Evaluating the Impact of Length Variation on Double-Lane Roundabout with an Additional Lane Design

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ABSTRACT

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. In case of a roundabout, what modification measures can be applied to improve performance? The roundabout entry has been found to have the most significant effect on operation, and this paper evaluates several modification measures that can be applied to the entry of a roundabout to improve operation. In this research, a hypothetical four-leg, double-lane roundabout with additional lane design at the entry is analyzed. The additional lane lengths are varied at the entry 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. Results indicate that shorter lengths are more effective in reducing delay and improving performance. 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 FHWA (1) 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. Additional lane at a double-lane roundabout entry provides additional storage space for entering vehicles. Depending on existing conditions and design constraints, a double-lane roundabout entry can have two infinitely long entry lanes or a one lane approach that widens at the entry to form two entry lanes. In some cases, the roads that connect a double lane roundabout may be single lane therefore the additional lane with taper design is used to connect the roads. When demand exceeds capacity at roundabouts with additional lane designs, does extending the length improve performance?

This research attempts to answer questions associated with widening and length associated with the roundabout approach. The major objective of this study is to investigate how the lengths affect vehicle delay. Earlier research on roundabout operation was conducted by the United Kingdom–based Transport and Road Research Laboratory (TRRL), where numerous experiments and observations were performed on existing roundabouts. Kimber incorporated findings from the TRRL studies and identified six geometric parameters as having a significant effect on capacity: entry width, approach half-width, effective flare length, flare sharpness, inscribed circle diameter, and entry radius. Out of the six parameters, entry width, approach width, and flare length were determined to be the most relevant with regard to capacity (4, 5).

As the entry has also been identified by the FHWA as the largest determinant of a roundabout’s capacity, this study uses microsimulation to examine how different lengths affect operation at a roundabout with additional lane length design. The microsimulation software used in this study is VISSIM. VISSIM is a microsimulation model from Germany where vehicles are modeled using parameters such as driver behavior, vehicle speeds, and vehicle type (6). 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 (7) considered VISSIM to be a very effective microsimulation 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 microsimulation software package was found to provide accurate results in roundabout performance analysis. Bared and Edara (8) 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 (3).

Delay was the primary measure of effectiveness (MOE) used in these roundabout performance analyses. According to the NCHRP Report, delay is a standard parameter used to measure the performance of an intersection. Delay was also used in the 2010 Highway Capacity Manual (HCM) in determining level of service for roundabouts (9). The delay measured in this study is the delay encountered within 250 feet from the yield line.
METHODOLOGY
This section details how the research effort was conducted with respect to modeling the impact of additional lane length on roundabout operation. A hypothetical double lane roundabout with four legs was first examined in VISSIM under varying additional lane lengths at the entry. For comparison purposes, similar variations were then tested on an existing double lane roundabout with data from NCHRP 572 (3). In order to layout the roundabout correctly in VISSIM, guidelines by Trueblood and Dale (7), and Li, et al (10) 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 (7). 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 simulations were made for each scenario using multiple-run simulations with a running time of one hour.

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 (3) 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 (3). The model was then calibrated using field data from NCHRP 572 (3). The calibration effort began with the VISSIM default values with gradual adjustments in 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 (3) that was obtained from Kittelson Associates.

HYPOTHETICAL DOUBLE LANE ROUNDBOOTH
The roundabout (Figure 1) used in this study was designed in AutoCAD with a focus on the six important parameters given by TRRL (4). 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.
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 driving 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 best replicate 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. This allowed turns to be 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. Starting with an additional lane length of 100 feet, the roundabout operational performance was analyzed in VISSIM for traffic volumes of 500, 600, 700, 800, 900, 1000 1100, 1200, 1300, 1400, and 1500 vehicles per hour on each approach and the output data uploaded unto a Microsoft Excel spreadsheet. The process was repeated in 50 feet long increments until 600 feet additional lane length was reached.

The 2010 highway capacity manual’s methodology for determining the capacity, delay and v/c ratio for roundabout was used in this study to approximate when the model would reach capacity. Assuming a time period of T = 1 (since the analysis was on hourly basis), the capacity for
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each approach was determined (Table 1). Each approach was found to reach capacity at approximately 1000 vehicles per hour volume, with the v/c = 1.

<table>
<thead>
<tr>
<th>Volume (vehicles per hour)</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry Volume, vehicles per hour (per lane)</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>Conflicting Flow, (vehicles per hour)</td>
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<td>600</td>
<td>700</td>
<td>800</td>
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<td>1000</td>
</tr>
<tr>
<td>Critical Lane Capacity, (vehicles per hour)</td>
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<td>717</td>
<td>655</td>
<td>599</td>
<td>547</td>
<td>500</td>
</tr>
<tr>
<td>v/c</td>
<td>0.32</td>
<td>0.42</td>
<td>0.53</td>
<td>0.67</td>
<td>0.82</td>
<td>1</td>
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<td>Delay, (sec/veh)</td>
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<td>8.6</td>
<td>11.8</td>
<td>17.9</td>
<td>34.6</td>
<td>120.9</td>
</tr>
</tbody>
</table>

Table 1. HCM Capacity Analysis

EXISTING DOUBLE-LANE ROUNDBOUD

For analysis purposes, 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, since it had a physical configuration comparable to the hypothetical model used in this study and was one of the roundabouts included in the NCHRP 572 study. The data from the NCHRP 572 study were used to calibrate and validate the hypothetical model in VISSIM. The Brattleboro roundabout was a double-lane roundabout with four legs aligned at 90 degrees. Its inscribed circle diameter was 176 feet, and all legs had additional lane lengths greater than 100 feet. Figure 2, obtained from the Vermont Transportation Agency, shows the different additional lane lengths on each approach. The south, east, and north legs have exceptionally long taper lengths, and these lengths were included in the model. The figure also shows new pavement markings where a three-lane alternative was being considered for the northbound entry. This research study used the existing configuration of a two-lane entry, which represented the configuration when field data were collected for NCHRP 572.
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 2). 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. The field data collection determined that the volumes for the eastbound, westbound, southbound, and northbound legs were 832 vehicles/hour, 441 vehicles/hour, 515 vehicles/hour, and 1051 vehicles/hour, respectively. Using the HCM analysis, the v/c ratio for each critical lane (right lane) was found to be 0.96, 0.58, 0.62, and 1.41, respectively. The field data used in NCHRP 572 did not include delay records for southbound traffic, so travel time data were used to validate this VISSIM model. For calibration, the headway, reduced-speed
area, driving behavior, and link arrangement were adjusted until the VISSIM travel time mirrored the field data.

**RESULTS AND DISCUSSION**

Figure 3 shows a plot of the average delays versus the additional lane lengths for the hypothetical model generated from the VISSIM simulation. The plot shows that in general, an increase in lane length resulted in an increase in vehicle speed, and the most effective length was between 100 feet and 200 feet. Within the same 100 feet and 200 feet interval Approaches with higher degree of saturation showed the more significant change in delay than approaches with lower degree of saturation.

![Figure 3. Plot of Average Delay versus Additional Lane Length](image)

There are three specific observations that deserve further examination on how the additional lane lengths impact roundabout delay. Table 2 shows the delay changes associated with the specific length changes. The first observation involves the occurrences associated with the 500 vehicles per hour volume. There was a significant decrease in delay from 100 to 200 feet length, while delays associated with distances beyond 200 feet remain fairly constant.
Table 2. Delay Percent Change

With the 800 vehicles per hour volume, delay decreases with increasing lane length. Further segmentation indicates a significant decrease in delay for lengths from 100 to 200 feet with less delay reduction beyond 200 feet. With the 1000 vehicles per hour volume, a similar overall trend occurs with decreasing delays as the length increased. There was a significant reduction in delay from 150 feet to 200 feet. There is also a larger reduction in delay from 200 feet to 600 ft for 1000 vehicle per hour than the 800 vehicle per hour curve. As a reminder, 1000 vehicles per hour is the estimated capacity, so the extra length seems to alleviate delay with a somewhat greater impact at capacity.

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 operated exceptionally well on all approaches. During peak hours, the northbound approach exhibited long queues with delays up to about 23 seconds from approximately 250 feet upstream of the yield line. The high traffic in this direction was 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 took about 30 seconds of travel time. During the peak hour, the east, west, and north legs that operated exceptionally well during off-peak hours also experienced an increase in delay.

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 4 conform to the findings from the hypothetical model. Shorter lengths within 100 feet on all legs resulted in the most significant decrease in delay. Increasing the existing length by 100-foot increments at all legs simultaneously resulted in less change in delay. Zero-foot lengths resulted in the highest delay, and delay decreased as increasing lengths approached the existing lengths.
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 (3).

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 (5) 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; less significant change in delay.

Figure 4. Delay data for existing model.
The VISSIM data showed varying capacity for different lengths but they were still around 1000 vehicles per hour. For shorter lengths (100 & 150 feet), the capacity was around 900 veh/ hr. Beyond this length, the flow did not have significant effect on the delay. For all the other lengths, capacity was around 1100 vehicles per hour beyond which the delay pretty much stayed the same. This is evident in the average speed versus flow plot, where the speed levels out at 900 vehicles per hour for shorter lengths and 1100 for longer lengths.

From an operations standpoint, shorter additional lane lengths between 50 and 150 feet at both the entry and exit were most effective. While adjusting the lane length of all legs was determined to be more beneficial than only adjusting one leg, at a location where only one leg can be modified, 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 already exist, other modification techniques need to be applied, as longer lengths will be ineffective in reducing delay. Increasing the lane length allowed vehicles to reach the circulatory roadway faster, but with more vehicles entering the roundabout, the likelihood of conflicting flow increased as well. NCHRP identifies design procedures that balance entry, circulatory, and exit flow through lane numbers and arrangements. Shorter lengths help regulate the rate of entry at a slow but constant rate, but longer lengths can result in an instantaneous increase in circulatory roadway flow with less capacity to handle the flow.
REFERENCES


5. U.K. Department of Transport (2007). Design Manual for Roads and Bridges, Volume 6, Section 2, Part 3


