Traffic Control Devices Pooled Fund Study

Lane Restriction Signing and Marking For Double-Lane Roundabouts

Final Report

October 2007

Prepared by:
John A. Molino (SAIC)
Vaughan W. Inman (SAIC)
Bryan J. Katz (SAIC)
Amanda Emo (FHWA)

Science Applications International Corporation
Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, F-215
McLean, VA 2210

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

Gerry Meis, California Department of Transportation
Mark Wilson, Florida Department of Transportation
Kathy Bailey, 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
David Partee, Nevada Department of Transportation
William Lambert, New Hampshire Department of Transportation
Patricia Ott, New Jersey Department of Transportation
Doug Bartlett, New Jersey Department of Transportation
David Woodin, New York Department of Transportation
Ron King, North Carolina Department of Transportation
Glenn Rowe, Pennsylvania Department of Transportation
Don Turner, South Carolina Department of Transportation
Doug Skowronek, 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, City of Los Angeles Department of Transportation

Guan Xu, Federal Highway Administration, Office of Safety
John Seabrook, Federal Highway Administration, Office of Program Development
Scott Wainwright, Federal Highway Administration, Office of Operations
Thomas Granda, 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 Thomas Granda at (202) 493-3365 or Scott Wainwright (202) 366-0857
• Visit www.pooledfund.org and search for study # TPF-5(065).

EXECUTIVE SUMMARY

A previous Federal Highway Administration (FHWA) study indicated that many drivers do not properly interpret lane restriction pavement markings at roundabouts. In that study traditional lane restriction markings had almost no influence on drivers' choice of lane on the approach to a double-lane roundabout. The present study investigated the effectiveness of different entry lane restriction signing and pavement marking schemes for double-lane roundabouts. Five signing and marking schemes were investigated:

1. Traditional Arrow signs and markings
2. Fishhook Arrows signs and markings
3. Traditional Arrow signs and markings with clarifying wording
4. Fishhook Arrow signs and markings with clarifying wording
5. Destination Lane Restriction sign with no lane restriction pavement markings.

The study was conducted in the FHWA Highway Driving Simulator. Ninety research participants were assigned to one of five groups, with 18 research participants in each group. Each of the five signing and marking schemes was assigned to one of these groups. Each participant drove through 18 simulated roundabouts that were signed and marked in accordance with the appropriate scheme. The entry lane used was recorded. After driving the 18 roundabouts, each participant passively viewed the same 18 roundabouts in a different order and reported his/her understanding of the meaning of the entry lane restrictions. Finally each participant rated the "workability" of each of the 5 schemes.

The results of the simulation experiment showed that the participants chose the correct roundabout entry lane between 89 and 91 percent, and this percentage did not vary significantly among signing and marking schemes. The passive viewing experiment revealed that, across all schemes, the participants correctly comprehended the right and left lane options about 90 percent of the time. However, the participants often did not understand markings that allowed them to use either entry lane: when "either lane" was the correct choice, that choice was selected only 44 percent of the time. This relatively poor performance was characteristic of all 5 signing and marking schemes (range from 39 to 48 percent correct). When the participants rated the "workability" of the 5 schemes, all were rated in the "might work" region, and no scheme was judged to be more workable than any other. No participant attempted to drive around the circulatory roadway in the wrong direction under any of the 5 signing and marking schemes. There was a 66-percent overall bias toward choosing the right entry lane. The single diagrammatic navigational sign before each roundabout performed very well, resulting in a correct exit choice 99 percent of the time.

In summary, all 5 of the entry lane restriction signing and marking schemes performed equally well in terms of driver compliance, with no meaningful differences among them. Furthermore, under no scheme did any participant attempt to drive around the circulatory roadway in the wrong direction. However, the research participants did not comprehend very well the concept of "either lane" being available as a roundabout entry choice.

Table of Contents

List of Figures and Tables

ACKNOWLEDGEMENTS

The FHWA sponsored this work through the Traffic Control Devices (TCD) Consortium Pooled Fund Study (PFS). The primary contractor was Science Applications International Corporation (SAIC). Many people contributed to the success of this study. The authors wish to acknowledge the assistance of a small but significant portion of these contributors. Tiana Petit, Nicole Fowler and Jason Kennedy of SAIC recruited and ran the research participants in the simulator. They were assisted by Vernese Edghill, Wanda Parham and Nicole Branch from Howard University. Megan Pavlock (SAIC) contributed bibliographic assistance. Jason Williams, Peter Chao, Mike Baumgartner, Barry Wallick and Ryan Cartwright, of AAI Services, Inc., created the driving scenarios. Scott Wainwright, Hari Kalla, and Joe Bared, all from FHWA, offered valuable advice. Thomas Granda (FHWA), Joe Moyer (FHWA), Stephen Fleger (SAIC) and Barry Wallick (AAI) managed the contracts under which the work was performed.

INTRODUCTION

Background

The objective of this effort was to investigate lane restriction signing and marking for double-lane roundabouts 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). A simulator experiment was conducted to evaluate several different signing and marking schemes from three different perspectives. The study was directed towards the development of consistent and effective design guidance for the signing and marking of roundabouts.

A previous FHWA Traffic Control Device (TCD) Pooled Fund Study (PFS) project, entitled "Navigation Signing for Roundabouts," indicated that many drivers do not properly interpret lane restriction pavement markings at roundabouts (Katz et al., 2004). In that study traditional lane restriction markings had almost no influence on drivers' choice of lane on the approach to a double-lane roundabout. Furthermore, a number of participants in that study indicated that the arrows incorrectly directed drivers to proceed clockwise around the circular path. Additional anecdotal evidence indicated that drivers were confused by the lane restriction pavement markings and tended to ignore them. Where operational and safety considerations result in the desire to restrict lane use in double-lane roundabouts, agencies need a method of indicating the restrictions that is: (1) understood by drivers; (2) achieves a high rate of compliance, and (3) is uniform nationwide.

Aside from the above mentioned TCD PFS research, there is little published research that addresses lane restriction signing and marking at double-lane roundabouts in the US. Some British research explored the effectiveness of multi approach lane arrow markings and spiral lane markings inside the circulatory roadway portion of the roundabout (Brown, 1995). Australian guidance suggests that entry lane directional arrows are not generally necessary in single- and double-lane roundabouts (AUSTROADS, 1993). Earlier U.S. guidance suggests some instances where lane use control signs and markings may be useful (Robinson et al., 2000). More complete U.S. guidance may be found in proposed updates to the MUTCD concerning roundabout signing and marking (NCUTCD, 2006). The NCUTCD has proposed using traditional lane control markings with an option for a "Fishhook" style marking. Markings may be used with or without lane restriction signing. Some jurisdictions merely suggest lane usage by placing restriction-like symbols within approach warning signs. New York has received permission from the FHWA to experimentally use Fishhook arrows in conjunction with Fishhook lane restrictions signage (McElroy, 2005). These novel symbols have been implemented in a number of roundabouts in New York. An Arizona case study includes design guidelines which show how to implement the Fishhook arrows in certain situations (Lee, et al., 2003).

In the previous FHWA TCD PFS research (Katz et al., 2004), it was not clear whether the test drivers' lacked comprehension of the traditional lane markings because the purpose of the markings at the roundabouts was unclear, or whether the context of the experiment, which elicited lane choice responses by means of static photographs, led the participants to ignore or fail to notice the markings. The authors of that study suggested that a further study be conducted to clarify the finding, and to determine what type of signing and marking scheme might be most effective.

Experiment

The present experiment was conducted in the FHWA Highway Driving Simulator (HDS), which is located at the Turner-Fairbank Highway Research Center (TFHRC). Six different double-lane roundabout geometries were created for testing five alternative signing and marking schemes. The correct entry lane(s) varied from trial to trial, as did the exit that was appropriate for the indicated destination. The six roundabout geometries were combined with the three exit directions to make 18 unique roundabouts. The correctness of approach lane choices was recorded, as well as the correctness of exit directions. Individual drivers saw only one scheme of signs and markings. At the end of their first experimental drive, the participants were exposed to the same 18 roundabouts which they just drove in a different order, only this time they were asked questions about their understanding of the lane restriction markings. Finally, the participants rated all 5 different alternative signing and marking schemes for their "workability". In this last portion of the experiment, the research participants saw all 5 schemes.

The primary dependent measure in the simulator experiment was the correctness of approach lane use. This simulator experiment differed from the earlier Navigation Signing study in that alternative lane restriction indications schemes were employed. In addition the lane indication signs and markings, when present, were seen from a distal location, further in advance of the roundabout, as well as from a proximal location, close to the roundabout circulating roadway. Moreover, the research participants actually drove through all of the roundabouts in this second experiment, instead of just viewing static pictures of roundabout approaches. The driving context not only made the simulator experiment more realistic than the earlier static Navigation Signing study, but offered an opportunity to study subsequent driving behavior through the roundabout, after approach lane selection.

Research Questions

In the present experiment the primary independent variables were sign and marking schemes for approach lane restriction in roundabouts. Five different sign and marking schemes were evaluated:

1. Traditional Arrow signs and markings (TA)
2. Fishhook Arrow signs and markings (FA)
3. Traditional Arrow signs and markings with clarifying wording (TAW)

4. Fishhook Arrow signs and markings with clarifying wording (FAW)
5. Destination Lane Restriction sign with no pavement markings (DLR).

The five signing and marking schemes are shown in Figures 1 to 5, along with a control condition with no lane restriction signing or marking (see Figure 6). The Type designation refers to various combinations of lane restrictions used in the experiment. These lane restriction combinations will be explained later. For the 5 lane restriction schemes, the primary research questions related to the relative effectiveness of the various schemes in terms of driver compliance, driver comprehension and driver ratings of workability. Thus the present study actually represents three separate experiments to investigate the same basic questions from three different perspectives. These three perspectives led to three parallel subsets of research questions.

Figure 1: Example of Traditional Arrows Scheme (TA) – Type A Lane Restrictions

In the first part of the experiment participants drove through simulated roundabouts. The driver behavior observed was intended to address:

1. How well do drivers comply with indicated entry lanes?
2. Do any of the signing and marking schemes perform unsatisfactorily?
3. Are any of the schemes superior to any of the others?

The second part of the experiment evaluated how well drivers comprehend which lanes are allowed. The recorded verbal responses were intended to address:

4. How well do drivers understand allowed options?
5. How well is the concept of "either lane" comprehended?
6. How effective might the various schemes be to control traffic flow?

Figure 2: Example of Fishhook Arrows Scheme (FA) – Type B Lane Restrictions

The third part of the experiment obtained participant ratings of the "workability" of the alternative signing and marking schemes. The ratings were intended to address:

7. What workability ratings do drivers assign to the different schemes?
8. Are any of the schemes rated as unworkable (would not work at all)?
9. Are any of the schemes rated as more workable than the others?

In addition there were a number of general research questions which could be answered from various portions of the three experiments, either singly or in combination. These general research questions were:

10. Do any schemes lead to wrong way rotation?
11. How effective are diagrammatic navigation signs?

12. Do drivers have a bias toward the right or left entry lane?
13. Is there evidence of a possible destination hypothesis?
14. Are rankings from 3 different portions of the experiment consistent?
15. Are there any meaningful age or gender effects?

Figure 3: Example of Traditional Arrows with Words Scheme (TAW) – Type C Lane Restrictions

METHOD

Research Participants

The experiment employed 5 groups of 18 research participants each, for a total of 90 participants. Each group consisted of equal numbers of men and women. Each group was also composed of an equal number of participants in each of three age categories: 1) younger: 18 to 25 years, 2) middle-aged: 26 to 64 years; and 3) older: 65 years of age or older. The participants were recruited through advertisements and from a database of participants from earlier studies at the TFHRC. Participants from earlier roundabout experiments were excluded. All participants had a valid driver license and passed a

vision screening test to a minimum criterion of 20/40 visual acuity in at least one eye (corrected, if necessary). Including instructions, informed consent, questionnaires and debriefing, participation took about two hours, and each participant was paid $60 for completing the study.

Figure 4: Example of Fishhook Arrows with Words Scheme (FAW) – Type D Lane Restrictions

Equipment

The FHWA Highway Driving Simulator (HDS) visuals were displayed by means of three overhead CRT projectors onto a 180-degree cylindrical wrap-around screen in front of the vehicle cab. This screen had a 43-degree vertical field of view, and did not move. The resolution of each projector was 2,048 by 1,536 pixels, with an overall horizontal resolution of 5,374 pixels over the entire 180-degree screen, including overlap for edge blending. The refresh rate of the projectors was 75 frames per second. The simulator was built around a 1998 Saturn SL-1 four-door sedan. The vehicle cab rested on an electro-dynamic actuator giving it limited motion with three degrees of freedom: roll, pitch and heave (maximum excursion of about plus/minus 1.5 ft, or 0.45 m, at each wheel for any combination of movements). An external loudspeaker system provided appropriate engine, wind and roadway noise. The vehicle dynamics model was calibrated to approximate the characteristics of a small passenger sedan. Data capture was synchronized to the frame rate of the graphics cards (about 130 frames/second). Variables

from the vehicle dynamics model (e.g., speed, longitudinal acceleration, lateral acceleration, throttle position, brake force, vehicle heading, vehicle position) were recorded with each frame.

Figure 5: Example of Destination Lane Restriction Scheme (DLR) – Type E Lane Restrictions

Participants drove the vehicle alone. A researcher observed from an adjacent control room equipped with a number of monitors that enabled observation of the participant, simulator performance, and driver performance. One of the monitors displayed a plan view of the roundabout with the entrance lanes and correct exit clearly marked. The researcher manually recorded the entrance lane and exit direction. This enabled later validation of the lane choice and exit data that was automatically collected by the simulator system.

Another 19-inch monitor was set up on a table adjacent to the experimenter's console in the simulator control room. After the research participant had completed the simulation drive, the participant moved to the control room to complete the signing and marking comprehension test. The third workability rating portion of the experiment was administered at this same desk by paper and pencil.

Procedure

Preliminary procedures consisted of obtaining the participant's informed consent and completing a vision test. In order to control for simulator sickness, a two-part postural stability test was administered, along with a simulator adaptation questionnaire in which participants rated their current degree of experience of symptoms associated with simulator sickness. Then the participant was introduced into the simulator and given instructions for the experiment.

Figure 6: Example of Control Condition (No Signs or Markings) – Type F Lane Restrictions (None)

The simulation consisted of a training drive, followed by an experimental drive. Each drive was about 20 minutes in duration. There was a brief break between drives. The training drive consisted of three simulated environments: 1) a broad striped expanse of roadway with no visible pavement edges to practice driving maneuvers in a safe environment; 2) a section of roadway with progressively sharper left and right curves; and 3) a series of single lane roundabouts with no lane restrictive signage. Each of these training environments was presented for about 6 minutes. There were short breaks between each environment. The experimental drive consisted of 18 roundabouts that, at the posted 45 mph (72 km/h) speed, were about one minute apart. Between roundabouts the participant drove on a straight four-lane roadway. When slowing for the roundabouts was taken into account, the total time for the experimental drive was also about 20 minutes. A second 5-minute break was given after this experimental drive.

The comprehension test followed the simulation and 5-minute brake. The same roundabouts seen in the simulation were presented again, except in a different order. Each roundabout approach was presented from a point upstream of the navigational guide sign to the yield line. The long straight drive prior to the diagrammatic navigation sign was eliminated. In this presentation the simulated drive appeared as it would from the driver's viewpoint on typical roundabout approach, except that the vehicle appeared to straddle the marking between the two approach lanes. The comprehension test took about 15 minutes to complete. A five-minute break followed the comprehension test.
The final experimental activity was a questionnaire in which participants rated each signing and marking scheme for "workability." Each rating was solicited after the participant viewed static pictures of examples of lane restriction markings from each of the five signing and marking schemes.

Following the workability questionnaire, the postural stability tests and the simulator adaptation questionnaire were repeated to assure the absence of simulator sickness. The participant was then debriefed and paid.

An approximate timeline for each experimental session follows:

1. Greet participant at guard desk and sign in	3 minutes
2. Obtain Informed Consent	5 minutes
3. Complete vision test	5 minutes
4. Administer postural stability test	5 minutes
5. Give simulator adaptation questionnaire	3 minutes
6. Introduce participant to simulator	3 minutes
7. Give instructions for experiment	3 minutes
8. Complete practice drive	20 minutes
9. Allow first break	5 minutes
10. Complete compliance drive in simulator	20 minutes
11. Allow second break	5 minutes
12. Complete comprehension drive at monitor	15 minutes
13. Allow third break	5 minutes
14. Complete workability ratings	5 minutes
15. Administer postural stability test	5 minutes
16. Give simulator adaptation questionnaire	3 minutes
17. Debrief participant	5 minutes
18. Pay participant	3 minutes
19. Escort participant to guard desk	2 minutes
TOTAL	120 minutes.

Driving Scenario

The simulation consisted of a series of rural roundabouts. There was no other traffic. The simulation of interactive traffic was difficult to program, and the fundamental approach was to research the simple case first. If an understanding of driver behavior

could be achieved without traffic, then the effects of traffic could be added later. For the compliance and comprehension portions of the experiment, the roundabouts all had a diagrammatic navigational sign located 542 feet upstream of the inscribed circle and a roundabout warning sign located at 410 feet upstream. Except for the Destination Lane Restriction scheme, all roundabouts had both distal (267 feet upstream) and proximal (69 feet upstream) indications of the proper approach lane. The Destination Lane Restriction sign was presented only once, at 236 feet upstream. In all cases there was a pedestrian crossing sign 46 feet upstream, and a yield sign 8 feet upstream of the inscribed circle. The sequence of signs and markings that the participant encountered on the approach to each roundabout is shown in Figures 7 through 11, except that examples of the proximal lane restriction signs and marking are not repeated, because those are shown in Figures 1 through 5. In the compliance portion of the simulator experiment, participants were instructed to drive as they normally would and to obey all regulatory traffic signs and signals. The participants were instructed that they were driving to "McLean", and that appropriate turns and exits would randomly occur to the right, left and straight ahead.

Figure 7: Example of Diagrammatic Navigation Sign at 541 Feet From Yield Line

Between the roundabouts were straight segments of four-lane rural roadway with a continuous double yellow center line, a continuous white edge line, and a white skip line between parallel travel lanes. For some distance after the distal lane restriction signing and marking, the marking between parallel travel lanes continued to consist of white skip lines, which permitted the participant to change lanes, if necessary. About 60 feet

upstream of the inscribed circle, the marking between parallel travel lanes changed to a solid white line, which, theoretically, committed the participant to the current lane.

Figure 8: Roundabout Warning Sign at 541 Feet From Yield Line

Combinations of Conditions

For the simulation and comprehension tests, participants were presented only one of the 5 signing and marking schemes. The 6 combinations of lane restrictions were the 5 combinations employed in the earlier Navigation Signing study (Katz et al., 2006), plus a signs and/or markings control condition. These six conditions were designated by the letters "A through F", and are given in Table 1.

Table 1. Lane Restriction Conditions Used in Experiment

Condition	Left Lane	Right Lane
A	Left turn only	No restrictions
B	Left turn only	No left turn
C	No right turn	No left turn
D	No right turn	Right turn only
E	No restrictions	Right turn only
F	No restrictions	No restrictions

Figure 9: Example of Distal Lane Restriction Signing and Marking at 267 Feet From Yield Line

There were 3 replications of each trial type, one for each exit direction (right, straight ahead and left). These replications were presented in a random order, making 18 trials with a single lane restriction indication scheme in the experimental drive, followed by a short break.

The comprehension test consisted of a repeat of the same 18 combinations of lane restrictions and exists in a different order. In the comprehension test, the participant did not drive the car, but answered questions about allowed lane choices. The car drove itself. Upon the approach to each roundabout, the participant indicated which lanes were "allowed" for entry. That is, the participant stated "right lane," left lane," or "either lane". The 5 signing and marking schemes combined with the 6 lane restriction conditions (A through F) are shown in Figures 1 to 6. The control condition (F) had no lane restriction signing or marking.

Circulatory Roadway Markings

The 6 different types of lane restriction combinations (Types A through F in Figures 1 to 6) were accompanied by appropriate roadway markings within the circulatory roadway.

Depending upon the lane restrictions, lanes were added or dropped, and the shape of the circulatory roadway was modified. Thus there were 6 uniquely different roundabout designs, one corresponding to each of the 6 lane restriction types. These 6 different types of roundabout designs followed guidance from proposed modifications to the NCUTCD, Chapter 3H (MUTCD, 2007), except that painted markings were used to modify all internal roadway geometries, rather than modifications to curbs and islands.

Figure 10: Pedestrian Crossing Sign at 46 Feet From Yield Line

The 6 unique types of roundabouts employed in the compliance portion of the experiment are shown from a birds-eye view in Appendices A through F. They correspond to lane restrictions types A through F with different exit directions portrayed. When the 3 exit directions are combined with the 6 lane restriction types the result is 18 uniquely different roundabouts for each signing and marking scheme. When these 18 uniquely different roundabout types are combined with the 5 different lane restriction schemes, the compliance portion of the experiment employed a total of 90 different simulated roundabouts. Within one signing and marking scheme, 18 research participants were each presented with18 roundabouts in a single experimental drive, for a total of 324 roundabouts tested per lane restriction scheme. Since there were 5 such schemes, in the compliance portion of the experiment 1,620 roundabouts were tested. The same number of roundabouts was tested in the comprehension portion of the experiment.

Figure 11. Yield Signs at 8 Feet From Yield Line

Response Measures

In the simulation, the dependent measure of greatest interest was whether the participant selected an appropriate approach lane (i.e., correct, incorrect) based on the signs and markings presented on a given trial. Whether the participant used the correct exit for the assigned destination (always McLean), was also recorded. Use of the correct exit was important, because the selection of an entry lane depends on the intended destination, and hence the intended exit. The direction of travel (i.e., counterclockwise, or clockwise) through the circulatory roadway was also recorded. The continuous data on vehicle speed, lane position and other driving variables were recorded but not analyzed.

Answers indicating the participant's understanding of the lane choice options constituted the dependent variable in the comprehension portion of the study. These answers were manually recorded by the experimenter by circling "right", "left" or "either" on a paper score sheet. Ratings of the "workability" of each of the 5 signing and marking schemes constituted the dependent variable for the rating portion of the experiment. The ratings were indicated by the participant making an "X" mark along a horizontal 7-point scale, where "1" was labeled "Would not Work at All"; "4" was labeled "Might Work": and 7 was labeled "Would Work Very Well".

RESULTS

Organization

The present study represented three different perspectives on the same fundamental set of research questions. These perspectives were embodied in three separate experiments, all employing the same sample of research participants. These three separate experiments were: 1) a compliance experiment, 2) a comprehension experiment, and 3) a subjective rating experiment. Each experiment had its own set of the specific research questions. In addition there was a fourth set of general research questions which could be answered from these three experiments (see Research Questions section above). Thus, the results of the present study will be reported in four separate sections: compliance experiment, comprehension experiment, workability ratings and general results.

Compliance Experiment

The entry lane use results of the compliance experiment are shown in Table 2. The various signing and marking schemes are listed in rank order, in terms of overall percent correct choices, with the highest scoring scheme at the top. The results for all of the schemes combined are shown in the last row. As can be seen in Table 2, the percent correct scores ranged from 90.7 to 88.6, with an overall percent correct of 89.2 collapsed across all 5 schemes. If 85 percent compliance were taken as the criterion for successful performance, then all 5 of the signing and marking schemes resulted in successful compliance performance. None of the schemes performed unsatisfactorily according to this criterion. Nor were the performance differences among the various schemes of meaningful magnitude, with a maximum spread of 2.1 percentage points. This maximum spread in percentages was not statistically significant at the 0.05 alpha level ($z = 1.24$, df = 1, $p = 0.11$). Thus no scheme performed better than any other. The Chi-square results showed essentially the same relationships. All of the Chi-square values were high, and all showed a statistically significant effect over chance responding. The Chi-square 0.95 criterion for chance responding was 3.8 or below. All of the Chi-square results given in Table 2 far exceeded this criterion. Thus, in terms of overall compliance, all of the signing and marking schemes performed equally well.

Table 2. Percent Correct and Chi-square for Compliance Experiment

Scheme	Entry Lane Percent Correct	Entry Lane Chi-square: Difference from Chance (50 percent)
Traditional Arrows	90.7	214.2
Fishhook Arrows With Words	89.2	198.8
Traditional Arrows With Words	88.9	195.7
Fishhook Arrows	88.6	194.5
Destination Lane Restriction	88.6	192.8
All	**89.2**	**995.0**

Table 2 portrays the overall percentage of correct lane choices regardless of which lane was actually correct. If either lane was allowed, the participant was scored as correct no matter what entrance lane was chosen. However, the same data may also be analyzed with respect to which entry lane was actually the correct one. Table 3 shows the percent correct choices when the left entry lane was the correct choice, and the percent correct choices when the right entry lane was the correct choice. The ordering of the schemes is the same as in Table 2, based upon overall performance not separated by lane. As can be seen in Table 3, the percentage correct was always higher for the right lane than for the left lane. Collapsed across all 5 schemes, when the left entry lane was the correct choice, the drivers responded correctly 82.3 percent of the time. When the right entry lane was the correct choice, the drivers responded correctly 94.8 percent of the time. This difference in percentages was statistically reliable ($z = 11.16$, df = 1, $p < 0.001$). Thus drivers responded more correctly when the right entry lane was the correct choice than when the left entry lane was the correct choice.

Table 3. Percent Correct by Lane for Compliance Experiment

Scheme	Left Entry Lane Percent Correct	Right Entry Lane Percent Correct
Traditional Arrows	86.2	94.4
Fishhook Arrows With Words	82.9	94.4
Traditional Arrows With Words	80.3	95.6
Fishhook Arrows	79.6	96.0
Destination Lane Restriction	82.4	93.8
All	**82.3**	**94.8**

Comprehension Experiment

In the comprehension experiment the research participants were shown abbreviated approaches to the same roundabouts in a different order. In this case there were three possible entry lane choice responses, because the participant could indicate that either lane was allowed. For the comprehension experiment, for each approach, the participants responded which entry lane choices were allowed: 1) right lane, 2) left lane, or 3) either lane. Table 4 shows the overall results of the comprehension experiment in terms of the percentage of correct response choices across all three response categories. Similar to Table 2, the various signing and marking schemes are listed in rank order, in terms of overall percent correct comprehension responses, with the highest scoring scheme at the top. The results for all of the schemes combined are shown in the last row. As can be seen in Table 4, the percent correct scores ranged from 78.1 to 70.1, with an overall percent correct of 74.9 collapsed across all 5 schemes. If 85 percent compliance were taken as the criterion for successful performance, then none of the signing and marking schemes resulted in successful comprehension performance. The overall comprehension score of 74.9 percent correct was substantially below the overall compliance score of 89.2 percent correct. This difference was statistically significant ($z = 14.99$, $df = 1$, $p < 0.001$). In the case of overall comprehension scores, the 8.0 percent maximum spread for the various schemes was statistically significant ($z = 3.29$, $df = 1$, $p < 0.001$). However, this spread was distributed among 5 different schemes, and the rankings in Table 4 do not reveal any orderly relationships. Thus it is not clear what how meaningful any differences in performance might be among the various signing and marking schemes. As was the case for compliance, all of the Chi-square values were high, and all showed a

statistically significant effect over chance responding. In this case the Chi-square 0.95 criterion for chance responding was 6.0 or below. All of the Chi-square results given in Table 4 far exceeded this criterion. Thus, in terms of overall comprehension, all of the signing and marking schemes performed significantly above the chance level, but the overall percentage of correct responding was significantly lower than that for compliance.

Table 4. Percent Correct and Chi-square for Comprehension Experiment

Scheme	Entry Lane Percent Correct	Entry Lane Chi-square: Difference from Chance (50 percent)
Fishhook Arrows	78.1	322.7
Destination Lane Restriction	77.5	307.0
Fishhook Arrows With Words	75.9	288.0
Traditional Arrows	72.8	247.5
Traditional Arrows With Words	70.1	221.8
All	**74.9**	**1368**

The reason for this poorer overall performance in the comprehension experiment becomes apparent when the same comprehension data were analyzed with respect to which response category was actually the correct one. Table 5 shows the percent correct choices when the left entry lane was the correct choice, when the right entry lane was the correct choice, and when either entry lane was the correct choice. The ordering of the schemes is the same as in Table 4, based upon overall comprehension performance not separated by lane. As can be seen in Table 5, for all 5 schemes, the percentage correct was always higher for the right lane and left lane responses, than for the either lane response. Collapsed across all 5 schemes, when the left or right entry lane was the correct choice, the drivers responded correctly about 90 percent of the time. If measured against an 85 percent correct criterion, drivers understood the left lane and right lane restrictions well. However, when either entry lane was the correct choice, the drivers responded correctly only about 44 percent of the time. This difference between 90 percent correct and 44 percent correct was statistically significant ($z = 20.8$, df = 1, $p < 0.001$). Thus drivers understood the right and left lane restrictions well, but the option of either lane was rather poorly understood. Even for the best signing and marking scheme, the Fishhook Arrows, the concept of either lane was only comprehended about 48 percent

of the time. The rank ordering of schemes on the basis of percent correct for the either lane response was the same as the rank ordering for the overall percent correct comprehension. This similarity in rank ordering may be taken as an indication that the relatively poor understanding of the either lane option was a major contributing factor in reducing the overall comprehension scores. This poor comprehension of the concept of being allowed to enter from either lane could interfere with the effectiveness of lane restriction signing and marking to control traffic flow through real roundabouts. If traffic engineers calculate the capacity of a roundabout design based upon drivers understanding the allowed entry lane options and distributing themselves accordingly across the entry lanes, the design calculations could seriously overestimate the working capacity of the operational roundabout.

Table 5. Percent Correct by Allowed Lane for Comprehension Experiment

Scheme	Left Lane Only Percent Correct	Right Lane Only Percent Correct	Either Lane Percent Correct
Fishhook Arrows	92.6	93.5	48.1
Destination Lane Restriction	91.7	94.4	46.3
Fishhook Arrows With Words	96.3	91.7	39.8
Traditional Arrows	89.8	83.3	45.1
Traditional Arrows With Words	82.4	88.9	38.9
All	**90.6**	**90.3**	**43.7**

Workability Ratings

The workability ratings portion of the study was the only opportunity that the participants had to view all five signing and marking schemes. Because of procedural errors, valid workability ratings were obtained from only 66 of the 90 participants. Table 6 shows the mean workability ratings from those 66 participants. The various signing and marking schemes are listed in descending rank order of mean ratings. The overall mean rating for all 5 schemes combined was 4.5, just greater than the 4.0 mid-point of the scale, which was labeled “might work”. The mean rating scores ranged from 4.2 to 5.0, all somewhat above this 4.0 mid-point. None of the schemes were rated as “unworkable” (would not work at all) on the 7-point scale. An omnibus *F* test revealed no significant difference

between the various signing and marking schemes. Thus, the questionnaire data provide no evidence that any one scheme is considered better than any of the others..

Table 6. Mean Workability Rating Scores

Scheme	Mean Rating	Standard Error
Destination Lane Restriction	5.03	0.25
Traditional Arrows	4.18	0.19
Traditional Arrows With Words	4.70	0.21
Fishhook Arrows With Words	4.38	0.22
Fishhook Arrows	4.66	0.22
All	**4.59**	0.25

General Results

An important safety question relates to whether or not any of the five schemes leads to attempts to drive in the wrong direction around the circulatory roadway of the roundabout. This question is particularly important with regard to the Traditional Arrow scheme (see Figure 1), where similar arrow symbols have commonly been used to indicate an immediate turn. When used as a lane restriction marking in the left approach lane to a roundabout, a left-hand arrow symbol of this type might be interpreted as an indication to make a left turn at the next possible opportunity, which could be construed as immediately after the approach splitter island (if such an island exists). This interpretation might lead drivers to attempt to navigate the circulatory roadway in the wrong direction, a maneuver with potentially strong negative safety consequences. However, of the 1,620 roundabouts driven in the compliance experiment, none of the participants drove in the wrong direction with any of the schemes. Thus, the simulation results provide no evidence that any of the signing and marking schemes might induce drivers to travel the circular roadway in a clockwise direction.

During training for the simulation, one research participant did initially attempt to drive the circulatory roadway in the wrong direction. This participant quickly recognized the mistake, backed up slightly, and proceeded around the circulatory roadway in the correct direction. During training, approximately 450 single-lane roundabouts were driven by the 90 research participants (about 5 roundabouts per participant). These training roundabouts were presented before the main experiment in order to accustom the research participants to navigating through roundabouts in a driving simulator. All of these single lane roundabouts used in training included only standard roundabout signs and markings:

a roundabout ahead warning sign with a 20 mph placard, crosswalk signs, yields signs, and a one-way sign and chevrons on the circulatory roadway. These training roundabouts had no lane restriction signing or markings. Thus, the only aborted attempt at a clockwise movement through the roundabout could not be attributed to lane restriction signing or marking.

In the simulation a diagrammatic navigation sign located 541 feet upstream of the inscribed circle (see Figure 7) preceded each roundabout. The diagrammatic sign was the only source of information concerning roundabout exit location prior to the exit itself. The diagrammatic sign performed well in that the participants rarely used the wrong roundabout exit. Participants were correct for 99.1 percent of left exits, 98.5 percent of straight through exits, and 99.1 of right exits. In three incorrect instances a driver made a U-turn by exiting the roundabout on the entry leg. In general the total number of navigation errors of all types was extremely small in the present study. Overall the diagrammatic navigation signs were effective, resulting in 99 percent correct responding for all exit directions.

The driving simulation included three control trials (Type F, see Figure 6) in which there were no lane restriction signs or markings. There was one trial in which each of three exits (right, straight through, or left) were assigned. Thus there was one observation per participant with each assigned exit destination. Table 7 shows lane use as a function of the appropriate exit to reach the assigned destination where there were no lane restriction signs and markings. When entry lane restrictions are not provided, convention, and some state laws, specify use of the right lane for right turns, either lane for straight through movements, and the left lane for left turns. Only one participant (one percent) violated the convention for the right turns. Nearly three-fourths (73 percent) used the right lane where convention does not specify a lane. Of greatest concern, however, is the use of the right lane by 26 percent of participants when they made a left turn movement. This finding suggests a strong bias towards use of the right entry lane.

Table 7. Percent of Entry Lane Use in Control Condition Where No Lane Restriction Signs or Markings were Used

Entry Lane Used	Destination Exit (Right)	Destination Exit (Through)	Destination Exit (Left)
Right	99	73	26
Left	1	27	74

The results of the compliance experiment may also provide some indication of a possible destination direction hypothesis on the part of the research participants. It is possible that the research participants could have responded according to an internal hypothesis which is altogether independent of any lane restriction markings. Ignoring the lane restriction markings, the participants could have responded according to the following hypothesis: if the destination is to the left, enter the roundabout in the left lane; if the destination is to the right, or straight ahead, enter the roundabout in the right lane. The data in Table 7 are

certainly consistent with this hypothesis with respect to use of the right lane for turning right. The data in Table 7 are also consistent with about two-thirds of the participants holding this hypothesis for proceeding straight through or turning left. Other tests of the possible use of this hypothesis would be: 1) the percentage of drivers who used the right entry lane to proceed straight through when the right lane was designated for right turns only (marking Types D and E), 2) the percentage of drivers who used the left lane to proceed straight through the roundabout when the left land was designated for left turns only (marking Types A and B), and 3) the percentage of drivers who used the right entry lane to make left turns when that maneuver was designated as not legal. Table 8 shows the percentage of participants who used the left lane to proceed straight through the roundabout when the left lane was designated for left turns only (Types A and B). It can be seen that a substantial minority of about 17 percent of the participants used the left lane in this case. This outcome indicates that at least 17 percent ignored or did not understand or respect the left-turn only lane restriction, and also that about 20 percent of the participants did not hold the suggested internal model that views the right lane as the proper lane for through movements.

Table 8. Percentage of Entry Lane Use when Left Lane was Designated Left Turn Only and Intended Exit was Straight Through

Entry Lane Used	Type A	Type B	Percent Lane Use
Right	81	88	83
Left	19	12	17

Table 9 shows the percentage of participants that used each entry lane for a through movement when the right lane was designated for right turns only. Over one-third of the participants used the right lane inappropriately.

Table 9. Percent of Entry Lane Use when the Right Lane was Designated Right Turn Only and the Intended Exit was Straight Through

Entry Lane Used	Type D	Type E	Percent Lane Use
Right	33	38	36
Left	66	62	64

The proposed internal hypothesis would have no participants turning left from the right lane. However, when the right lane was designated such that left turns were prohibited, i.e., the signs and marking allowed either right turn only or right and through movements, almost an average of 18 percent of participants still entered the roundabouts from the right lane to make a left turning movement (see Table 10). Formal vehicle path data through the roundabout were not analyzed for what drivers did when they made a mistake and entered the roundabout in the wrong lane. However, general observation indicated that, in these cases, drivers simply crossed over lanes in the circulatory roadway to position themselves correctly for the appropriate exit.

Table 10. Percent of Entry Lane Use when the Right Lane was Designated for Right or Right and Through Movements and the Intended Exist Required a Left Turn

Entry Lane Used	Type B	Type C	Type D	Type E	Percent Lane Use
Right	20	19	18	14	18
Left	80	81	82	86	82

In the present study three different approaches were used to evaluate the relative performance of five signing and marking schemes. These evaluation approaches were driving simulation, comprehension and workability ratings. The rank orderings of the three outcome measures of effectiveness may be compared to determine whether a consistent pattern emerges. A consistent pattern might indicate one of the schemes is superior or inferior to the other, even though with the single effectiveness measures no significant difference emerged. Table 11 shows the rank orderings using the three evaluation approaches. No consistent ordering emerged. This result points toward the conclusion that none of the signing and marking schemes was substantially better or worse than any other scheme in terms of a practical or usable performance advantage.

An important corollary of this conclusion relates to there being no consistent difference between an Arrow condition and its corresponding Arrow with Words condition. The inclusion of the words “only” and “all” on some trials was designed to assist drivers to distinguish between restrictive or permissive designations. Table 11 reveals that in 4 out of 6 cases the arrows alone performed better than the arrows with words. The fact that the Arrow with Words condition did not consistently perform better than the Arrows alone condition provides evidence that, as far as the present experiment is concerned, the inclusion of such wording was of little help in promoting understanding

Table 11. Rankings from Three Different Evaluations

Rank	Compliance	Comprehension	Workability Ratings
1	Traditional Arrows	Fishhook Arrows	Destination Lane Restriction
2	Fishhook Arrows With Words	Destination Lane Restriction	Traditional Arrows
3	Traditional Arrows With Words	Fishhook Arrows With Words	Traditional Arrows With Words
4	Fishhook Arrows	Traditional Arrows	Fishhook Arrows With Words
5	Destination Lane Restriction	Traditional Arrows With Words	Fishhook Arrows

The question may also be asked whether there were any significant or meaningful age or gender effects in the results from the present study. Table 12 shows the age and gender effects for the Compliance, Comprehension and Workability evaluations. The data are given in terms of overall percentages of correct responding for compliance and comprehension, and in terms of mean rating scores for workability. For both compliance and comprehension, the younger participants had a higher percentage of correct responses than the middle aged participants, who in turn had a higher percentage of correct responses than the older participants. These two seemingly consistent age effects were not statistically significant, however, neither for compliance ($F(2, 84) = 2.52$, $p = 0.09$) nor for comprehension ($F(2, 84) = 1.89$, $p = 0.16$). Nor was there a statistically significant age effect for the mean workability scores ($F(2, 36) = 0.157$, $p = 0.86$). Thus the age group of the participants had no significant effect on any of the overall performance evaluations of entry lane restrictions.

A somewhat similar picture emerged for the effect of gender. For both compliance and comprehension, the males had a higher percentage of correct responses than the females. Only the gender effect for the compliance experiment turned out to be statistically significant ($F(1, 84) = 18.1$, $p < 0.001$). The gender effect for the comprehension experiment was not statistically significant ($F(1, 84) = 1.02$, $p = 0.32$), nor was the gender effect for the workability ratings ($F(1, 36) = 1.91$, $p = 0.18$). Thus the only gender effect observed was for the compliance experiment, where the males performed better (93.2 percent correct) than the females (85.2 percent correct). It is not certain of what practical importance such a performance difference might be. None of the age by gender interaction effects was statistically significant for any of the three evaluation approaches. These scant age and gender effects might be expected, considering the small sample sizes involved (only 6 people in each age group, and only 9 people in each gender group). In summary, based upon the results of the present study, age and gender had little meaningful effect upon lane restriction performance.

Table 12. Results by Age and Gender

Age and Gender	Compliance – Percent Correct	Comprehension – Percent Correct	Workability – Mean Scale Score
Younger	91.9	77.6	4.56
Middle Age	89.1	76.7	4.66
Older	86.7	70.4	4.58
Female	85.2	73.2	4.39
Male	93.2	76.5	4.84

DISCUSSION

The results of the current evaluations provided possible answers to a number of questions concerning signing and marking schemes for double-lane roundabouts. These answers

are discussed below using the same numbers as the corresponding research questions enumerated above (see Research Questions).

Compliance

The compliance experiment conducted in the driving simulator showed that:

1. Drivers complied with indicated entry lanes about 89 percent of the time.
2. None of the signing and marking schemes performed unsatisfactorily by an overall 85 percent correct criterion.
3. None of the schemes were superior to any of the others in terms of correct lane choices.

These observations corresponded to research questions 1 to 3. The overall failure to comply with lane restrictions of 11 percent of the time is worrisome. It is a strong indication that, regardless of lane restriction signing and marking scheme, many drivers either do not understand the lane restrictions in general, do not understand lane restrictions in a roundabout context, or do not feel that compliance is important in a roundabout context. The finding that drivers continued to make left turns from the right lane, even when the signs and/or markings clearly showed that the right lane must turn right, is of both a safety and an operational concern. Furthermore, in all cases, except the Destination Lane Restriction scheme, the lane restriction markings were presented twice: once distally at 267 feet and then again proximally at 69 feet ahead of the yield line. Such redundancy was an important feature of the present study, and is often not implemented in the field. In field conditions, where there may be less redundancy in signs and markings, and where traffic may cause drivers to miss some lane restriction indications, overall compliance might be less than 89 percent.

The simulation results suggest that conventional arrow signs and markings, fishhook signs and markings, or lane restrictions included on diagrammatic navigation signs would be equally effective and are equally deserving of possible inclusion in the MUTCD. However, the simulation results also imply that where lane restriction compliance is deemed important for either operations or safety, additional steps may be needed to achieve a higher rate of compliance. The simulation does not suggest what those steps should be.

Comprehension

The comprehension test showed that:

4. Drivers understood left and right lane options about 90 percent of the time.
5. The concept of “either lane” was poorly comprehended, and was correctly identified only 44 percent of the time.
6. The lack of comprehension of allowed lane choices may reduce the effectiveness of lane restrictions to control traffic flow.

These observations corresponded to research questions 4 to 6. In the present study the research participants displayed a poor understanding of situations where the signing and marking indicated that either entry lane was allowed. Poor comprehension was consistent across all five signing and marking schemes, ranging from 39 to 48 percent correct, depending upon the scheme. Comprehension was poor even with the Destination Lane Restriction scheme, which was markedly different from the other four schemes in its presentation of lane restriction information, and which even included the words "either lane" on the sign.

The high error rate when "either lane" was the correct response may be partially attributable to the participants' propensity to say which lane they would use. The instructions for the comprehension test were reworked several times during pilot testing, before participants stopped making statements such as "I would use the … lane". The final instructions were:

> *"In the session you just finished you were instructed to follow the signs to McLean by choosing the lane you were most comfortable with. Now for this session I would like for you to tell me, when following the signs to McLean which lane (right, left, or **either**) that you are **allowed** to use.*
> *Do you have any other questions?*
> *Remember. You have **three** choices:*
> *Right, Either, or Left."*

The bold faced words in the instructions were emphasized with intonation when read to the participants.

The difficulty in getting participants to use the "either lane" choice may have caused a higher error rate than true comprehension. However, the error rate of 10 percent in left and right lane choices is consistent with the overall 11 percent error rate in the simulation, and supports the conclusion from the simulation that many drivers do not understand the current lane restriction signing and/or markings.

As in the compliance experiment, in the comprehension experiment, there was no scheme that was significantly better than the others, and no scheme that was significantly worse than the others.

It is possible that the poor comprehension of the concept of "either lane" may be symptomatic of a more fundamental misunderstanding which extends beyond the realm of roundabouts. There may be pervasive confusion about lane indications in general, as to whether they are "permissive" (allow drivers to go in the indicated direction, but also allow other directions) or "restrictive" (allow drivers only to go in the indicated direction, and no other direction). Such confusion may come from other encounters with lane restrictions and could carry over to the roundabout situation. In the present study the addition of clarifying wording to the Arrow with Words conditions was directed at reducing such potential confusion. However, the lack of consistency in ranking the

Arrows with Words condition always being higher than the corresponding Arrows alone condition (see Table 11) indicates that such supplemental wording did not produce the intended effect. Thus, either the wording was not effective, or the source of the confusion may reside somewhere other than the "permissive" / "restrictive" distinction. Whatever the cause, the current study clearly demonstrates poor comprehension of the concept of being allowed to enter the roundabout in either lane. As mentioned before, such poor comprehension could reduce the predicted effectiveness of lane restrictions to control traffic flow, and seriously restrict the potential operational capacity of real roundabouts.

Workability Ratings

The workability ratings showed that:

7. Drivers rated all schemes slightly above the mid-point of the scale, which was labeled "Might Work".
8. None of the schemes were rated as unworkable (would not work at all).
9. None of the schemes were rated as more workable than any of the others.

These observations corresponded to research questions 7 to 9. The workability ratings represented the only portion study in which each participant saw all five signing and making schemes. The fact that none of the mean ratings indicated an unworkable scheme corroborates findings of the simulation and comprehension tests. The fact that none of the mean ratings approached "would work very well" corroborates the lack of understanding of the lane restriction signing and marking schemes that was evident in the other evaluations.

General Observations

In addition a number of general research observations emerged from the present study:

10. None of the schemes led to wrong way rotation.
11. Diagrammatic navigation signs were extremely effective (99 percent) in indicating the correct exit for the intended destination.
12. Drivers exhibited a bias toward the right entry lane (66/34).
13. There was mixed evidence of a possible destination hypothesis.
14. Rankings of the results from the three evaluation measures were not consistent.
15. There were no meaningful age or gender effects.

These observations corresponded to research questions 10 to 15. General Conclusion Number 10 is the most important in the above list. One of the primary advantages of roundabouts from a safety perspective is the uniform flow of traffic in a similar direction. Properly designed, signed and marked roundabouts direct drivers so as to eliminate right angle and near head-on vehicle conflicts. However, if a signing and marking scheme

induced some drivers to drive the circulatory roadway clockwise, the potential for a head-on crash would be introduced, and the safety advantages the roundabout would be reduced. In the present study one attempt to enter the circulatory roadway in the wrong direction was encountered during training. However, the participant aborted the wrong turn before completing it, presumably because he/she noticed the one-way sign and chevrons on the central island.

During the simulation which consisted of a total of 1,620 double lane entries to simulated roundabouts, no wrong way rotations occurred. Thus even though wrong way rotation may be encountered as a rare event, the results of the present study do not suggest any evidence that a particular signing and marking scheme is likely to induce drivers to enter the circulatory roadway in the wrong direction. This outcome is especially important with regard to the Traditional Arrows and Traditional Arrows with Words conditions. As explained above, traditional left-hand arrows in the left entry lane might be interpreted as an indication to turn left at the next opportunity and enter the circulatory roadway in the wrong direction. The Fishhook Arrow scheme was devised to counteract such a misinterpretation by indicating the proper circulatory direction and providing a visual reference symbol for the center of the roundabout. The results of the present study showed no evidence of the Traditional Arrows inducing wrong way rotation, or of the Fishhook Arrows reducing wrong way rotation. Neither scheme produced any wrong way rotation responses in 324 trials each. In this study all the roundabout entrances had the recommended amount of splitter-island deflection (Robinson, et al., 2001), which is intended to slow vehicles, as well as orient them towards the right and a counterclockwise rotation. In addition, one way signs and chevrons were placed as recommended in the FHWA Informational Guide. The present findings might not generalize to roundabouts that lack adequate deflection or are missing directional signing.

Summary

In summary, all five of the entry lane restriction signing and marking schemes performed equally in terms of driver compliance, with no meaningful differences among them. Furthermore, under no scheme did any participant attempt to drive around the circulatory roadway in the wrong direction. However, the research participants did not comprehend very well the concept of “either lane” being available as a roundabout entry choice.

REFERENCES

Austroads, Australia and New Zealand. *Guide to Traffic Engineering Practice: Part 6 Roundabouts*. Austroads Publication No. AP-11.6/93. Sydney, 1993.

Brown, M., *The Design of Roundabouts*. Transportation Research Laboratory, Crowthorn, Berkshire, UK, 1995.

Katz, B., Hanscom, F.R., Inman, V.W., *Navigation Signing for Roundabouts.* Traffic control devices pooled fund study. Study No. TPF-5(065). Accessed on August 27, 2007. http://www.pooledfund.org. December, 2004.

Land Transport New Zealand. *Guidelines For Making Multi-lane Roundabouts.* ISBN 0-478-28910-3. Accessed on August 27, 2007. http://www.transfund.govt.nz/roads/docs/guidelines-multi-lane-roundabouts.pdf. Wellington, New Zealand. September 2005.

Lee, J.C., Robinson, B., Kidd, B.D., Scarbrough, W., *Roundabouts: An Arizona Case Study and Design Guidelines.* Final Report 545, Arizona Department of Transportation, Phoenix, 2003.

McElroy, R.S. Director, Office of Transportation Operations. U.S. Department of Transportation. Federal Highway Administration. Correspondence with Bruce W. Smith Director, Traffic Engineering & Highway Safety Division New York State Department of Transportation. Refer to HOTO-1. April 7, 2005.

NCUTCD, National Committee on Uniform Traffic Control Devices, Markings Technical Committee. *Chapter 3H: Roundabout Markings.* Attachment No.30. Accessed on August 27, 2007. http://www.ncutcd.org/meetings-200601.shtml. Approved in NCUTCD council on January 20, 2006.

Robinson, B., Troutbeck, R., Brilon, W., Bondzio, L., 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, 2000.

APPENDIX A

This Appendix consists of 6 Figures. The Figures show a plan view of each of the 6 unique types of roundabouts employed in the compliance portion of the experiment. They represent the plan views displayed to the experimenter in the simulator control room for the purpose of manually recording driver responses. The 6 different types of markings are portrayed for the entry (always from the bottom), the circulatory roadway, and the exits of each roundabout type. The light green rectangles represent the entry lane recording positions. The blue rectangles represent the possible exit lane recording positions in the correct exit direction. The rose colored rectangles represent the possible exit lane recording positions in an incorrect exit direction. The correct exit destination is indicated by blue text, while the incorrect exit direction is indicated by red text. All of the colored rectangles and colored text overlays were depicted purely as aids to the experimenter in recording driver responses, and were not visible in the simulation driven by the research participants. The simulator vehicle is portrayed in the center of the roundabout because each plan view was obtained by elevating the driver eye position far above the simulator vehicle. The 6 different roundabout types are shown in Figures A1 to A6:

Figure A 1. Roundabout Markings – Type A – Exit Right

Figure A 2. Roundabout Markings – Type B – Exit Left

Figure A 3. Roundabout Markings – Type C – Exit Right

Figure A 4. Roundabout Markings – Type D – Exit Right

Figure A 5. Roundabout Markings – Type E – Exit Straight

Figure A 6. Roundabout Markings – Type F – Exit Right.

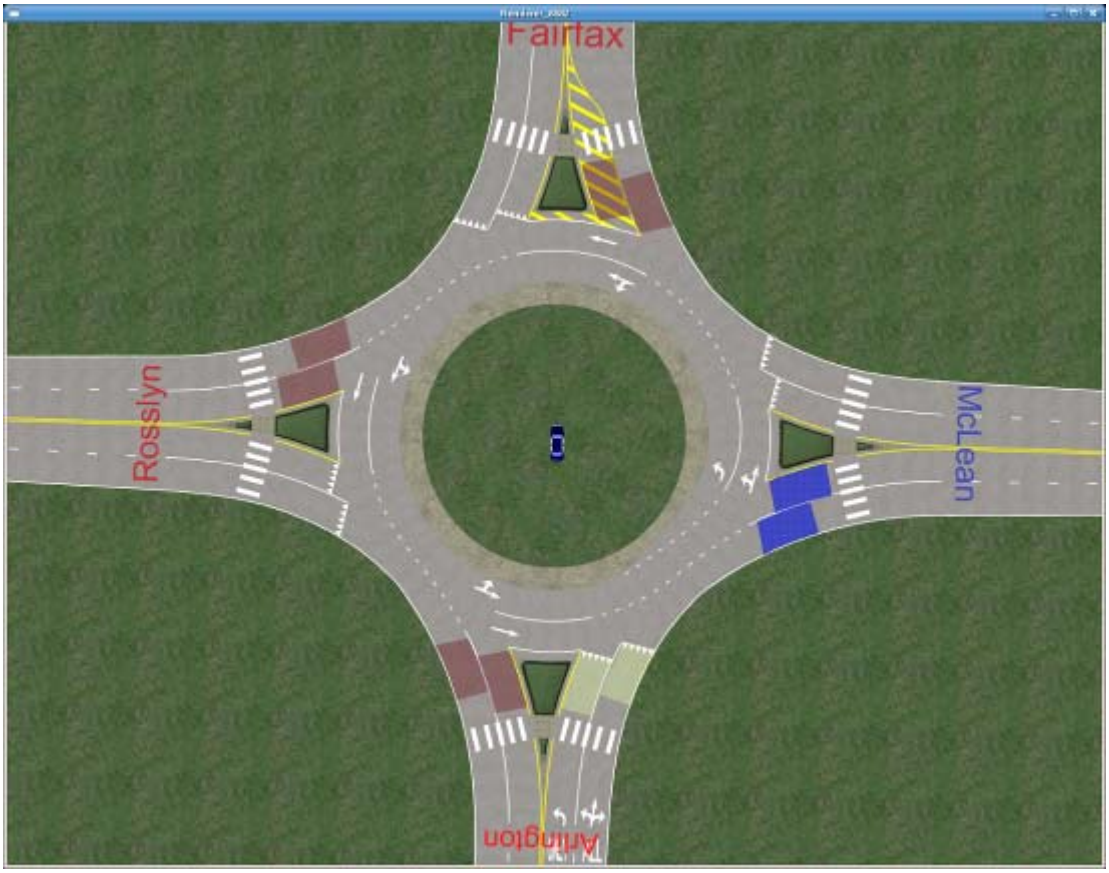

Figure A 1. Roundabout Marking – Type A – Exit Right

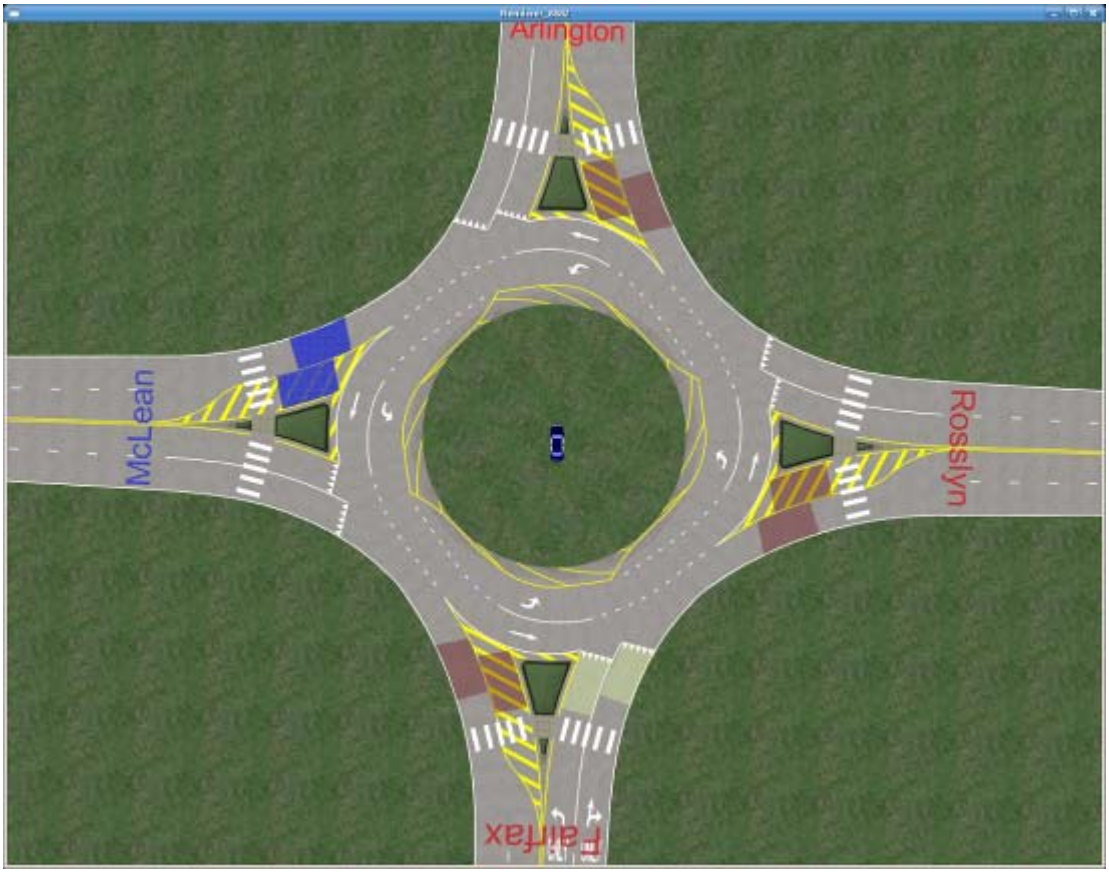

Figure A 2. Roundabout Marking – Type B – Exit Left

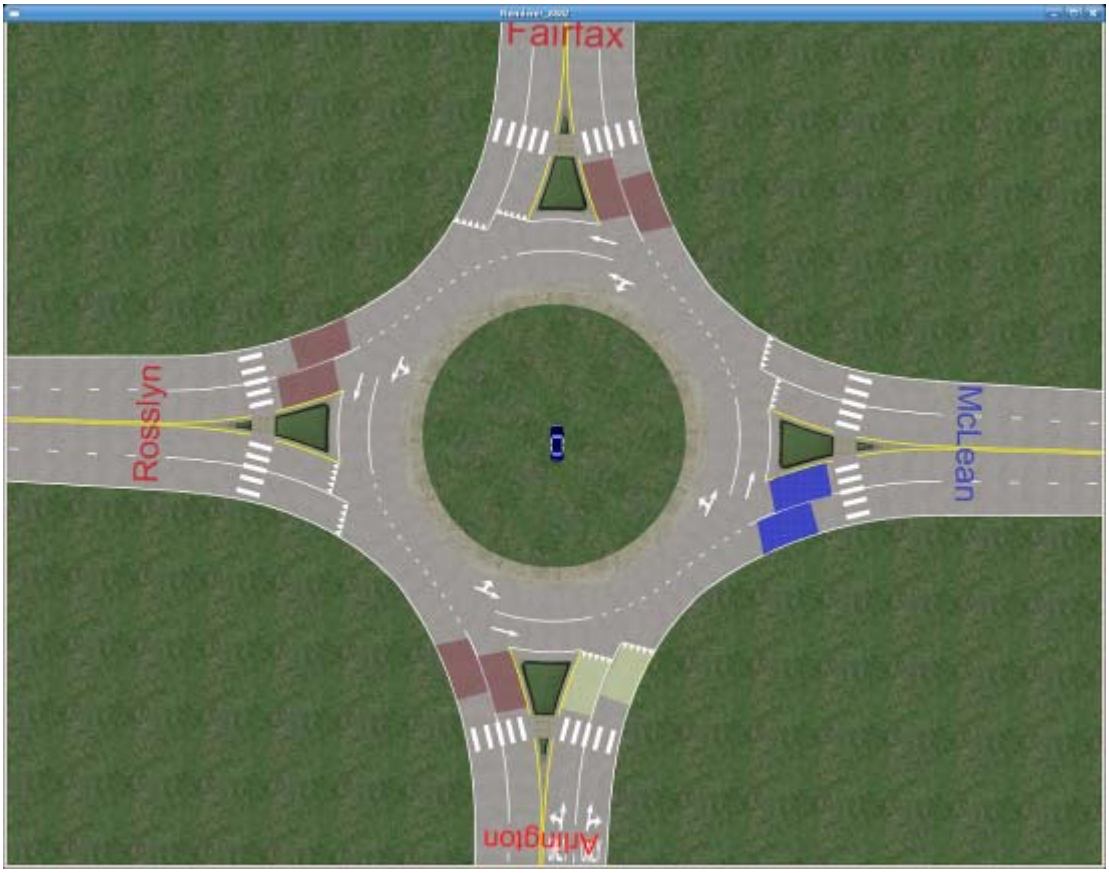

Figure A 3. Roundabout Marking – Type C – Exit Right

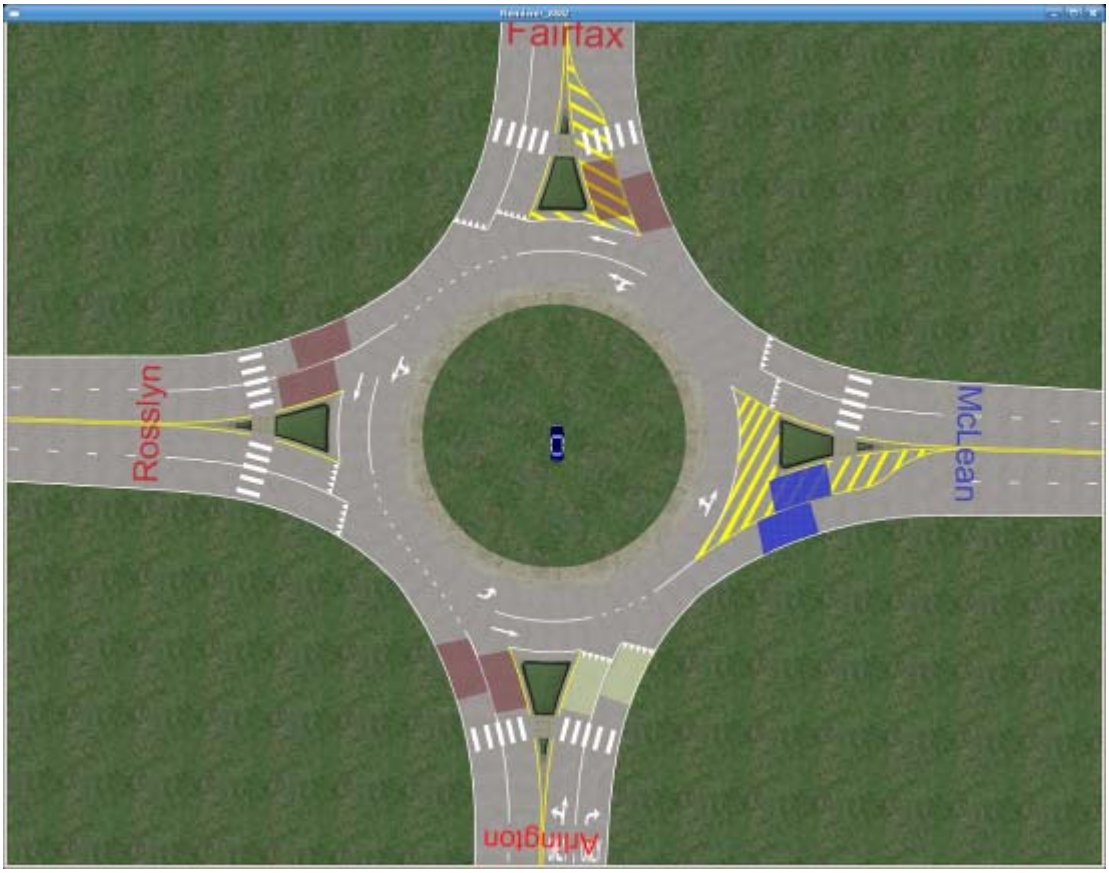

Figure A 4. Roundabout Marking – Type D – Exit Right

Figure A 5. Roundabout Marking – Type E – Exit Straight

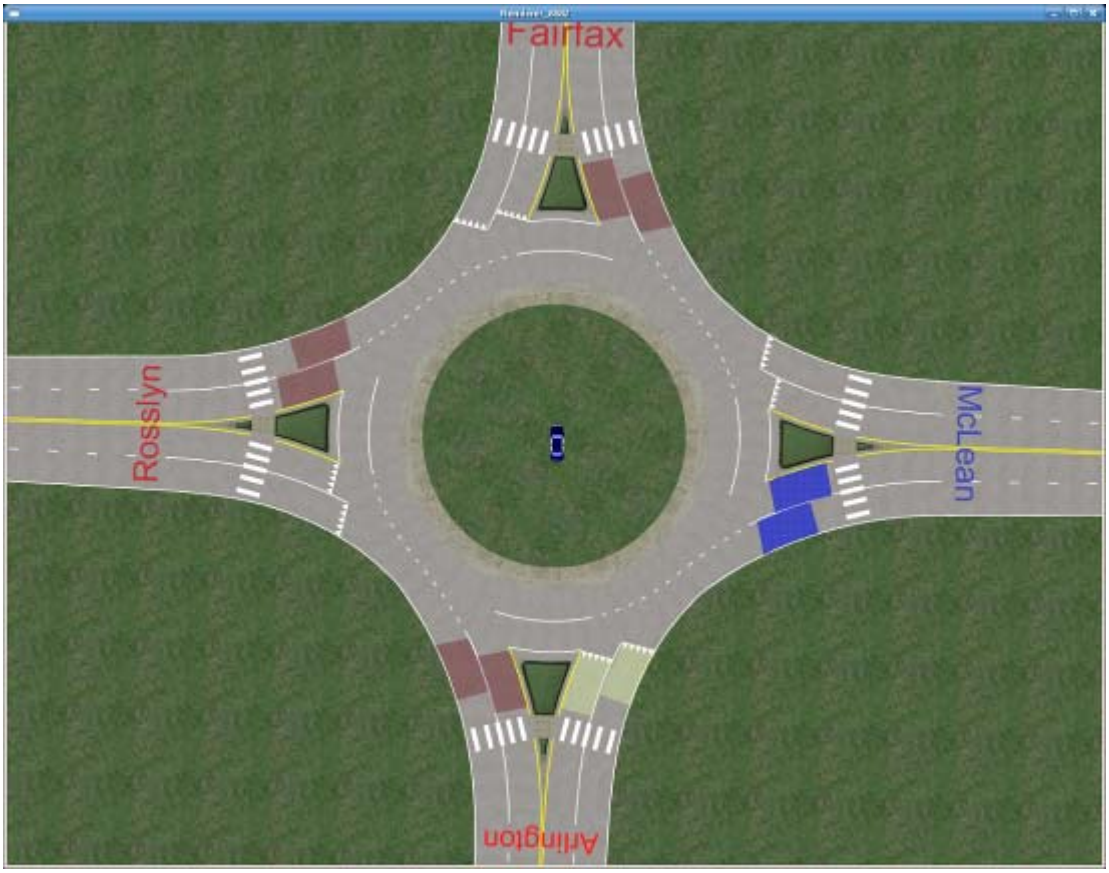

Figure A 6. Roundabout Marking – Type F – Exit Right