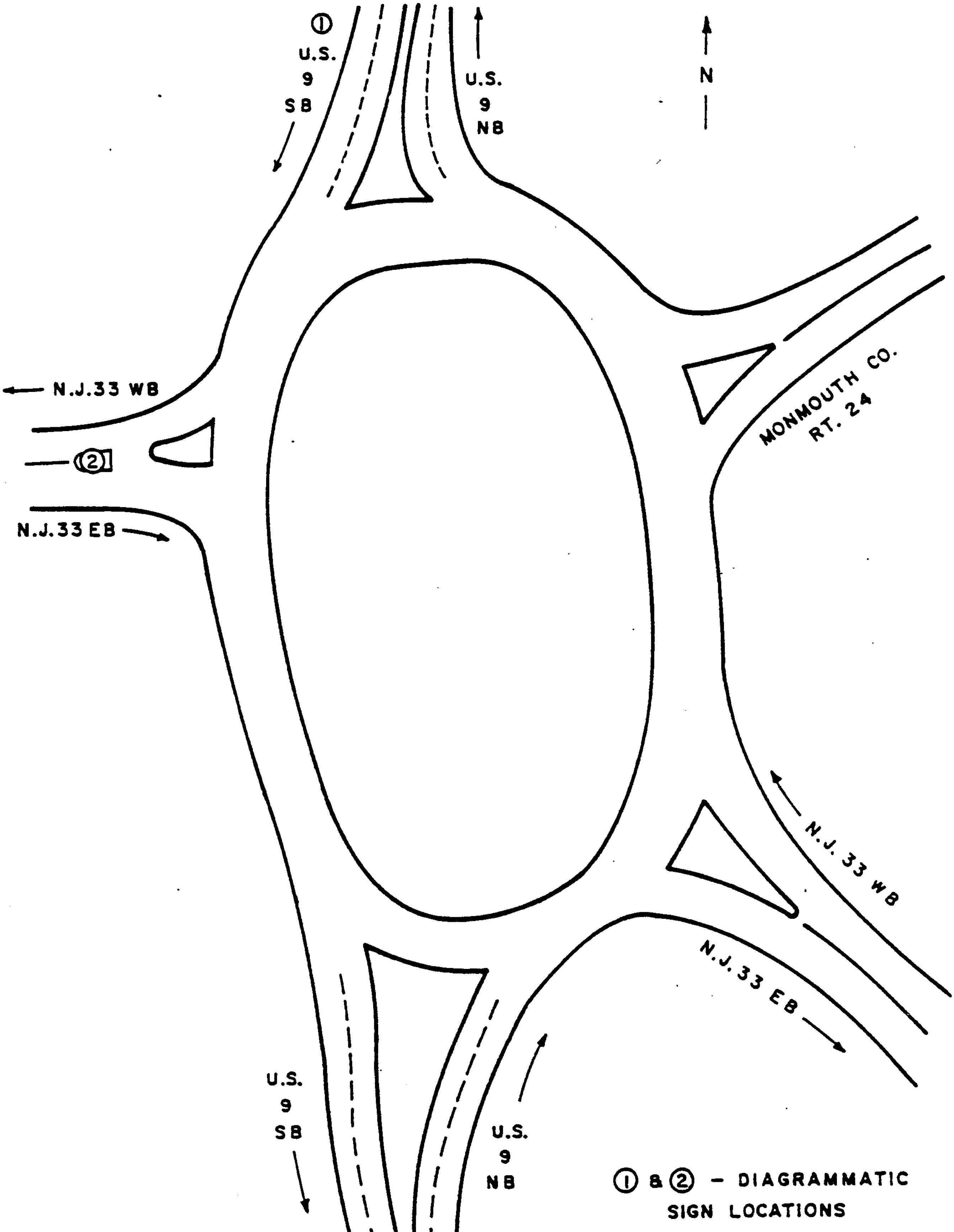
APPENDIX C

CIRCLE SITES PHYSICAL LAYOUTS


N.J. 34 SB
N.J. 34 NB
N
N.J. 35 SB
N.J. 35 NB
N.J. 70 WB
N.J. 70 EB
①
① & ② - DIAGRAMMATIC SIGN LOCATIONS
②
N.J. 35 SB
N.J. 35 NB
BRIELLE CIRCLE



LAKEHURST CIRCLE



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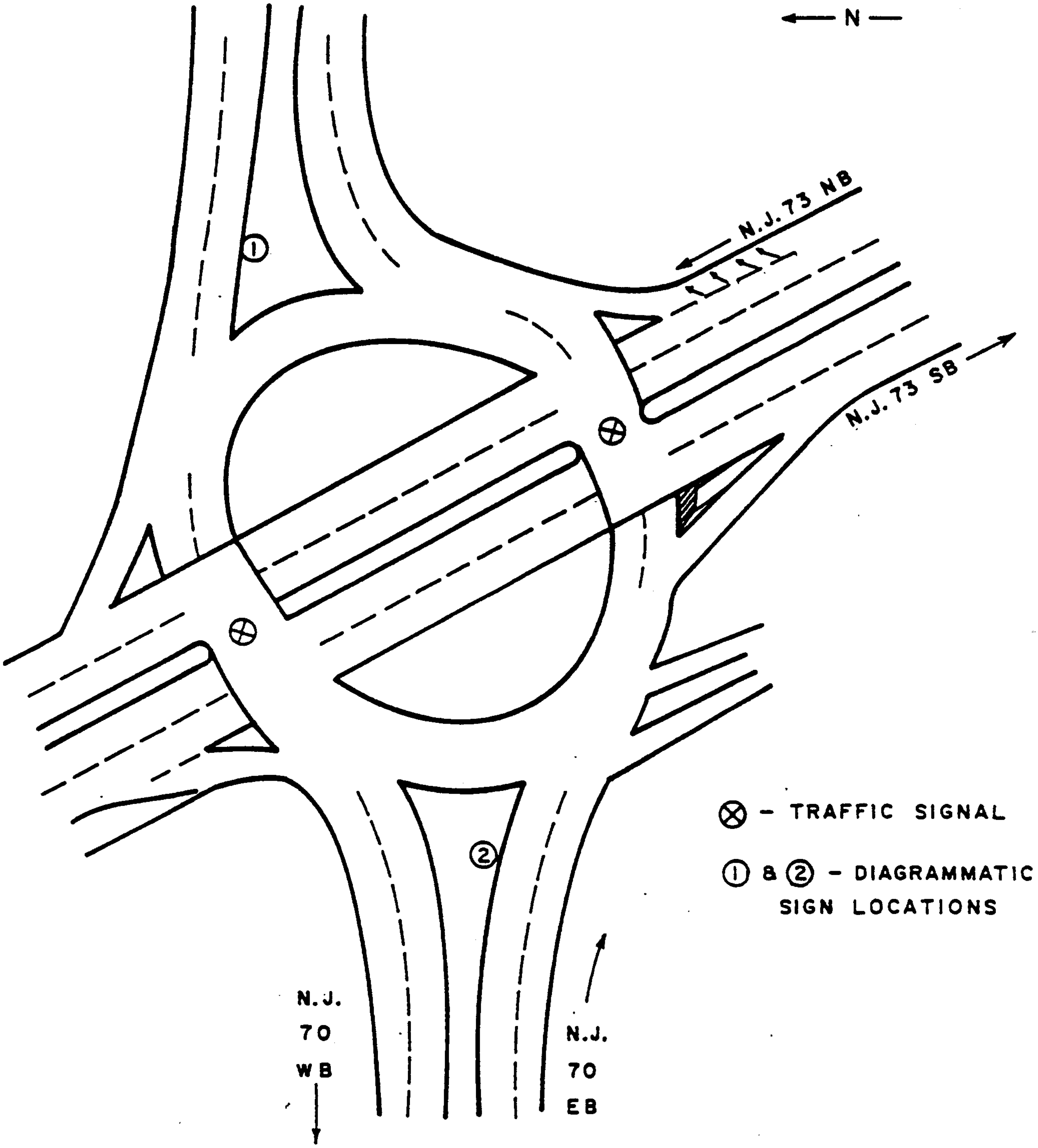
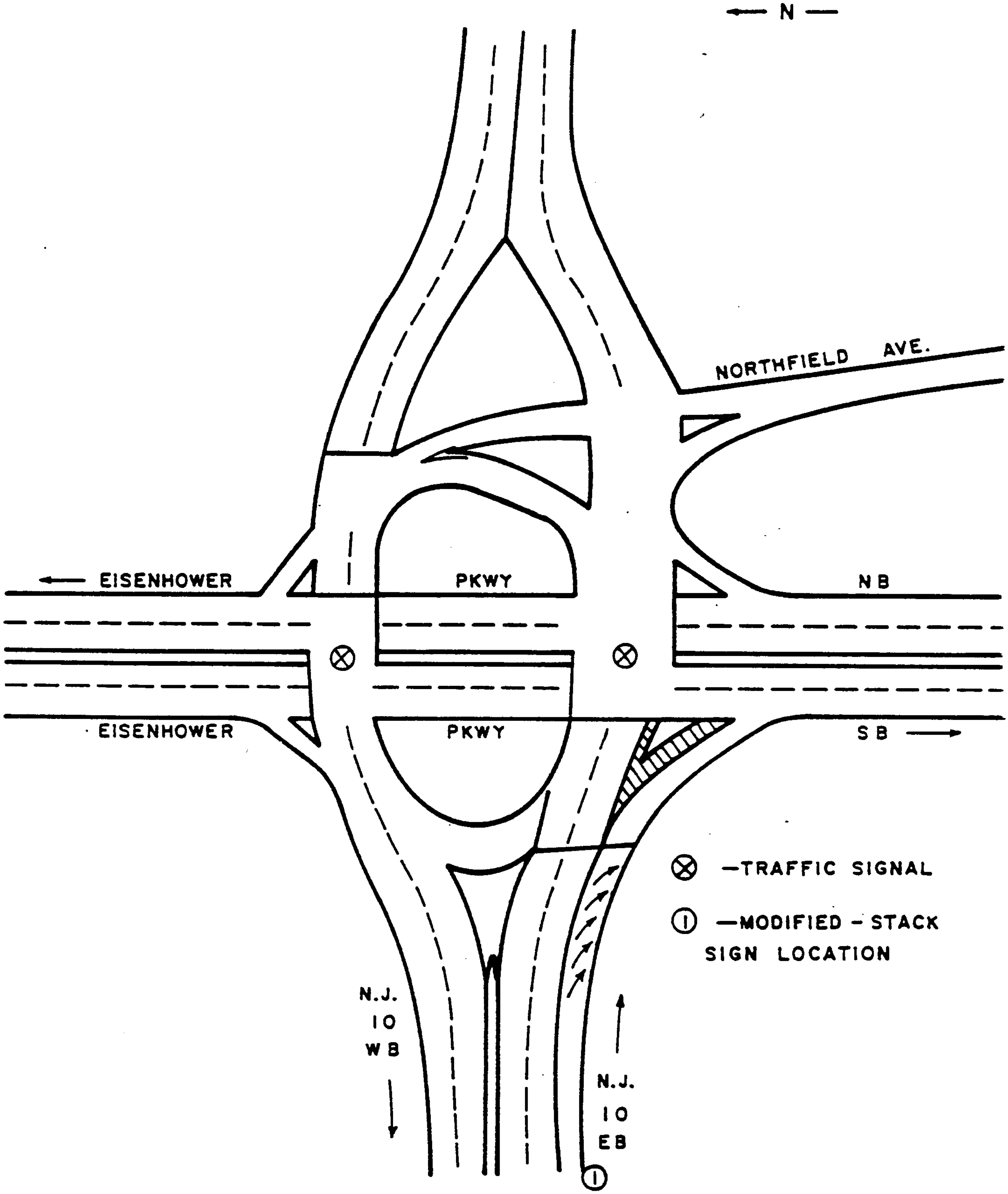


MARLTON CIRCLE



LIVINGSTON CIRCLE