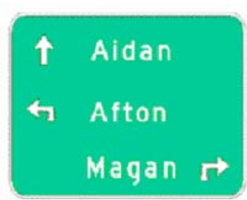
Traffic Control Devices Pooled Fund Study

Navigation Signing for Roundabouts

Final Report

December 2004



Prepared by:

Bryan J. Katz
Fred R. Hanscom
Vaughan W. Inman

Science Applications International Corporation
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, F-215
McLean, VA 22101

This research project was sponsored by the Traffic Control Devices Pooled Fund Study, TPF-5(065). Members of the Pooled Fund Study Panel are as follows:

Gerry Meis, California Department of Transportation
Mark Wilson, Florida Department of Transportation
Keith Golden, Georgia Department of Transportation
Larry Gregg, Illinois Department of Transportation
Tim Crouch, Iowa Department of Transportation
Steven Buckley, Kansas Department of Transportation
John Smith, Mississippi Department of Transportation
Julie Stotlemeyer, Missouri Department of Transportation
Randy Peters, Nebraska Department of Transportation
Scott Thorson, Nevada Department of Transportation
Patt Ott, New Jersey Department of Transportation
Doug Bartlett, New Jersey Department of Transportation
David Woodin, New York Department of Transportation
Lori Cove, North Carolina Department of Transportation
Kenneth Williams, Pennsylvania Department of Transportation
Don Turner, South Carolina Department of Transportation
Greg Brinkmeyer, Texas Department of Transportation
Tom Notbohm, Wisconsin Department of Transportation
Roger Wentz, American Traffic Safety Services Association (ATSSA)
Lee Billingsley, Broward County, Florida Department of Transportation
John Fisher, Los Angeles, California Department of Transportation

Debra Chappell, Federal Highway Administration, Office of Safety
Butch Wlaschin, Federal Highway Administration, Office of Program Development
Scott Wainwright, Federal Highway Administration, Office of Operations
Joe Moyer, Federal Highway Administration, Office of Safety R&D
Bryan Katz, Science Applications International Corporation

The objective of the Traffic Control Devices Pooled Fund Study (TCD PFS) is to assemble a group composed of State and local agencies, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test, and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

To join the TCD PFS, or for more information about the TCD PFS

- Contact Joe Moyer at (202) 493-3370 or contact Scott Wainwright (202) 366-0857
- Visit www.pooledfund.org and search for study # TPF-5(065).

EXECUTIVE SUMMARY

The objective of this effort was to support recommendations to the Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) Team as well as to the National Committee on Uniform Traffic Control Devices (NCUTCD) on double-lane roundabout signage. The objective was addressed by undertaking two studies. One study examined how the amount of information on roundabout exit signs might affect drivers' ability to use them. The other study focused on navigational signage that is intended to assist motorists to anticipate the correct roundabout exit and to select an appropriate approach lane for that exit. The scope of the latter study was limited to four currently used navigation-signing methods (Conventional, Maryland, Diagrammatic, and New York).

The exit sign study included an operational observation to verify that speed in roundabouts is predicted by the R_4 radius design speed. Sign information lead time, i.e., the time available for detecting and reading a sign, can be determined from operational speed and detection distance to a roundabout exit sign. The time required to read sign components, e.g., words and numbers, and to make the appropriate choice decisions, was derived from the literature. The available information lead time was combined with field observational data and reading time requirements to estimate the maximum amount of information that may be put on roundabout exit signs.

The second navigation-signing study consisted of a laboratory test of the four types of navigation guide sign. It measured accuracy of lane choice selection, accuracy of leg choice selection, reaction time for each decision, and confidence of each decision. Overall, the conventional and diagrammatic signs yielded the best performance, particularly when looking at participants' reaction time and confidence in their decision. Lane selection performance was below 70 percent correct, and not different from chance given the assumption that the left lane would be used for left turns and the right lane for right turns. The current NCUTCD markings subcommittee recommendations for lane markings were used in the stimuli presented to participants. Further research is recommended to determine whether the current recommended markings will be comprehended by drivers.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ACKNOWLEDGEMENTS

The authors of this report would like to thank the Federal Highway Administration's Human Centered Systems Team, both FHWA and Science Applications International Corporation (SAIC) employees, for their support on this project. Bobby Haas (SAIC) provided the computer program used for data collection on the project. Tiana Petit and Jason Kennedy (SAIC) aided in data collection activities and administrative support for this project as well. The authors would also like to thank Thomas Granda (FHWA), Joe Moyer (FHWA), and Steve Fleger (SAIC) for their management support of this project.

INTRODUCTION

Background

The objective of this effort was to obtain data and perform analyses on double-lane roundabout signage to support recommendations to Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) Team as well as to the National Committee on Uniform Traffic Control Devices (NCUTCD). To this end, two studies were performed. One study examined how the amount of information on roundabout exit signs might affect drivers' ability to use them. The other study focused on navigational signage that is intended to assist motorists to anticipate the correct roundabout exit and to select an appropriate approach lane for that exit. The scope of the study was limited to four currently used navigation signing methods. Both studies were directed towards the development of consistent and effective design standards for roundabouts.

Statement of Problem

The negotiation of roundabouts involves a series of navigation decisions. To safely approach and negotiate an unfamiliar roundabout, a motorist may be confronted with a complex navigational challenge that must be resolved quickly within an unfamiliar traffic and roadway environment. Current roundabout sign practice in the U.S. varies both within and among the States. Nonstandard signing practice may compound the challenge to drivers who are unfamiliar with roundabouts. There is little documentation regarding U.S. motorists' understanding or comprehension of roundabout signage and markings. As a result, the Federal Highway Administration, as well as state and local traffic engineers, have little empirical basis for developing roundabout signing recommendations.

There is a need for roundabout signing guidelines and standards, as the current Manual on Uniform Traffic Control Devices (MUTCD) does not represent current practice and does not meet the unique requirements of roundabouts (United States Department of Transportation, 2001). There are currently no roundabout-specific guide sign specifications in the MUTCD.

Research Goals

There are several alternatives for developing roundabout navigation signs. The goals of this study were to:

- Perform a literature review and state-of-practice survey to determine current roundabout signing practices.
- Perform an analysis to estimate the time to process the information on a sign and develop recommendations on the maximum amount of information to put on a sign based on roundabout geometry.
- Perform a laboratory study to assess the effectiveness of alternative navigation sign approaches.
- Provide recommendations to the NCUTCD on roundabout signing.

Research Approach

Navigating an unfamiliar roundabout requires drivers to process navigation signage within a limited the amount of time. Effective navigation signage should provide the required information while still allowing drivers to process other necessary information (e.g., markings, and other traffic) within that limited time and without impairing overall driving performance. Engineers may adopt different lane assignments or recommendations at roundabout approaches based on the amount of flow on each leg. Therefore, this study examined drivers' lane choice performance in response to navigational signs combined with turn restriction pavement markings.

Research Assumptions

Because roundabouts are relatively new to the U.S., and have yet to be deployed in many states, it was assumed that the target audience for these signs is motorists who are unfamiliar with the particular roundabout, and may be unfamiliar with the concept of a roundabout. It was further assumed that the information on the signs is the information that the motorist needs. For instance, if the destination name on the sign is *Afton*, it is assumed that the motorist knows that Afton is in the direction of her/his intended destination. In the real world, this assumption might be wrong; motorists heading for New York City might be looking for that destination, not for Afton, which might be between the motorist's current position and New York. We do not address the issue of which destinations, route symbols, or heading indications should appear on navigational signs. This study only examines whether one type of navigation sign may yield better lane choices and exit identifications than another type.

Drivers from the greater Washington, DC, metropolitan area served as test participants. It was assumed that the performance of drivers from that area would be representative of drivers in other parts of the country. This assumption might be wrong. It might be worthwhile to confirm the present findings by replicating a portion of the study with participants from other regions.

INFORMATION LOAD ANALYSIS

Research Method

To estimate the amount of information that on a sign that can be comprehended by drivers, an estimate is needed of the amount of time drivers have to process the information. This time is affected by operational conditions such as merge and lane-change requirements, and sign placement. Processing time must be adequate for drivers to both read and make the appropriate decision, e.g., whether or not to exit. This time is constrained by sign letter size, i.e., legibility distance, vehicle speed, and sight distance, as well as by the competing demands of merge activity, conflict avoidance, and the curved path tracking requirements posed by the roundabout geometry.

A literature review produced no roundabout specific studies that could be directly applied to estimate available roundabout sign-viewing time. Therefore, as part of the current effort, a roundabout operations observation was conducted with the three objectives:

1. **Establish basis for available sign information processing time.** Within the constraints imposed by roundabout geometric and operational conditions, determine a basis for estimating the amount of available sign-viewing and response time
2. **Validate the theoretical association between speed and geometry.** Determine whether the FHWA's *Roundabouts: An Informational Guide* (Robinson et al., 2001) speed-curve relationships for roundabouts are suitable as input for driver sign-viewing time estimates.
3. **Determine the impact of merge activity on available sign viewing time.** Given that merge requirements within roundabouts divert driver attention from sign viewing, account for this effect in the determination of sign-viewing time.

Data Collection

Observations were made in October 2003 at two Colorado roundabouts, one in Vail Village and the other in Avon at the I-70 interchange. Site selection criteria included the presence of a suitable elevated vantage point and sufficient traffic volume to sample both vehicle merge interactions and free-flow vehicle passes.

Free-flow vehicles were randomly selected as they entered a roundabout and tracked via high-resolution digital video surveillance until they reached an exit. This tracking method produced accurate speeds because: (1) the digital image (aided by zooming and panning) provided sufficient resolution to identify the video frame in which each vehicle entered and exited the roundabout, and (2) counting the frames for which a vehicle was within the inscribed circle yield durations accurate to 1/30th of a second.

Tracked paths were the 270-degree 'left turn', i.e., the path whose critical radius is R_4 as noted on page 138 of FHWA informational guide (Robinson et al., 2001) and illustrated below. This path was deemed critical with respect to available driver sign viewing time. Although higher speeds may be experienced with paths with a critical radius of R_1, R_2, and R_5, it was assumed that in majority of cases sight distance would be most limited on the R_4 path, and that sight distance would generally be more limiting than speed on sign reading.

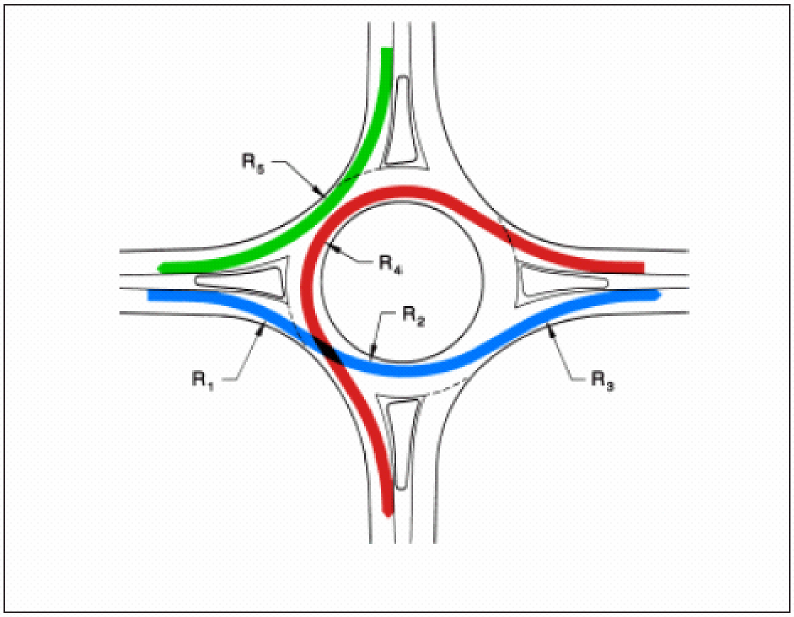


Figure 1: Roundabout turn paths and radii (Robinson et al., 2001).

Field Observations

Two types of roundabout design were included in this study. Vail Village is a 5-leg circular roundabout with an inscribed circle diameter of 200 feet, and Avon is a 3-leg teardrop design characterized by a 150-foot tear radius. Table 1 shows observed speeds at these roundabouts. A sufficient sample size (total of 100 vehicles) was gathered to ensure stable mean speeds: the 95 percent confidence interval about the mean was ±0.67 mph. Results indicated that observed mean speeds were not significantly different from those estimated on the basis of the speed-curve relationship in the FHWA information guide.

Table 1: Operational study observed speeds.

	Vail Village	Avon at I-70
Sample Size	54	46
Mean Speed, mph	18.1	18.7
Standard Deviation, mph	2.49	2.13
95_{th} % C.I. about the Mean	±0.67	±0.61
Design Speed, mph	17.5	18.0

Observed mean path speeds, alone, are not sufficient to estimate sign information-processing time because drivers often have to attend to other vehicles in addition to the signs. Figure 2 illustrates a "merge conflict" where the driver of the vehicle in the circle must attend to the vehicles entering the roundabout. Two approaches were taken to estimate the effect of roundabout merge conflicts on the amount of time available to process signs. First, the literature was reviewed with regard to merge conflict demands, and, second, a comparison was made within the field observations between circular path travel times of vehicles that passed without conflicts and those that may have had to resolve potential conflicts.

Although we could not identify prior studies of merge conflicts in roundabouts, Robinson et al. (1972) measured visual search behaviors for drivers making lane changes at speeds that are representative of roundabout driving. Drivers' head movements were recorded via a helmet outfitted with a potentiometer. Segments of search behavior were glance time to mirrors, head movement time, and glance time to road ahead. The results indicated the glance time away from the forward roadway when vehicles were present was about 2.47 s, and about 1 s more than when other vehicles were not present. The Robinson et al. findings are shown in Table 2.

Figure 2: Example of merge conflict while navigating a roundabout

Table 2: Visual search time (s) for right-hand merge in traffic (Robinson et al., 1972).

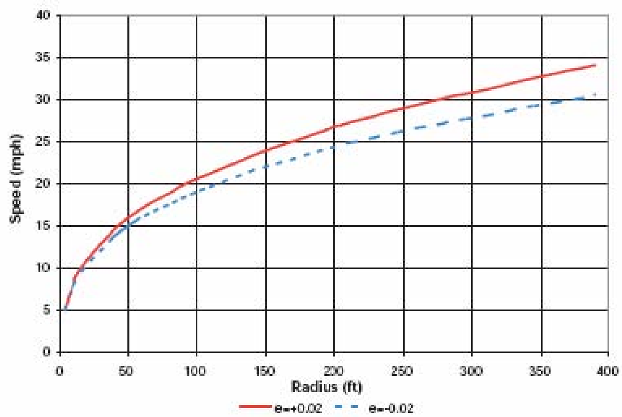
	No Traffic	Traffic	Difference
Time from command to start of merge	3.37	4.53	1.16
Visual input time (mirrors, back, side)	0.99	1.79	0.80
Visual loss due to head movement	0.43	0.68	0.25
Remaining search time	1.95	2.06	0.11
Pre-maneuver time away from forward roadway	1.42	2.47	1.05

The data gathered at the Vail Village roundabout included a number of vehicles with potential merge conflicts, i.e., vehicles that made a left turn when other vehicles were present. These vehicles averaged 2.45 s longer to travel from entrance to exit than vehicles that turned when other vehicles were absent. The implication of this result may be that drivers with a merge conflict slow to offset visual distraction of the merge. This slowing hypothesis is consistent with the Robinson et al. finding that merge maneuvers were delayed by 1.2 s when traffic was present. Additional study would be required to determine whether the slowing was because of visual demands or other reasons, such as to allow for spatial separation between vehicles. However, the close correspondence between the glance time data reported by Robinson et al. and the travel time reduction documented here is encouraging for the distraction hypothesis.

The close correspondence between the observed left-turn maneuver times and the speed predictions using R_4 suggest that R_4 is valid for use in estimating available sign processing time.

Application of Results to the Design of Signs

Given R_4, exit sign approach speeds within roundabouts may be derived from the design formula and speed-radius graph shown in Figure 3.



$$V = \sqrt{15R(e+f)} \text{ (U.S. customary)}$$

where: V = Design speed (mi/h)
R = Radius (ft)
e = Superelevation (ft/ft)
f = Side friction factor

Figure 3: Speed versus radius for roundabouts (Robinson et al., 2001).

Development of Exit Sign Information Loads

In an unfamiliar roundabout, for a driver to use exit signage to identify or confirm the appropriate exit, the driver must (1) detect the exit sign; (2) read and comprehend the information on the sign; (3) make an exit/no-exit decision; and (4) execute the required maneuver. Requirements for these tasks are:

1. **Detect the exit sign.** Roundabout exit signs may be in a driver's direct field of view for only a few seconds before an exit maneuver is required. Although head or eye movements will likely be required to detect the sign, the driver's normal scanning of the road ahead should facilitate the search process. The placement of the exit sign, either on the outside of the circular roadway or on the splitter island may also affect sign detection. No literature was found that examines detection times and sight distances for exit sign placement.

2. **Read and comprehend the sign.** The sign-reading process is affected by various factors such as legibility distance and the amount of information on the sign (information load).

3. **Make sign-related decision.** After comprehending the sign, the driver must make a decision based on available information, e.g., exit or no-exit choice.

4. **Execute exit maneuver**. Subsequent to making an exit decision, a path adjustment is necessary in advance of the exit point. Deceleration is often

unnecessary at roundabout exits because exit radii are often larger than the circular path (R_4) radii. However, some steering and lane position adjustment is necessary. In addition, there may be cases when a lane change is required.

Two articles were identified that appeared particularly relevant to reading and comprehension time for roundabout signage: Agg (1994), and Smiley (2000).

In the *Direction Sign Overload* study, Agg (1994) used a driving simulator to measure participant response times to two types of European signs with application to roundabouts: “Map” signs contained intersection graphics of similar complexity to roundabout advance signs, and “Flag” signs, which are typically applied to European roundabout exits. The objective of the Agg study was to determine the amount of sign information (i.e., combination of words and symbols) appropriate to avoid overload. The premise of the study was that overload will occur if a sign has more information than can be processed in the available viewing time. Participants in the simulator were given a route-following assignment and then were shown slides of signs in the context of the driving situation. Respondents indicated the direction they needed to follow in to reach the target destination. Performance measures were of the correctness of the indicated direction and the time required to respond. Based on the study results, Agg suggested the following relationships between response time and the amount of information on signs:

For map signs, $T_{99.9} = 0.27N + 2.44$,

For flag signs, $T_{99.9} = 0.33N + 2.02$,

where $T_{99.9}$ is the 99.9th percentile response time in seconds, and N is the number of destinations listed on the navigation signs.

According to Smiley (2000), sign reading time should generally be considered to be on the order of 1/2 second per word or number (with 1 second as a minimum for total reading time), and 1 second per symbol. If some of the sign information is redundant, then reading time should be calculated only for the critical words. For example, when drivers read destination signs, they do not need to read every word of each destination. If drivers are reading a list of destination names, they only need to read the arrow direction for the place name they are searching for. Therefore, according to Smiley, reading time can be approximated by:

$$T = 1 \times \text{(number of relevant symbols)} + 0.5 \times \text{(no. of words and numbers)},$$

where T is reading time in seconds.

The similarity between Agg’s TRL study and Smiley’s applied results is evident in the example of a stack sign with two symbols and three destination names. The reading time according to Smiley is 3.5 seconds compared with a 3.8 second response time computed from the Agg formula. Because of the similarity between participants’ task in the Agg study and the participant task in the current study (below), the results obtained by Agg were used for comparison.

Table 3 lists comparative results of the Agg and Smiley studies for varied information loading conditions. While both studies simulated sign reading and choice decision times, Smiley added 0.75 s additional glance time for signs containing more than four words or numbers. The diagrammatic sign results showed slightly longer reading/decision times for low to moderate information loading. A plausible explanation for slightly shorter reading/decision times for the higher-loaded diagrammatic conditions is that laboratory participants had a general sense of their intended direction and did not read all of the destination names.

Table 3: Agg (1994)and Smiley (2000) study results for reading and decision choice time.

Words or Numbers on Sign	Reading and Decision Choice Time, seconds			
	Conventional			Diagrammatic
	Smiley, 2000	Agg, 1994	Average	Agg, 1994
2	2	2.7	2.3	3
3	2.5	3	2.8	3.3
4	3	3.3	3.2	3.5
5	4.3*	3.7	4.0	3.8
6	4.8*	4	4.4	4.1
7	5.3*	4.3	4.8	4.3
8	5.8*	4.7	5.2	4.6
9	6.3*	5	5.6	4.9
10	6.8*	5.3	6.0	5.1

*Includes additional glance time for more than 4 words/numbers

Sign Information Lead Time in the Circular Roadway

Sign information lead time is the amount of time available to the driver to detect and read a sign. The driver's maximum available sign viewing time is the distance (e.g., feet) to the sign as it appears in the field of view divided by the vehicle operating speed (e.g., fps). Nettleton and Millin (1981) suggest that a drivers' visual perception of highway signs at typical roundabout speeds occurs within a 90-degree visual cone, i.e., ± 45 degrees of the direction of travel. However, navigating the circular roadway of a roundabout typically involves some degree of head movement as the driver scans the roadway ahead and for merge conflicts. Therefore, the visibility distance calculations for roundabout exit signs assumed a visual cone of 120 degrees for sign detection and 90 degrees for reading/decision. The resulting calculations of the time available to detect and read roundabout exit signs are given in Table 4

Table 4. Available information lead time within roundabouts from 45- and 60-degree lateral visual fields.

			Sign Detection (60-degree lateral visibility)		Sign Reading/Decision (45-degree lateral visibility)	
Inscribed Circle Diameter (ft)	R_4 Path Radius (ft)	Operating Speed (mi/h)	Visibility Distance (ft)	Information Lead Time (s)	Visibility Distance (ft)	Information Lead Time (s)
Single Lane Roundabout						
100	35	13.6	73	3.7	55	2.8
115	45	14.7	94	4.4	71	3.3
130	55	16.0	115	4.9	86	3.7
Double Lane Roundabout						
150	50	15.5	105	4.6	79	3.4
165	60	16.4	126	5.2	94	3.9
180	65	17.1	136	5.4	102	4.1
200	75	18.4	157	5.8	118	4.4
215	85	18.9	178	6.4	134	4.8
230	90	19.1	188	6.7	141	5.0

Pre-exit Maneuvers within the Circular Path

The driving task within a roundabout circular roadway may involve maneuvers that compete with sign information processing. Depending upon the roundabout design and exit sign placement, it may be necessary for a driver to change lanes or execute an exiting path change during the sign information lead time. The extent to which these maneuvers affect available sign information processing time is addressed as follows:

Possible Lane Change Requirement

Modern roundabout design and pavement striping practice often preclude the need for a lane change once a vehicle enters the circular roadway. Nevertheless, there are situations in which lane changing may be required in double lane roundabouts. Although it is likely drivers will reduce their speed to compensate for the additional attention demanded by a lane change, as was inferred above for merging drivers, this slowing was not confirmed in the present study.

In unmarked roundabouts a lane change may involve a maneuver in which a vehicle crosses into an adjacent lane and continues into an exit without realigning itself into the concentric orientation of its original path (i.e., straightening its wheels). This lane change pattern requires less time and distance than typical arterial or freeway lane-to-lane shifts. Table 5 shows time and distance lane-change requirements for 12-foot lateral shifts at the applicable lateral design accelerations associated with the respective circular roadway vehicle paths (Adapted from Exhibit 6-9 of FHWA's *Roundabouts: An Informational Guide*).

Table 5: Lane change time and distance requirements at double lane roundabouts (Robinson et al., 2001).

Inscribed Circle Diameter (ft)	R_4 Path Radius (ft)	Operating Speed (mi/h)	Lane Change Distance (ft)	Lane Change Time (s)
150	50	15.5	33.6	1.5
165	60	16.4	37.0	1.6
180	65	17.1	37.0	1.6
200	75	18.4	40.7	1.6
215	85	18.9	43.1	1.6
230	90	19.1	43.9	1.7

Exit Preparation Path Change

An exit sign located on the splitter island requires that drivers complete their exit maneuvers before reaching the sign. This effectively reduces sign information lead time. The present calculations of exit maneuver time requirements assume:

- Deceleration is not required because roundabout exit radii are usually larger than circular path radii.
- A lane-change is not required because contemporary roundabout design and pavement marking practice usually preclude the requirement for a lane change, and if the roundabout design allows a lane change in the circular roadway, the effect on sign information lead time is independent of the exit path preparation and can be accounted for by incorporating the distance adjustment from Table 5.

As roundabout design principles simplify the exit process, one additional second (beyond sign-reading, decision-making, and lane-changing) is allocated for a driver to concurrently execute the necessary steering response and travel the required distance needed to affect the exit maneuver. The one-second steering initiation time is consistent with alerted driver response times, e.g., drivers are aware of the exit location.

Based on the above assumptions, the proposed the maximum available time for exit detection and processing is given in Table 6. Additional research is needed to validate the proposed time values, as they are based on several assumptions and the sensitivity of the model of roundabout driving to violations of these assumptions is unknown. Furthermore, our model does not consider factors that may reduce sight or legibility distances. Such factors, for example lighting, intervening vehicle obstructions, and variations in vertical curvature may exist.

Table 6: Maximum allowable sign information load: available reading and decision time (s).

			Exit Sign on Splitter Island		Exit Sign in Advance of Splitter Island	
Inscribed Circle Diameter (ft)	R_4 Path Radius (ft)	Operating Speed (mi/h)	No Lane Change Design	Lane Change Permitted	No Lane Change Design	Lane Change Permitted
Single Lane Roundabout						
100	35	14	1.8	N/A	2.8	N/A
115	45	15	2.3	N/A	3.3	N/A
130	55	16	2.7	N/A	3.7	N/A
150	65	17	3.1	N/A	4.1	N/A
Double Lane Roundabout						
150	50	16	2.4	0.9	3.4	1.9
165	60	16	2.9	1.3	3.9	2.3
180	65	17	3.1	1.5	4.1	2.5
200	75	18	3.4	1.7	4.4	2.7
215	85	19	3.8	2.2	4.8	3.2
230	90	19	4.0	2.4	5.0	3.4

Information Loading for Roundabout Exit Signs

The sign reading time prediction, based on the Agg (1994) stacked flag-sign equation, can be combined with the predictions in Table 6 to derive the maximum amount of information that drivers could process from an exit sign. The results of this combination are shown in Table 7. Again, it should be emphasized that both Table 6 and Table 7 are based on a number of mutually dependent assumptions. Further research is required to investigate issues such as the partitioning of attention among driving and navigation tasks and how information is processed. Further research is also needed to calibrate the various parameter estimates and to validate the underlying assumptions. Nonetheless, a useful model is provided that is based on earlier research and that can serve as a conceptual model for further development. Practitioners may find these sign information load recommendations useful, but they are cautioned to treat the values in Table 6 and Table 7 as maximums, and to strive to minimize information load to the extent practicable.

Table 7. Recommended maximum sign information load: number of destination names or route numbers.

			Exit Sign on Splitter Island		Exit Sign, Advance of Splitter Island	
Inscribed Circle Diameter, ft	R_4 Path Radius, ft	Operating Speed, mph	No Lane Change Design	Lane Changes Permitted	No Lane Change Design	Lane Changes Permitted
Single Lane Roundabout						
100	35	14	1	N/A	3	N/A
115	45	15	2	N/A	4	N/A
130	55	16	2	N/A	4	N/A
150	65	17	3	N/A	5	N/A
Double Lane Roundabout						
150	50	16	2	*	4	1
165	60	16	3	*	4	2
180	65	17	3	1	5	2
200	75	18	4	1	6	3
215	85	19	4	2	6	4
230	90	19	5	2	7	4

* Does not allow adequate sign reading and decision time

LABORATORY STUDY

Research Method

The second phase of the project was a laboratory study performed in the Sign Simulator Laboratory at Turner-Fairbank Highway Research Center. With increasing use of modern roundabouts, issues have arisen regarding the variety of signing unique to roundabouts. An evaluation of alternatives was needed to suggest how to best communicate to drivers in advance of a multi-lane roundabout the lane they should be in for a given destination. Alternative forms of guide signing as well as pavement markings have been suggested. All these devices have been used in various combinations by various jurisdictions. The Traffic Control Devices Pooled Fund Study members perceived the need for a uniform set of guidelines. The NCUTCD Markings committee has already recommended markings for roundabouts. Therefore, our laboratory study used the NCUTCD recommended markings in combination with four advance navigation sign types to evaluate each sign type.

The objective of the laboratory study was to evaluate the effects of sign information load, as determined by the number of destination names and route numbers, on lane choice and exit selection. Participants were presented a destination followed by a guide sign, or guide sign and route assembly, followed by a picture of a roundabout entrance with turn restriction markings. Participants were asked to make an entrance-lane choice and an exit leg choice based on the presented stimuli. Response measures were decision accuracy, decision latency, and decision confidence.

From the state-of-practice survey, four navigation signing alternatives were selected for evaluation. The first, "Conventional", followed the current MUTCD standard used in conventional intersections. That is, two separate signs were presented: a route assembly that was followed by guide sign. The route assembly and guide sign were displayed one after the other for 2 s each. The route assembly and conventional guide signs are illustrated in Figure 4.

Figure 4: Conventional roundabout route assembly (left) and guide sign (right).

The second alternative was the "Maryland" advanced guide sign. The "Maryland" type is used at many Maryland roundabouts. With this type, route shields are placed on the sign itself and horizontal lines separate sections. This type is illustrated in Figure 5.

Figure 5: Maryland roundabout guide sign.

The third alternative was the "Diagrammatic" advance guide sign. This type is used at many roundabouts throughout the United States. It includes route shields and destinations names shown in relation to a roundabout diagram. The Diagrammatic type is illustrated in Figure 6.

Figure 6: Diagrammatic roundabout guide sign.

The fourth type selected for evaluations was the "New York" advance guide sign. In this type, the left and right sides of the sign indicate the lane that motorist needs to be in for routes or destinations displayed on that side of the sign. A dashed line down the center of the slide symbolizes a lane marking. The New York type is illustrated in Figure 7.

Figure 7. New York roundabout guide sign.

Research Design

There were three independent variables: Guide Sign Type with four levels (Conventional, Maryland, Diagrammatic, and New York); Information Items with 4 levels; and Turn restriction with five levels.

Destinations were designated with a destination name, a route shield with cardinal heading, or both. Destination names and shields were combined factorially so that each guide sign type was presented with seven different combinations of destination name and route shield. These seven combinations are shown in Table 8. The total number of information items on the signs was factor of interest in this study, not comparisons of route shields versus destination names. Therefore, the dependent measure of interest is the total number of items on the sign, which had four levels: 3, 4, 5, or 6 items.

Table 8: Combinations of destination names and route shields.

Number of Destination Names	Number of Route Shields	Total
0	3	3
1	3	4
2	3	5
3	3	6
3	2	5
3	1	4
3	0	3

There are five turn restrictions options that were factorially combined with the other independent variables. The five options are shown in Figure 8.

Option 1

Option 2

Option 3

Option 4

Option 5

Figure 8: Pavement marking turn restriction options.

The design was a 4 (Navigation Sign Type) × 4 (Information Items) × 5 (Turn restriction) mixed factorial. Navigation Sign Type was a between subject factor. Information Items and Turn restriction were within group factors in which every participant was presented each level of those factors. There were two reasons for making Navigation Sign Type a between group factor. First, there might have been a carryover learning effect from one type to another. Second, states and localities tend to use a limited number of sign types, so that a particular driver would normally only experience one or two types of signs in their daily driving.

Sixty-four drivers were tested, sixteen in each of the four Navigation Sign Type conditions. Each participant experienced 90 trials with a random order of Turn restriction, Destination, and Exit (1^{st}, 2^{nd}, and 3^{rd}). The correct lane responses (i.e., left, either, or right) occurred equally often. The correct turn restriction also occurred equally often. Destination names were assigned at random subject to constraints that: (1) each destination occurred approximately equally often, (2) no more than 2 destination names per trial started with the same letter, and (3) no destination name appeared more than 3 times for the same leg. To equate destination names across conditions, all destination names had 5 letters and 2 syllables.

With each trial taking about 15 seconds, data collection required 23 minutes per participant. With the addition of briefing, debriefing, and preliminary testing (a vision test), the entire procedure was completed in slightly less than one hour.

Procedure

Participants began by completing an informed consent form. Next, they were given a vision test using a Snellen eye chart to ensure that their vision met the legal 20/40 acuity requirement for operation of a motor vehicle in the Commonwealth of Virginia.

Participants were informed that the purpose of the experiment was to learn more about the best way to indicate which lane they should use at double-lane roundabouts.

Each participant was given 5 practice trials that were followed by 90 test trials. On individual trials, participants were first shown text which specified either a destination name (e.g., Mason) or route number and cardinal direction (e.g., US 460, West). After reading the destination aloud, the participant struck a green button on the top of the touch pad, which caused, a guide sign, route assembly, or route assembly followed guide sign, to be projected onto a rear projection screen. In the Maryland, Diagrammatic, and New York conditions, the guide signs were projected for 2 s. In the conventional condition, there could be one or two projections of 2 s each. Whether there were one or two projections depended on the information presented: If there were only destination names, then only a conventional guide sign was presented for 2 s. If only route numbers were presented, then only a route shield assembly was presented for 2 s. If both route numbers and destination names were given, then the route shield assembly was presented first for 2 s and was followed by a guide sign that was also presented for 2 s.

The guide signs or route assembly presentations were followed by one of the roundabout options shown in Figure 8. The roundabout picture was displayed for until the participant pressed a key to indicate which lane they should be in for their destination: left, either, or right. Both lane choice and choice latency were recorded. After making a lane choice, the participant was prompted to indicate choice confidence on a scale from 1 to 7, where 1 was labeled “Very Sure” and 7 was labeled “Not at All Sure”. All responses were made on a programmable touch pad, the overlay for which is shown in Figure 9. Following the lane choice confidence response, the participant was prompted to indicate which exit leg of the roundabout was appropriate for the assigned destination. Finally, the participant was prompted to indicate confidence in the exit leg choice on the same scale used for lane choice confidence. Response time was recorded for leg choice. After completing the experiment, the participant was paid $30.

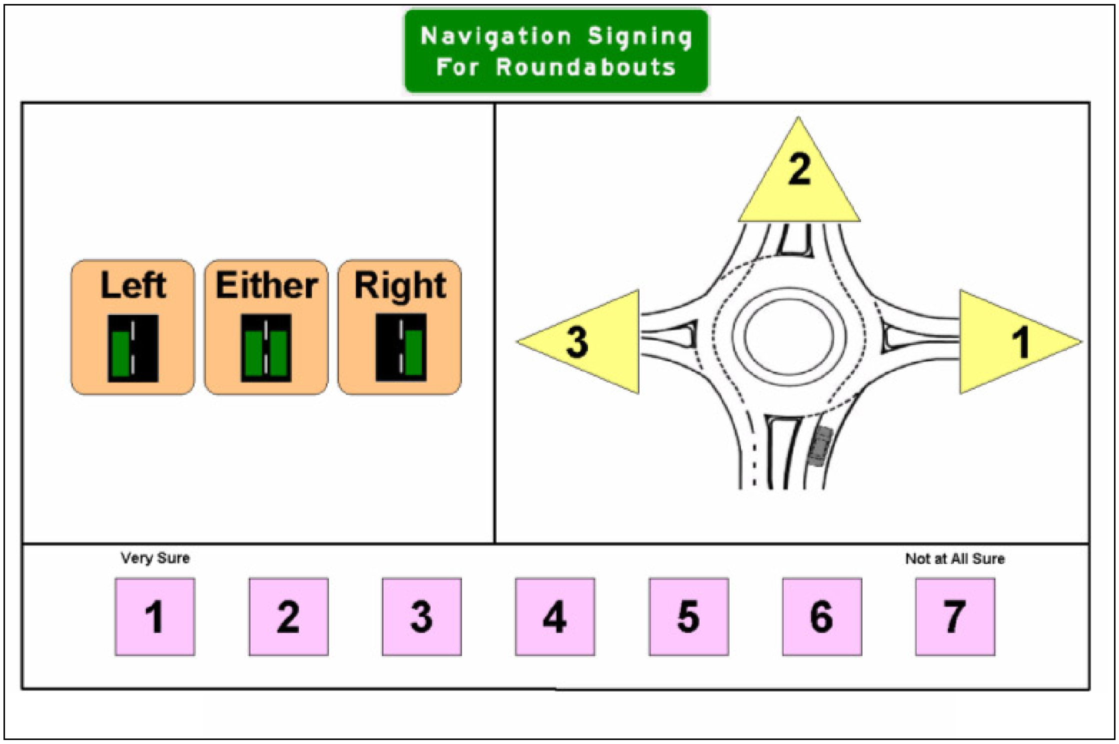


Figure 9. Programmable touch pad overlay with lane choice selections to left, leg choice selections to right, and confidence ratings across the bottom.

Results

All statistical tests were evaluated with $\alpha = 0.05$ level. The findings for each dependent measure are provided separately. For each variable, a multivariate repeated measures analysis of variance was performed with the number of information items (route shields + destination names) as the repeated measure and navigation sign type, age group, and gender as between group variables.

Lane Choice Accuracy

Overall, participants selected the correct lane only 68.6 percent of the time. As can be seen, lane selection accuracy with 4 item signs was significantly better than that with 6 item signs. The only statistically reliable effect was that for the number of items on the sign, $F\ (1, 48) = 6.2$, $p < 0.05$. Figure 10 shows the proportion correct as a function of number of items on the signs. Error bars in the figure represent two standard errors of the mean and may be used for comparison of significant effects. In general, any mean that is outside the area enclosed by the error bars of another mean is significantly different from that mean. Conversely, means that fall within the range of the error bars of another mean are not significantly different from that other mean.

With three equally probable responses, chance performance in lane choice would be 33.3 percent. The mean observed response of 68.6 was well above chance. However, if participants used only a simple heuristic of choosing the left lane for left turn movements, the right lane for right turn movements, and either lane for straight through movements, then performance would have been 65 percent correct. The 95 percent confidence limits for the overall mean were from 65.2 percent to 71.8 percent. The finding that correct lane selection was only marginally better than what would have been achieved using a the simple heuristic suggests that most participants did not understand the importance of the turn restriction arrows, and that most New York group participants did not understand the importance of the left-right organization of information on that sign type.

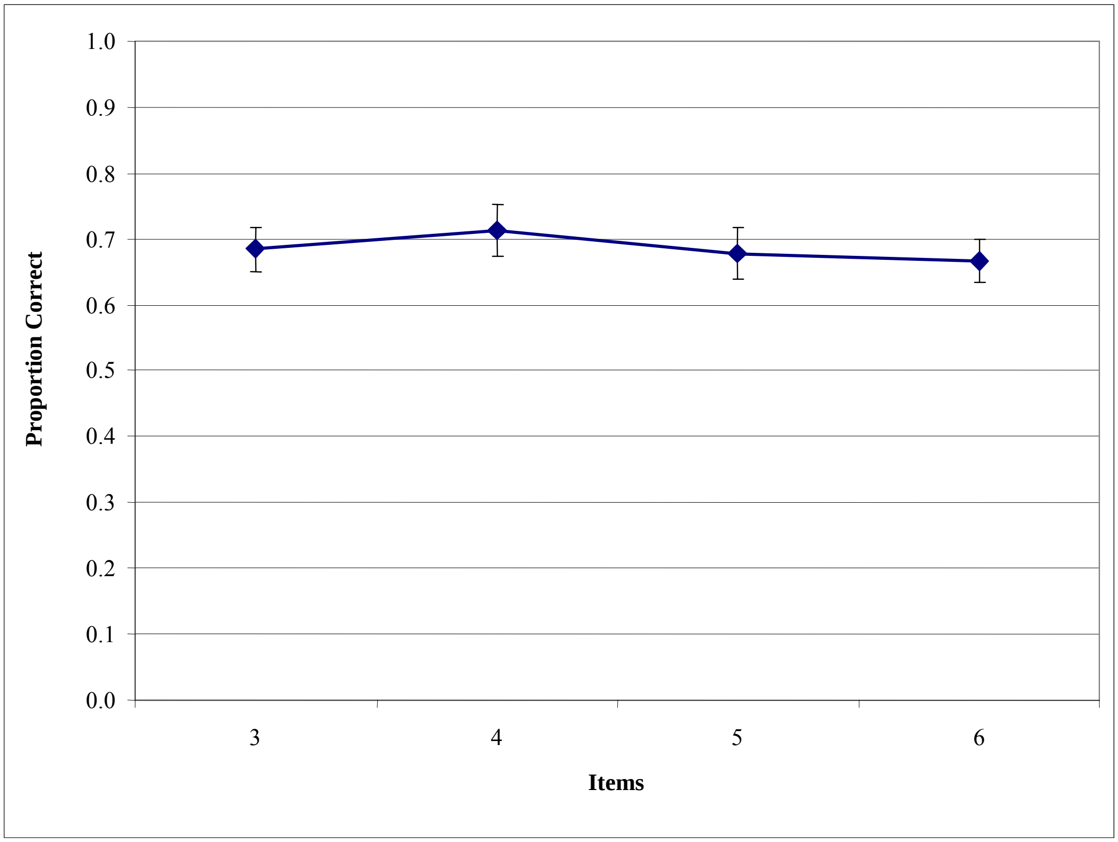


Figure 10. Lane choice accuracy as a function of the number of text and route shield items

Lane Choice Response Time

Figure 11 shows the mean response times for the lane choice response. To avoid cluttering the figure, error bars that represent two standard errors have been placed only around the means for the diagrammatic signs. The variability of the remaining means was quite similar. This older and younger groups responding differently to the sign types, as reflected in the significant 3-way interaction of sign type, age group, and number of items, F (9, 144) = 3.7, $p < 0.01$. The younger group responded more quickly than the older group to the Conventional and Maryland type signs. Both age groups were slower in responding to the New York and Maryland type signs, The slowest times of the younger group were to the Maryland type with 3 or 4 items. The older group responded most slowly to the New York sign when it had 5 or 6 items. Overall, responses to the New York and Maryland type signs were slower than those to the Conventional and

Diagrammatic signs. This main effect of sign type, F (3, 48) = 3.1, $p < 0.05$, was not negated by the 3-way interaction.

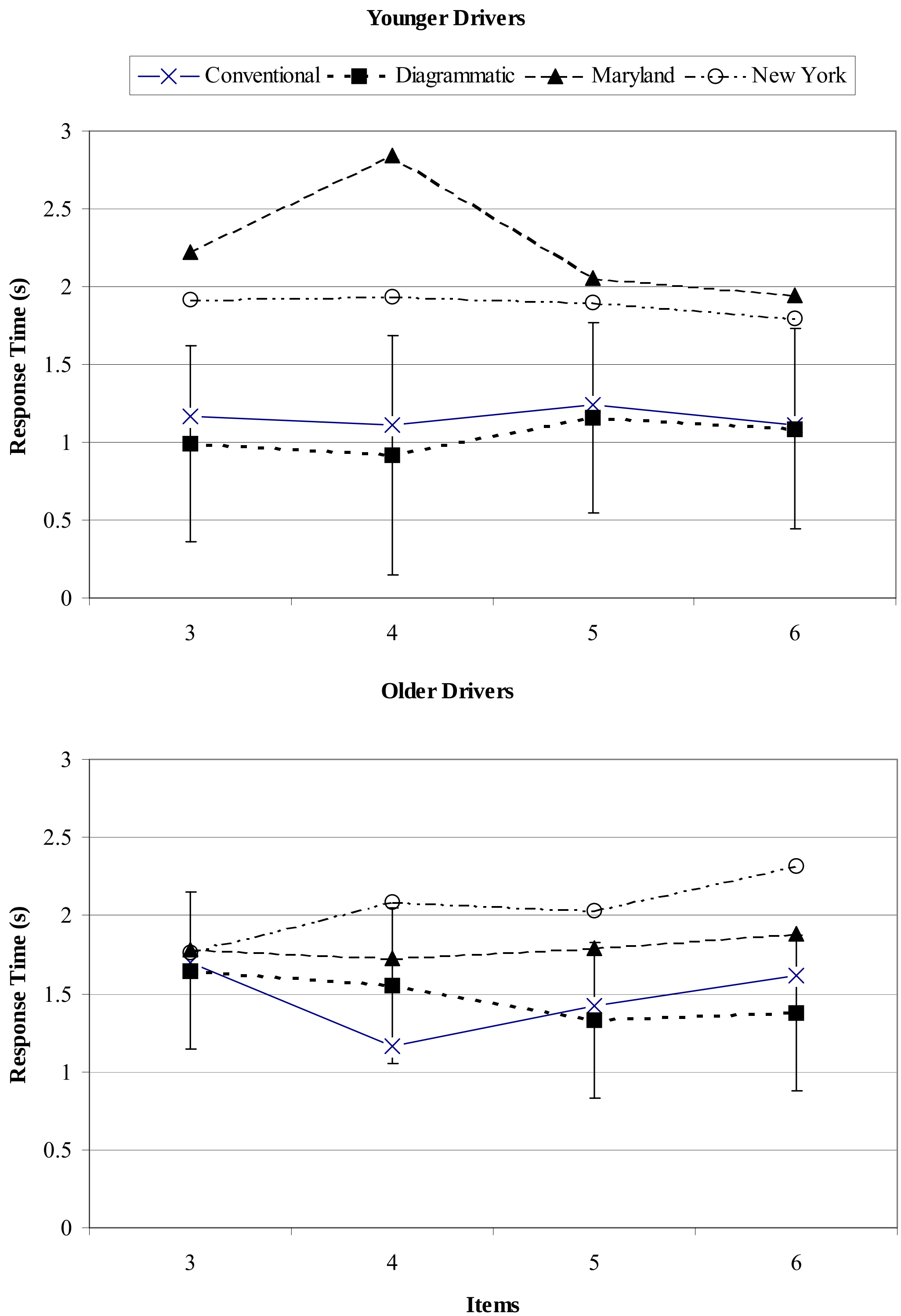


Figure 11. Response times, in seconds, for lane choice decision as a function of navigation sign type, age group, and number of information items.

Leg Choice Accuracy

Figure 12 shows exit leg selection accuracy as a function of sign type, age group, and the number of items of information on the sign. As a result of the notably poor performance with the New York type sign, the sign type effect was statistically significant, $F\ (3, 48) = 43.1$, $p < 0.001$. The finding that leg identification was poorer with the New York sign is not surprising given that the New York sign provides no reliable clues for leg selection. Overall, the younger group was more accurate than the older group, which resulted in a statistically reliable age effect, $F\ (1, 48) = 8.0$, $p < 0.01$. Where performance was not near the ceiling, the proportion correct tended to decrease with an increase in the number of items on the sign, $F\ (3, 48) = 2.8$, $p < 0.05$.

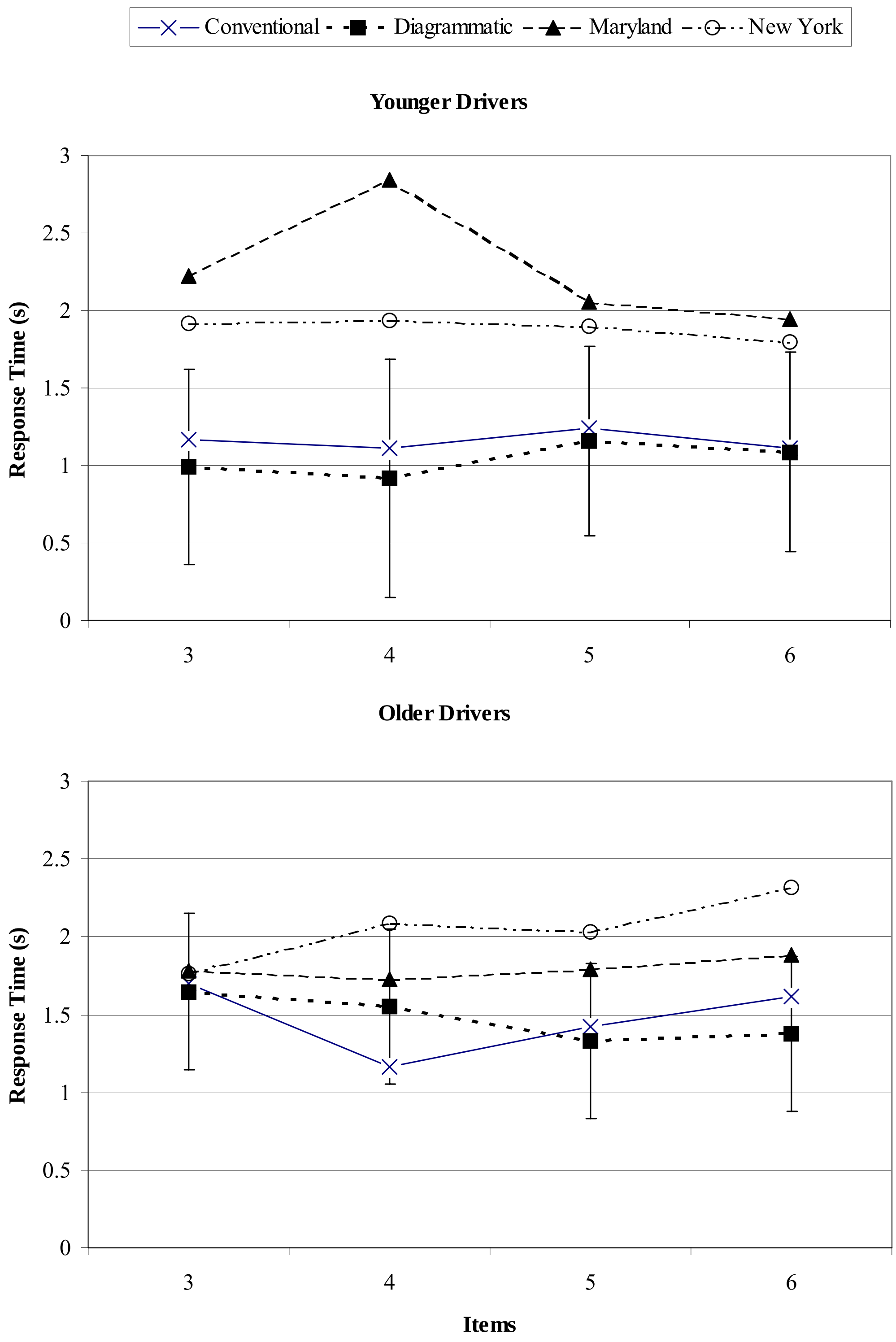


Figure 12: Mean proportion of correct exit leg selections as a function of sign type, age group, and items.

Leg Choice Response Time

Only the older group gave slower leg choice responses as the number if information items increased, and then only for the New York type sign. This pattern, shown in Figure 13, resulted in a 3-way interaction of sign type, age group, and number of items, $F\ (9, 144) = 3.7$, $p < 0.001$.

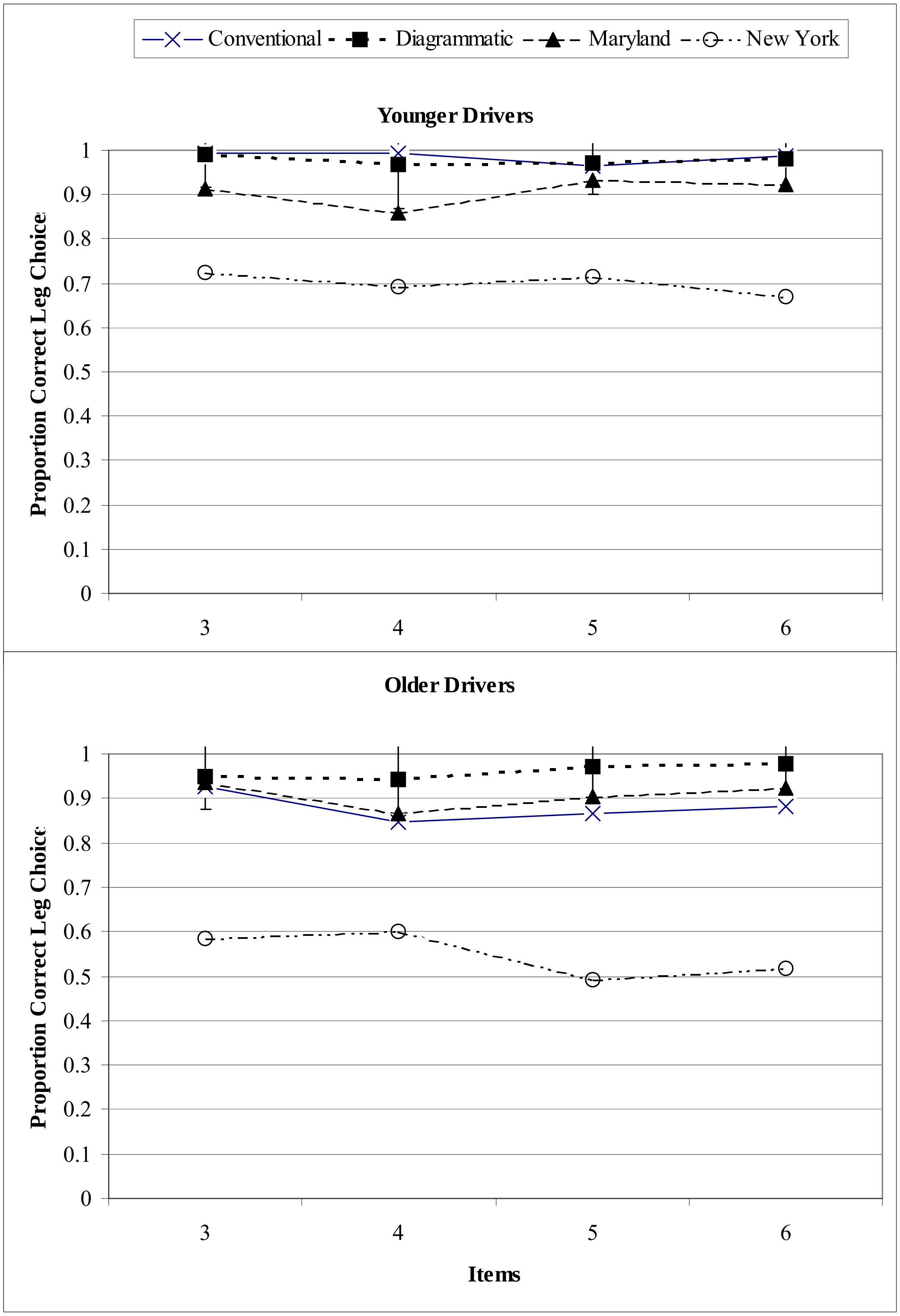


Figure 13: Mean leg choice reaction time by sign type and information level.

Lane Selection Confidence

As can be seen in Figure 14, participants were fairly confident of their lane selection choices despite the finding that they were only correct 68.5 percent of the time. Participants were somewhat less confident with the New York and Maryland signs than from the Conventional and Diagrammatic signs. The difference resulted in a significant sign type effect, *F* (3, 48) = 3.8, $p < 0.05$.

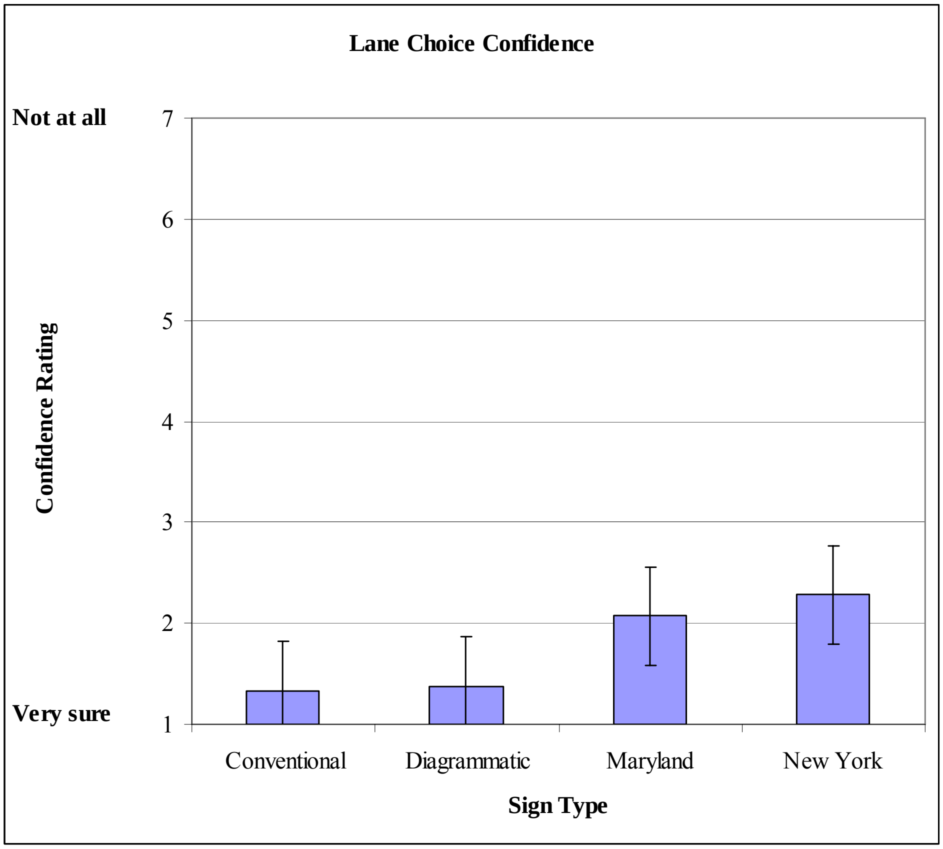


Figure 14: Mean lane choice confidence rating by sign type.

Leg Selection Confidence

Consistent with the high error rate for leg selection with the New York type sign, participants, New York group participants provided the lowest leg choice confidence ratings. Mean confidence ratings as a function of sign type and number of items are shown in Figure 15. Although Maryland group was more confident of its lane selection then was the New York group, those with Maryland type signs were less confident in their leg choices than were either the Conventional sign group or the Diagrammatic sign group. The latter to groups exhibited almost total confidence in their decisions. The sign type effect was significant, *F* (3, 48) = 11.4, $p < 0.001$. There was a slight, but nonetheless statistically significant, effect of number of items. Confidence decreased with an increasing number of items, *F* (3, 144) = 3.9, $p < 0.05$.

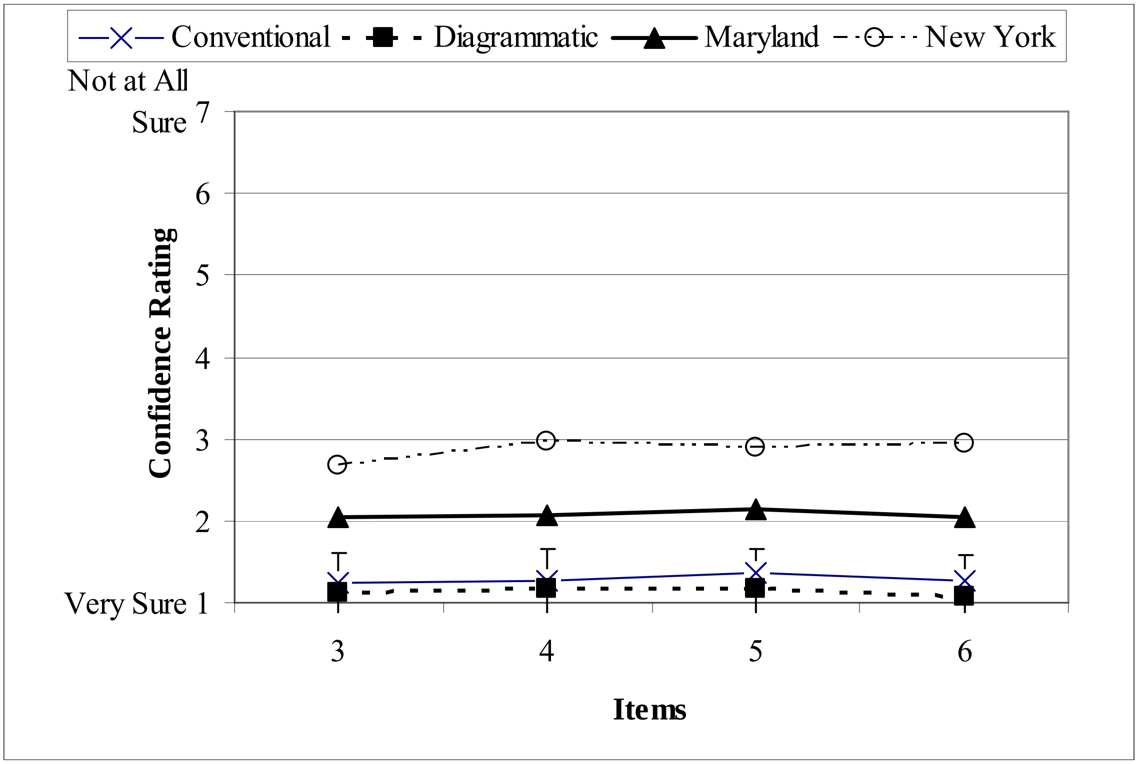


Figure 15. Mean Leg choice confidence rating by sign type and information load.

CONCLUSIONS AND RECOMMENDATIONS

Operational Analysis portion of this study developed a concept for sign information load in the context of competing roundabout driving task demands. The analysis included operational observations that confirmed that operational speed closely correlated to the R_4 radius design speed. Sign information lead time, the time available for detecting and reading a sign, can be estimated from R_4 design speed and detection distance to a roundabout exit sign. The required time needed to read sign information and to make the appropriate choice were derived the literature. Available sign reading and decision time in roundabouts was assumed to be the difference between total sign information lead time and an estimate of the time consumed by competing tasks. A table of maximum sign items as a function of R_4 radius and lane change restriction was proposed. This concept requires further research, but the proposed table may serve as a basis for validation of such a table for roundabout designers.

In the laboratory experiment, participants did not appear to use either the turn restrictions markings proposed by the NCUTCD, or the lane choice information available on the New York guide signs. Overall participant chose the correct lane only 68.5 percent of the time, a performance level that would be unacceptable if observed at actual intersections. This level of performance should raise concerns. It is possible that the low level of performance in lane choice was an artifact of the experimental design: that participants didn't process the roundabout picture with turn restriction markings because of some experiment specific context. Participants were not told that the roundabout pictures contained turn restriction arrows, or what the arrows mean in a roundabout context. Indeed, some participant admitted in the post-experiment debriefing that they did not notice the arrows. Others commented that they ignored the arrows because they were obliviously wrong: that you should never driver clockwise through a roundabout.

In designing the experiment it was assumed that drivers understand the meaning of turn restriction arrows at intersections, and that no explanation of the arrows as necessary. Because this assumption proved wrong, two questions should be considered: (1) do US drivers consider roundabouts to be intersections, and (2) are standard turn restriction arrows understood by US drivers in the roundabout context? The results of this experiment cannot answer these questions, but they strongly suggest that these questions should be addressed.

The New York type sign was not well understood by participants in this experiment. Lane choice decisions were not better than with the other signs, even though the New York sign contains all necessary lane choice information, and none of the other signs do. The test was not conducted in New York, and it is unlikely that many of the participants who live in the greater DC metropolitan area, had experience with this sign type. It is possible that lane choice would improve if the New York sign was explained to the participants.

For lane choice, the New York and Maryland signs responses were significantly longer than the Conventional and Diagrammatic signs. Because response time is assumed to be related to sign processing time, this finding implies that the New York and Maryland signs require more time to process than the Conventional and Diagrammatic signs. Theoretically, the greater the time to process implies greater demands on a driver's attention and the fewer attention resources that are available to process other roadway and traffic information.

Visual demand was not directly measured in this experiment, as responses were not made until the signs were removed from the display and the roundabout picture with lane markings was displayed. Visual demand is more directly related to eyes-off-road time than number of items, as organization of information on a sign can be as important as the amount of information. As information was defined in this study, all the sign types had the same amount of information, and so all differences between signs types must be attributed to the organization of the information. The conventional sign type is the only one that potentially spreads information across two signs: the route number assembly and the conventional guide sign. An important consideration for driver visual attention is whether eyes-off-road time varies when the same information is spread across two signs. Because the conventional and diagrammatic types yielded the best performance in this study, and because eye glance demands can be an important safety consideration, it is recommended that glance behavior, i.e., number and duration of glances, be assessed for these two sign types.

For exit leg identification, participants performed significantly worse with the New York sign type when compared to the Conventional and Diagrammatic signs. Additionally, the Conventional and Diagrammatic signs were given higher confidence ratings compared to the Maryland and New York type signs. Taken together, the findings from the laboratory experiment suggest that the Conventional and Diagrammatic guide signs are better understood and processed more than the Maryland and New York guide signs. From an agency perspective, one of the advantages of the conventional guide sign is that it does not take as much space to portray information as the Diagrammatic sign does. However, it is important to note that Diagrammatic signs might be more likely to provide the needed information at locations with geometry that varies from a standard four-way approach. For example, three-way and five-way roundabouts as well as roundabouts where the approaches intersect at odd angles might benefit from the use of a Diagrammatic sign. The present study only presented an orthogonal four-approach intersection, so it cannot address the relative benefits of diagrammatic versus conventional guide signs for other geometries.

The present study provides no explanation for why the Maryland and New York Guide signs yield lower performance, compared to the conventional and diagrammatic guide signs. The Maryland sign is similar in most respects to the conventional sign, differing only on the added lines to separate information for different exits, and the inclusion of route shields on the same sign instead of on a separate assembly in the conventional case. It should be noted that when only route shields or only destination names were provided, a subset of trials with only 3 items on the signs, the Maryland and conventional sign performance did not differ on any performance measures. In these cases, 3 items, all route shields or all destination names, performance with the New York sign was also equivalent across all performance measures.

When route shields and destination names are combined on the same sign or set of signs, conventional or diagrammatic signs are recommended.

Lane choices in the laboratory study appeared to be unaffected by the turn restriction markings that were displayed just before participants were to respond. Either the participants did not understand the meaning of the lane markings in the roundabout context, or they did not notice the markings. Given that the participants were specifically told that the purpose of the study was to identify the best way to indicate which lane should be used, it would be surprising that they would intentionally ignore turn restriction markings. However, it is possible that the laboratory task did not provide sufficient context for the markings, and that in a dynamic driving task the markings would be processed and understood. Further evaluation of turn restriction markings in a dynamic roundabout environment is recommended.

References

Agg, H.J. Direction Sign Overload, *TRL Project Report 77,* Transport Research Laboratory, Crowthorne, Berkshire, UK, 1994

Berger, W.G., *Criteria for the Design and Development of Advance Graphic Guide Signs*, Final Report, Contract FH-11-7284, Serendipity, Inc. Arlington, VA, September 1970

Nettleton, T. and Millin, I. *Placement Guide for Traffic Control Devices,* Forest Service, US Department of Agriculture, Washington, DC 1981

Robinson, B. W., Troutbeck, R., Werner, B., Lothar, B., Courage, K., Kyte, M., Mason, J., Flannery, A., Myers, E., Bunker, J., Jacquemart, G. *Roundabouts: an Informational Guide.* FHWA-RD-00-067. Federal Highway Administration, McLean, VA, 2001.

Robinson, G. H.; Erickson, D. J.; Thurston, GL; Clark, RL,; Visual Search By Automobile Drivers, *Human Factors*, Vol.14, No. 4, 315-23, 1972.

Smiley, A. *Sign Design Principles*, in the *Ontario Traffic Manual,* Ontario Ministry of Transportation, Ottawa, Canada, 2000.

United States Department of Transportation. *Manual on Uniform Traffic Control Devices*. Washington, DC, 2001.