

**Signing and Pavement-Marking Strategies for Multi-Lane Roundabouts:
An Informal Investigation**

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Abstract. Multi-lane roundabouts present motorists with a complex set of decisions. Unlike single-lane roundabouts, for which the only rule on entry is “yield to the driver on your left, then circulate to your right”, multi-lane roundabouts also require decisions about lane positioning – and these decisions are necessary at multiple points: entering, circulating and exiting. Many American motorists are not educated on the proper way to negotiate a multi-lane roundabout, and don’t always know which lane is correct for making a given movement. As roundabouts have become more common in the United States over the past several years, resolving driver confusion has become an important task for the designer. An important question to answer, therefore, is: What design features can maximize clarity for motorists?

Signing and pavement marking are perhaps the two most important tools designers can use to simplify driver understanding of multi-lane roundabouts. Jurisdictions across America and abroad have employed a variety of philosophies and approaches in signing and marking multi-lane roundabouts, ranging from minimal to elaborate treatments. This variation in practice, coupled with the relative lack of published guidance, provides evidence that the industry remains in an “experimental” phase and further standardization may be helpful.

This paper examines and categorizes many of these signing and marking strategies. Arguments for and against the underlying design philosophies are presented, and general conclusions are drawn regarding the effectiveness of the various approaches. The paper also recommends future research, with an eye toward establishing reasonable and intuitive uniformity in signing and pavement-marking practice.

Introduction and Working Definitions

A *roundabout* can be defined as “a circular traffic intersection featuring yield control on all entering legs, one-way continuous flow within the circulatory roadway, channelization of approaches, and appropriate geometric curvature to keep circulating speeds low.”¹ This paper focuses on *multi-lane roundabouts*, which the author defines as “roundabouts with more than one circulating lane on any portion of the circulatory roadway.” To simplify the discussion, and to convey general principles, the paper restricts its investigation to “standard” two-lane roundabouts – four-leg, right-angle intersections with two entering and exiting lanes on each approach, and two circulating lanes all the way around the central island. The author acknowledges that such configurations represent a small subset of all possible multi-lane roundabouts, but the intent is to develop general principles that can be extended (with some modifications) to more complicated forms. **Figure 1** illustrates the two-lane roundabout form used as the basis for this paper.

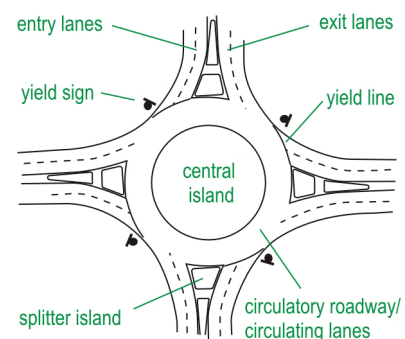


Fig 1. “Standard” two-lane roundabout and key terms

Complex Decisions: Driver's Perspective

Roundabouts have been touted for the fairly simple decision-set they present to the driver², and this is certainly true for single-lane roundabouts. On entry, the simple rule is “yield to the driver circulating from your left, and then circulate to your right.” Once circulating, the driver experiences no vehicular conflicts (assuming all other entering motorists yield as required), and there is only one decision to be made: where to exit the roundabout. (The presence of pedestrians can add complexity to the driver's decision-making.)

However, a motorist approaching a multi-lane roundabout faces a more complex set of decisions, including:

- *What lane should I use to enter the roundabout?*
- *Can/should I change lanes while circulating?*
- *Can I exit the roundabout from the lane in which I'm currently circulating?*

This last question highlights perhaps the most significant potential conflict at a multi-lane roundabout: At the exit point, it is possible that a motorist in the outside lane may desire to continue circulating, while the motorist in the inside lane desires to exit (see **Figure 2**).

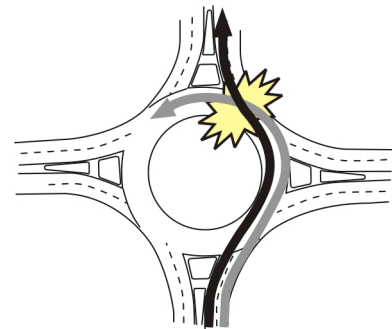


Fig 2. One of the more obvious potential conflicts

Such conflicts are inherent in the operational nature of a roundabout. In contrast to a “normal” intersection, a roundabout presents a series of decision points *after* the driver has entered the intersection (circulatory roadway). In many ways, a roundabout operates as a *series of intersections*, rather than a single intersection. Experiencing these decision/conflict points sequentially might cause the driver to defer certain important decisions (such as lane positioning) in absence of further guidance, which could result in “last-minute” lane-changes and lead to collisions.

A Matter of Definition: Legal Perspective

Although an argument can be made that a roundabout should be considered as a series of intersections, the current impetus in the United States is to define a roundabout as a *single intersection*. In fact, *Roundabouts: An Informational Guide*, published by the Federal Highway Administration (FHWA), recommends that legal definition of a roundabout be revised in this manner.³ **Figure 3** illustrates the contrast between the two definitions. The FHWA guide does not elaborate on the motivation for this definition, but does discuss some implications.

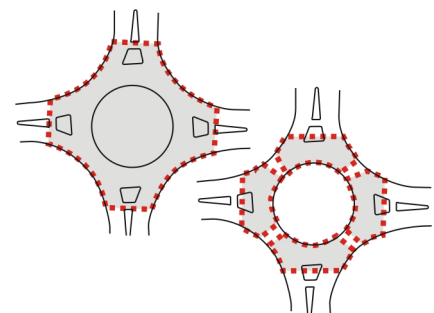


Fig 3. Single intersection vs. four intersections

The definition of the roundabout as a single intersection is important in that it not only affects driving rules, but can play a role in the selection of signing and marking strategies, as will be demonstrated.

Bridging the Gap: Designer's Responsibility

Defining a multi-lane roundabout as a single intersection has the potential to resolve many of its confusing aspects (especially exit conflicts). Allowable movements from entering lanes can be assigned to ensure that vehicle paths do not cross within the circulatory roadway. The most common method of assigning lane usage is to allow “left” turns (and U-turns) only from the inside (left) lane, and to allow “right” turns only from the outside (right) lane. “Through” movements may be made from either entering lane. **Figure 4** demonstrates the analogy to a standard four-way intersection without exclusive turn lanes. This analogy is fairly intuitive in “plan-view.” However, although most motorists would be likely to understand the allowed movements in Part A of the figure – even without any additional signage or pavement markings – it is likely that many American motorists approaching a multi-lane roundabout would not immediately grasp the allowable movements shown in Part B without additional guidance.

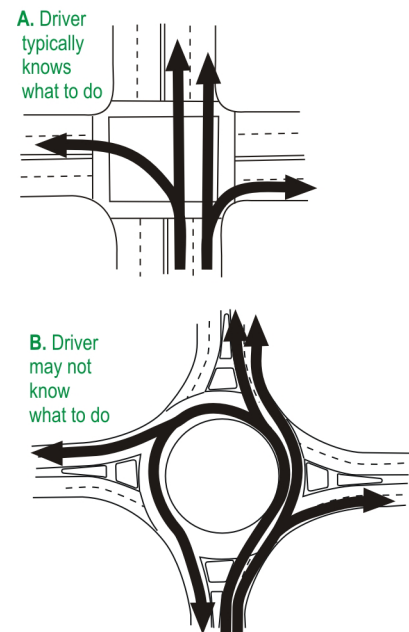


Fig 4. Lane usage analogy

An apparent gap exists, therefore, between motorist perception and designer's intent. Can additional information provided to the driver, conveyed through means such as signing and pavement marking, bridge this gap? If so, are there optimum strategies for providing such information? It is the designer's task to select and implement these strategies, but even the roundabout design community is not immune to floating on either side of this gap. For example: despite the FHWA guide's push to define a roundabout as a single intersection, the same document uses the term “circulatory roadway” throughout, implicitly acknowledging that the middle of a roundabout operates, and is perceived, differently from the middle of a “normal” intersection.

A second “gap” also exists - within the roundabout design community itself. As evidenced by the variation among roundabout designs throughout the United States, there is hardly a consensus that additional guidance *is* necessary. There appear to be two distinct schools of thought:

- The “laissez faire” approach provides no markings within the roundabout, and no advance lane-usage signage/markings. Lane changes within the roundabout are not discouraged, so the circulatory roadway functions as a wide area in which motorists can (and often need to) jockey for position. Some motorists may not be comfortable entering the roundabout side-by-side under this scheme, because it is not clear what their “neighbors” might do once circulating (or even how they should navigate the roundabout themselves).
- The “positive guidance” approach reinforces lane discipline within the circulatory roadway, typically via circulatory striping and advance lane-use control signs. Circulatory striping designs often attempt to match the circulating lane choice with the exit lane choice. Motorists may be more comfortable entering the roundabout side-by-side under this approach, because lane positioning is made explicit.

This second gap, regarding which there is not much discussion to be found in the literature, is one of the central questions in multi-lane roundabout design and should receive more attention and research. Should lane discipline be enforced? Should lane changes be discouraged?

“When All Else Fails, Read the Manual”

The FHWA guide tends to fall on the “laissez faire” side of the debate, as evidenced by the following excerpts:

- “There is no international consensus of the effectiveness of lane-use signs and/or pavement markings [at multi-lane roundabouts].” (p.187)
- “Given the general unfamiliarity of roundabouts to drivers in the United States at this time, it is recommended that double-lane roundabouts be designed to avoid the use of lane-control signs wherever possible, at least until drivers become more accustomed to driving in roundabouts.” (p.187)
- “In general, lane lines should not be striped within the circulatory roadway, regardless of the width of the circulatory roadway.” (p.200)

However, the FHWA guide is not policy. The document that has a much larger degree of control over intersection signing and marking is the *Manual on Uniform Traffic Control Devices* (MUTCD)⁴. Since this document spells out the principles of signing and marking in the United States, what information relative to roundabouts can be extracted from it? Put another way: can the principles of the MUTCD, whether explicitly roundabout-related or not, be applied to this emerging intersection form to clarify driving rules for motorists?

The remainder of this paper addresses this question. The paper treats the various strategies in an abstract fashion, but where actual implementations are known to the author, they are listed in the “Extant Examples” section at the end of the paper. An important note: the paper treats signing, advance marking, and circulatory striping individually – but the designer *must* consider all design elements of a roundabout as a whole, evaluating their combined effect on the motorist.

Circulatory Striping

Section 3B.24 of the MUTCD offers a single sentence regarding circulatory striping in multi-lane roundabouts: “Lane lines *may* be used on the circular roadway if there is more than one lane” (emphasis added). Also, Figure 3B-27 of the MUTCD illustrates “Typical Markings for Roundabouts with Two Lanes”, but the figure shows single-lane entries and exits on all approaches, and thus represents a configuration not addressed by this paper. What other MUTCD guidance can influence the design of circulatory striping?

Section 3A.06 of the MUTCD defines four types of marking patterns, and Sections 3B.04 and 3B.08 indicate the application to intersections:

- ===== A **double line** indicates maximum or special restrictions, and shall be used where crossing the lane markings is **prohibited**.
- A **solid line** prohibits or discourages crossing, and shall be used where crossing the lane line markings is **discouraged**. A solid lane line can also be used to extend a lane line through an intersection, indicating greater restriction than a dotted line (see below).
- - - A **broken line** indicates a permissive condition, and shall be used where crossing the lane line markings **with care is permitted**.
- - - - A **dotted line** provides guidance, and should be used, when desirable, to extend a lane line through an intersection.

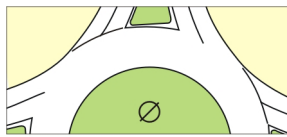
The legal definition of a roundabout becomes important at this point. If a roundabout is defined as a single intersection, then the striping in the circulatory roadway is technically not a lane line, but an *extension* of a lane line through the intersection. This may seem like a trivial distinction, but it can influence the choice of marking pattern. The MUTCD (Section 3B.08) states the following regarding lane-line extensions (emphases added):

*Where highway design or reduced visibility conditions make it desirable to provide control or to guide vehicles through an intersection or interchange, such as offset, skewed, **complex**, or multi-legged intersections, **on curved roadways**, or where multiple turn lanes are used, **dotted line markings** should be used to extend longitudinal line markings through an intersection or interchange area. Where greater restriction is required, **solid lane lines or channelizing lines** should be extended into or continued through intersections.*

The text in bold above can be interpreted to support the idea of circulatory striping within multi-lane roundabouts, and to encourage considering this striping as a lane line extension. It follows that circulatory striping within a multi-lane roundabout, if used, should be dotted or solid, but not broken – because the MUTCD does not provide for broken lines through an intersection. Applying these general MUTCD concepts to a roundabout can perhaps reinforce the idea of a single intersection for the driver.

STRIPING SYMBOLS		
	solid	dotted
circulating	C	c
inbound	I	i
outbound	O	o
null (no striping)	∅	
continuous striping	C _∞	
solid exit striping with gaps	O'	

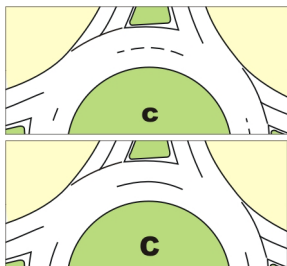
The following discussion highlights circulatory striping strategies that the author considers compliant with general MUTCD policies, and includes brief assessments of driver interpretation. Many of these striping patterns have been known by various names. This paper adopts a naming convention using the letters **I**, **C**, and **O**, as the legend at left illustrates. **I** represents striping extending the *inbound* lanes into the roundabout, **C** represents *circulating* striping, and **O** represents striping extending *outbound* from the circulating lanes to the exit lanes. Upper- and lower-case letters distinguish between solid and dotted striping. “Families” of similar patterns are grouped together.



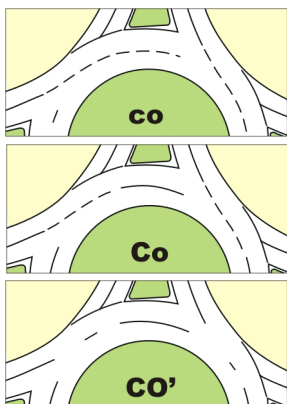
No striping. The absence of circulatory striping is characteristic of the “laissez faire” philosophy described earlier. This strategy tends to rely on driver understanding and familiarity. It does not provide an explicit interior indication that the roundabout carries two circulating lanes.



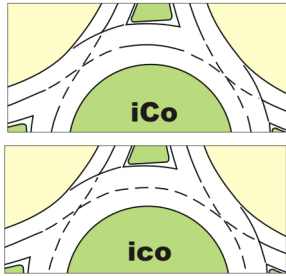
io. This strategy provides extensions of the inbound and outbound lanes, but no circulating striping. It provides some enforcement of lane discipline by encouraging entering and exiting motorists to maintain their lanes. It does not discourage circulating lane changes. Drivers may perceive a lack of guidance while circulating. Only a dotted implementation (**io**) of this pattern is considered MUTCD-compliant by the author, because it allows motorists already circulating to cross the extensions.



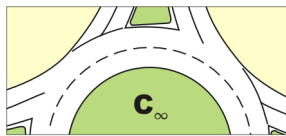
C. Also known as “partial” or “partial concentric” striping, this strategy begins to discourage lane changes within the roundabout, especially in its solid (**C**) form. Although entering motorists are likely guided into the correct lane by seeing the circulating striping ahead, exiting motorists may be less likely to perceive such guidance.



co. Also known as “Alberta” or “concentric-spiral” striping, this strategy adds to the **C** strategy by guiding motorists at the most confusing point – the exit. The graphics at right illustrate at three sub-options that the author considers MUTCD-compliant. The **co** option is a basic implementation, and the **Co** option more strongly discourages lane changes in front of the splitter islands (leaving dotted striping in front of entering motorists). A more tailored adaptation is the **CO'** version, which uses all solid striping, but with gaps in front of entering lanes. The **CO'** option is perhaps the clearest to drivers, but relies on very careful implementation to properly locate the gaps.



iCo. This strategy adds entry extensions to the **Co** strategy. There is some potential for driver confusion regarding the intersection extension lines; however, drivers do encounter similar patterns at signalized intersections at which left-turn lane-line extensions from adjacent approaches cross each other.

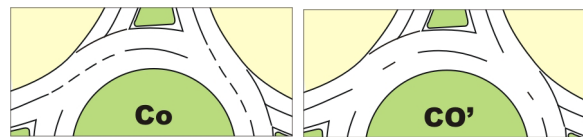


C_∞. Commonly known as “concentric” striping, this pattern includes a continuous lane-line throughout the entire circulatory roadway. This pattern can cause confusion, potentially “trapping” circulating motorists in the inside lane. It does not provide guidance at the crucial location – the exit – and in fact may create the misleading impression that it is wrong to exit from the inside lane, and permissible to continue circulating from the outside lane.

The following general principles should be considered in the design of circulatory striping:

- Solid line markings represent an MUTCD-compliant method to discourage lane changes within the roundabout, and should be used in areas where traffic circulates but no traffic crosses (i.e. in front of the splitter islands).
- Dotted extension striping at the exits can provide much-needed guidance to motorists - discouraging continued circulation from the outside lane - while not creating a barrier to entering motorists on the preceding leg.
- Dotted extension striping at the entries is typically not necessary; motorists at the yield line should be able to choose the correct circulating lane if the entry geometry is designed to guide them correctly.

The **Co** striping is most aligned with these principles, and the **Co'** striping is a nearly equal substitute. As mentioned earlier, the **Co'** strategy may be the most understandable by motorists, but it also is arguably the most difficult to implement since the striping gaps need to be precisely located.



Circulatory striping strategies can reinforce driving rules within the roundabout, but it is equally important that motorists choose an entering lane well before entering the roundabout to avoid unnecessary conflicts. Therefore, a striping strategy must be coupled with an effective advance signing strategy. The following section highlights potential signing strategies.

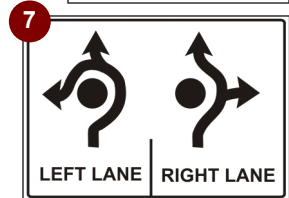
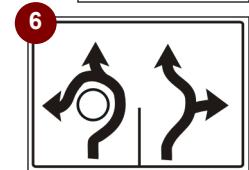
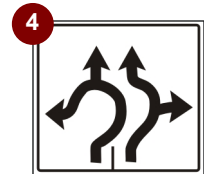
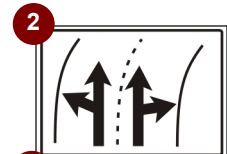
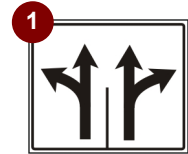
Advance Lane-Use Signage

The MUTCD does not prescribe additional signage for multi-lane roundabouts beyond standard warning (“CIRCULAR INTERSECTION AHEAD”), regulatory (YIELD) and pedestrian crossing signs. However, The FHWA guidelines allow the use of standard MUTCD lane-use control signage at multi-lane roundabouts. Sign 1 would be the resulting application at a “standard” two-lane roundabout. The potential disadvantage of this sign is that it fails to convey the circular nature of the intersection, and could confuse motorists into thinking that a left turn just past the splitter island is allowable. The design of the sign assumes an understanding of the roundabout as a single intersection, but does not effectively convey this impression to the driver. Can this sign be adapted to enhance driver understanding, while conforming as closely as possible to MUTCD standards?

An initial modification would be to introduce curvature to the illustration of the roadway, as Sign 2 illustrates. A further adaptation of this approach would be to introduce curvature to the arrow symbols as well, as Sign 3 illustrates. These adaptations remain similar to the MUTCD standard, but begin to convey the notion of curvature to the driver. However, they still do not completely convey the idea of circulation around the central island.

Configuring the arrows in a “fishhook” arrangement adds further clarification. Sign 4 illustrates the basic design of the fishhook, which continues to convey that there are two entering lanes, and to indicate the movements allowed from each, but adds the idea of circulation. Representing the central island, as with Sign 5, reinforces the presence of an obstruction – the central island – but also adds complexity to the sign. The author has observed, and has received anecdotal evidence suggesting, that this sign may be difficult to absorb in the context of the typical driving experience - perhaps because of the closeness of the two sets of arrows. A further variation of this sign would be to provide more visual distinction among the two entering lanes and the central island, as in Sign 6. This perhaps more closely conforms to the original MUTCD sign, but requires more width than do Signs 4 and 5. Further guidance is given by Sign 7, which adds lane labels and includes two representations of the central island. Showing the central island on the right side of this sign could possibly confuse drivers, leading them to believe that entering from the outside lane and circulating in the inside lane is acceptable and even encouraged.

It should be noted that none of the signs above indicate the possibility of a U-turn movement. Most, if not all, of the actual field implementations of these types of signs echo this omission. The addition of even this extra information would increase the sign’s complexity as well as the time needed to absorb the sign as a whole.

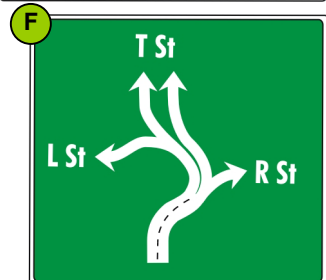
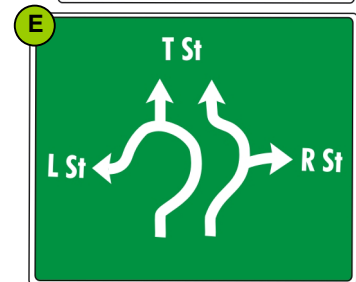
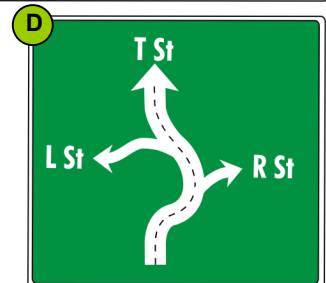
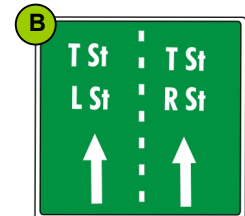
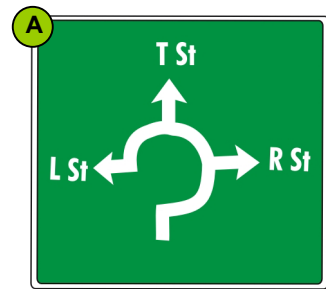


Incorporation of Directional Signage

Many roundabouts also have advance directional (guide) signage, such as Sign **A**, to convey to motorists what destinations can be reached from what exits. In the interest of sign economy, it is worth exploring whether the guide function can be combined with the regulatory lane-control function.

At most “standard” two-lane roundabouts, the simple addition of a street name sign and/or advance placard may be adequate destination guidance. But if street names change, or state routes are involved, or geometries become more complex, more detail may be required. Regarding guide signage, Section 2D.08A of the MUTCD states: “On a ground-mounted sign, a directional arrow for a straight-through movement should point upward. For a turn, the arrow on a guide sign should point upward at an angle related to the sharpness of the turn.” One potential implementation of these principles would include street names and up arrows, divided by a vertical line, as illustrated in Sign **B**. The drawback of this sign is similar to that of the MUTCD’s standard lane-use control sign – it does not convey circulatory motion around the central island. (Note: the designations “L St”, “T St”, and “R St” are used by the author to denote exits which – at “normal” intersections – would be accessed by left, through and right turns, respectively. In many cases, if the cross-street name was constant on both sides of the roundabout, cardinal directions such as “WEST” and “EAST” would also be needed, increasing the sign’s complexity and size.)

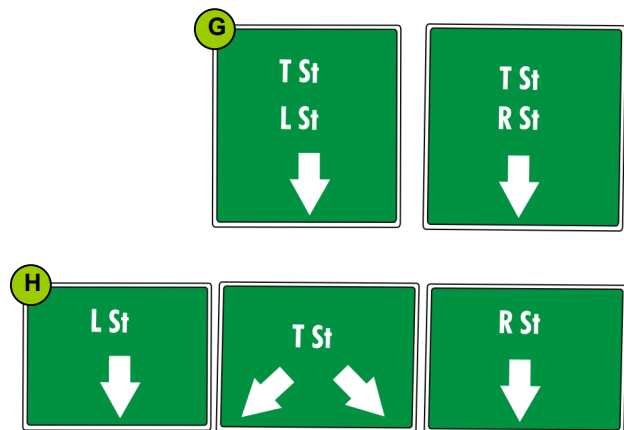
The only standard sign on which the MUTCD combines destination signage with lane-use control signage is a *diagrammatic* sign, such as Sign **C**. Diagrammatic signs are typically used for freeways and interchanges, although the MUTCD allows their use on conventional roads. The MUTCD (Section 2E.19) states that “no more than one destination should be shown for each arrowhead, and no more than two destinations should be shown per sign.” In actual practice, the latter condition is routinely violated, and would *have* to be at most roundabouts, since there are usually three or more exits to choose from. Sign **D** is a fairly straightforward adaptation of the diagrammatic sign, but may convey lane usage too subtly. Even though a lane line is used, and the turns are shown with a one-lane thickness, the lane-use control component of the message might not be perceived by the average driver traveling at speed. Sign **E** adopts the advance lane-use signage principles discussed previously, but may result in information overload. Sign **F** attempts to meld the two approaches, but is probably similarly confusing. It is not clear which, if any, of these signs is optimal. The author is not aware of field implementations of any of these three signs.



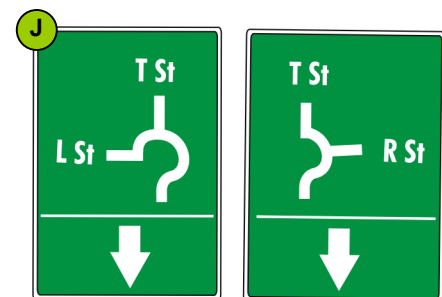
Overhead Signs

The discussion so far has centered on ground-mounted signs. In some cases, overhead signs may be desirable for added emphasis – such as oddly configured roundabouts, or intersections with sight-distance concerns. MUTCD Section 2D.08 offers basic guidance: “On overhead signs where it is desirable to indicate a lane to be followed, a down arrow shall point downward toward the center of that lane. Down arrows shall be used only on overhead guide signs that restrict the use of specific lanes to traffic bound for the destination(s) and/or route(s) indicated by these arrows.”

Theoretically, any of the regulatory lane-use signs discussed previously could be split in two for an overhead application. Guide signs, however, may yield additional strategies. Perhaps the most straightforward application is Installation **G**, with one sign over each entering lane. This installation answers the question: “What destination(s) can I access from this lane?” Perhaps the more relevant question to answer, however, is “What lane should I use to access my particular destination?” The typical driver’s thinking pattern is probably more aligned with this second question. Installation **H**, which admittedly occupies additional width (while reducing height), better addresses the second question.



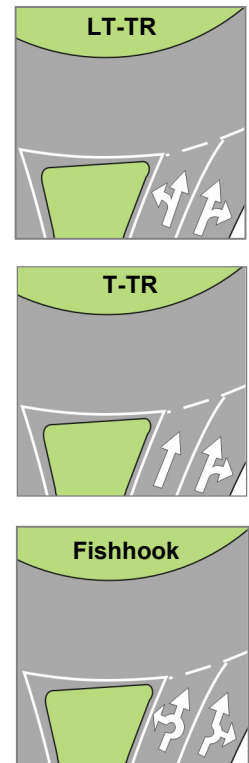
Installations **G** and **H** fail to convey the circulatory nature of the roundabout. An adaptation such as Installation **J** does address this issue, but perhaps at the cost of information overload. (Although one might consider adding arrows pointing to each destination, having two sets of arrows with different meanings on the same sign could potentially confuse drivers. For this reason, the arrows are omitted from the illustration.)



Theoretically, combining guide/destination signage with lane-use control signage could provide valuable assistance to motorists. As the examples on this and the previous page illustrate, however, a design that clearly conveys both destination and lane-use information is elusive. In extreme cases - where odd geometry or other considerations dictate - implementation of these principles could enhance driver understanding. At most “standard” multi-lane roundabouts, however, it is probably best that the destination and lane-use control functions remain separate.

Advance Pavement Markings

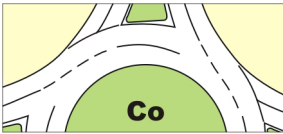
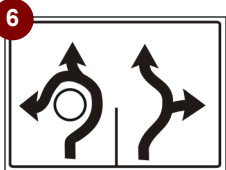
Pavement arrows, often used effectively at non-roundabout intersections to designate lane usage, can also be adapted to roundabouts. A straightforward adaptation of standard usage is the *LT-TR* configuration, with a shared left/through arrow in the inside lane, and a shared through/right arrow in the outside lane. Although this configuration delineates allowed movements in the standard way, a potential perception problem is evident: a motorist could misinterpret the left-turn arrow and turn the wrong way into the circulatory roadway. An adaptation that addresses this potential confusion is the *T-TR* configuration, which removes the left-turn arrow. This configuration may enhance driver understanding at the roundabout entry, but it has at least two potential drawbacks: (1) the roundabout is treated as a two-stage decision process, and the motorist may not be clearly aware of allowable movements once circulating; and (2) if the roundabout is defined as a single intersection, a “left turn” is certainly legal from the inside lane – therefore the omission of the left-turn arrow is potentially contradictory. The first drawback could be ameliorated by the addition of pavement arrows within the circulatory roadway. The second drawback is not as easily overcome. An arrow treatment that could potentially resolve both difficulties is the *fishhook* configuration, which more explicitly delineates circular motion. The author is not aware if this configuration has been applied to any American roundabouts, but it could increase driver understanding.



Another treatment meriting consideration is the application of advance pavement legends. The MUTCD allows the use of pavement legends for guide purposes, but Section 3B.19 indicates that “Symbol messages are preferable to word messages”. The Section gives further guidance: “Word and symbol markings should not exceed three lines of information... The number of different word and symbol markings used should be minimized to provide effective guidance and avoid misunderstanding...” Pavement legends may be most applicable at oddly configured roundabouts, especially for entering lanes from which only one destination is accessible. In general, it would not be advisable to mix pavement arrows with pavement destination legends, because it would typically not be possible to match destinations with the correct arrow.

Conclusions

ITE’s *Traffic Engineering Handbook*⁵ states: “Drivers should not be overloaded with complex events that can render traffic signs and markings ineffective. By separating anticipated points of conflicts and the traffic signs and markings associated with them, the road user’s task will be simplified. Not all road users on a given route are familiar with it; the traffic professional should recognize this and install the traffic control devices where they will provide adequate time for the road user to safely respond and maneuver. This process is referred to as ‘positive guidance.’” (p. 414). With this directive in mind, and based on the investigations reported in this paper, the following conclusions are drawn regarding multi-lane roundabout signing and marking practice:

- *Driver Expectations.* Signing and marking for multi-lane roundabouts should conform to standard driver expectations while reinforcing the unique driving rules of roundabouts. This means adapting the principles of the MUTCD wherever possible.
- *Circulatory Striping.* Solid lines are best used at all locations within the roundabout except in areas where entering/exiting vehicles need to cross, at which dotted striping should be used. Dotted striping is important at exits, but less important at entries. The **Co** striping pattern exemplifies this approach. 
- *Lane-Use Signage.* The “fishhook” family of configurations, of which Sign  is an example, is a reasonable adaptation of the standard MUTCD lane-use control sign, reinforcing the circular nature of the roundabout and identifying the central island.
- *Directional Signage.* Combining the lane-use control and directional guidance functions into a single sign or installation may overwhelm the driver with information, or may omit important information. Advance signage linking destination choice with entry lane choice, coupled with lane-use control signage near the entry, may be a viable strategy. Overhead signage may be advisable in more extreme instances.
- *Advance Pavement Markings.* Advance “fishhook” pavement arrows may be more easily understood than more traditional pavement arrows. Advance pavement legends may also be helpful in certain instances, but the two should never be used in combination. 

Suggestions for Future Research/Action

The primary intent of this paper is to compile both actual and potential strategies for signing and pavement marking at multi-lane roundabouts. Because of the wide array of solutions available, and because uniformity is important in conveying traffic control to the driving public, future research into the effectiveness of these strategies is essential. Potential areas/directions for such research are discussed below.

Field Research

Comparisons among existing multi-lane roundabouts that have implemented strategies described above are not likely to yield much information regarding the relative merits of each strategy, because so many other elements (geometrics, volumes, etc.) can vary from site to site. Comparisons of changes at a given roundabout over time may be more fruitful, as discussed in the following paragraphs.

There are multi-lane roundabouts within the United States at which signing and striping changes have been implemented in response to operational or safety concerns⁶. Useful before/after data may be extractable at these locations, such as accident statistics, capacity improvements, or anecdotal/video evidence of changed driver behavior. Detailed correlations may be difficult to develop, not only because available data are scarce, but also because various types of improvements are often implemented at the same time – making it difficult to isolate the effects

of any individual strategy. (International experience could add robustness to this data set, although the variation of driver behavior from country to country would taint such comparisons.)

Additionally, there are undoubtedly multi-lane roundabouts that are candidates for signing/markings upgrades. These sites would provide excellent opportunities for the kind of detailed before/after studies that could yield more significant correlations between signing/markings strategies and driver behavior.

Field research of the kinds described above can begin to yield understanding of the *effects* of particular strategies, but cannot systematically answer the fundamental questions of driver perception, understanding, and behavior. In cases where roundabouts are modified, familiar drivers will already have established driving habits, and the roundabout modifications may not result in the desired amount of behavioral modification. The following section explores other methods of evaluating the effectiveness of various strategies.

Human Factors Research

Human factors has been defined as “the study of how humans behave physically and psychologically in relation to particular environments, products, or services.”⁷ In regards to the topic of this paper, human factors research would be directed at answering the question: What signing and pavement marking strategies are most readily comprehended (and complied with) by drivers? Although not easy to answer, this question is worth study because it could provide a scientifically defensible foundation for the development of a more uniform set of strategies.

The target population of human factors research would be United States drivers, and the research would need to control for factors such as age, geographical area of residence, and familiarity with roundabouts (single- and/or multi-lane). Three potential study techniques would be:

- *Surveys.* Participants could be shown illustrations or photos of various strategies and queried regarding their understanding of the meaning of each.
- *Simulators.* Participants could drive through a virtual street network including multi-lane roundabouts implementing various strategies, and their behavior recorded. This approach would be expensive to implement, but would be superior to a survey because it would more directly measure driver behavior.
- *Direct Observation.* Analysts could observe operations at roundabouts at which the various strategies have been implemented to get a sense of driver behavior.

Either of the first two applications would need to be carefully designed to avoid biasing the sample through “reactive effects” resulting from user awareness that roundabouts were the subject of the study.

In addition to these potential actions, a thorough literature search should be undertaken regarding the link between signing/markings and driver understanding. Research already conducted may provide important insight into the multi-lane roundabout question.

Driver Education

Although signing and pavement marking can play a strong role in enhancing driver understanding of multi-lane roundabouts, other traditional methods of educating motorists are also needed:

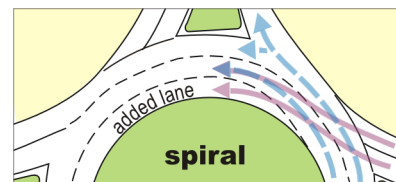
- State driver manuals should be updated to incorporate roundabouts - both single- and multi-lane.
- Public education campaigns should be considered – involving brochures, Web sites, and other print/broadcast media.
- Roundabout seminars can disseminate information to practitioners, public officials, and key decision-makers.

All of these tools can increase public awareness and understanding of multi-lane roundabouts.

Next Steps

It is hoped that future research on this topic will result in consensus on the most effective strategies for signing and marking at multi-lane roundabouts. At the very least, the advantages, drawbacks, and context-appropriateness of the various strategies can be further understood through research. One important outcome of future research should be the incorporation of further, specific guidance into the MUCTD. Uniformity on essential principles is crucial to enhance driver understanding and acceptance.

More complicated roundabout forms should be evaluated, to determine the extent to which the principles discussed in this paper are adaptable to such configurations. In some cases, alternative strategies may result. For example, the *spiral* marking strategy allows for lanes to be added within the circulatory roadway and for circulating motorists to be guided out of certain lanes as necessary. The graphic at right illustrates a potential application of the spiral marking strategy, which permits a “double left” turn from the bottom of the picture while not forcing movements entering from the right side of the picture to exit on the left side.



A final note: regardless of signing and pavement marking, well-designed multi-lane roundabouts tend to be “forgiving” due to slow speeds and driver caution when approaching an unusual traffic control device. Many of the strategies investigated in this paper can be found at successfully operating roundabouts across the United States (and the world). This demonstrates that, although uniformity is desirable, variation has not necessarily proven harmful. One result of future research may be to determine that several strategies are equally viable. Regardless of the results, it is important that the research be conducted, so that the knowledge of this unique form of traffic control can be advanced.

Appendix: Extant Examples

Following is a brief list of (primarily) United States locations at which some of the strategies discussed in this paper have been implemented.

Striping

Ø (No striping). Four roundabouts at two interchanges in Vail, Colorado do not include lane-use striping: two roundabouts at the I-70/Chamonix Road interchange and two at the I-70 Vail Road interchange. (Also, no lane-use signage is used at these intersections.)

io. The intersection of U.S. 101 Northbound Ramps/Milpas Street in Santa Barbara, California incorporates a form of **io** striping using “Botts Dots” extensions.

c. Six roundabouts in Avon, Colorado include **c**-type striping. They are found on Avon Road at the intersections with I-70 Westbound Ramps, I-70 Eastbound Ramps, Beaver Creek Road, Benchmark Road, and U.S. 6.

Co. The roundabout at the intersection of Prairie Star Parkway/Monticello Road in Lenexa, Kansas, incorporates **Co** striping.

CO'. The roundabout at the intersection of Sheridan Road/Rogers Road in Olathe, Kansas, incorporates **CO'** striping.

iCo. The roundabout at the intersection of State Route 60/Coronado Drive/Mandalay Avenue/Poinsettia Avenue in Clearwater Beach, Florida exhibits a form of **iCo** striping in at least one quadrant. This roundabout also uses pavement arrows at some locations within the circulatory roadway.

C_∞. The roundabout at the intersection of 110th Street and Lamar Avenue in Overland Park, KS, uses a form of concentric striping, using solid lines with gaps at entries and exits.

Lane-Use Signage

Variations on Sign **2** can be found at the Avon roundabouts mentioned above. These signs are implemented with white symbols on a blue background.

Versions of Sign **5** can be found at the Olathe, Lenexa and Overland Park roundabouts mentioned above.

The author is aware that a version of Sign **7** exists somewhere in the Pacific Northwest, but is unsure of the exact location.

Combined Directional/Lane-Use Signage

A version of Sign **B** can be found at the Clearwater Beach roundabout mentioned above.

Advance Pavement Markings

The Fishhook configuration is shown in a photograph taken in the Netherlands, contained in an article entitled *Turbo Circuits: A Well-Tried Concept in a New Guise*, by Fortuijn, L. and Carton, P., Province of South Holland. Publication date unknown.

The Clearwater Beach roundabout mentioned above contains pavement arrows in the circulatory roadway approaching many of the exit points.

Notes and References

- ¹ Roundabout definition adapted from *Roundabouts: An Informational Guide*, U.S. Department of Transportation, Federal Highway Administration, Publication No. FHWA-RD-00-067, June 2000. One-way qualifier added.
- ² “At roundabouts, once at the yield line, the entering driver can focus attention entirely on the circulating traffic stream approaching from the left.” *Roundabouts: An Informational Guide*, p. 27. This statement is made in contrast to driver decision-making at signalized intersections.
- ³ *Roundabouts: An Informational Guide*, p.37. The guide identifies areas in the 1992 Uniform Vehicle Code (UVC) where application to roundabouts may cause difficulties, and recommends changes to the legal definition.
- ⁴ *Manual on Uniform Traffic Control Devices*, U.S. Department of Transportation, Federal Highway Administration, Millennium Edition, December 2000.
- ⁵ *Traffic Engineering Handbook*, Fifth Edition, Institute of Transportation Engineers, 1999.
- ⁶ Multi-lane roundabouts with signing/markings modifications of which the author is aware include:
- *State Route 60/Coronado Drive/Mandalay Avenue/Poinsettia Avenue, Clearwater Beach, Florida*. Modifications to this roundabout were made about a year-and-a-half after it opened, including revisions to striping and signing as well as the addition of new pavement arrows. These changes are alluded to in an article entitled *Roundabouts in the United States*, reprinted in *KUTC Newsletter*, University of Kansas Transportation Center, Winter 2002.
 - *Avon Road south of I-70, Avon, Colorado*. Striping and signing were added to several roundabouts on Avon Road (among other modifications) after a period of operation under the initial design, which included no special lane-use signing or markings. This information is based on conversations with Norman Wood, Town Engineer, in August of 2002.
- ⁷ Definition of “human factors” taken from the Web site of *Usability By Design*:
<http://www.usability.uk.com/glossary/human-factors.htm>