TECHBRIEF

TRAFFIC CONTROL DEVICES POOLED FUND STUDY: SIGNING FOR INTERSECTION GEOMETRICS THAT REQUIRE U-TURNS

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INTRODUCTION

Alternative intersection designs can improve traffic operations and safety but may be confusing to drivers due to turn prohibitions at intersections, such that drivers may be unaware where they can make a U-turn. Some alternative designs include median U-turns (MUT), restricted crossing U-turns (RCUT), J-turns, and through U-turns (ThrU). Each intersection type requires a driver to make a U-turn at a location downstream from the main intersection for minor, major, or both approaches. Transportation agencies have used a variety of signing approaches, with combinations of regulatory and guide signs, to address wayfinding through these intersections.

A driver navigating any of the intersection types discussed in this document will experience a series of decision points for which key information is needed. Similar decision points and information needs exist for each intersection type. An effective signing sequence would answer each of these questions a driver may ask. Sign sets are developed systematically using the principles inherent in the Federal Highway Administration *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA 2009). In section 2A.16, the MUTCD discusses relative locations of regulatory, warning, and guide signs for approaches to intersections. Other sections of the MUTCD also address sign sets on the approach to intersections, as well as designs of individual signs. Much of MUTCD chapter 2D contains provisions for junctions, route marker assemblies, and destination signs. In a systematic approach, similar signing styles are used for the relevant signs at intersections.

OBJECTIVE

This research project aimed to explore and evaluate the effects of directional signing alternatives for intersections requiring U-turns on drivers' comprehension of the signs, time required to comprehend each alternative, and preferences among the alternatives.

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APPROACH

The research team identified the state of the practice by reviewing State design guidelines, as well as studying photographs from alternative intersections identified by the Traffic Control Device Consortium Pooled Fund Study members. The team also reviewed the MUTCD. In addition, the team reviewed research literature concerning driver understanding of intersection and freeway signing.

MUTCD sections on signs for circular intersections (roundabouts) and jughandle intersections provide provisions for guide and regulatory signs that could be applied to intersections that require U-turns. Roundabouts and jughandles share features with RCUTs and other alternative intersection designs. For instance, they all counter driver expectations about allowed movements and direction of movement. Trailblazer signs were also considered, as they provide path confirmation to reach a desired route.

The focus of this research was to identify the signing strategies required to lead a driver through the desired movement in order to improve wayfinding and to provide information on optional signs to enhance wayfinding. The research team examined individual styles and design features of specific signs for each location type in a full sign set approaching the intersection. The research team examined the MUTCD to identify signing alternatives to test. The team considered sign sets and individual sign layouts for traditional interchanges and intersections, as well as alternative intersection designs, such as jughandles and roundabouts.

To organize the questions that needed investigating for each decision point, key locations were identified for an intersection design that includes a U-turn, as shown in figure 1.

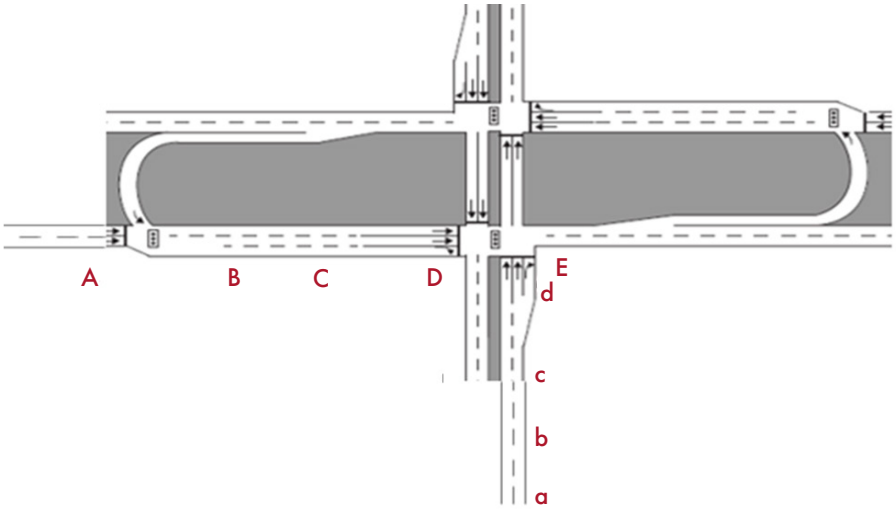
Table 1 gives the purpose or function of a sign at each decision point shown in figure 1.

Table 1. Purpose or function of each sign in a set for approach to intersection.

Road	Position in Set	Purpose/Function
Major	A	Announces upcoming junction or intersection.
Major	B	Advance guide: Provides route, city, or street name.
Major	C	Lane assignment: Regulatory or guide sign assigns allowed movements to specific lanes on the approach.
Major	D	Guide: Provides route, city, or street name.
Major	E	Confirmation: Sign provided downstream of intersection to confirm route.
Minor	a	Announces upcoming junction or intersection.
Minor	b	Advance guide: Provides route, city, or street name.
Minor	c	Mandatory lane control: Regulatory sign assigns allowed movements to specific lanes on the approach.
Minor	d	Guide: Provides route, city, or street name.

The team selected the following eight research questions to be addressed in a human factors study. Multiple sign alternatives were evaluated for each of the eight research questions. In all, 32 unique individual signs or sets of 4 or 5 signs were tested.

Figure 1. Diagram. Key decision points within an alternative intersection design.



1. Which sign designs on the *major* leg are best for a desired *left* turn at intersections that prohibit left turns?
    a. Sign set 1: Conventional road guide signs similar to MUTCD section 2B.27 and chapter 2D.
    b. Sign set 2: Advance intersection sign style used for jughandles with U-turn arrow (MUTCD section 2B.27) for positions C–E.
    c. Sign set 3: Jughandle regulatory U-turn signs added for positions C and D.
    d. Sign set 4: Similar to sign set 1 but with U-turn arrow used on advance guide and confirmation signs.
2. Which sign designs on the *minor* leg are best for a desired *left* turn at intersections that prohibit left turns?
    a. Sign set 5: Signs using MUTCD M1-4, route sign auxiliaries, and an arrow configuration similar to those shown in MUTCD section 2B-4.
    b. Sign set 6: Advance signs using route marker; other signs using text guide.
    c. Sign set 7: First sign in set is the guide sign with U-turn directional arrow.
    d. Sign set 8: First sign in set is the guide sign. U-turn arrows used on guide and route marker assemblies.
3. Which style of guide or other wayfinding sign is best for approaches on the *major* leg with a desired *left* turn movement?
    a. Sign set 9: Same sign as sign set 1, position B–advance guide sign.
    b. Sign set 10: Both destinations listed. Similar to sign set 9 with U-turn arrow for first destination.
    c. Sign set 11: Full diagrammatic sign.
    d. Sign set 12: Destination only for unusual maneuver with U-turn arrow.
    e. Sign set 13: Destination only for unusual maneuver with U-turn ahead panel.
4. Which style of guide or other wayfinding sign is best for approaches on the *minor* leg with a desired *left* turn movement?
    a. Sign set 14: Sign similar to those in MUTCD section 2D.45 with M1-4 US route sign.
    b. Sign set 15: MUTCD guide with modified directional arrow.
    c. Sign set 16: Full diagrammatic sign with single route marker.
    d. Sign set 17: Full diagrammatic sign with route marker and cardinal direction paired.
    e. Sign set 18: Full diagrammatic sign with intersecting minor road shown.
5. Which style of guide or other wayfinding sign is best for approaches on the *minor* leg with a desired *through* movement?
    a. Sign set 19: Route sign assembly with MUTCD-compliant signs, including those similar to M1-2 off-interstate business route and route sign auxiliaries with jughandle U-turn sign.
    b. Sign set 20: Trailblazer assembly.
    c. Sign set 21: Full diagrammatic sign with intersecting minor road shown.
6. Is a confirmation sign downstream of the main intersection needed?
    a. Sign set 22: No confirmation sign presented.
    b. Sign set 23: Regulatory route marker assemblies with directional arrows.
    c. Sign set 24: Regulatory route marker assemblies with directional arrows using 90-degree arrow.
    d. Sign set 25: Route assembly with new vertical U-turn arrow.
    e. Sign set 26: Destination with lane assignment.
7. What advance lane assignment is needed for multilane minor approaches that require downstream U-turns for prohibited movements?
    a. Sign set 27: Signs similar to sign set 5 using those similar to MUTCD M1–2, route sign auxiliaries, and an arrow configuration similar to those in MUTCD section 2B-4.
    b. Sign set 28: Overhead final guide/lane assignment sign only.
    c. Sign set 29: All ground-mount signs with hook arrow on route assembly.
    d. Sign set 30: Overhead guide and lane assignment signs.
8. Should directional arrows be modified to illustrate the U-turn maneuver for the major approach?
    a. Sign set 31: Destination sign with auxiliary to message with standard up arrow.
    b. Sign set 32: Destination sign with auxiliary to message with U-turn arrow.

HUMAN FACTORS RESEARCH METHODS

The researchers used a combination of still images of signs and short computer animation video clips created using their driving simulator. The scenarios animated and illustrated were a two-lane major approach, one-lane minor approach, and two-lane minor approach to an intersection that required U-turns. Video clips of these scenarios were played at a speed equivalent to 40 mph, and the still images were displayed for 5 s. In practice, most of the signs under investigation were positioned on the approach to the intersection. The animation video clips showed the advance signs on the approach to the intersections, not the actual U-turn location itself. Figure 2 shows an example of a still image.

Videos were used for research questions 1, 2, 6, and 7, and still images were used for research questions 3, 4, 5, and 8, as follows:

Figure 2. Screenshot. Example still image from video clip.

- Question 1: Participants saw a short video clip of the major leg approach to an intersection where it appeared that a driver could use the paved median to turn left, but left turns were prohibited (e.g., MUT or ThrU intersection designs).
- Question 2: Participants saw a short video clip of the minor leg approach to an intersection where it appeared that a driver could use the paved median to turn left, but left turns were prohibited (e.g., MUT or ThrU intersection designs).
- Question 3: Participants were shown a still photo of a sign on a major approach. The median at the intersection was visibly closed.
- Question 4: Participants were shown a still photo of a sign as seen from the minor road approach to an intersection where left turns are prohibited. The actual intersection was not visible on these photos, as the signs being tested appeared in advance of the intersection. These signs showed an advance route turn assembly with arrows of different designs.
- Question 5: Participants were shown a still photo of signs on a minor road with the intersection visible in the distance.
- Question 6: Participants saw a video animation that asked them to press the button as soon as they identified where to turn. The state-of-the-practice review revealed some transportation agencies used confirmation signs in areas with a long separation between the main intersection and the U-turn location.
- Question 7: Participants looked at multilane minor approaches by viewing an animation of a two-lane minor leg approach to an intersection.
- Question 8: Participants compared two styles of advance route turn signs. The state-of-the-practice review showed several States using some variant of an advance turn sign or regulatory turn lane assignment sign with a U-turn hook arrow shape.

Each participant completed the test individually at a computer workstation in a room with other participants. Participants were given a destination, route number, or movement as a goal. Participants worked through the test using a response box with seven keys that were separate from the computer keyboard. They pressed a button to see the visual aid (either a short video clip of approaching a sign location or a still image). The participants then answered a multiple-choice question about their interpretation of the sign after the still image disappeared or after the video was automatically paused after the sign was passed. An example question sequence for a still image is shown in table 2, illustrating the four steps to each test question. For video clips, the animation stopped automatically after each sign was passed, and then the test question and the confidence rating question were presented.

The study was conducted in St. Paul, MN, and College Station, TX, with 48 licensed drivers from each area. An even number of male and female drivers was recruited. Approximately half of the drivers were over the age of 65 yr, and half were younger than 65 yr. Each participant saw 16 test questions, and most completed the test within 25 min.

The sign set treatments were counterbalanced across each version of the survey, meaning that one version of the test may include one variant of a sign, and another

Table 2. Example question sequence for a still image.

Steps	Question Sequence
1	In this scenario, you are driving north on County Road 5, approaching the intersection with a roadway called Oak Street. You want to go WEST on Oak Street. To continue to the photo, press button 7. The photo will be displayed for 5 s. After the photo is displayed, we will ask you a question about how you can reach your destination.
2	 © 2019 TTI. Note: Shown for 5 s.
3	Answer: You want to go WEST on Oak Street. How would you proceed? 1) I would turn left at this intersection. 2) I would turn right at this intersection. 3) I would go straight at this intersection and look for any opportunity to make a U-turn to come back from the other direction and turn right. 4) I would go straight at this intersection because I know there will be a designated place for me to make a U-turn to come back from the other direction and turn right.
4	How confident are you of your answer? 1) 100 percent confident. 2) 95 percent confident. There is a slight chance I am wrong. 3) 75 percent confident. I am pretty sure I am right. 4) 50 percent confident. I could narrow my answer down to two of the options. 5) Not at all confident. I am basically guessing.

version would contain a different variant of the same sign. For example, one participant would see sign set 2, and another would see sign set 3. Each version of the test always contained the baseline sign set that represented the current MUTCD provisions. Thus, a participant's answer to a particular sign variant could be compared with his/her answer for the MUTCD sign applied in the same scenario.

For the analysis, descriptive summaries were first produced for all sign sets, as well as cross tabulations when appropriate. The responses were assessed for whether the participant answered a question correctly, semi-correctly, or incorrectly. Semi-correct answers were those that indicated the participant understood the left-turn prohibition but was not certain that there would be a designated U-turn location downstream. For the statistical analysis, the categories of correct, semi-correct, and incorrect were translated into a numerical scheme that was coded as 0 for incorrect or 1 for correct. The research team conducted the analysis using both a strict and a lax criterion to categorize the responses. The *strict* scoring scheme placed answers deemed semi-correct into the incorrect category and assigned them a value of 0, whereas the *lax* criterion scoring scheme assigned semi-correct answers a value of 1. Several statistical tests were used, including Wilcoxon signed-rank, McNemar, conditional logistic regression, and Kruskall Wallis.

RESULTS

This section describes the results of each research question. This section is split up into eight subheadings to explain the results of each research question.

> The information provided in this Results section is specific to the context of this research study. Tested signs and sign assemblies do not necessarily comply with MUTCD provisions. State departments of transportation (DOTs) and local jurisdictions are required to use MUTCD-compliant signs and sign assemblies. If a State DOT and/or local jurisdiction is interested in using a new traffic control device or a different application of an existing device, they must go through the MUTCD experimentation process (FHWA 2009).

Research Question 1: What Sign Designs on the Major Leg Are Best for a Desired Left Turn at Intersections That Prohibit Left Turns?

Using both strict and lax scoring criteria, there were statistically significant differences between the scores on sign set 1 and those for all of the other experimental groups (sign sets 2–4). The differences were as follows:

- For the sign set leading up to the intersection (positions B and C), the current MUTCD signs performed worst overall.
- Sign set 4, which included the vertical hook U-turn arrow in place of the up arrow, performed the best overall on the first advance sign position (position B).
- Sign set 3, which included a turn direction sign with a U-turn arrow and the U-turn plaque currently used for jughandle intersections, performed the best in positions B–D.

These signs for question 1 are shown in table 3.

Research Question 2: What Sign Designs on the Minor Leg Are Best for a Desired Left Turn at Intersections That Prohibit Left Turns?

Using the strict scoring criterion, the participants performed best overall on the sequence presented in sign set 5 (table 4), but the scores were not statistically different from those for sign set 8, which used a hook U-turn arrow on the final assembly. Sign set 5 uses standard MUTCD route marker assemblies. The lax scoring analysis found statistically significant differences between the scores on sign set 5 and all of the other experimental groups (sign sets 6–8). Note that by using this lax criterion, sign set 5 scored higher than sign set 8, whereas by using the strict scoring, they were not statistically different.

Research Question 3: Which Style of Guide or Other Wayfinding Sign Is Best for Approaches on the Major Leg with a Desired Left Turn Movement?

The analysis indicated sign set 13 (figure 3), which contained the regulatory sign with U-turn, performed the best. This sign assembly uses sign R3-26a, a regulatory sign for jughandle intersections, shown in MUTCD section 2B-8 and figure 2B-9 sheet 1. This result, based on using still photos, agrees with the results from research question 1 that examined the full sequence of signs on a major approach using video.

Figure 3. Illustration. Sign set 13 with a plaque adapted from the regulatory signs for jughandle intersections.

Table 3. Signs that performed the best for major approaches to intersections that require a U-turn downstream of the main intersection.

Junction	Advance Route Turn	Destination	Directional Assembly	Confirmation
				

All photos: © 2019 TTI.

Table 4. Sign set 5, which uses the standard MUTCD route marker assemblies.

Junction	Advance Route Turn	Intersection Lane Control	Directional Assembly
			

All photos: © 2019 TTI.

Research Question 4: Which Style of Guide or Other Wayfinding Sign Is Best for Approaches on the Minor Leg with a Desired Left Turn Movement?

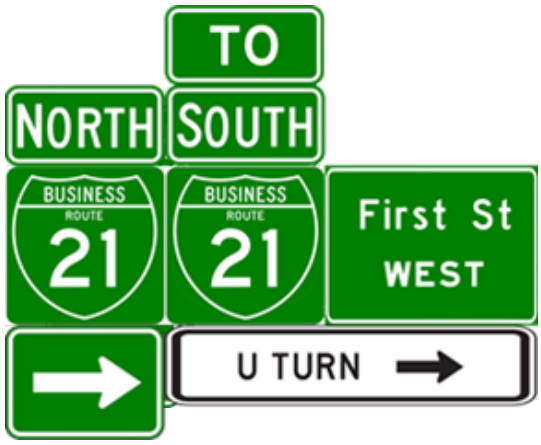
The analysis showed the MUTCD advance route turn assembly with a horizontal right-pointing arrow (i.e., sign set 14) performed well (figure 4-A) as did a version of this sign with a horizontal U-turn arrow (i.e., sign set 15) (figure 4-B).

Figure 4. Illustrations. Two sign sets that performed the best for advance turn assembly for minor leg approach.

A. Sign set 14.

B. Sign set 15.

Figure 5. Illustration. Directional assembly for minor approaches that performed the best.



Research Question 5: Which Style of Guide or Other Wayfinding Sign Is Best for Approaches on the Minor Leg with a Desired Through Movement?

The directional assembly developed using MUTCD-compliant signs that utilized the U-turn regulatory sign adapted from jughandle intersections (i.e., sign set 19) performed the best out of the signs tested (figure 5). Note that the U-turn sign in this assembly is being used as a destination directional sign, as opposed to its intended purpose of simply indicating where there is a U-turn.

Research Question 6: Is a Confirmation Sign Downstream of the Main Intersection Needed?

The participants selected their lane choice sooner with any of three sign designs shown in figure 6 (i.e., sign set 24, 25, or 26). There was no difference among these signs, but each did better than no sign at all (i.e., sign set 22) or the route assembly with up arrows under both route markers (i.e., sign set 23).

Figure 6. Illustration. Sign sets that performed the best for confirmatory or advance turn signs on a major road in advance of the U-turn lane.

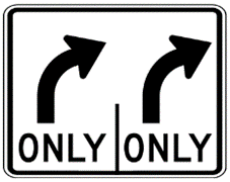
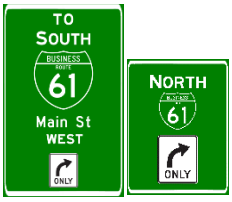
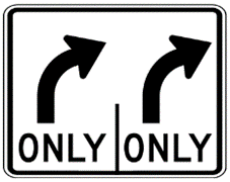
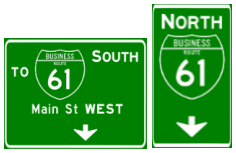
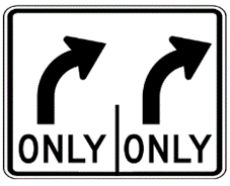
Research Question 7: What Advance Lane Assignment Is Needed for Multilane Minor Approaches That Require Downstream U-Turns for Prohibited Movements?

The analysis showed that all signs performed well overall, and there were no statistically significant differences among the alternatives. Both ground-mounted and overhead-mounted signs were tested. Table 5 shows the four sign sets tested.

Research Question 8: Should Directional Arrows Be Modified to Illustrate the U-Turn Maneuver for the Major Approach?

The intent of research question 8 was to evaluate the situation where drivers see a turn bay and may not realize that the turn bay is where they need to perform the U-turn, especially if they had just entered from the minor approach. Given the nature of the still photo and the wording of the question, there was no clearly correct answer. The emphasis on the analysis of this item was in looking at how the confidence ratings were associated with their response.

Table 5. Four sign sets tested for multilane minor approaches.

Sign Set	Position A: Junction	Position B: Advance Guide	Position C: Lane Assignment	Position D: Guide
27				
28 (overhead)				
29 (ground mounted)				
30 (overhead)				

All photos: © 2019 TTI.

Note: Sign positions are shown in figure 1.

Participants chose the option that included the phrase, "I would go straight at this intersection," more often when an up arrow was used than when the sign showed a U-turn arrow. The state-of-the-practice review showed several States using some variant of an advance turn sign or regulatory turn lane assignment sign with a U-turn hook arrow shape (figure 7). The U-turn hook arrow sign also performed well when tested for the major approach using a video clip in research question 1. The results suggest the U-turn hook assures drivers that they need to stay left. The up arrow does not give assurance that the driver should stay left.

Figure 7. Illustration. Sign set 32 provided a source of confidence as advance route turn on major approach.

LIMITATIONS

This study used computer-based testing to evaluate drivers' comprehension of traffic signs. One limitation of computer-based testing is that participants are fully attentive to the road signs. They are not in control of a vehicle, neither are they maneuvering in traffic, distracted, or pressured for time to respond. This limitation may affect the results by inflating the comprehension levels.

Another limitation is that the order of presentation of the items was the same for all participants. Care was taken to structure that order to ensure that like roadway scenarios did not appear in sequence. The overall order of items, however, was the same. As participants progress through the study, they become more accustomed to the procedure (practice effect), which may produce lower comprehension scores on items early in the test. At the same time, as the research session progresses, participants may grow fatigued or impatient, producing lower comprehension scores on items later in the test. In a perfect world, multiple orders would have been used that would have resulted in many more versions of the test. This outcome has ramifications for the statistical analysis. The research team felt that three versions of the test were the most that could provide a reasonable sample size for each version.

Finally, there may be additional alternatives for some of these scenarios, such as research question 5, that were not included.

CONCLUSIONS

In general, the guide and regulatory signs in the MUTCD provisions that were tested performed well for the minor leg approaches to intersections that require U-turns. For the major leg approaches, signs that contained the word "U-turn" or included a U-turn-shaped arrow produced more accurate and more confident responses. With minor modifications to arrow design on arrow auxiliary plaques and route turn direction signs, driver navigation through U-turn intersections may be improved.

Given the limitations of this study, additional research is needed to evaluate these signs in a more natural environment. Research using a high-fidelity driving simulator could be needed before research on roadways. Additionally, the MUTCD notice of proposed amendment contains versions of these signs that should be included (FHWA 2020).

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