THE STUDY OF THE OPERATIONAL CHARACTERISTICS AT A HEAVILY CONGESTED ROUNDABOUT

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ABSTRACT

Field data were collected at a heavily congested roundabout in Wisconsin to determine its operational characteristics and compare them to the state of the practice in the US. The left and right lanes were queued for about 90% and 25% of the five hour data collection period. Critical gaps were estimated using the maximum likelihood method assuming a log-normal distribution. The results for all vehicles are similar to the lower bounds reported in past research, although with considerably lower standard deviations. When adjacent exiting vehicles' impact is considered, the estimated average critical gaps decrease significantly. The average critical gaps for trucks were found to be considerably greater than for cars. The average follow-up headways were found identical to the previously reported values. Data from this location does not support the notion that the dominant lane would have a lower follow-up headway than the sub-dominant lane. The average follow-up headway decreases considerably when exiting vehicles' impact is considered. One-minute entering and circulating volumes were compared to the proposed capacity model in the new HCM 2010 and the UK model. Although, numerically the RMSE for the UK and HCM2010 models are very similar, they are for approach and critical lane capacity, respectively. Therefore, the HCM 2010 model may result in a larger RMSE than the UK model when converted to approach capacity. A linear capacity model fitted to the field data had a similar slope as the calibrated UK model. Further validation of these findings is strongly recommended using data from multiple congested roundabouts.

INTRODUCTION

A modern roundabout is an unsignalized intersection where the entering traffic is required to yield to the circulating traffic. The yield-to-circulating rule is one of the main differences between modern roundabouts and traditional traffic circles. While modern roundabouts were first designed in the United Kingdom (UK) in the 1960s, their prevalence in the United States (US) did not begin until 1990 *(1)*. Since the 1990s, the construction of modern roundabouts has grown rapidly in the US.

One of the most comprehensive studies on roundabouts is documented in the *NCHRP Report 572: Roundabouts in the United States (1)*. Data were collected from 15 roundabouts in six states and models were developed for capacity and control delay. A method for calibrating the capacity model using field data such as critical gap and follow-up headway was also presented. These models are incorporated in the 2010 Highway Capacity Manual *(2)*. The authors of NCHRP Report 572 acknowledge that further research at congested roundabouts is necessary to verify these findings. To the best knowledge of the authors, the capacity model has not been independently validated. NCHRP Report 572 also reported average critical gaps and follow-up headways observed at the study sites. Possibly because of the small sample size, critical gaps were not reported for different vehicle types.

Wisconsin has a heavily congested roundabout with a queue in the left lane that lasts the entire peak period and in the right lane for a significant portion of the peak period. Data were collected at this roundabout using similar data collection and reduction procedures as NCHRP 572. The aim of this study was to compare the capacity of this heavily congested roundabout with the proposed HCM 2010 model as well as the UK capacity model *(3)*. In addition, follow-up headway and critical gap were computed for the various vehicle types.

LITERATURE REVIEW

The critical gap is defined as the minimum acceptable gap for a driver. According to the definition of critical gap, the driver would consider a gap acceptable when it is equal to or larger than the critical gap. Conversely, the driver would reject a gap when it is smaller than the critical gap. Therefore critical gap cannot be measured directly in the field. Researchers have proposed several approaches to estimate the critical gap using rejected gaps/lag and accepted gaps of individual drivers *(4-12)*. Miller and Brilon, et al. evaluated several approaches and concluded that the maximum likelihood method is the most accurate and robust procedure *(13, 14)*. Therefore, this method was used in NCHRP 572 as well as this study for estimating critical gaps.

NCHRP Report 572 performed a comprehensive study on roundabouts in the US *(1)*. As part of its operational findings, the critical gap and follow-up headway were estimated for 25 roundabout approaches from 15 roundabouts, 11 of which were single-lane and four were multi-lane. However, this sample covered only six states, and the adjacent exiting vehicles' impact was not taken into consideration. The estimated critical gap for single lane roundabouts was 5.0 seconds and 4.8 and 4.3 seconds for left and right lanes of multilane roundabouts respectively. The average follow-up headway for single lane roundabouts was 3.4 seconds (queued) and 3.1 and 3.0 seconds for left and right lanes of multilane roundabouts respectively. Also, critical gaps were not reported by vehicle type.

Mereszczak, et al. indicated in their study that, by using the critical gap estimation without considering the influence from the exiting traffic, the capacity would be underestimated

(15). In their paper, a reliable procedure was proposed to consider exiting vehicles' impact into the extraction of gaps. The concept of equivalent travel time was generated to adjust the gaps involving exiting vehicles. Nevertheless, the effect of exiting vehicles on follow-up headways was not studied. Additionally, Mereszczak, et al. only investigated single-lane roundabouts.

Capacity of a roundabout approach is defined as the maximum rate at which vehicles can reasonably be expected to enter during a given time period under prevailing traffic and roadway conditions *(16)*. Two methods currently used for analyzing the capacity of roundabouts are gap acceptance and empirical regression. For the gap acceptance framework, two parameters typically define the capacity: the critical gap and the follow-up headway. Equations for calculating roundabout capacity from the critical gap and follow-up headway can be found in a study completed by Troutbeck *(17)*. Empirical regression models are based on one-minute observations of traffic flows in oversaturated conditions. A linear or exponential regression equation is fit to the field data which relates capacity to geometric variation and driver behavior. Kimber's research led to the development of the empirical regression model currently used throughout the UK *(3)*.

NCHRP Report 572 investigated the efficacy of existing capacity and delay models with data from US roundabouts *(1)*. Results from the existing capacity models suggested that drivers in the US use roundabouts less efficiently than models suggest is the case in other countries. The report also concluded that geometry in the aggregate sense (i.e., number of lanes) has a clear effect on capacity; however, the fine details of geometric design (i.e., lane width) appear to be secondary and less significant than variations in driver behavior at a given site and between sites. Because driver behavior affects roundabout performance most significantly, the ability to calibrate capacity models to local conditions is imperative to the success of the model. After the existing capacity models were evaluated, the NCHRP 572 researchers developed single and multilane roundabout capacity models based on data collected for the project. Both the single and multilane capacity models are based on exponential regression equations and have the ability to be calibrated to local conditions with known critical gap and follow-up headway parameters. It was recommended that the capacity models fit the observed field data better than any of the existing capacity models, even after the models were calibrated.

Of the existing capacity models, the uncalibrated UK model produced the largest error, although the slope of the entry versus conflicting graph matched the data reasonably well *(1)*. Because of its strengths in providing geometric sensitivity and its common use throughout the US, Lenters and Rudy investigated three different methods to calibrate the y-intercept of the UK equation to better match US data *(18)*. The most promising calibration method was that proposed by the original research in TRRL LR 942 *(3)*. This study uses the method proposed in the original research to calibrate the y-intercept of the UK capacity model.

DATA COLLECTION AND REDUCTION

The study roundabout is located at the intersection of State Truck Highway 32 and Broadway Street in De Pere, Wisconsin. This roundabout and subsequent northbound approach were chosen because of the following characteristics: 1) multi-lane roundabout in an urban area; 2) roundabout opened in July 2007 thus resulting in stable traffic conditions at the time of study; 3) high percentage of trucks for the northbound and eastbound approaches; 4) heavy queuing was reported on the northbound approach; and 5) significant circulating traffic present during the afternoon peak hours resulting in a large sample of gap data.

Video data were collected in the afternoon of May 19, 2010 from approximately 1 to 6 PM. There was no inclement weather or any traffic incidents at the roundabout during the data collection. Two digital cameras and a Miovision^{TM} camera system were used for the field video recording. The upper part of Figure 1 illustrates the field setup for the three camera systems. The views of the three cameras covered the whole path of the northbound through movement (dashed-arrow line in Figure 1). The three sets of videos were synchronized and rendered into a single video file as shown at the bottom of Figure 1. The rendered video was then used for data reduction. The video views in Figure 1 also show that there was significant queuing in the northbound and eastbound approaches.

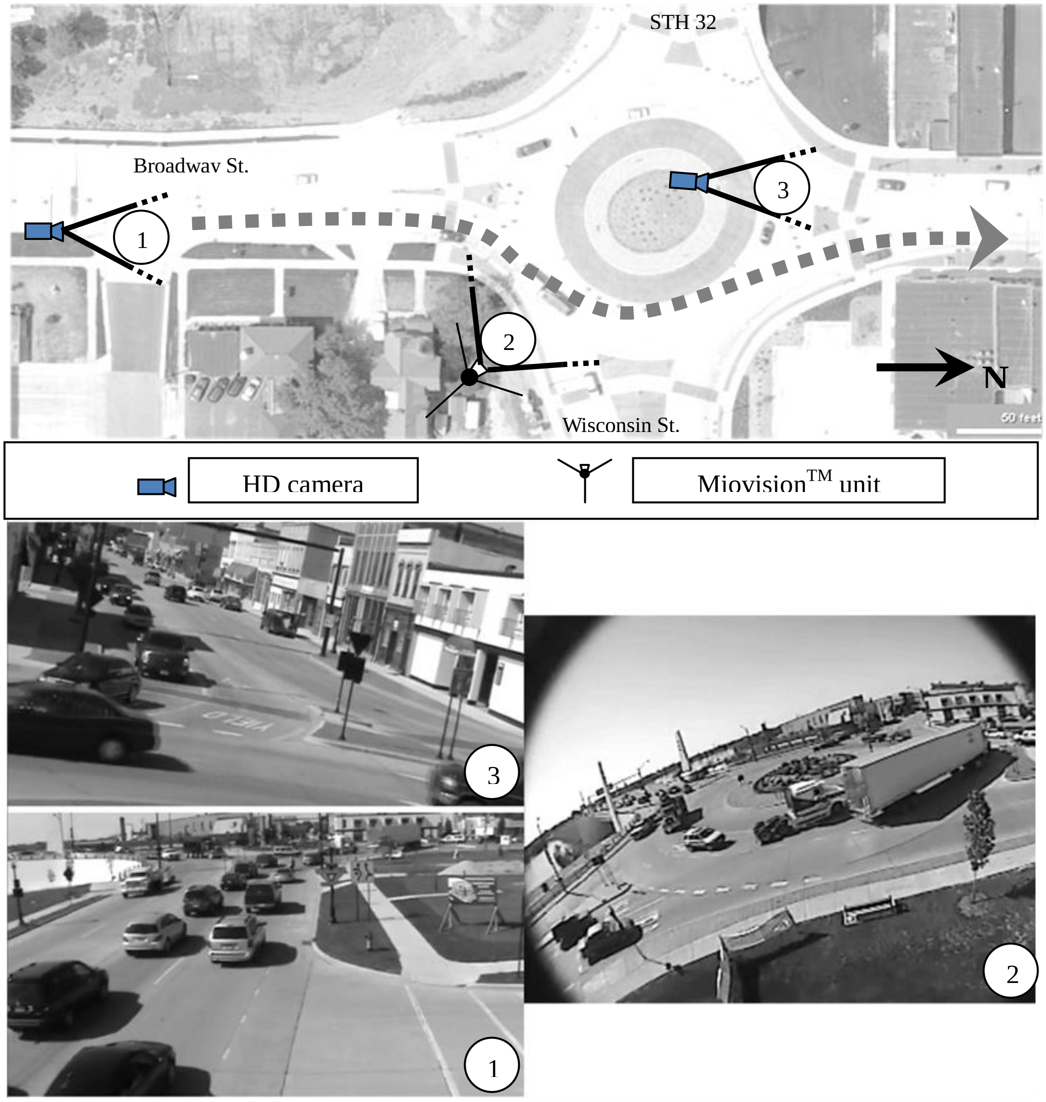
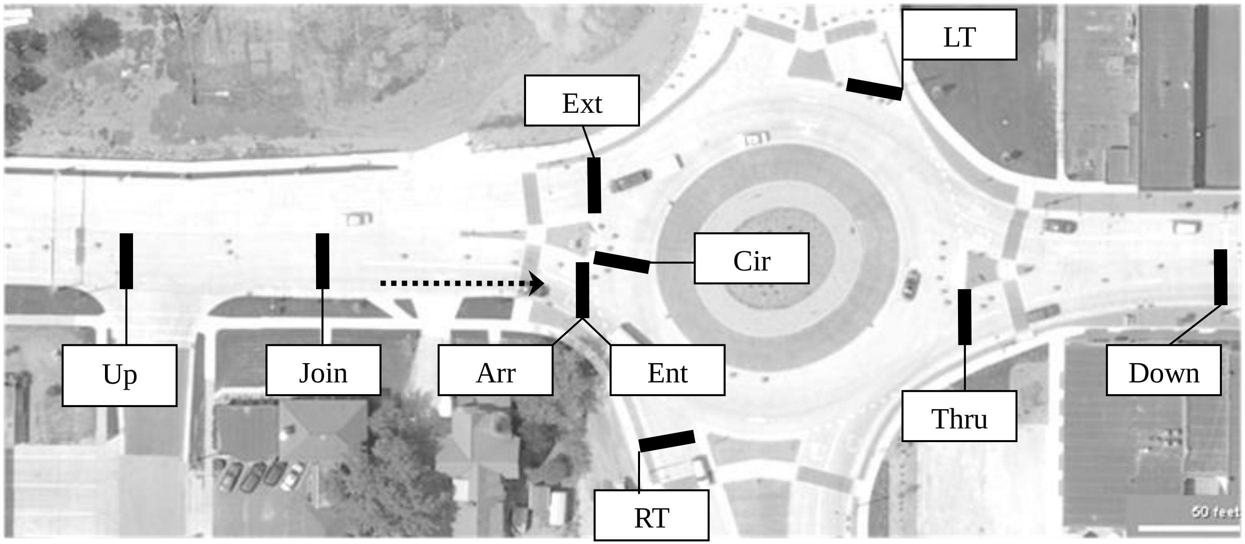


FIGURE 1 The field camera setup and the synchronized video.

After the video was synchronized and rendered, time stamps of ten relevant events were recorded using a video-based program developed by the research team. Figure 2 illustrates and defines the ten relevant vehicle events that were recorded. The dashed-line arrow indicates the study approach. Events 1 through 8 were tracked for each of the entering vehicles. Event 9 is for conflicting circulating vehicles and event 10 is for exiting vehicles. Labels were also assigned to differentiate between the left and right lanes and different vehicle types. The research team developed a program to extract the traffic counts, gaps, and follow-up headways using the timestamps associated with these events. The program also computes the number of entering, circulating, and exiting vehicles for each minute.



Event #	Event Code	Definition
1	Up	An entering vehicle appears on the upstream of the approach.
2	Join	An entering vehicle joins the end of a queue. The position of this event could vary according to the queue length. If there is no queue, the event could be considered the same as the “Arr” event below.
3	Arr	An entering vehicle arrives in front of the yield bar and starts judging the gaps.
4	Ent	An entering vehicle enters the roundabout with its nose crossing the yield bar.
5	Thru	An entering vehicle exits as a through vehicle.
6	Down	An entering vehicle gets to the downstream after exiting through.
7	RT	An entering vehicle exits as a right-turn vehicle.
8	LT	An entering vehicle exits as a left-turn vehicle.
9	Cir	A circulating vehicle reaching the cross line which intersects the yield bar at the tip of the splitter island.
10	Ext	A circulating vehicle exits to the left of the entering vehicle, without creating a conflict.

FIGURE 2 Relevant vehicle events.

Measuring Gaps and follow-up headway

For each entering vehicle (northbound approach only), the lag and gap sequence information was extracted. The gap data were computed for two scenarios: circulating vehicles only and circulating plus the impact from exiting vehicles. When the adjacent exiting vehicles' impact is considered, the procedure for measuring the lags and gaps are different. Merscezlak et al. describes in detail the procedures *(15)*. Following the NCHRP 572 study, the two circulating lanes were considered for estimating the gaps for both left and right lane entering vehicles.

Merscezlak, et al. used equivalent time to include the effect of exiting vehicles on gaps *(15)*. The equivalent travel time was calculated by dividing the travel length between the exit point and the conflicting point with the average speed. However, in this study, the authors measured the equivalent travel time directly by reviewing the video and timing circulating vehicles between the exit point and the conflicting point. Average equivalent times for each lane were determined by sampling 105 inner circulating vehicles and 106 outer circulating vehicles. The sampling was done every 15 min on the original videos, and five to six free-flowing vehicles were chosen every time for inner and outer lanes separately. For the inner lane, the average equivalent travel time was 1.12 seconds with a standard deviation of 0.16 seconds. For the outer lane, the average equivalent travel time was 1.93 seconds with a standard deviation of 0.26 seconds. These two average equivalent travel times were applied in the data extraction process when considering the exiting vehicles' impact. The follow-up headway was computed as the average of headways between vehicles using the same gap to enter the roundabout.

DATA SUMMARY

Table 1 is a summary of the extracted data. Data were collected for approximately 300 minutes, of which there were 268 full minutes of queuing in the left lane (90% of the time) and 77 full minutes in the right lane (25% of the time). With the large percentage of queues, this illustrates the roundabout is heavily congested (also confirmed by Figure 1) and has a left dominant lane (1,959 versus 1,582 entering vehicles). The lane configuration for the northbound approach is as follows: the right lane is shared for right-turn and through movements and the left lane is shared for through and left-turn movements. However, because of heavy queuing in the left lane, 30% of the vehicles in the right lane made left turns. This incorrect lane usage may violate driver expectancy at the other approaches and potentially create safety issues. Therefore optimal lane assignment is imperative in designing roundabouts.

Table 1 also shows the number of gap sequences in each lane by vehicle type when exiting vehicles' impact is considered and not considered. This roundabout approach had approximately 5% trucks and about 2% motorcycles so the critical headways for these vehicle types were also computed separately from the passenger cars. The follow-up headways considering and not considering exiting vehicles' impact are also displayed in Table 1. The sample size of follow-up headways reduced significantly when exiting vehicles' impact is considered because a gap between circulating vehicles that was accepted by two vehicles could be split into two if there was an exiting vehicle within that gap. Therefore, the headway between the two entering vehicles would not be considered a follow-up headway.

TABLE 1 Summary of Extracted Data

	Left Lane	Right Lane	Both Lanes
Queuing condition			
• Number of fully queued one-minute intervals	268	77	76
• Maximum duration of queue	01:28:44.17	00:06:29.98	00:06:29.98
Traffic condition			
• Total numbers of entering vehicles	1959	1582	3541
One-minute entry flow range (veh/min)	0 – 14	0 – 12	0 – 23
Turning proportions	RT Thru LT 0.00 0.02 0.98	RT Thru LT 0.30 0.54 0.16	RT Thru LT 0.13 0.25 0.62
• Total numbers of conflicting vehicles	4060	1571	5631
One-minute conflicting flow range (veh/min)	3 – 23	0 – 13	7 – 33
• Total numbers of adjacent exiting vehicles	837	3973	4810
One-minute adjacent exiting flow range (veh/min)	0 – 9	3 – 20	4 – 23
Travel time			
• Average approach time (from upstream to entering the roundabout) for entering vehicles (second)	51.39	23.73	39.03
Gap information (Corresponding information when considering exiting vehicles' impact)			
• Total number of gap sequences	1948 (1951)	1576 (1577)	3524 (3528)
• Number of gap sequences with an accepted lag	921 (850)	837 (746)	1758 (1596)
Number of gap sequences with a rejected lag and an accepted gap	247 (194)	230 (183)	477 (377)
Number of gap sequences with more than one rejected gaps	780 (907)	509 (648)	1289 (1555)
• Number of gap sequences involved in queued conditions	1879 (1882)	1163 (1164)	3042 (3046)
• Number of gap sequences of trucks	138 (138)	49 (49)	187 (187)
• Number of gap sequences of passenger cars	1769 (1771)	1495 (1496)	3264 (3267)
• Number of gap sequences of motor cycles	40 (41)	32 (32)	72(73)
Follow-up headway information (Corresponding information when considering exiting vehicles' impact)			
• Number of follow-up headways	702 (236)	433 (129)	1135 (365)
• Number of follow-up headways involved in queued conditions	691 (230)	393 (117)	1084 (347)

DATA ANALYSES

The data analyses consist of two parts. The first part is the estimation of critical gaps and follow-up headways for different scenarios and their comparison to the results from NCHRP 572 and the study from Mereszczak, et al. *(1, 15)*. The second part presents the capacity data, compares the data between left and right lanes, and compares the observed capacity to the calibrated and uncalibrated NCHRP 572 and UK models.

Critical Gaps and Follow-Up Headways

The estimation of critical gaps was done using the maximum likelihood method, assuming that the critical gap follows a log-normal distribution. For the critical gap estimation, only the gap sequences that rejected at least one gap (or a lag) were used. Further, the drivers with the largest rejected gap which was greater than the accepted gap were thought to be inconsistent, and the corresponding gap sequences were not included in the sample size *n*. The number of gap sequences for the inconsistent drivers is n_I. Table 2 summarizes the estimated critical gaps and follow-up headways by lane and vehicle type. The estimated critical gaps not considering the impact of adjacent exiting vehicles are under the "N/E" columns while those considering their impact are under the "W/E" columns. In the table, each estimate of mean ($\hat{\mu}$) was followed by the estimate of standard deviation ($\hat{s}$).

TABLE 2 Summary of Critical Gap and Follow-up Headway Estimates

	Left lane				**Right lane**				**Both lanes**			
	N/E		W/E		N/E		W/E		N/E		W/E	
Vehicle Type	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**	***n*** **(n_I)**	**$\hat{\mu}$ ($\hat{s}$) (sec)**
Critical Gap												
All	966 (61)	4.2 (0.93)	875 (226)	3.3 (0.60)	670 (68)	3.4 (1.02)	639 (192)	3.1 (0.62)	1636 (129)	3.8 (1.09)	1514 (418)	3.2 (0.62)
Passenger Car	870 (55)	4.1 (0.95)	787 (207)	3.3 (0.58)	638 (63)	3.3 (0.97)	610 (180)	3.0 (0.61)	1508 (118)	3.8 (1.06)	1397 (387)	3.2 (0.61)
Truck	76 (5)	5.0 (1.13)	73 (12)	3.6 (0.70)	20 (3)	4.7 (2.06)	18 (8)	3.6 (1.03)	96 (8)	4.9 (1.40)	91 (20)	3.6 (0.78)
Motor cycle	20 (1)	3.7 (0.64)	15 (7)	2.9 (0.63)	12 (2)	3.4 (0.28)	11 (4)	3.0 (0.29)	32 (3)	3.6 (0.55)	26 (11)	3.0 (0.51)
Follow-up Headway												
All	702	3.1 (1.38)	236	2.5 (1.32)	433	3.1 (1.58)	129	2.7 (1.53)	1135	3.1 (1.46)	365	2.6 (1.40)

The critical gap estimation without considering the adjacent exiting vehicles' impact is comparable to the "method 2" results by NCHRP 572 *(1)*. For the left lane, the critical gap is 4.2 seconds, which is the lower bound of the 4.2 to 5.5 second range given in NCHRP 572. However, the standard deviation, 0.9 seconds, is much lower than the 2.2 seconds reported for the roundabout with the 4.2 second critical gap in NCHRP 572. The right lane shows a similar trend. The critical gap is 3.4 seconds with a standard deviation of 1.0 second, while NCHRP 572 has a range of 3.4 to 4.9 seconds and a standard deviation of 1.5 seconds for the location with the critical gap of 3.4 seconds.

In summary, when exiting vehicles' impact is not considered the average critical gaps (of all vehicles) computed for this location are similar to the lower bound values reported in NCHRP 572 although the standard deviations were considerably lower. This difference in standard deviation could be due to that fact that lower bound critical gaps reported in the NCHRP 572 were from a roundabout with 16 full minutes of queuing in the right lane and 33 minutes in the left lane as opposed to this roundabout where queuing was for 268 and 76 minutes in left and right lanes, respectively.

When adjacent exiting vehicles' impact is considered, as expected, the estimated critical gaps decrease from 4.2 to 3.3 seconds in the left lane and from 3.4 to 3.1 seconds in the right lane. This finding corroborates the finding from Mereszczak, et al. at single lane roundabouts *(15)*.

Table 2 also shows the computed average critical gaps for different vehicle types. When exiting vehicles' impact is not considered, the average passenger car critical gap is 4.1 and 3.3 seconds respectively for the left and right lanes. However for trucks, the corresponding numbers are 5.0 and 4.7 seconds for left and right lanes, respectively and for motorcycles, the numbers are 3.7 and 3.4 seconds, respectively. Although based on a smaller sample size, these numbers indicate that trucks have a considerably longer critical gap than passenger cars. One ramification of this difference in critical gaps could be that increasing truck volumes can significantly reduce the capacities of roundabouts and this difference in critical gap needs to be accounted for in roundabout design.

The average follow-up headway was estimated to be 3.1 seconds for both lanes (when exiting vehicles' impact is not considered) which is identical to 3.1 seconds weighted average follow-up headway reported for multilane sites in NCHRP 572 *(1)*. In NCHRP 572, weighted average follow-up headways for left and right lanes were found to be 3.1 and 3.0 seconds, respectively.

NCHRP 572 reported that follow-up headways in the dominant lane were shorter than the follow-up headways in the other lane. Dominant entry lane is defined as the lane with the largest arrival flow *(1)*. Data from the DePere roundabout indicates that follow-up headway for both lanes is practically identical (3.09 versus 3.14 seconds) although the left lane is the dominant lane. Closer inspection of the NCHRP 572 report indicates that the sample sizes used for left and right lanes to reach this conclusion are vastly different. For the one roundabout (MD04-E) with large samples for both lanes (by including data when move-up time was less than six seconds), the average follow-up headways were identical (3.1 seconds) for both left and right lanes. Therefore, an average follow-up headway for both lanes at a congested US roundabout appears to be 3.1 seconds.

Mereszczal et al. state that exiting vehicles significantly affect the critical gap and that excluding the effect of exiting vehicles might result in underestimating capacity *(15)*. However, the effect of exiting vehicles on follow-up headways was not studied. Table 2 shows that follow-up headways could be reduced considerably from 3.1 to 2.5 seconds and 3.1 to 2.7 seconds for the left and right lanes, respectively.

Capacity Analysis

For all full minutes of queuing, one-minute entry, and circulating volumes were computed. These were converted to hourly passenger car equivalent flows using the Federal Highway Administration (FHWA) passenger car equivalents of 2 and 0.5 for trucks and motorcycles, respectively *(16)*. Figure 3 shows the one minute entering and conflicting flow (in passenger car units per hour) for the left and right lanes separately. Data appears to indicate that the capacity of the right lane is greater than the left lane. Consequently, it might not be appropriate to divide approach capacity by two to obtain individual lane capacities. And as a corollary, it may not be appropriate to multiply the dominant lane capacity by two to obtain approach capacity for a two-lane roundabout.

NCHRP 572 capacity model (or the proposed HCM 2010 model) was developed for the critical lane and therefore the left lane data are compared to the calibrated and default NCHRP capacity models. Since the UK capacity model is for the approach and does not recognize a "critical lane," the calibrated and default models were compared to the observed approach data.

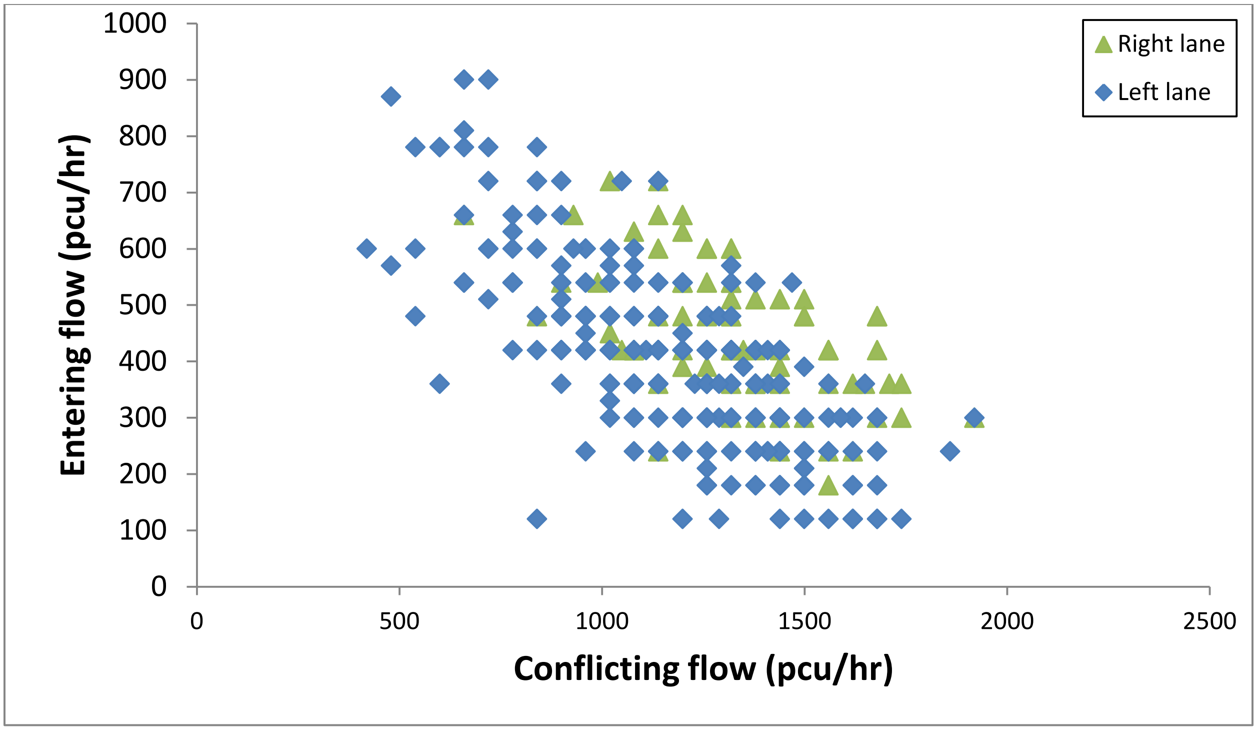
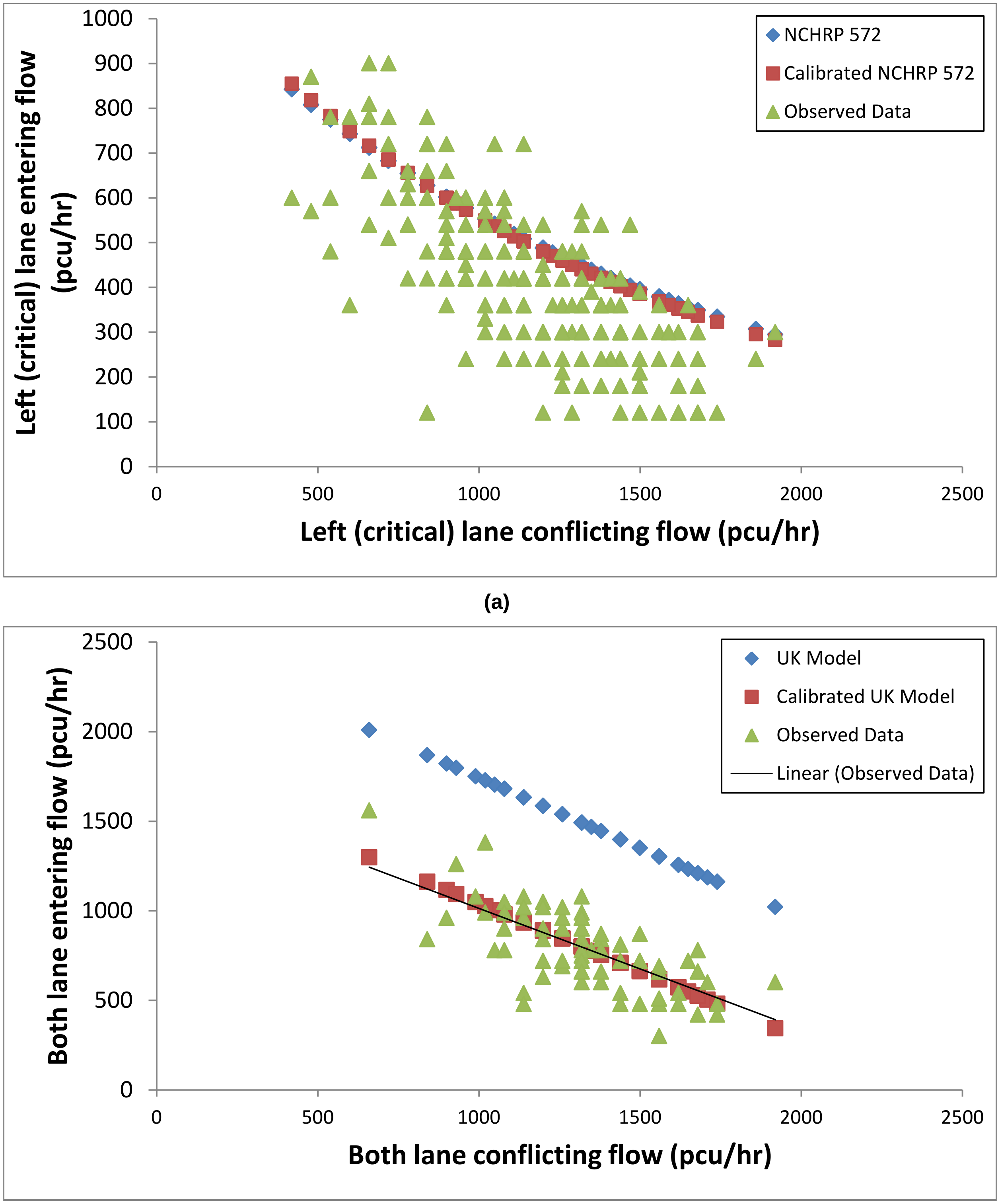


FIGURE 3 Conflicting vs. entering by lane.

The NCHRP 572 model was calibrated using the critical gap and follow-up headway data presented earlier in this section. No exiting vehicles were included in the circulating flows and only the left lane was included in the critical gap calculations. The resulting critical gap and follow-up headway values used in the analysis were 4.2 and 3.1 seconds, respectively. The local critical gap and follow-up headway parameters are very similar to the default parameters recommended by NCHRP Report 572. Consequently there is little difference between the calibrated and uncalibrated NHCRP 572 models as shown in Figure 4a. The root mean square errors (RMSE) for the calibrated and uncalibrated NCHRP 572 models were 145 pcu/hr and 150 pcu/hr respectively.



(a)

(b)

FIGURE 4 Comparing field data to different capacity models: (a) Field data compared to NCHRP 572 model; (b) Field data compared to UK model.

The UK model was calibrated to the field data using the procedure described in TRRL LR 942 *(3)*. The *F* constant in the UK model of 303 was revised to 223 based on local driver behavior. A lower constant implies a smaller y-intercept and lower entry capacity. The RMSE for the uncalibrated and calibrated models is 711 pcu/hr and 161 pcu/hr. The small RMSE for the calibrated model indicates that the UK model can represent the field data much better when calibrated as shown in Figure 4b. The RMSE for the UK model and NHCRP 572 models are very similar; however, the UK model is for approach capacity while the NCHRP 572 model is for critical lane capacity. This data indicates that the UK model might have smaller RMSE than the NCHRP 572 model when used to compute approach capacity.

A linear model, similar in form to the UK model was also fitted to the data. As reported in the NCHRP 572 model, the slope of the calibrated UK model (-0.757) closely matches the slope of the fitted model (-0.676) and the intercepts are 1798 and 1690 pcu/hr respectively. The drawback of this calibration procedure is that it requires that entering and circulating flow data be collected for queuing conditions and most of the current roundabouts are not under queuing conditions.

CONCLUSIONS AND RECOMMENDATIONS

The number of modern roundabouts in the US has been rapidly increasing since the first one opened in 1990 in Summerlin, Nevada. However there is limited knowledge on the operation of congested roundabouts in the US. Field data were collected at a heavily congested roundabout in Wisconsin to determine its operational characteristics (critical gap, follow-up headway, and capacity) and compare them to the state of the practice in the US. The left and right lanes were queued for about 90% and 25% of the five hour data collection period.

Critical gaps were estimated using the maximum likelihood method assuming a log-normal distribution. The average critical gaps for all vehicles in the left and right lanes were found to be 4.2 and 3.4 seconds, respectively (when exiting vehicles' impact was not considered). The average critical gaps (for all vehicles) computed for this location are similar to the lower bound values reported in past research, although the standard deviations were considerably lower. When adjacent exiting vehicles' impact is considered, the estimated average critical gaps decrease to 3.3 and 3.1 seconds in the left and right lanes, respectively. The average critical gaps for trucks were found to be considerably greater than for cars (5.0 vs. 4.1 seconds in left lane and 4.7 vs. 3.3 seconds in right lane).

The average follow-up headway was estimated to be 3.1 seconds for both lanes (when exiting vehicles' impact is not considered) which is identical to the previously reported values. Data from this location does not support the notion that the dominant lane would have lower follow-up headway than the sub-dominant lane. The average follow-up headway was reduced considerably (from 3.1 seconds in both lanes to 2.7 and 2.5 seconds in left and right lanes, respectively) when exiting vehicles' impact was considered.

One-minute entering and circulating volumes in the left lane (critical lane for this roundabout) were compared to the proposed capacity model in the new HCM 2010. The RMSE for capacity were 145 and 150 pcu/hr for the uncalibrated and calibrated models respectively. One-minute entering and exiting volumes for the approach were compared to the UK capacity model. Following calibration, RMSE reduced from 711 pcu/hr to 161 pcu/hr for the UK Model. Although, numerically the RMSE for the UK and HCM2010 models are very similar, they are for approach and critical lane capacity respectively. Therefore, the UK model may result in smaller RMSE than the HCM 2010 model when considering approach capacity. As reported previously, a linear capacity model fitted to the field data had a similar slope as the calibrated UK model. Further validation of these findings is strongly recommended using data from multiple congested roundabouts.

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