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CALIBRATING VISSIM ROUNDABOUT MODEL USING A CRITICAL GAP AND FOLLOW-UP HEADWAY APPROACH

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ABSTRACT

Roundabouts have been continuously constructed in the U.S. in recent years, as studies have shown their capability of reducing crash risk and severity when compared with signalized intersections. Despite of the safety benefits offered by roundabouts, operational efficiency is required be analyzed when considering building roundabouts. As a prevailing simulation platform for modeling roundabouts, VISSIM have been widely applied in practice to facilitate analyzing the operational performance of roundabouts. Considering that an essential prerequisite to preparing a VISSIM roundabout model is to calibrate the model by adjusting VISSIM parameters, comprehensive calibration guidance is of great importance to practitioners. Previous calibration research has conducted qualitative analysis to study the impact of VISSIM parameters on roundabout capacity. However, parameter values based on field data and quantitative calibration guidelines are more helpful to facilitate fast and accurate modeling of roundabouts. This paper addresses these important needs. Speed trajectories of free-flow entering vehicles were collected in the field using a radar sensor. Location, length, speed distribution, and deceleration rate parameters for the VISSIM Reduced Speed Areas (RSA) were determined through the analysis of the radar data. The impact of VISSIM parameters on critical gap and follow-up headway was quantitatively

analyzed through sensitivity analysis of minimum gap for PR, speed distribution and deceleration rate for RSA, and additive and multiplicative settings for the Wiedemann 74 model. Numerical guidelines for calibrating VISSIM roundabout models were ultimately developed, and validated via a case study.

1 INTRODUCTION

Roundabouts have been widely constructed in the U.S. in recent years as studies have shown that roundabouts can reduce crash severity for all crash types (*Qin et al, 2011*). This safety benefit results from the "drive-around" mode pertaining to roundabouts, which can eliminate all crossing vehicular conflicts (*Zheng et al., 2012*). In addition, the vehicle approaching speed to a roundabout is relatively reduced compared to traditional intersections, which also helps lower crash risks at the intersection (*Zheng et al., 2012*). Despite this safety benefit brought by roundabouts, their operational efficiency is also an important factor that affects the final decision of constructing a roundabout at a roadway intersection. Therefore, analysis of the operational performance of a roundabout is an essential step towards the final decision.

Among many commercial microscopic traffic simulation software packages, VISSIM offers excellent support for modeling roundabouts. This support is reflected by the roundabout modeling instruction being documented in the VISSIM User's Manual (*PTV, 2011*). In practice, VISSIM roundabout models have also been heavily discussed as one of the most widely applied microscopic simulation packages for modeling roundabouts (*Schroeder, 2012; Wei et al., 2012; Cicu et al., 2011; Duong et al., 2011; Bared and Afshar, 2009; Gallelli and Vaiana, 2008; Vaiana and Galllelli, 2011; Gagnon et al., 2008; Al-Ghandour et al., 2011*).

An essential prerequisite to the preparedness of a VISSIM roundabout model is model calibration by adjusting VISSIM parameters to make the model best representing the real-world operations. Therefore, comprehensive calibration guidance is of great importance to practitioners. Previous studies have summarized that the settings of three elements in VISSIM have critical impact on the operational performance of roundabout simulation models (*Schroeder, 2012; Wei et al., 2012; Cicu et al., 2011; Fortuijn, 2009; Valdez et al., 2011; Gallelli and Vaiana, 2008; Vaiana and Galllelli, 2011*). These elements include: (1) Priority Rules (PR) or Conflict Areas (CA), which control the yielding logic; (2) Reduced Speed Areas (RSA), which provide temporary speed control over a short roadway distance; and, (3) Wiedemann 74 and 99 car following models, which can fine-tune the simulated car-following behavior.

Research has been conducted to investigate appropriate methods for the calibration of VISSIM roundabout models. A primary method was adjusting parameter settings of VISSIM elements repeatedly until a calibration goal was reached (*Schroeder, 2012; Wei et al., 2012; Cicu et al., 2011; Fortuijn, 2009; Valdez et al., 2011; Gallelli and Vaiana, 2008; Vaiana and Galllelli, 2011*). The typical calibration goal was to match the capacity curve obtained from the simulation model to the capacity curve based on field observation (*Schroeder, 2012; Wei et al., 2012; Cicu et al., 2011), while some other studies tried to match the simulated travel time or speed to field data (Valdez et al., 2011; Gallelli and Vaiana, 2008; Vaiana and Galllelli, 2011*).

Most previous studies focused on qualitative investigations of different VISSIM parameters' impact on the capacity output of the roundabout simulation model. Only a few studies used field collected data as input for calibrating the simulation model or as ground truth data for model validation. In summary, previous research has not adequately fulfilled the need for realistic and quantitative calibration guidelines. To address this issue, in-depth sensitivity analyses are needed to quantify the impact of changing various VISSIM parameter settings on simulated capacity. Therefore, the objective of the paper is to (1) conduct sensitivity analysis of roundabout capacity when different VISSIM parameter values are used; (2) develop quantitative calibration guidance on selection of VISSIM parameters; and, (3) recommend field-estimated parameter values for calibration.

2 METHODOLOGY

2.1 Data Collection

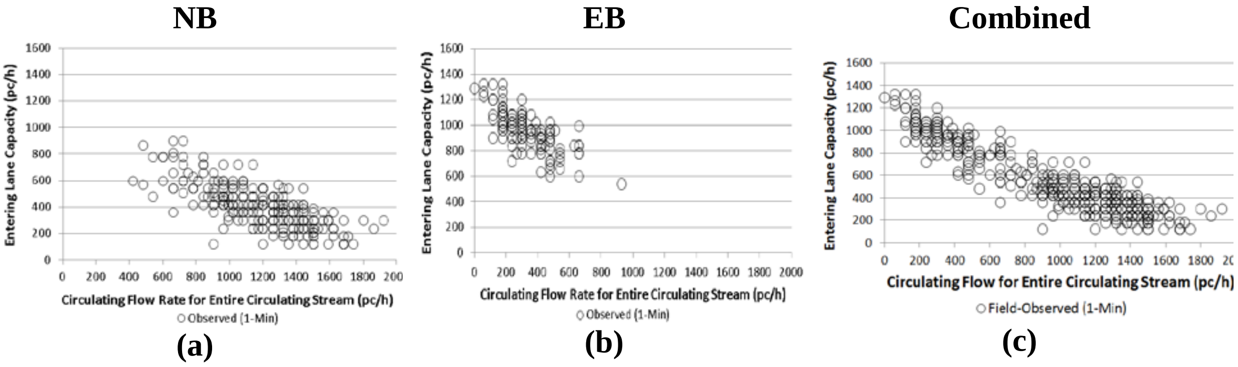
To collect field data as input for calibrating the simulation model and as ground truth for validating the simulation model, data collection was conducted at a congested two-lane roundabout in De Pere, Wisconsin, and a roundabout in Oshkosh, Wisconsin. The De Pere roundabout was chosen because it experienced heavy congestions. The Oshkosh roundabout approach was selected for speed data collection because it has a similar entrance 85th percentile speed with that of the De Pere roundabout.

At the De Pere roundabout, video cameras were set up in the field to capture vehicle events including arrival, entry, and exit, as well as conflicts between entering and circulating vehicles of the NB and EB approaches. Based on the recorded time stamps of these events, one-minute circulating, and entering flow, as well as critical gap and follow-up headways were then derived. Specifically, the estimation of critical gaps was based on the maximum likelihood (ML) method (*Brilon et al., 1999; Troutbeck, 2001; Zheng et al., 2012*), assuming that the critical gap follows a log-normal distribution. As a result, Table 1 summarizes the observed critical gaps and follow-up headways for passenger cars and heavy vehicles for the left lane of NB approach, which is the most congested lane of the De Pere roundabout.

Table 1: Gap acceptance data for NB left lane of the De Pere roundabout

		NB Left Lane			
		n*	t_c^* **(s)**	**n**	t_f^* **(s)**
Gap Acceptance	**Passenger Car**	648	4.3 (1.0)	638	3.1 (1.2)
	Truck	58	5.2 (1.2)	36	3.7 (1.2)

** n denotes the sample size; t_c denotes critical gap; t_f denotes follow-up headway; ()denotes standard deviation.*



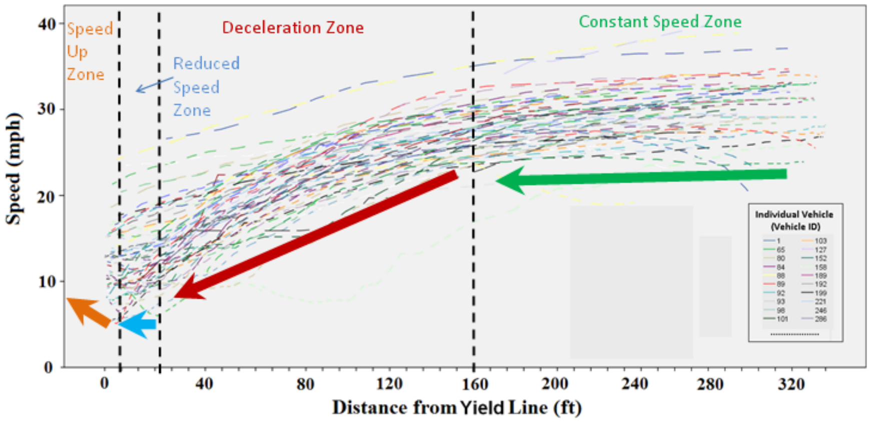
NB **EB** **Combined**

(a) **(b)** **(c)**

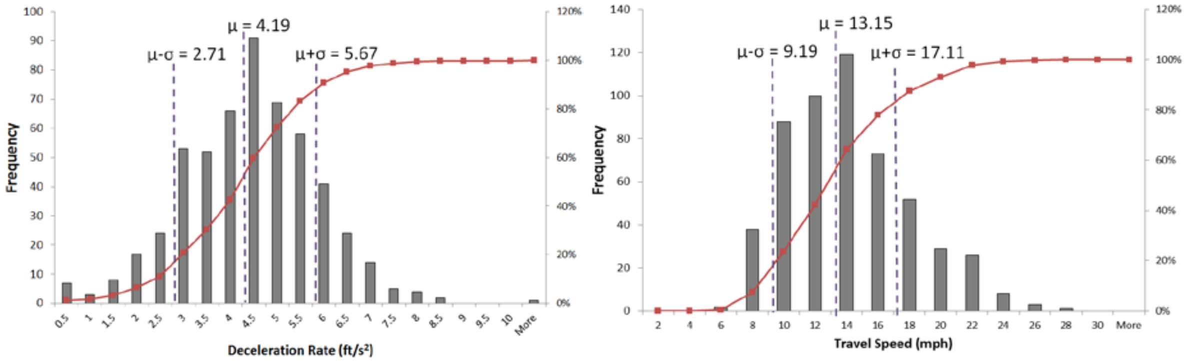
Figure 1: Capacity data collected at the De Pere roundabout

Figures 1.a and 1.b summarize the capacity data collected at the left lanes of the NB and EB approaches of the De Pere roundabout. All capacity data are 1-minute-based, and were collected under queuing conditions and then converted to passenger car equivalents using the conversion factor of one heavy vehicle equivalent to two passenger cars. Due to the traffic pattern at the roundabout during the data collection period, no circulating flows below 400 pc/hr were observed at the NB left lane, while no circulating flows above 1000 pc/hr were observed at the EB left lane. Since the validation of a roundabout simulation model requires the ground truth capacity data to have a full range of circulating flows, all capacity data from EB (low circulating flows) were merged into the NB capacity data in order to prepare a complete dataset of ground truth capacity, as shown in Figure 1.c. The merge is based on the fact that the EB left lane has similar critical gap and follow-up headway with the NB left lane.

At the Oshkosh roundabout, free-flow speed data were collected at an approach using a microwave radar sensor. The purpose of collecting the speed data is to provide field estimation for input parameters of the RSAs in VISSIM. Also, there is no horizontal curve on the approach to the roundabout (upstream of the roundabout). Hence, the geometric effect on speed is minimized. The radar sensor scanned the approaching traffic every 0.3 s covering distances up to 500 feet from the sensor. The corresponding location and speed data were recorded. Note that all data pertaining to the non-free-flow vehicles, which are vehicles that stopped during the entire course of approaching and entering the roundabout, were dropped during the data reduction process.



a. Speed Change Profiles



b. Distribution of Deceleration Rate in Deceleration Zone

c. Distribution of Speed in Reduced Speed Zone

Figure 2: Analysis of vehicle's speed change pattern when approaching the roundabout

Analysis was conducted on the collected speed data, which aimed at giving recommendations on the placement and settings of RSAs based on vehicles' speed trajectories. Figure 2.a shows the speed profiles of 65 free-flow entering vehicles as they approached the roundabout. Different colors are used to represent different vehicles. These 65 vehicles were randomly selected from a total of 539 observed free-flow vehicles to achieve an easier recognition of speed patterns. However, in the detailed data analysis, the full sample of 539 vehicles was used. In Figure 2.a, the entire roundabout approach could be approximately divided into four speed zones, namely, Constant Speed Zone (>160 feet from yield line); Deceleration Zone (25-160 feet from yield line); Reduced Speed Zone (8-25feet from yield line); and Speed Up Zone (0-8 feet from yield line).

Figure 2.b shows the distribution of deceleration rates in the Deceleration Zone for all observed free-flow vehicles. The mean deceleration rate and standard deviation were found to be 4.19 ft/s^2 and 1.48 ft/s^2, respectively.

According to Figure 2.a, vehicle speeds in the Reduced Speed Zone vary slightly at different distances; however they are relatively stable when compared to the speeds in the Deceleration Zone. Therefore, the assumption was made that each vehicle maintained near constant speed in the Reduced Speed Zone (similar assumption used by VISSIM RSA), and the constant speed (termed as travel speed) for each vehicle could be computed by taking the average of each vehicle's speed measurements within the Reduced Speed Zone. Figure 2.c shows the distribution of travel speeds in the Reduced Speed Zone. The mean travel speed and standard deviation were found to be 13.15 mph and 3.97 mph.

According to the definition of RSA in VISSIM user's manual (*PTV, 2011*), the location of the entrance RSA should exactly overlap with the Reduced Speed Zone as shown in Figure 2.a. Therefore, deceleration rate and speed distribution parameters correspond to the observed deceleration rate in the Deceleration Zone and the travel speed distribution in the Reduced Speed Zone, respectively.

2.2 Quantifying Roundabout Capacity as A Function of Critical Gap and Follow-up Headway

Most previous studies used capacity curve based sensitivity analysis when exploring the calibration guidelines for VISSIM roundabout model. Typically, the output capacity cloud from VISSIM (i.e., dots representing entering flow versus circulating flow), or the cloud's regression curve, was used as the only performance measure in the sensitivity analysis. Due to the fact that the capacity cloud is a distribution, results of these types of sensitivity analysis were hard to quantify other than qualitatively describing the change of the capacity curve's intercept and slope.

According to the Highway Capacity Manual 2010, the capacity of the critical lane of a multilane roundabout is an exponential function of critical gap (t_c) and follow-up headway (t_f), as expressed by the following equation (*HCM*, *2010*).

$$C_{pce} = Ae^{(-Bv_c)} \qquad A = \frac{3600}{t_f} \qquad B = \frac{t_c - (t_f/2)}{3600} \tag{1}$$

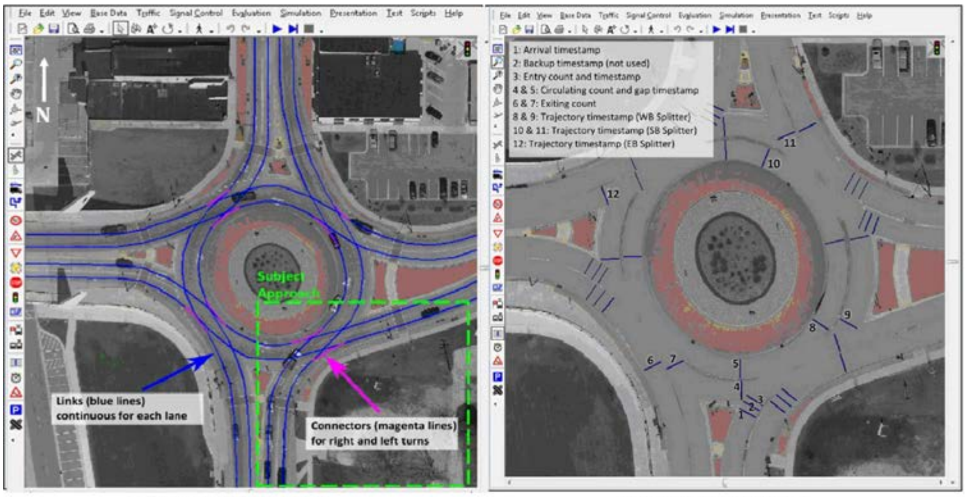
Where, C_{pce} is lane capacity, passenger car equivalent (pc/hr); v_c is conflicting flow (pc/hr); t_c is critical gap (s); and, t_f is follow-up headway (s) .

Since t_c and t_f are the only parameters of the capacity model, the roundabout capacity can hence be simply determined by these two parameters. Considering that t_c and t_f are much easier to describe quantitatively than the capacity cloud, they are a better quantitative performance indicator in sensitivity analysis, replacing the traditional capacity cloud. Based on this fact, in this research, t_c and t_f were estimated from VISSIM's output data using similar methods as used in field data collection. They were used as the major performance measure in the sensitivity analysis and the calibration process.

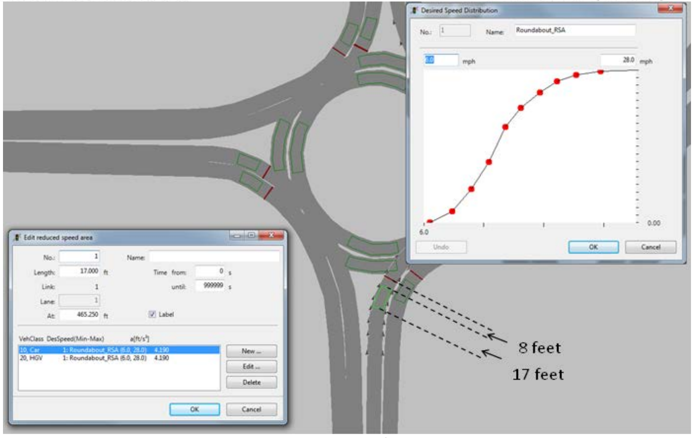
2.3 Building the Roundabout Model in VISSIM

As the study site, the De Pere roundabout was coded in VISSIM based on its aerial map, as shown in Figure 3.a. Priority Rules were used to define yielding behavior, and were implemented by the placement of yielding lines at the roundabout entrance points. Data collection points, as shown in Figure 3.b, were placed to facilitate collection of traffic flow data as well as timestamps of vehicles' gap acceptance events. The timestamps were used to estimate the critical gap and follow-up headways.

RSAs were placed at the entrance of each roundabout approach. Figure 3.c illustrates the layout of the entrance RSA in the VISSIM roundabout model. Based on the findings from Figure 2.a, the length of the RSA equals the length of the Reduced Speed Zone, i.e., 17 feet. The end boundary of the RSA is located at 8 feet from the yield line. The speed distribution in the RSA conforms to the cumulative speed curve as shown by the red curve in Figure 2.c. The default deceleration rate has been changed to 4.19 ft/s^2 as it is the mean deceleration rate observed in field.



a. Overall roundabout network **b. Data collection point setup**



No.: 1
Name: Roundabout_RSA

No.: 1
Name:
Length: 17.000 ft
Time from: 0 s
until: 999999 s
Link: 1
Lane: 1
At: 465.250 ft
☑ Label

VehClass DesSpeed(Min-Max) a[ft/s²]
10, Car 1: Roundabout_RSA (6.0, 28.0) 4.190
20, HGV 1: Roundabout_RSA (6.0, 28.0) 4.190

c. Placement of RSAs

Figure 3: Modeling roundabout in VISSIM

In addition to the placement of the entrance RSA, recommendations by Trueblood and Dale were also taken into account in this research in regards to placement RSAs within the circulatory roadway (*Trueblood and Dale, 2003*). Instead of having large, continuous RSAs, smaller RSAs at the splitter islands were defined to enable vehicles to realistically travel at speeds typically observed within roundabouts (*Trueblood and Dale, 2003*). The placement of these circulatory RSAs is illustrated in Figure 3.c.

All simulation experiments performed in this research were based on simulation runs of 1800 s (30 minutes) at a resolution of 10 time steps per simulation second. A five minute warm-up time was included in each run to allow traffic to stabilize before collecting data between 300 s and 1,800 s (25 minutes). Each run was used to obtain the entering flow under one regime of circulating flow. A total of fifteen flow regimes were used to generate data throughout a range of practical circulating flows, with 10 simulation runs using different random seeds per regime, resulting in a total of 150 simulation runs per experimental trial. The first two flow regimes correspond to circulating flows of 25 veh/hr/ln and 100 veh/hr/ln, respectively. For each subsequent regime, 100 veh/hr/ln were added starting from flow regime #3. Flow regime #15 has a circulating flow of 1400 veh/hr/ln.

Because the NB approach was selected as the study approach, the NB entry volume demand was fixed at 2500 veh/hr in each lane to ensure that there was always sufficient entering demand at this approach. The circulating flow was only from the EB approach (adjacent entry) to allow an easy control of circulating flow rate. Considering that VISSIM provides options to model the operations of cars and heavy vehicles separately, such as establishing separate PRs and reduced speed areas, the critical gaps and follow-up headways for cars and heavy vehicles can therefore be calibrated separately. Based on this consideration, all simulation runs in this research used vehicle composition of 100% passenger cars in order to simplify the process of exploring the calibration approach. The difference between cars and heavy vehicles is that the heavy vehicles have larger critical gaps and follow-up headways. Therefore, the calibration recommendations developed based on cars can be easily used for heavy vehicles by setting the calibration goals of longer critical gaps and follow-up headways.

2.4 Estimating Critical Gap and Follow-up Headway in VISSM

Gaps were calculated as the time difference between timestamps of vehicles crossing data collection points 4 and 5 as shown in Figure 3.b. Locations of points 4 and 5 matched the PR conflict markers for the left lane. Gaps were then indexed chronologically. Finally, characteristics of the gaps accepted and rejected for each vehicle were computed in order to find maximum likelihood method estimates of critical gap. Headway between two entering vehicles was considered as a follow-up headway if the two vehicles accepted the same gap. The differences between timestamps of vehicles crossing data collection point 3 (See Figure 3.b) during a single gap were used to estimate average follow-up headway. In summary, the same method for estimating the field-observed critical gap and follow-up headway was used for VISSIM data.

3 SENSITIVITY ANALYSIS

The following subsections are dedicated to sensitivity analyses of settings of different VISSIM elements to investigate their impact on the roundabout model’s capacity (i.e., t_c and t_f). The results of the sensitivity analyses are expected to provide quantitative reference for calibrating the roundabout simulation model. Specifically, the VISSIM elements that are considered in this section include:

- PR: minimum gap;
- RSA: speed distribution and deceleration rate;
- Wiedemann 74 Model (W74M): safety distance factors: additive and multiplicative.

The main idea of the sensitivity analyses was to test how sensitive the changes in critical gap (t_c) and follow-up headway (t_f) were when changing parameter values of a subject VISSIM element. Since the left lane of the NB entrance was selected as the study lane in this research, changes in parameter settings only applied to the NB left lane in the sensitivity analyses, except changes in some global settings like the W74M. In each analysis, only the parameter values of the subject VISSIM element were changed. The parameter values of other elements remained at defaults. For RSA and PR, the default parameter values were the field-observed values. For W74M, the default parameter values were values that are recommended by VISSIM (*PTV, 2011*). Each analysis included multiple experiments. The selection of values included in the sensitivity analysis for each parameter is based on the default value, plus and minus some intervals. Table 2 summarizes the settings of VISSIM parameters and the results of the sensitivity analyses.

3.1 Results of Priority Rule

The sensitivity analysis for PR was designed to quantify the impact of the PR's minimum gap setting on the roundabout capacity.

Seven different minimum gaps, ranging from 3.0 s to 5.5 s, were tested in the analysis. Figures 4.a and 4.b illustrate the results of the minimum gap's impact on critical gap and follow-up headway, respectively. As expected, increasing the minimum gap significantly increased the critical gap according to Figure 4.a. Additionally, all critical gaps were observed to be greater than the minimum gaps. Regression analysis was conducted to identify the best-fit numerical relationship between the minimum gap and the resulting critical gap. It was found that the relationship is logarithmic, rather than linear as initially expected. Numerically, the relationship is represented by the following equation:

$$\begin{aligned} t_c &= 3.2473\ln(g_{\min}) + 0.17 \\ R^2 &= 0.9998 \end{aligned} \qquad (2)$$

Where t_c is critical gap (s), and g_{min} is the minimum gap setting for the PR (s).

Increasing the minimum gap did not change the follow-up headway according to Figure 4.b. The regression line was quite flat, indicating that the minimum gap did not have a significant impact on the follow-up headway as expected.

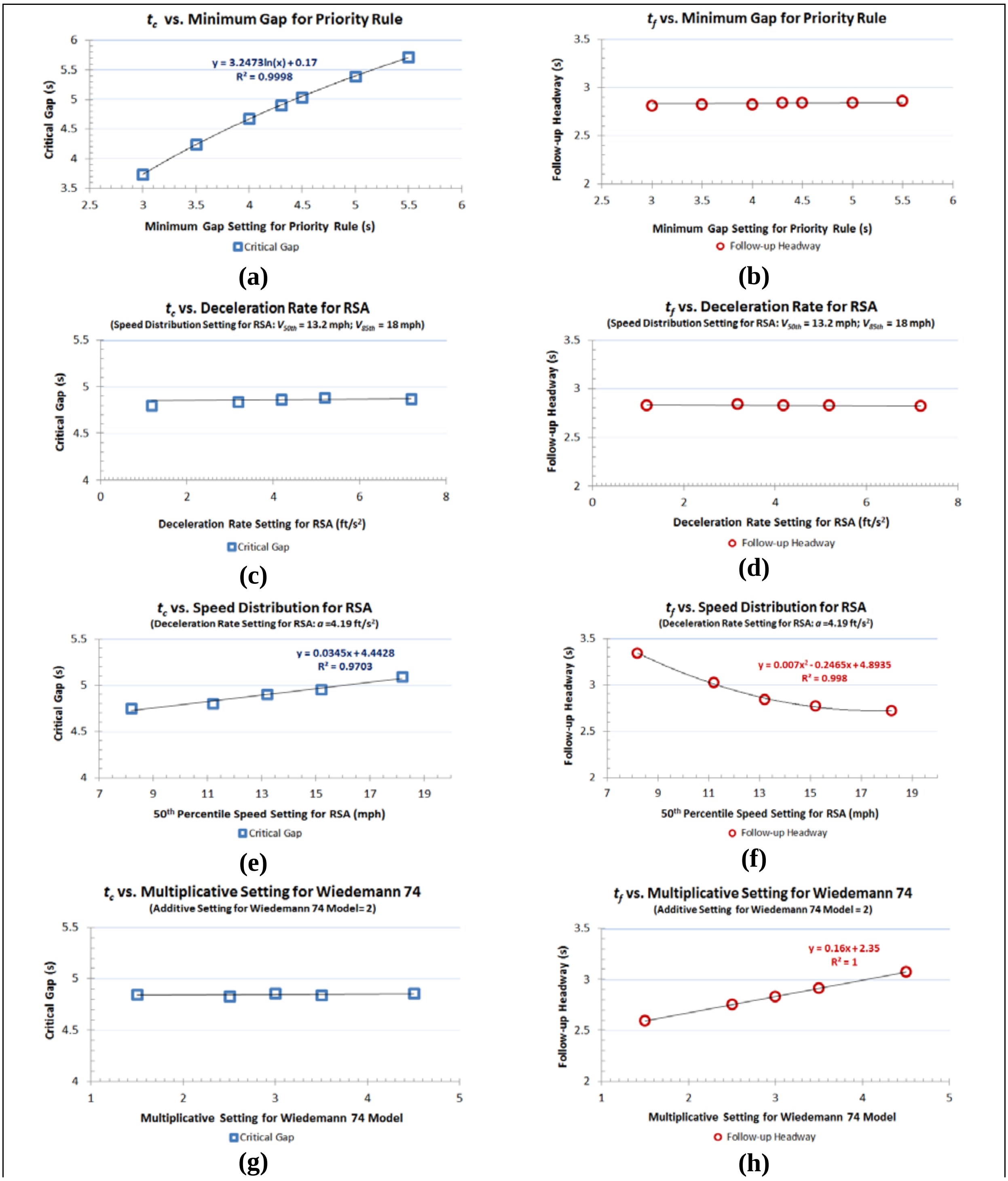
Table 2: Settings of parameters and results of sensitivity analyses

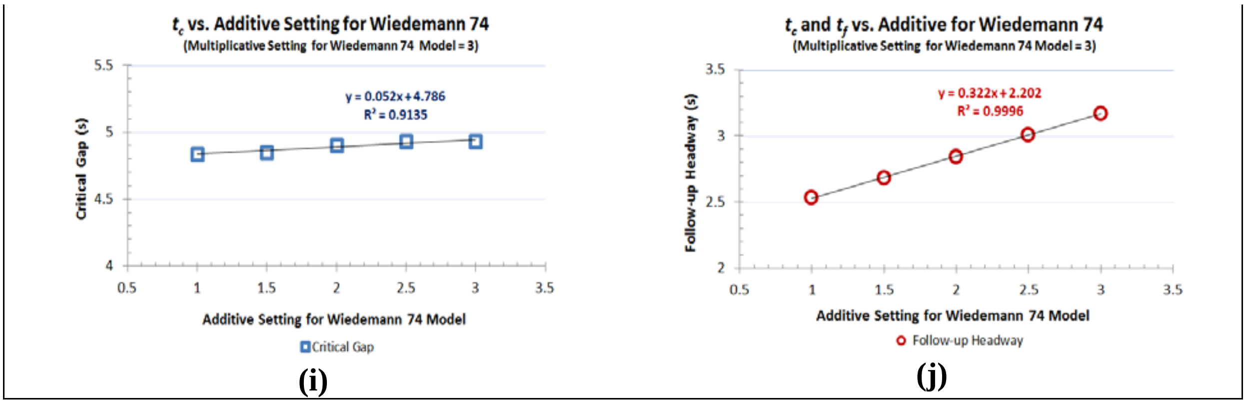
				Parameter	Result	
				Minimum Gap (s)	t_c (s)*	t_f (s)*
Priority Rules	Default Value			4.3		
	Value in Sensitivity Analysis	Experiment ID	1	3.0	3.74 (0.13)	2.81 (0.45)
			2	3.5	4.24 (0.16)	2.82 (0.44)
			3	4.0	4.68 (0.18)	2.82 (0.44)
			4	4.3	4.90 (0.19)	2.84 (0.43)
			5	4.5	5.04 (0.22)	2.84 (0.45)
			6	5.0	5.39 (0.29)	2.84 (0.44)
			7	5.5	5.72 (0.43)	2.86 (0.49)

				Parameter		Result	
				Speed Distribution (mph)	Deceleration Rate (ft/s^2)	t_c (s)	t_f (s)
Reduced Speed Areas	Default Value			V_{50th}* = 13.2; V_{85th}* =18.0	4.19		
	Value in Sensitivity Analysis	Experiment ID	11	V_{50th} = 13.2; V_{85th} =18.0	1.19	4.84 (0.26)	2.84 (0.45)
			12	V_{50th} = 13.2; V_{85th} =18.0	3.19	4.88 (0.28)	2.84 (0.44)
			13	V_{50th} = 13.2; V_{85th} =18.0	4.19	4.90 (0.19)	2.84 (0.43)
			14	V_{50th} = 13.2; V_{85th} =18.0	5.19	4.92 (0.29)	2.84 (0.44)
			15	V_{50th} = 13.2; V_{85th} =18.0	7.19	4.91 (0.31)	2.83 (0.43)
			16	V_{50th} = 8.2; V_{85th} =13.0	4.19	4.75 (0.15)	3.34 (0.58)
			17	V_{50th} = 11.2; V_{85th} =16.0	4.19	4.80 (0.18)	3.02 (0.50)
			18	V_{50th} = 13.2; V_{85th} =18.0	4.19	4.90 (0.19)	2.84 (0.43)
			19	V_{50th} = 15.2; V_{85th} =20.0	4.19	4.95 (0.21)	2.77 (0.45)
			20	V_{50th} = 18.2; V_{85th} =23.0	4.19	5.09 (0.26)	2.72 (0.47)

				Parameter		Result	
				Additive Part of Safety Distance	Multiplicative Part of Safety Distance	t_c (s)	t_f (s)
Wiedemann 74 model	Default Value			2.0	3.0		
	Value in Sensitivity Analysis	Experiment ID	21	2.0	1.5	4.89 (0.21)	2.60 (0.40)
			22	2.0	2.5	4.87 (0.20)	2.76 (0.43)
			23	2.0	3.0	4.90 (0.19)	2.84 (0.43)
			24	2.0	3.5	4.88 (0.19)	2.92 (0.45)
			25	2.0	4.5	4.90 (0.19)	3.08 (0.47)
			26	1.0	3.0	4.84 (0.20)	2.53 (0.43)
			27	1.5	3.0	4.85 (0.20)	2.68 (0.42)
			28	2.0	3.0	4.90 (0.19)	2.84 (0.43)
			29	2.5	3.0	4.93 (0.21)	3.01 (0.44)
			30	3.0	3.0	4.93 (0.20)	3.17 (0.44)

** t_c denotes critical gap; t_f denotes follow-up headway; () denotes standard deviation; V50th denotes 50th percentile speed; V85th denotes 85th percentile speed.*


t_c vs. Minimum Gap for Priority Rule
y = 3.2473ln(x) + 0.17
R² = 0.9998
Critical Gap (s)
Minimum Gap Setting for Priority Rule (s)
Critical Gap
(a)
t_f vs. Minimum Gap for Priority Rule
Follow-up Headway (s)
Minimum Gap Setting for Priority Rule (s)
Follow-up Headway
(b)
t_c vs. Deceleration Rate for RSA
(Speed Distribution Setting for RSA: V50th = 13.2 mph; V85th = 18 mph)
Critical Gap (s)
Deceleration Rate Setting for RSA (ft/s²)
Critical Gap
(c)
t_f vs. Deceleration Rate for RSA
(Speed Distribution Setting for RSA: V50th = 13.2 mph; V85th = 18 mph)
Follow-up Headway (s)
Deceleration Rate Setting for RSA (ft/s²)
Follow-up Headway
(d)
t_c vs. Speed Distribution for RSA
(Deceleration Rate Setting for RSA: a = 4.19 ft/s²)
y = 0.0345x + 4.4428
R² = 0.9703
Critical Gap (s)
50th Percentile Speed Setting for RSA (mph)
Critical Gap
(e)
t_f vs. Speed Distribution for RSA
(Deceleration Rate Setting for RSA: a = 4.19 ft/s²)
y = 0.007x² - 0.2465x + 4.8935
R² = 0.998
Follow-up Headway (s)
50th Percentile Speed Setting for RSA (mph)
Follow-up Headway
(f)
t_c vs. Multiplicative Setting for Wiedemann 74
(Additive Setting for Wiedemann 74 Model = 2)
Critical Gap (s)
Multiplicative Setting for Wiedemann 74 Model
Critical Gap
(g)
t_f vs. Multiplicative Setting for Wiedemann 74
(Additive Setting for Wiedemann 74 Model = 2)
y = 0.16x + 2.35
R² = 1
Follow-up Headway (s)
Multiplicative Setting for Wiedemann 74 Model
Follow-up Headway
(h)



(i) **(j)**

Figure 4: Plotting of the sensitivity analysis results

3.2 Results of RSA

Although the location, speed distribution, and deceleration rate of RSA have been determined using field observation in the previous section, sensitivity analyses of RSA settings were still required to investigate how these settings would quantitatively impact the roundabout capacity. The analysis was comprised of two sets of sensitivity analyses.

The first set was designed to test the impact of RSA's deceleration rate on the roundabout capacity. In the analysis, the RSA's speed distribution remained the default value (i.e., 50th percentile speed = 13.2 mph and 85th percentile speed = 18.0 mph). Five different deceleration rates, ranging from 1.19 ft/s^2 to 7.19 ft/s^2, were tested in the analysis. Figures 4.c and 4.d illustrate the results of the deceleration rate's impact on critical gap and follow-up headway, respectively. According to Figure 4.c, increasing the deceleration rate did not change the critical gap significantly. Similar results were found for follow-up headway according to Figure 4.d.

The second set of analysis was designed to test the impact of RSA's speed distribution setting on the roundabout capacity. In the analysis, the RSA deceleration rate remained at the default value (i.e., deceleration rate = 4.19 ft/s^2). Five different speed distributions with 50th percentile speed ranging from 8.2 mph to 18.2 mph were tested in the analysis. Figures 4.e and 4.f illustrate the analysis results. Figure 4.e showed that increasing the 50th and 85th percentile speeds in the speed distribution significantly increased the critical gap. Through regression analysis, a linear relationship between the 50th percentile speed and the critical gap was identified, represented by the following equation:

$$\begin{aligned} t_c &= 0.0345 v_{50th} + 4.4428 \\ R^2 &= 0.9703 \end{aligned} \qquad (3)$$

Where t_c is critical gap (s), and v_{50th} is 50th percentile speed in the RSA's speed distribution setting (mph).

In regards to follow-up headway, increasing the 50th and 85th percentile speeds in the speed distribution for RSA was found to significantly reduce the follow-up headway as shown in Figure 4.f. The increment in the 50th percentile speed tended to reduce the follow-up headway in a polynomial form. Through regression analysis, the relationship between the 50th percentile speed and the follow-up headway was represented by the following equation:

$$t_f = 0.007v^2_{50th} - 0.2465v_{50th} + 4.8935 \qquad (4)$$
$$R^2 = 0.998$$

Where t_f is follow-up headway (s), and v_{50th} is 50th percentile speed in the RSA's speed distribution setting (mph).

3.3 Results of Wiedemann 74 Model

In VISSIM, the W74M includes two important adjustable parameters. Namely, the additive and multiplicative parts of the safety distance. Therefore, the analysis of the W74M was comprised of two sets of sensitivity analyses. The first set was designed to test the impact of the multiplicative setting on the roundabout capacity. In the analysis, the additive setting remained at the default value (i.e., additive = 2.0). Five different multiplicative settings, ranging from 1.5 to 4.5, were tested in the analysis. Figures 4.g and 4.h illustrate the results of the multiplicative setting's impact on critical gap and follow-up headway, respectively. According to Figure 4.g, increasing the multiplicative setting did not change the critical gap significantly. However, it did have significant impact on the follow-up headway according to Figure 4.h. The follow-up headway increased linearly with the multiplicative setting. Regression analysis summarized the relationship between the multiplicative setting and the follow-up headway using the following equation:

$$t_f = 0.16m + 2.35 \qquad (5)$$
$$R^2 = 1$$

Where t_f is follow-up headway (s), and m is the multiplicative part of the safety distance for the W74M.

The second set of analysis was designed to test the impact of the additive setting on the roundabout capacity. In the analysis, the multiplicative setting remained at the default value (i.e., multiplicative = 3.0). Five different additive settings, ranging from 1.0 to 3.0, were tested in the analysis. Figures 4.i and 4.j illustrate the analysis results. It was identified from Figure 4.i that increasing the additive setting slightly increased the critical gap. Through regression analysis, a linear relationship between the 50th percentile speed and the critical gap was identified, and represented by the following equation:

$$t_c = 0.052a + 4.786 \qquad (6)$$
$$R^2 = 0.9135$$

Where t_c is critical gap (s), and a is the additive part of the safety distance for the W74M.

Increasing the additive setting was found to increase the follow-up headway in a linear form according to Figure 4.j. The magnitude of increment in follow-up headway is 0.32 s per unit increment in the additive setting. Through regression analysis, the relationship between the 50th percentile speed and the follow-up headway was represented by the following equation:

$$t_f = 0.322a + 2.202 \qquad (7)$$
$$R^2 = 0.9996$$

Where t_f is follow-up headway (s), and a is additive part of the safety distance for the W74M.

4 CALIBRATION GUIDANCE

The following recommendations have been made for calibrating VISSIM roundabout models based on the sensitivity analysis results:

- The entrance RSA is recommended to be placed at approximately 8 feet from the yield line, and the length of the RSA is 17 feet. The speed distribution setting is recommended to conform to the speed cumulative curve shown in Figure 2.c. Since the RSA’s deceleration rate setting does not impact the roundabout capacity, the deceleration rate can vary to adapt to the actual approach speed of a specific roundabout.
- Speed distribution of RSA and the additive setting for W74M are *not* recommended to be used in calibrating the roundabout model, as they impact both the critical gap and follow-up headway simultaneously. Using these two parameters will make the calibration hard to control. Therefore, the RSA’s speed distribution and the additive setting for W74M are recommended to remain at default values during the calibration.
- Minimum gap for PR impacts the critical gap only, and hence is recommended to be used in calibrating the critical gap. The critical gap can be calculated by inputting the minimum gap into Equation (2).
- The multiplicative setting for W74M impacts the follow-up headway only, and hence is recommended to be used in calibrating the follow-up headway. The follow-up headway can be calculated using Equation (5) and a multiplicative input.

5 VALIDATION OF THE CALIBRATION GUIDANCE

Using the study site as a case study, the effectiveness of the calibration recommendations developed in the previous section is validated in this section.

According to Table 1, the study entrance lane (i.e., NB left lane of De Pere roundabout) had a field-observed critical gap of 4.3 s and follow-up headway of 3.1 s. In the validation process, the study lane’s critical gap and follow-up headway were attempted to be calibrated following the calibration recommendations. Specifically, the minimum gap of 3.6 s and the multiplicative value of 4.7 were used based on Equations (2) and (5) in order to obtain the 4.3 s critical gap and the 3.1 s follow-up headway. All other VISSIM parameters remained at default values as summarized in Table 2. Validation results obtained from 150 simulation runs showed that the resultant critical gap and follow-up headway after calibration were 4.31 s and 3.09 s, respectively. Both numbers were almost identical to the calibration goal. Figure 5 further illustrates the validation of the calibrated simulation model by comparing the simulated capacity cloud (i.e., plots of entering flow vs. circulating flow) with the field-observed ground-truth capacity cloud.

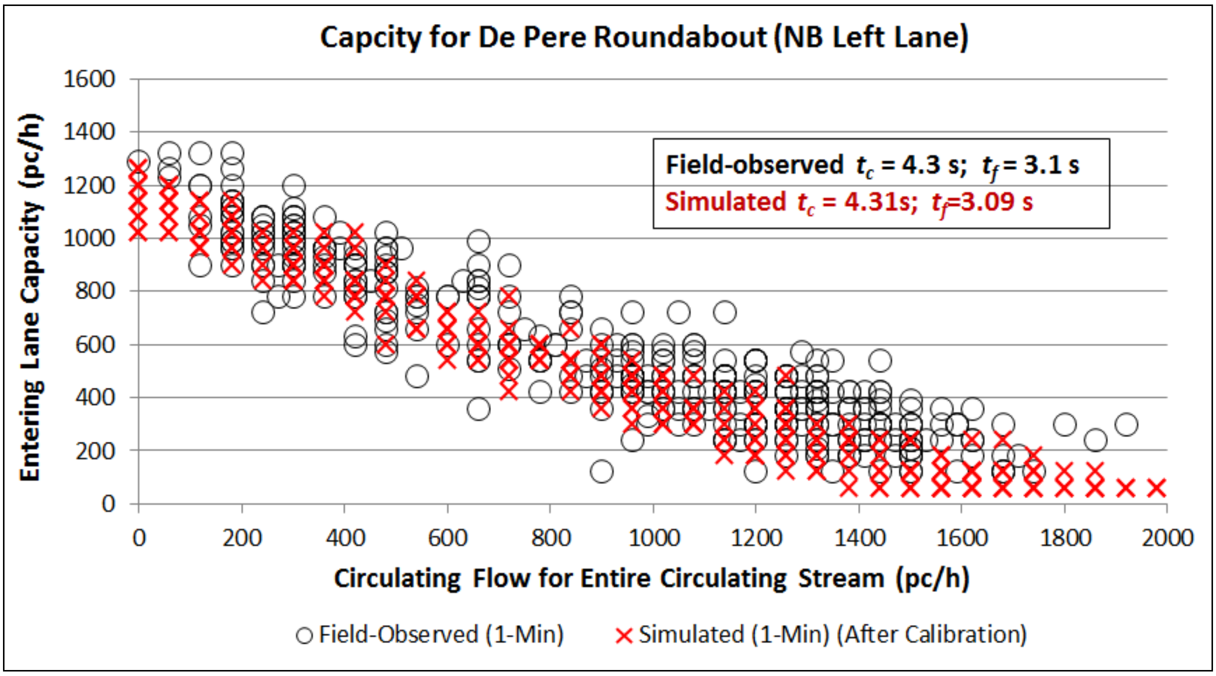


Figure 5: Validation of the roundabout simulation model

According to Figure 5, the capacity cloud obtained from the calibrated simulation model matches very well with the field-observed capacity cloud, which indicates that the VISSIM roundabout model was successfully calibrated. Based on these validation results, the proposed calibration recommendations for VISSIM roundabout models demonstrated their applicability in calibrating VISSIM roundabout models.

6 CONCLUSIONS

In summary, the paper tries to develop simple and numerical calibration recommendations based on the comprehensive discussion of the calibration process. Despite the complex process of developing such recommendations, the final product is simple and it provides formulated solutions to researchers and practitioners to simplify their calibration of VISSIM roundabout models. The limitation is that the calibration recommendations were validated based on data from only one roundabout. Future research will focus on investigating the transferability of the proposed calibration recommendations via exploring more study sites in the validation process.

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