The Effect of Additional Lane Length on Roundabout Delay

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ABSTRACT

The purpose of this paper is to provide insight on how the use of an additional lane as an approach affects roundabouts. Currently, there is no United States guideline on how the additional lane lengths affect roundabout operation. Hence, most transportation professionals refer to studies conducted overseas that do not necessarily translate directly to domestic roundabout design and operation. As the number of modern roundabouts in the United States increases, the desire is to provide effective information to professionals on roundabout operation and design for conditions similar to their jurisdiction. Using delay as the measure of effectiveness, a hypothetical four-leg, double-lane roundabout with additional lane design at both entry and exit is analyzed. The additional lane lengths are varied at both entry and exit in order to study the effect of different additional lane lengths on roundabout operation. Similar length variations are applied to an existing roundabout with known data after calibration and validation. Findings from this study are intended to provide transportation professionals quantitative means of improving existing roundabout operational performance and also help design future roundabouts with appropriate additional lane lengths that yield better performance. While the design of an additional lane differs from a flared entry, findings from this study can also be applied to flare lengths if they are designed to operate in a similar fashion as additional lane entry.

Key words: Roundabout, additional lane length, flare length, delay, VISSIM
INTRODUCTION

The modern roundabout has become an increasingly popular form of intersection control in the United States due to its effectiveness in improving safety and reducing traffic congestion. Since the first modern roundabout (in the U.S.) was built in Nevada in 1990, the number has increased drastically, and as of December 2012, more than two thousand have been constructed (1).

As roundabouts have become increasingly popular in the United States, it is very important to establish some means of improving their performance in the near future when vehicle demand nears or exceeds capacity. At signalized intersections, U.S. transportation professionals regularly consider numerous parameters such as green time, cycle length and number of lanes to adjust in order to improve traffic operation. However, there has not been much research performed domestically that addresses how to vary different geometric parameters to improve operations for a roundabout when analysis shows that a nearby development will impact traffic operation. Hence, most transportation professionals refer to studies conducted overseas that do not necessarily translate directly to U.S. roundabout design and operation.

One of the design requirements that needs further exploration is the entry approach. The entry can be designed to increase capacity by either adding a full lane upstream of the roundabout or by widening the approach gradually (flaring) through the entry geometry (2). Most of the studies on roundabout entry design have been looking at the widening effect of the width of the approach lane. However, little attention has been given to the length of the approach over which to widen the lane and its effect on roundabout operation.

The National Cooperative Highway Research Program (NCHRP) Report (2) on roundabout design neither provides recommended lengths nor does it give information on how long the entry lane needs to be widened along the approach. The Federal Highway Administration (FHWA) (3) roundabout guideline, which was superseded by the NCHRP Report suggests a minimum flare length of 80 feet in urban areas and 130 feet in rural areas. It is not clear whether the suggested flare length also applies to additional lane design. The question of what the specific maximum length should be also arises.

In general, the increasing popularity of roundabouts in the U.S. underscores the need for more research on roundabouts in the United States to address issues that traffic engineers face in practice. The means of improving signalized intersections to meet specified demands has been well researched and documented; methods to predict their performances are well established. However, roundabouts lack such research on performance improvement. This research examines the effect of additional lane lengths on a double-lane roundabout operation. Delay was the primary measure of effectiveness (MOE) used in this study. VISSIM micro-simulation software was determined to be an appropriate tool for this study. The study is intended to provide transportation professionals with a means of improving existing roundabout operational performance, and aid during the planning and design stages so that future roundabouts can be built with appropriate additional lane lengths to yield better performance.
LITERATURE REVIEW

Roundabouts when compared to signalized intersections lack research on means of improving their operations due to increased traffic flow. Signalized intersections usually go through several modifications to improve safety and performance from time to time due to new developments or simple increases in traffic flow. Since roundabouts handle traffic flows similar to signalized intersections, it is possible for the v/c ratio to approach or exceed 1.00. Under such conditions, long queues form and delay increases at roundabouts. Such conditions require modifications to improve performance.

Earlier research on roundabout operation was started by the U.K. based Transport and Road Research Laboratory (TRRL) where numerous experiments and observations were performed on existing roundabouts. Kimber (5) incorporated findings from the TRRL studies in the paper “The Capacity of Roundabouts”, where six geometric parameters were identified as having significant effect on capacity. The six key parameters were: entry width, approach half-width, effective flare length, flare sharpness, inscribed circle diameter, and entry radius. Out of the six parameters, the Transportation Research Laboratory (TRL) article Roundabout Design For Capacity and Safety: The U.K. Empirical Methodology (6), found three parameters, entry width, approach width, and flare length to be the most relevant with regard to capacity.

The approach width is the width of the traveled-way in advance of any entry flare. The typical approach width in the United States is 12 feet. The entry width is the width of the traveled-way at the point of entry. The FHWA (3) identifies the entry width as the “largest determinant of a roundabout’s capacity”. The entry can be designed to increase capacity by either adding a full lane upstream of the roundabout or by widening the approach gradually (flaring) through the entry geometry (2). The NCHRP recommends an entry width of 24 to 30 feet for two-lane entry and 36 to 45 feet for three-lane entry. It does not however, specify how far back the additional lane or flaring should begin. In Europe, where flaring design is more common than an additional lane design, the U.K. Department of Transport Design Manual (6) recommends flare lengths of about 82 feet (25 meters) for widening to effectively increase capacity. Flare lengths greater than about 328 feet (100 meters) results in higher speed which undermines the main purpose of modern roundabout configuration. The configuration of a modern roundabout reduces speeds to improve safety and enhance traffic flow. Therefore, when increasingly long lane lengths are used, the safety benefit of roundabouts may be forfeited. The 82 foot recommendation by the U.K. Department of Transport Design Manual (6) has not been tested in the U.S., but since no data on the additional lane or flare length has been provided some state agencies follow the overseas guidelines. Interim requirements and guidance on roundabouts by the New York Department of Transportation (7) suggest a flare length of 41 feet (12.5 meters) to 328 feet (100 meters) for urban areas and 66 feet (20 meters) to 325 feet (100 meters) for rural areas.

The FHWA (3) used a model developed by Wu (8) in determining the capacity of a roundabout whereby short length widening at the approach is considered. Wu (8) estimated the capacity of an unsignalized crossroad and T-junction intersections by taking into account the length of the turn lanes. Wu (9) later analyzed this model at a roundabout intersection and introduced an enhancement/correction factor for determining the capacity of a double lane entry at a roundabout. Wu (9) points out that the exit cannot be less than the entry capacity if the full potential of the entry is to be utilized. Wu (9) was able to identify the effect of entry length but the effect of the additional lane length at the exit was not mentioned. Wu also assumes that the
capacities of both lanes are identical and the traffic flows in both lanes at the entry are equally
distributed. However, studies conducted on some double lane roundabouts in the U.S. by the
NCHRP 572 (10) shows that the right lane is utilized more frequently than the left lane and the
right lane is usually considered to be the critical lane. For instance, data obtained from Kittelson &
Associates on one of the double lane roundabouts in Brattleboro, Vermont showed that the right
lanes had about 70% of the entry total flow (10), so capacity in the WU model could be over
estimated. This research tries to examine the effect of the flare/additional lane length on
roundabout operation using typical U.S. driving behavior where the right lane is considered the
critical lane and is utilized more frequently than the left lane.

In order to mimic typical U.S. driving behavior, the microsimulation modeling software
VISSIM is used for analysis purposes. VISSIM is a microsimulation model from Germany where
vehicles are modeled using parameters such as driver behavior, vehicle speeds, and vehicle type
(11). VISSIM has the ability to control gaps and headways on a lane-by-lane basis to more
accurately replicate these types of operations present at roundabouts. Numerous studies have used
VISSIM microsimulations to examine roundabout performance due to its unique ability to mimic
real world traffic operations. Trueblood and Dale (12) considered VISSIM to be a very effective
micro simulation software package for roundabout performance analysis. Because of this,
Trueblood and Dale used VISSIM to model existing roundabouts in the state of Missouri, and this
micro-simulation software package was found to provide accurate results in roundabout
performance analysis. Bared and Edara (13) used VISSIM to model roundabouts for various
ranges of circulating and entry traffic volumes. They found that simulation results from VISSIM
were significantly lower than from the SIDRA analytical and RODEL empirical models and were
similar to field measured data used in NCHRP 572 (10).

METHODOLOGY

This section details how the research effort was conducted with respect to modeling the impact of
additional lane length on roundabout operation. In full additional lane design as shown in Figure 1,
a full lane is added on the right side at the entry and a taper with sufficient length is provided to
enable vehicles to diverge into the additional lane. In flare design, a single lane is gradually
widened into two lanes at the entry. Both design cases result in the widening of the entry to
increase the rate at which vehicles enter the roundabout at a given time. This means that in terms
of operation, a single traffic stream separates for both the additional and flare design into two
streams. The additional lane design was used in this research to examine the effect of on a
roundabout with findings applied to flared entry as well.

A hypothetical double lane roundabout with four legs was first examined in VISSIM under
varying additional lane lengths at the entry and exit. For comparison purposes, similar variations
were then tested on an existing double lane roundabout with data from NCHRP 572 (10). In order
to layout the roundabout correctly in VISSIM, guidelines by Trueblood and Dale (12), and Li, et al
(14) were used. From both studies, the techniques of placing the reduced areas at the conflicting
sections were adapted. The reduced speed areas were kept at a length of 17 feet and placed at 8
feet from the yield line on each lane of the approach. Reduced speed areas were also placed in the
circulatory roadway at a length of 17 feet right before the entry areas. Travel speeds of 20 miles
per hour were used in the reduced speed zones as recommended by Trueblood and Dale (12).
Since VISSIM is a stochastic model whose results vary depending on the random seed number
used, the model was run multiple times and the average results were used. For this study, five
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Simulations were made for each scenario using multiple-run simulations with a running time of one hour.

FIGURE 1 Flaring and Additional Lane Design (Source: FHWA Roundabout Guide)

For the hypothetical model, VISSIM default values for headway were used. Data collection points used for capturing delay data in VISSIM for the hypothetical model were placed in at similar locations specified in the NCHRP 572 (10) so as to be able to compare results. The travel time sections in VISSIM were placed at 250 feet from the yield line on the approach and the exit where
the vehicles exit the circulatory roadway. This allowed the software to compute the delay in travel
250 feet from the yield line on the approach to the point where a vehicle exits the circulatory
roadway. The existing roundabout used for comparison was set up in VISSIM with data collection
points placed at similar locations as those used in the NCHRP 572 (10). The model was then
calibrated using field data from NCHRP 572 (10). The calibration effort begun with the VISSIM
default values and gradually adjusting the reduced speed, driving behavior, yield bar placement,
headway, and minimum gaps until the measured field travel time data closely matched the
VISSIM data. The field travel time data was the same data used in the NCHRP 572 (10) that was
obtained from Kittelson Associates.

HYPOTHETICAL DOUBLE LANE ROUNDABOUT

The roundabout (Figure 2) used in this study was designed in AutoCAD with a focus on the six
important parameters given by TRL. The design was based on the guidelines in the NCHRP (2).
The roundabout had two circulatory lanes and four legs with single lanes that diverged into two
lanes at the entry and merged into one at the exit. An inscribed circle of 180 feet was used for this
study. The model had the four approaches aligned at 90 degrees. The AutoCAD layout was
subsequently uploaded into VISSIM.

FIGURE 2 Hypothetical Roundabout Design
For the purpose of this analysis, no specific volume was assigned on lane basis. Vehicles were allowed to freely choose lanes but the links and diving behavior were configured such that the right lanes would be used more frequently (about seventy percent usage was observed from simulation). This allowed the roundabout model to operate with driving behavior similar to real life driving behavior were vehicles are free to change lanes when prevailing conditions are not favorable. A quarter of the traffic made right and left turns and one half proceeded straight through past the roundabout. These turns were made by freely choosing either the left or right lanes depending on downstream conditions but the right lane was used most of time during less delays and short queues. A degree of saturation less than 0.80 was targeted based on the following assumptions:

- North-south movements were on the major road with the same volume of 800 vehicles per hour in each direction
- East-west movements were on the minor road with the same volume of 350 vehicles per hour in each direction
- The right lane was assumed to be the critical lane in both movements
- Fifteen percent of all demand volumes consisted of heavy vehicles

The v/c ratio for the north and southbound leg critical lane was 0.78 and 0.41 for the east and westbound leg critical lane was 0.41 using the analytical method presented in the HCM.

Starting with additional lane length of zero (single lane entry and exit), the roundabout operational performance was analyzed in VISSIM for five simulation runs. The delay data captured was the average from the five simulation runs. Table 1 shows the different scenarios used for the hypothetical model analysis. Two scenarios were analyzed:

Scenario 1: Only the entry additional lane length was varied while the exit additional lane length was kept at zero (single exit).
Scenario 2: Both entry and exit additional lane length were varied.

Under Scenario 1, three variations were considered:

1. Additional lane lengths at the entry at all four legs are varied. This scenario was represented by HA in this study, where H represents the hypothetical model and A represents all legs.
2. An additional lane at the entry with the maximum volume (south leg) is varied. This scenario was represented by HS, where H represents the hypothetical model and S represents south leg.
3. An additional lane at the entry with the least volume (west leg) is varied. This scenario was represented by HW, where H represents the hypothetical model and W represents leg.

Under Scenario 2, three variations were considered:

1. Additional lane lengths at the entry and exit at all four legs are varied at the same time. This scenario was represented by HAX in this study, where H represents the hypothetical model, A represents all legs and X represents exit.
2. An additional lane at the entry and exit with the maximum volume (south leg) is varied at the same time. This scenario was represented by HSX, where H represents the hypothetical model, S represents south leg and X represents exit.
3. Only one additional lane at the entry and exit with the least volume (west leg) is varied at the same time. This scenario was represented by HWX, where H represents the hypothetical model, W represents west leg and X represents exit.
The additional lane lengths that were analyzed in VISSIM for both scenarios included: 0 feet, 150 feet, 250 feet, 350 feet, 450 feet and 550 feet. The VISSIM lane closure feature was utilized to make the zero foot length possible. Reducing the exit and entry lanes on a double lane roundabout to single lanes is not practical; it was done in this study only to illustrate the extent of the delay effect up to zero feet.

**EXISTING DOUBLE LANE ROUNDBOUD**

An existing roundabout was analyzed in a similar manner as the hypothetical model. The roundabout chosen for this analysis was the Brattleboro roundabout in Vermont. This is one of the roundabouts that the NCHRP 572 \(^{10}\) collected data on to study the roundabout operations in the United States. The data from the NCHRP 572 \(^{10}\) study was used to calibrate and validate the model in VISSIM. The Brattleboro roundabout has similar configuration to the hypothetical model used in this study. It is a double lane roundabout with four legs aligned at 90 degrees. Its inscribed circle diameter is 176 feet and all legs have additional lane lengths greater than 100 feet. Figure 3 which is the latest drawing of the roundabout obtained from Vermont Transportation Agency shows the different additional lane lengths on the approach. The south, east and north legs have exceptionally long taper lengths and these lengths were included in the model set up. The figure also shows new pavement markings where three lanes have been proposed for the northbound entry. This study used the exiting configuration (two lane entries) at the time the field data was collected for the NCHRP 572 \(^{10}\).

**FIGURE 3 Brattleboro Roundabout Design (Source: Vermont Transportation Agency)**
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The field data collection determined that the volumes for east, west, south and northbound legs were 832 veh/hr, 441 veh/hr, 515 veh/hr and 1051 veh/hr, respectively. Using the HCM analysis, the v/c ratio for the critical lanes (right lanes) for the east, west, south and northbound traffic was found to be 0.96, 0.58, 0.62 and 1.41, respectively. The field data used in the NCHRP 572 (10) was missing delay records for the southbound traffic so the travel time data was used to validate this VISSIM model. Using the t-test, a two tail p-value of 0.764 was calculated, indicating no statistically significant difference between the VISSIM and field travel time data. For calibration, the headway, reduced speed area, driving behavior and link arrangement were adjusted until the VISSIM travel time was close to the field data. Figure 4 shows a comparison of the field data with the result of the final VISSIM trial that gave an acceptable error. Individual movements are labeled showing the direction of travel; for example, W-S indicates a movement entering from the west leg and exiting to south leg exit.

![FIGURE 4 Field and VISSIM Travel Time Comparison](image)

After the model was validated, various lane lengths were analyzed following the same procedure as described earlier for the hypothetical model (see table 1). The additional lane length was varied for the same two scenarios as for the hypothetical model after the model was validated. Only the additional lane lengths were varied; all parameters remained the same. For each scenario in the existing model, the letter “E” was used, differentiating these scenarios from the hypothetical model which used “H”. Also, for the variation 3 of the existing model, the volume from the north leg was as it represented the leg with the lowest entering volume. As an example, where additional lane lengths at the entry are varied at all four legs, this scenario was represented by EA in this study, where E represents the existing model and A represents all legs.

Since the existing model had varying additional lane lengths of 150 to 180 feet, the following lengths were analyzed for both scenarios: 0 feet, 50 feet, 100 feet and the existing lengths (see Figure 3). Also, 100 feet, 200 feet, 300 feet and 400 feet were added to the exiting additional lane lengths and analyzed in VISSIM to study the effect of longer lengths on roundabout operation. The VISSIM lane closure feature was utilized to make the zero foot length possible.
TABLE 1 Model Scenarios

<table>
<thead>
<tr>
<th>Location</th>
<th>Additional Lane</th>
<th>Hypothetical Model Scenario 1</th>
<th>Hypothetical Model Scenario 2</th>
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<tbody>
<tr>
<td></td>
<td>East</td>
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<td>South</td>
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<tr>
<td>Variation 1</td>
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<td>X</td>
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<tr>
<td>Variation 2</td>
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<td>Variation 3</td>
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<table>
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<th>Location</th>
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<th>Existing Model Scenario 2</th>
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<td></td>
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<tr>
<td>Variation 3</td>
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RESULTS AND DISCUSSION

The delay and speed data for the hypothetical model is shown in Figure 5. The delay data reported is the difference between the measured travel time and free flow travel time from 250 feet approaching the yield line to the exit line on the circulatory roadway. Figure 5 also shows the average speed between these points. Data from the hypothetical model shows that the highest delay point value was when the model had a single lane (zero additional lane length) for all scenarios. There was no significant difference between scenario 1 and 2. The delay data was slightly higher for scenario 2 (when the additional lane length at the entry and exit were varied at the same time). Increasing the length up to approximately 150 feet was effective in reducing delay, but beyond that point there was no significant decrease. In general, an increase in lane length resulted in an increase in vehicle speed. The most effective length was between 50 feet and 150 feet.

The analysis of the different variations showed that increasing the length on all four legs at the same time was more effective than just increasing the length on one leg. Increasing the length on the leg with the least volume slightly increased delay at the intersection. As the speed data shows, increasing the lengths caused the speed to increase at the entries; this increases the time at which vehicles reach the circulatory roadway. When more vehicles reach the circulatory roadway within a short period of time the conflicting flow increases and reduces the likelihood of finding an acceptable gap. It is for this reason that the delay increases even though speed will be increasing. Increasing the lengths on just one leg reduced the delay on just that entry, but resulted in more vehicles in the circulatory roadway and increased the conflicting flow for other entries. Increasing the length on the entry with the least volume (minor road) increased the conflicting flow and caused delay on the major road. The delay on the minor road which had minimum effect on the intersection was decreased but the delay on the major road increased. Increasing the length on the entry with the highest volume was more effective than increasing the length on the entry.
with the lowest volume. This was because the delay on the major road, which affects the entire
intersection’s delay the most, was reduced. Increasing the length on just one entry (either highest
or lowest volume) was not as effective as increasing all four legs at the same time. As increasing
the length on all four legs reduced the delay on each approach, thus reducing the delay for the
entire intersection.

Wu (9) suggested balancing the exit and entry capacities in order for the potential of
widened entry to be achieved. By balancing the capacities, Wu (9) suggested that bottleneck
effects at the exit can be avoided. From this data, the double lane exit did not affect the delay at
the intersection. The difference was more noticeable within short intervals of zero to 150 feet;
beyond 150 feet, increasing the exit length did not result in any significant change in the delay.
This could be due to the fact that low volumes (or v/c ratios) were considered. It is also possible
that the conflict at the exit was minimal because that the roundabout configuration was carefully
laid out per NCHRP (2) guidelines.

The same variations were applied to the existing roundabout in Brattleboro, Vermont.
Observations during site visits (Spring 2013) to this roundabout determined that some adjustments
to improve its operation during peak hours were needed. During off peak hours, the roundabout
operates exceptionally well on all approaches. During peak hours, the south approach sees long
queues with delays up to about 23 seconds from approximately 250 feet upstream from the yield
line. The high traffic in this direction is due to the increased development of restaurants, offices
and other businesses south of this roundabout. Under free flow conditions, the travel time from
approximately 250 feet upstream to the yield line was measured to be about 7 seconds (but during
peak hours, this short interval takes about 30 seconds of travel time). During the peak hour, the
east, west and north legs that operate exceptional well during off peak hours sees some increase in
delay as well.

In order to evaluate the operations at this roundabout, the length variation applied to the
hypothetical model was also applied to the Brattleboro roundabout model in VISSIM after
calibration and validation. The results in Figure 6 conform to the findings from the hypothetical
model. On the east, west, north and south legs of this roundabout, about 180, 160, 150 and 180
feet of respective lane length exist at both entry and exit (Figure 3). The additional lane lengths
were decreased so that all lengths were zero (single lane), 50 and 100 feet using the above stated
scenarios. Shorter lengths within 150 feet on all legs resulted in the most significant decrease in
delay. Increasing the existing length by 100 foot increments at all legs at the same time resulted in
the less change in delay. Zero foot lengths resulted in the highest delay and delay decreased with
increasing lengths up to the existing lengths. As noticed in the hypothetical model, adjusting just
one leg was not as effective as adjusting all legs at the same time. Adjusting just the leg with the
least volume was the least effective means of improving delay. There was no significant difference
in varying the length on the exit lane; the difference was more noticeable within short intervals of
zero to 150 feet but beyond 150 feet, increasing the exit length did not result any significant
change in the delay.
FIGURE 5 Delay & Speed Data for Hypothetical Model
FIGURE 6 Delay & Speed Data for Existing Model
CONCLUSION AND RECOMMENDATIONS

The findings from this study are based on double-lane roundabouts with varying approach geometries and additional lane configurations. The delay values reported in this study were measured from 250 feet from the yield line on the approach and the exit where the vehicles exit the circulatory roadway. Delays upstream before the 250 foot line and beyond the exit line were not recorded. Delays beyond these lines could add to the magnitude of the data reported in this study. Understanding how delay varies within this short interval under the above stated conditions is a better representation of roundabout operation as it was used in the NCHRP 572 (10).

Analyses of both the hypothetical and existing roundabout models indicated that very long additional lane lengths were not effective in reducing delay at roundabouts. Shorter lengths of up to 150 feet determined to be were the most effective. This finding corroborates with results from the U.K. Department of Transport Design Manual (6) which recommended shorter flare lengths of about 82 feet to effectively increase capacity. The manual points out that longer flare lengths result in higher speed. The findings from this study can also be applied to flare designs. Where flaring is used, additional analysis is needed if the flaring does not result in two entry lanes. At entries where two full lanes are used, longer lengths will result in the same effects, namely increased speed and less significant change in delay.

In all cases, delay decreased with increasing lengths, but was most effective with shorter lengths between 50 and 150 feet at both the entry and exit. Varying the lengths was more effective if applied to all legs. In the situation where only one leg can be adjusted, the leg with the most volume should be adjusted and length variation should be within the 50 to 150 foot range. If lengths of 150 feet exist, other modification techniques need be applied as longer lengths will be ineffective in reducing delay. Increasing the additional lane lengths allowed vehicles to use the extra space to reach the roundabout at a faster time thus increasing the speed. But when more vehicles enter the roundabout, the conflicting flow increases and, if there are still sufficient gaps in circulating traffic, more entering vehicles are able to enter at a faster rate, reducing delay. It is important to have enough capacity in the circulatory roadway to receive the entering traffic. The NCHRP (2) addresses design procedure that balances entry, circulatory and exit flow through lane numbers and arrangements. The shorter lengths help regulate the rate of entry at a slow but constant rate than the longer lengths which can result in an instantaneous increase in circulatory roadway flow with less capacity to handle the flow.

The findings from this will help transportation professionals in dealing with roundabout design and operations. This study confirms that additional lane length can be varied in a manner that effectively reduces delay without wasting money on unnecessary lane construction. This study can also be used during the planning and design stage of a new roundabout in order to determine the appropriate additional lane length without expanding resources on the design and construction of unnecessarily long lengths. Additional analysis is needed to determine the effect of different lengths on safety since this study has shown that increasing the lengths increase speed at the roundabout. The main goal for modifying the old configuration of roundabouts was to reduce speed and thereby increase safety. If increasing the lengths results in increased speed, this could undermine the operational benefits of a modern roundabout.
REFERENCES


