SOLUTIONS TO DRIVER ERRORS AT MULTI-LANE ROUNDABOUTS

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1.0 INTRODUCTION AND BACKGROUND

1.1 SAFETY PERFORMANCE OF MULTI-LANE ROUNDABOUTS

It is acknowledged that multi-lane roundabouts result in more collisions between users than single-lane roundabouts. Much of this has to do with the fact that multi-lane roundabouts handle more traffic. The safety performance of multi-lane roundabouts should therefore be compared to signalized intersections that accommodate similar traffic flows.

However recent data in the United States and Canada are showing that collision frequency at multi-lane roundabouts is often higher than expected, and sometimes higher than the prior signalized intersection. This trend is worrisome given that roundabouts are often constructed as a means of increasing safety. The good news is that fatal and injury crashes are almost always reduced with roundabouts, even if property-damage-only crashes are not. The bad news is that often only total crashes are reported by a road agency or picked up on by the public. This is starting to foster the impression that multi-lane roundabouts are not all that safe.

Multi-lane roundabouts have tremendous safety potential. Unlike single-lane roundabouts, which are applicable at lower-volume locations, multi-lane roundabouts can all but eliminate the high-speed angle crashes that injure and kill motorists, cyclists and pedestrians at large signalized intersections. But unless the trend toward higher-than-expected collision frequency is reduced, the future of multi-lane roundabouts may be in doubt.

1.2 CRASH TYPES AT MULTI-LANE ROUNDABOUTS

Several collision types can occur at multi-lane roundabouts that are not possible at single-lane roundabouts. The two most common are the left-turn crash and the “merge” crash. Both tend to be low-speed sideswipe crashes and are shown in Figure 1.1.

Figure 1.1 Common Crash Types at Multi-Lane Roundabouts

The left-turn crash is an exit-circulating crash that can occur after a driver makes a left turn from the right entry lane and collides with a driver making a through movement from the left lane. Typical countermeasures are repeated Lane Designation signs and pavement arrows to get drivers into the correct lane before entering, and to otherwise convey to drivers that a roundabout is a single intersection (albeit with an island in the middle) such that left turns should be made from the left entry lane like at other intersections.

The other problem is an entry-circulating or failure-to-yield crash sometimes referred to as a merge-type crash. This is where a driver in the right lane enters beside traffic circulating in the inside lane and collides with a circulating driver exiting immediately downstream. Here, "merge" is used in quotations to denote that the movement is not a true merge because drivers entering in the right lane are not necessarily merging with traffic in the outside lane. Rather, they are turning in beside someone in the inside lane.

This situation is similar to what can occur at other intersections, as depicted in Figure 1.2. In the case of a roundabout (left illustration) turning in beside circulating traffic is a problem because the circulating driver may be exiting the roundabout immediately downstream. However in the case of a rotary or traffic circle (middle) a weaving section provides some space for the entering driver to change lanes and circulate, and for the circulating driver to change lanes and exit. At a stop- or traffic signal-controlled intersection (right), drivers are free to enter and turn right if there is no traffic in the curb lane of the cross-street (although such a move is not a defensive one, as drivers in the median lane of the cross-street could change lanes).

Figure 1.2 "Merge" Behaviour at Intersections

In April 2016 the Road Commission of Washtenaw County, Michigan, circulated an online survey to gain an understanding of driver perception of roundabouts. The impetus was a multi-lane roundabout, at State Street and Ellsworth Road, that was experiencing a high rate of the merge-type crash. The survey asked a series of multiple-choice questions such as how often do you travel through certain roundabouts, how safe do you feel, whether single-lane or multi-lane roundabouts are easy to understand, etc. Approximately 4,300 residents of the County responded. The main focus of the survey was a question that asked how should you enter a multi-lane roundabout. Of the four responses to choose from, 62% of the respondents selected "wait for an appropriate gap in all circulating traffic" and 34% selected "merge into circulating traffic."

Outside of roundabouts, Yield signs are typically used only at right-turn bypass lanes and freeway on-ramps. In both cases drivers need only to check for a gap in the nearest lane before merging into the traffic stream. The survey indicates that about a third of the driving population thinks of a roundabout as a similar situation, or considers a through movement at a multi-lane roundabout to be, in effect, a right turn. This implies that a roundabout may be viewed by many as a series of T-intersections rather than a single intersection.

1.3 POSSIBLE COUNTERMEASURES FOR THE "MERGE" PROBLEM

A number of countermeasures have been proposed to mitigate the "merge" problem. They can be grouped into geometric treatments that are best incorporated during the geometric design of the roundabout, and non-geometric treatments that may be applied later.

Geometric countermeasures can include:

- A single-lane instead of a multi-lane roundabout.
- A lane configuration such that a multi-lane roundabout has single-lane exits.
- Narrow lane widths and truck accommodation appropriate for the context. This can bring the point of conflict between entering and circulating traffic closer to the entry and result in less space to "merge" into.
- Higher entry angles, so entries are more perpendicular to the circulatory road. This may be achieved through the design of the entry or by having a flatter or more tangential exit, or by a combination of both.

With regard to entry angles, making an entry look less like a merge (i.e. more orthogonal) is still no guarantee that drivers will not try to turn into the nearest lane like they do at stop- or traffic signal-controlled intersections.

Non-geometric countermeasures can include:

- Yield lines pulled back from the inscribed circle of the roundabout so entries appear more perpendicular to the circulatory road.
- Special approach signs.
- Special Yield sign tabs.
- Sightline screening. This may act to limit driver sight to the left and provide less time for a driver to decide to "merge" into the roundabout.
- Regular instead of fish-hook arrows. It is possible the curved stems of fish-hook arrows suggest to the driver that entering can be a "merge" movement.
- Not installing or removing the circulatory road lane lines. This is discussed below.
- More public education.

Lane lines in the circulatory road is a relatively recent addition to roundabouts in the United States and Canada. Most multi-lane roundabouts elsewhere such as the United Kingdom do not have them unless justified by complex lane configurations. Most roundabouts in the United States did not have them prior to about 2001. Normally lane lines are not carried through other intersections except to aid certain movements, such as the line extensions placed for double left turns.

It is possible the absence of circulatory road lane lines may subtly convey the message that a roundabout is a single intersection, and cause drivers to hesitate slightly before entering because they have more difficultly determining which "lane" circulating traffic is using. The City of Fort Worth, Texas, has constructed 10 multi-lane roundabouts without circulatory road lane lines. For about two years they have not generated a safety record that might suggest this was a mistake (1).

2.0 CASE STUDIES

This section presents two roundabout case studies in Ontario in an attempt to gain insight into identifying factors that contribute to driver errors and the “merge” problem.

2.1 ST. JOSEPH BOULEVARD AND JEANNE D’ARC BOULEVARD

This roundabout is located in the east side of the City of Ottawa in a built-up suburban setting. It has two-lane entries on all approaches and yield-controlled right-turn bypass lanes eastbound and westbound on St. Joseph Boulevard. The inscribed circle diameter (ICD) is 48 metres. Average annual daily traffic (AADT) in 2015 was 42,700 vehicles per day (vpd). The roundabout is shown in Figure 2.1.

Source: Google Maps

Figure 2.1 St. Joseph Roundabout

Since opening in late 2010 the roundabout has experienced a high collision frequency. It is by far the busiest roundabout in the City so comparison with other similar roundabouts is not possible. Nevertheless the sheer number of collisions is a concern, especially compared to the previous signalized intersection, even though only 6% resulted in injury. Almost half of the total collisions have been classified as entry-circulating (EC) crashes, and it is suspected many of them are of the “merge” type. The other predominant crash type is exit-circulating, likely the result of drivers entering in the right lane and making a left turn.

Tables 2.1 and 2.2 list total and entry-circulating (EC) crashes by year and approach. Crash frequency is reported per million vehicles entering (MVE).

Table 2.1 Collisions by Year at St. Joseph Blvd. and Jeanne d'Arc Blvd.

Year	AADT (vpd)	Total Crashes	Total Crash Frequency	Total EC Crashes	% EC Crashes
2011	35,210	87	2.47/MVE	36	41%
2012	34,970	68	1.94/MVE	33	49%
2013	NA	63	NA	28	44%
2014	35,840	61	1.70/MVE	23	38%
2015	42,720	55	1.29/MVE	10	18%

Table 2.2 Collisions by Approach at St. Joseph Blvd. and Jeanne d'Arc Blvd.

Approach	% AADT	% EC Crashes
Northbound	25%	41%
Southbound	23%	19%
Eastbound	29%	16%
Westbound	23%	24%

As seen in Table 2.2 traffic volumes are similar among all four approaches. This creates potential for a high number of conflicts between entering and circulating traffic. The northbound approach is generating a significantly higher proportion of EC collisions than the others. It is possible the other approaches have inherent issues that have led to more collisions of other types, such as rear-end crashes on the approach or exit-circulating crashes. However since the focus of this study is merge-type crashes the northbound approach is of most interest.

In November 2011 tabs were installed under the Yield signs reading "Yield to All Lanes", and in October 2013 Yield pavement symbols were painted at the entries. Both are seen in Figure 2.2. It is acknowledged by the City the Yield sign tabs are likely too small to be effective.

Source: City of Ottawa

Figure 2.2 Yield Sign Tabs and Pavement Symbols at St. Joseph Blvd.

In April 2014 it was directed that the circulatory road lane lines not be refreshed. Since then the markings have been allowed to wear out. Table 2.1 shows that the percentage of EC crashes decreased significantly in 2015. Although some other crash types, such as sideswipes in the circulatory road, have gone up overall crash frequency seems to be on the decline since this countermeasure was adopted.

2.2 HOMER WATSON BOULEVARD AND BLOCK LINE ROAD

This roundabout is located within the Region of Waterloo in a low-density suburban setting. It has a three-lane entry southbound on Homer Watson Boulevard and two-lane entries on the other approaches. The ICD is 62 metres. Homer Watson Boulevard is a limited access arterial with high operating speeds. AADT in 2015 was 38,100 vpd. The roundabout is shown in Figure 2.3.

Source: Google Maps

Figure 2.3 Homer Watson Roundabout

Since opening in August 2011 the roundabout has experienced more than double the number of collisions compared to other high-volume roundabouts in the Region. Approximately 11% of the collisions resulted in injury. As with the St. Joseph roundabout a high percentage of collisions are EC (in this case more than half), and it is likely that many of them are of the “merge” type. The other predominant crash type is rear-end, likely the result of high prevailing speeds on the approaches. Safety performance is of special concern at this roundabout since there is a nearby high school that generates considerable pedestrian activity across the north leg during morning and early afternoon peak periods.

Tables 2.3 and 2.4 summarize total and EC crashes by year and by approach.

Table 2.3 Collisions by Year at Homer Watson Blvd. and Block Line Rd.

Year	AADT (vpd)	Total Crashes	Total Crash Frequency	Total EC Crashes	% EC Crashes
2011 partial	38,000	43	NA	29	67%
2012	37,500	53	1.41/MVE	31	58%
2013	35,100	72	2.05/MVE	40	56%
2014	35,600	107	3.01/MVE	57	53%
2015	38,100	110	2.89/MVE	54	49%
2016 partial	40,100	44	NA	24	55%

Table 2.4 Collisions by Approach at Homer Watson Blvd. and Block Line Rd.

Approach	% AADT	% EC Crashes
Northbound	34%	34%
Southbound	36%	43%
Eastbound	17%	15%
Westbound	13%	9%

Due to the way collisions are recorded by police officers on scene it is suspected the actual percentage of EC crashes is higher than reported, as some may have been classified as sideswipe collisions in the circulatory road.

As seen in Table 2.4 traffic volumes are higher on the northbound and southbound approaches, and the three-lane southbound approach is generating a higher proportion of EC collisions than the others (43%). Again since the focus of this study is merge-type crashes the southbound approach is of most interest.

Speed studies have shown that average entry speeds on all approaches are in the range of 26 to 30 km/h. In fact, the Region has observed through video recordings that some of the EC crashes occurred after drivers stopped at the yield line.

Since opening the following countermeasures have been installed:

- September 2011 – Yield sign tabs and 30 km/h advisory speed tabs under the upstream Roundabout Ahead signs.
- October 2011 – increased width for the yield lines, oversized Yield signs with “To Oncoming Traffic” tabs, 50 km/h regulatory speed limit signs upstream of the roundabout on Homer Watson Boulevard, school crossing guard on the north leg.
- November 2011 – “Stop for Pedestrians” signs at the pedestrian crosswalks (replacing the smaller “Yield to Pedestrians” signs).
- May 2012 – “sharks teeth” markings to supplement the yield lines, and conversion of the third entry lane southbound to a right-turn-only lane with corresponding installation of flexi-posts in the circulatory road (as seen in Figure 2.3).
- January 2015 – “To Traffic in All Lanes” tabs under the Yield signs.
- March 2015 – “Caution: Motorists May Exit from Any Lane” warning sign in the central island opposite the northbound and southbound entries.
- April 2016 – “Yield to Both Lanes” sign overhead at the northbound and southbound entries.

Several of the countermeasures are depicted in Figure 2.4. Table 2.3 indicates that none seem to have had a demonstrable effect on safety performance, although it may be too early to draw conclusions about a couple of the more recent additions.

Source: GHD

Figure 2.4 Extra Signs at Homer Watson Blvd.

It should be noted that the circulatory road lane lines have at various times been installed, left to wear out, and reinstalled. Unlike at the St. Joseph roundabout this countermeasure does not seem to have had an observable effect on collisions.

2.3 INDEPENDENT HUMAN FACTORS ASSESSMENT

In 2015 the Region of Waterloo had a Human Factors Assessment of the roundabout undertaken by Intus Road Safety Engineering Inc. (2). The assessment consisted of an analysis of crash data, site visit and road scene analysis, review of video recordings, and human factors analysis.

The following are some of the conclusions reached in the assessment (paraphrased from the Final Report):

- It is unlikely the subject crashes are due to failures at the psychomotor subtask level. Furthermore, since the design, signing and pavement markings for the roundabout conform to good practice and visibility on the approaches is satisfactory, it is unlikely the crashes are due to perceptual subtask failures.
- The failure-to-yield crashes are most likely the result of failures at the cognitive subtask level and are likely the result of motorists applying driving schemas that are not appropriate to the task.
- The approach to a two-lane roundabout has a similar appearance to a dual right turn at a traditional orthogonal intersection. In the instance of an orthogonal intersection, the motorist turning right from the curb lane has learned that there is no requirement to yield to traffic approaching from the left in the median lane.

- Since orthogonal intersections are more prevalent than roundabouts the driving schema for the orthogonal intersection has dominance. Motorists are having difficulty suppressing the strong habitual response to ignore the vehicle in the inner lane when entering ("turning right") at the roundabout.
- A motorist who enters the roundabout on the right/outer lane must yield to vehicles exiting the roundabout at the next downstream exit from the inner lane of the circulating lanes. In all other multi-lane driving environments, vehicles in the lane to the left of a motorist do not have the right-of-way to cross over the right lane and execute a "right turn" at the next downstream "intersection" (latter quotes added).

These conclusions are similar to the findings in the Washtenaw County survey, and suggest that a certain percentage of the driving population considers a through movement at a roundabout to be similar to a right turn. Drivers are then applying behaviour learned making right turns at other intersection types to roundabouts.

The assessment noted that motorists on Homer Watson Boulevard are treated to a roadway environment with little access density and a wide continuous centre median. Compared to motorists on Block Line Road this has led to higher approach speeds (although similar entry speeds at the roundabout), lower driver workload, and possibly a different driver expectation concerning right-of-way at intersections.

It was out of this assessment that the "Yield to Both Lanes" sign in Figure 2.4 was suggested and subsequently installed overhead at the northbound and southbound entries.

2.4 SIMILARITIES BETWEEN THE PROBLEMATIC APPROACHES

The Human Factors Assessment made the case for special consideration of the northbound and southbound entries in light of the different driving environment compared to Block Line Road. Another consideration was a higher proportion of overall traffic. However at the St. Joseph roundabout the most problematic approach is northbound (41% of all EC crashes), even though it handles about the same amount of traffic as the other approaches (25%), so driver expectancy is not likely the same there as on Homer Watson Boulevard.

On Homer Watson Boulevard the closest signalized intersections to the roundabout are 700 metres to the north and 1200 metres to the south. On Jeanne d'Arc Boulevard south of the St. Joseph roundabout the closest signalized intersection is 850 metres away. There is a wide continuous centre median on the northbound approach similar to along Homer Watson Boulevard. Finally, there are downhill approaches northbound at the St. Joseph roundabout and southbound at the Homer Watson roundabout. The approach is relatively flat northbound on Homer Watson Boulevard.

It is possible that a long intersection spacing, wide median and downhill approach, either individually or in combination, can act to reinforce the incorrect schema that drivers entering in the right lane of a multi-lane roundabout do not have to yield to traffic in the inside circulating lane.

3.0 SIGN EFFECTIVENESS TESTING

This section describes comprehension testing undertaken to determine the effectiveness of several signs in addressing the “merge” problem.

3.1 EXPERIMENTAL DESIGN

A comprehension testing procedure was developed based on work undertaken by Hanscom (3,4). The intent was to evaluate awareness that drivers entering a two-lane roundabout need to yield to traffic in both circulating lanes, and in particular that drivers in the right lane need to yield to traffic in the inside circulating lane. The testing consisted of evaluating the following three possible countermeasures:

- An approach sign reading “Yield to Both Lanes” (the overhead sign in Figure 2.4).
- Yield sign tabs reading “Do Not Merge”.
- Yellow box markings in the trapezoidal section of circulatory road between an entry and downstream exit. This corresponds to a treatment sometimes used to indicate that drivers are not to enter and block an intersection.

A series of test slides were created to depict the three countermeasures, plus a case where none of them are employed. In order to develop a complete experimental design the testing also had to show both cases of an approaching driver (left lane or right lane) and all three possible cases of circulating traffic (none, inside lane and outside lane). The corresponding 24 test cases are summarized in Table 3.1.

Table 3.1 Cases for the Sign Effectiveness Testing

Test Case	Approach Lane	Circulating Traffic	Countermeasure
1	Left	None	None
2	Left	Inside	None
3	Left	Outside	None
4	Right	None	None
5	Right	Inside	None
6	Right	Outside	None
7	Left	None	Yield to Both Lanes sign
8	Left	Inside	Yield to Both Lanes sign
9	Left	Outside	Yield to Both Lanes sign
10	Right	None	Yield to Both Lanes sign
11	Right	Inside	Yield to Both Lanes sign
12	Right	Outside	Yield to Both Lanes sign
13	Left	None	Do Not Merge tabs
14	Left	Inside	Do Not Merge tabs
15	Left	Outside	Do Not Merge tabs
16	Right	None	Do Not Merge tabs
17	Right	Inside	Do Not Merge tabs
18	Right	Outside	Do Not Merge tabs
19	Left	None	Yellow box markings
20	Left	Inside	Yellow box markings
21	Left	Outside	Yellow box markings
22	Right	None	Yellow box markings
23	Right	Inside	Yellow box markings
24	Right	Outside	Yellow box markings

Three slides were developed for each test case: 1) an approach to a two-lane roundabout, 2) just upstream of the entry crosswalk, and 3) at the yield line looking left. An example sequence of slides (case 23, in Table 3.1) is shown as Figure 3.1.

Figure 3.1 Example Sequence of Sign Effectiveness Slides

The experiment involved presenting the sequence of slides corresponding to each test case on a screen in front of a number of subjects, and asking them to indicate on a form whether they think it is okay to enter the roundabout (yes or no) and how confident they are in their response (very sure, somewhat sure, or not at all sure). In all cases the correct response was “no” except when there was no circulating traffic.

The testing was carried out within the Region of Waterloo at two seniors residences and at a university. All participants had some familiarity with roundabouts. Two roughly equal-sized groups were tested at each seniors residence: one (of 17 participants in total) was given the 24 test cases in a random order, and the other (of 15 participants in total) was given the 24 test cases in the exact opposite order. This counterbalances the experiment to some extent to account for learning effects. The university students (45 in total) were presented with both random sets of 24 test cases, one after the other, for a total of 48 cases.

Before the testing began the subjects completed a series of multiple-choice questions, similar to the questions in the Washtenaw County survey. For the last question responses to choose from were:

- Wait for an appropriate gap in all circulating traffic.
- Merge into circulating traffic.
- Wait for the roundabout to be clear of all traffic.
- Wait for circulating traffic to stop.

The testing controlled for reading time, and attempted to control for legibility of the signs being tested (letter-height to driver distance ratio) to be representative of actual driving conditions (5). This meant each group of subjects had to be kept to a reasonable size so they could view the screen at an appropriate reading angle and distance.

A session comprising the 24 test cases, plus introductory questions, took about 30 minutes to complete. The session comprising 48 test cases took about 50 minutes to complete. Data were gathered on 77 participants, and in total among all the sessions each test case was responded to 122 times. Subjects were licensed drivers ranging in age from under 20 to over 70 years.

3.2 RESULTS OF TESTING

A summary of all the test results is provided in Table 3.2.

Table 3.2 Summary Results of the Sign Effectiveness Testing

Test Case	Approach Lane	Circulating Traffic	Countermeasure	Correct Response	% Correct		
					Seniors	Students	Total
1	Left	None	None	Yes	100%	92%	94%
2	Left	Inside	None	No	66%	86%	80%
3	Left	Outside	None	No	78%	98%	93%
4	Right	None	None	Yes	78%	97%	92%
5	Right	Inside	None	No	56%	42%	46%
6	Right	Outside	None	No	88%	98%	95%
7	Left	None	Yield to Both Lanes	Yes	94%	98%	97%
8	Left	Inside	Yield to Both Lanes	No	78%	82%	81%
9	Left	Outside	Yield to Both Lanes	No	88%	98%	95%
10	Right	None	Yield to Both Lanes	Yes	97%	90%	92%
11	Right	Inside	Yield to Both Lanes	No	72%	43%	51%
12	Right	Outside	Yield to Both Lanes	No	84%	94%	92%
13	Left	None	Do Not Merge	Yes	81%	96%	92%
14	Left	Inside	Do Not Merge	No	72%	90%	85%
15	Left	Outside	Do Not Merge	No	88%	99%	96%
16	Right	None	Do Not Merge	Yes	75%	96%	90%
17	Right	Inside	Do Not Merge	No	72%	50%	56%
18	Right	Outside	Do Not Merge	No	91%	96%	94%
19	Left	None	Yellow box	Yes	97%	96%	96%
20	Left	Inside	Yellow box	No	81%	83%	83%
21	Left	Outside	Yellow box	No	91%	100%	98%
22	Right	None	Yellow box	Yes	91%	86%	87%
23	Right	Inside	Yellow box	No	50%	37%	40%
24	Right	Outside	Yellow box	No	78%	94%	90%

For the test cases where there is no circulating traffic shown in the third slide, thereby meaning the correct answer is “yes” (it is okay to enter the roundabout), one would expect all participants to answer correctly. Since the percentage is correct responses was not always 100% it is possible not all understood the intent of the experiment.

The test cases of interest are 5, 11, 17 and 23, all having an approaching driver in the right lane and a circulating vehicle in the inside lane as seen in Figure 3.1. Here the percentage of correct responses is lower than for the other cases by a considerable margin. At first glance it appears the countermeasure corresponding to case 17 (the Yield sign tabs reading “Do Not Merge”) is the most effective, followed by the one corresponding to case 11 (the approach sign reading “Yield to Both Lanes”). It is worth noting that neither resulted in a correct response rate close to the other test cases. It is also interesting the yellow box markings (test case 23) produced fewer correct responses than doing nothing (test case 5).

There was some uncertainty as well with cases 2, 8, 14 and 20, corresponding to an approaching driver in the left lane and a circulating vehicle in the inside lane, although not nearly to the same extent as for an approaching driver in the right lane. All other cases had correct response rates of 87% or higher.

A few more observations regarding test cases 5, 11, 17 and 23:

- The seniors scored higher in these cases than the students, even though only 53% of them responded correctly to the preliminary question of how should you enter a multi-lane roundabout (wait for an appropriate gap in all circulating traffic) compared to 93% of the students. Seniors generally scored lower in the other cases.
- There seemed to be little correlation between how comfortable or safe one feels travelling through a roundabout and how one scored in the questions of interest.
- Those that answered correctly were generally less confident of their responses than those that answered incorrectly.

Given the lack of success with the yellow box markings, further analysis concentrated only on determining whether there was any statistical difference in correct responses between the approach sign reading "Yield to Both Lanes" and the Yield sign tabs reading "Do Not Merge" (test cases 11 and 17). They are seen circled in Figure 3.2.

Figure 3.2 Slides Showing the "Yield to Both Lanes" Sign and "Do Not Merge" Tabs

McNemar's Test was used to compare the two countermeasures with each other, and individually with no countermeasure ("None"). This follows from Hanscom (3,4). The test was done by comparing the proportion of subjects who correctly understood the meaning of one treatment (Treatment A) but not the other (Treatment B), and vice-versa. Subjects who understood both A and B correctly, or neither, did not count since the outcome is no distinction between treatments. Having established the proportion of each then a z-test is applied to determine the significance. The results are shown in Table 3.3.

Table 3.3 McNemar's Test Results

Treatment A	Treatment B	2-Tail z-Test Score
None	Yield to Both Lanes sign	0.36
None	Do Not Merge tabs	0.11
Yield to Both Lanes sign	Do Not Merge tabs	0.42

McNemar's Test indicated a statistical difference in correct responses only between "None" and the "Do Not Merge" tabs, and even then only at a 12% level of significance (0.12 being larger than the z-test score of 0.11). Typically a 5% level of significance is used to indicate statistical differences, so the results are not very definitive. The test indicated even less chance the difference between "None" and the "Yield to Both Lanes" sign, or between the "Yield to Both Lanes" sign and the "Do Not Merge" tabs, was significant.

The seniors at one of the residences, and the university students, were asked after the testing was completed and explained which they thought was the most effective message. Most seem to agree on “Yield to Both Lanes” with the accompanying arrows, even though the “Do Not Merge” tabs elicited more correct responses. It is possible the “Yield to Both Lanes” sign contained an effective message, but that the approach sign was not sufficiently noticeable in the testing or that the “Do Not Merge” tab enjoyed a better location. However this could not be determined without further testing.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 RECOMMENDED COUNTERMEASURES FOR THE "MERGE" PROBLEM

Implementing single-lane instead of multi-lane roundabouts, or multi-lane roundabouts such that exits are single-lane, would no doubt be effective in addressing the "merge" problem. However neither may be possible at high-volume locations. Some of the other geometric and non-geometric countermeasures listed earlier may be effective as well.

Anecdotal evidence at 10 roundabouts in Fort Worth, Texas, and recent safety performance at the St. Joseph roundabout in Ottawa, suggests that constructing multi-lane roundabouts without circulatory road lane lines, or allowing the lines to wear out, is a viable countermeasure when the lane configuration is straightforward. In fact, it is recommended that not having lane lines in a roundabout be pursued wherever possible before adding more signs to the traffic information system.

Otherwise more signs may be the only viable engineering countermeasure. The comprehension testing confirmed that drivers have much more difficulty deciding whether to enter a multi-lane roundabout when they are approaching in the right lane and there is circulating traffic in the inside lane. The testing also revealed that, unfortunately, none of the three tested countermeasures greatly improved understanding that at multi-lane roundabouts entering drivers have to yield to all circulating traffic.

Based on the McNemar's Test the "Do Not Merge" tab seems to hold the most promise, although a number of test subjects thought "Yield to Both Lanes" with the accompanying arrows was a more effective message. "Do Not Merge" may have elicited more correct responses because of the location of the message within driver sightlines at the roundabout entry, where the decision to enter is made. It is worth noting the Homer Watson roundabout has "To Traffic in All Lanes" tabs under the Yield signs, and "Yield to Both Lanes" signs overhead at two of the entries, neither of which have proven effective so far. It is possible the reason the "To Traffic in All Lanes" tabs are not effective is because they are not accompanied by arrows on the sign, and the reason the "Yield to Both Lanes" (with arrows) signs are not effective is the overhead location.

Accordingly, it is recommended both the "Do Not Merge" and "Yield to Both Lanes" messages be considered for implementation through the use of Yield sign tabs as illustrated in Figure 4.1. Further experimentation is still advisable due to the limitations of the sign comprehension testing, the outcome of which may be that one tab is preferred over the other. An important consideration will be size such that either message is sufficiently legible to drivers. This may include some experimentation to find the optimal layout for the "To Both Lanes" tab. Another is the need for bilingual messages in certain regions in Canada.

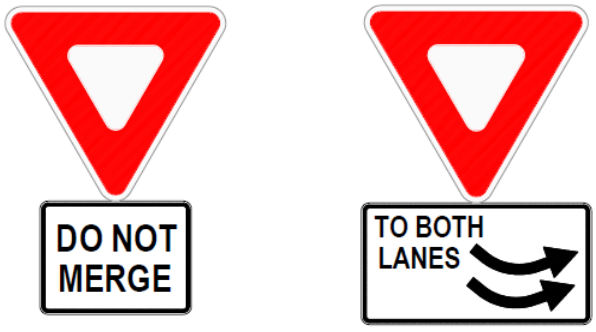

Figure 4.1 Recommended Signing Countermeasures

The most problematic entries at the St. Joseph and Homer Watson roundabouts have a long intersection spacing, wide median and downhill approach. These conditions, either individually or in combination, may act to reinforce the incorrect schema that drivers entering in the right lane do not have to yield to traffic in the inside circulating lane. Therefore on such approaches at roundabouts is it suggested the Yield signs and tabs be accompanied by extra treatments where possible. One suggestion is embedded Light Emitting Diodes (LED) in the sign faces.

4.2 SUGGESTIONS FOR FURTHER STUDY

It was hoped the comprehension testing carried out as part of this study would reveal more definitive results. Obviously it had a number of limitations, and further sign effectiveness testing could help to determine if either the “Do Not Merge” and “Yield to Both Lanes” messages have a statistical effect on test subjects, and if so whether they could be improved upon. Suggestions consist of:

- A larger sample size.
- More sign types.
- More investigation into the effects of sign location.
- The inclusion of different pavement markings, some of which may be more effective than the yellow box markings.
- The use of video clips or a driving simulator instead of static images.

Given the results of the testing, non-geometric engineering countermeasures are likely to only have limited effectiveness in addressing the “merge” problem. Education and enforcement are also needed. Education should include making sure police officers are aware of which driver is at fault when a merge-type crash occurs, and making sure driving instructors are imparting correct information to students.

The Washtenaw County survey, Human Factors Assessment of the Homer Watson roundabout and comprehension testing all confirmed that a significant percentage of the driving population does not completely understand the meaning of a Yield sign in the context of a multi-lane roundabout. They consider a through movement at a roundabout to be equivalent to a right turn, or interpret the Yield sign in the context of a right-turn bypass lane or freeway on-ramp where they need only to check for a gap in the nearest lane before merging in. The public needs to understand that a roundabout is not a series of T-intersections but rather a single intersection, and that entering drivers have to yield to all circulating traffic.

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