SENSITIVITY ANALYSIS IN TRAFFIC MICROSCOPIC SIMULATION MODEL FOR ROUNDABOUTS

Rosolina Vaiana, Vincenzo Gallelli, Teresa Iuele

Dept of Civil Engineering, University of Calabria, Via P. Bucci, cubo 46/B, 87036 Arcavacata di Rende (CS), Italy
E-mails: 1vaiana@unical.it; 2vincenzo.gallelli@unical.it; 3teresa.iuele@unical.it

Abstract. In the literature, many analytical techniques allow the study of the performance (capacity, queues, delays, etc) of roundabouts which are divided into two groups: analytical models and microscopic simulation models. Each method, when formulated, has to consider some aspects of roundabout circulation in comparison to others (geometric elements, vehicular flow and user behaviour). In particular, microscopic simulation models offer several advantages, compared to analytical ones (such as realistic modelling of vehicle arrivals and departures or the ability to study the spatial extent of queues), but they must be carefully calibrated. In this paper the authors introduce the results of a large survey conducted on an ample range of roundabout scenarios through the application of VISSIM simulation software. Each scenario describes a fixed roundabout phenomenon using geometric elements (inscribed circle radius, circular roadway, central and splitter islands etc.) and characteristics of the traffic flow (density, distribution, crossing and approach speeds, etc.) as variables. The results allow authors to evaluate the effects of these parameters on roundabout stop-line delays through a significance analysis.

Keywords: roundabout, microsimulation models, stop-line delay, queues, analysis of variance, driver behaviour.

1. Introduction

Microscopic simulation models contain many independent parameters to describe driver behaviour and traffic control operations. These models provide a default value for each parameter, but also allow users to change the values to simulate local traffic conditions. However, along with a more and more refined analysis of micro-simulation algorithms, it is frequently necessary for the user (researcher, engineer, planner, etc.) to understand the real sensitivity of these packages to the most important key parameters.

This study evaluates the effect of geometric and behavioural parameters in the simulation of roundabouts by an analysis of variance. In fact, ANOVA analysis of variance is a good statistical methodology in order to evaluate the influence of several control factors with different levels on a response variable (Montgomery 1997). Therefore, three different sets of scenarios, for single-lane roundabouts were analyzed using the VISSIM (Vissim Manual User 2005) micro-simulator: R-scenarios, I-scenarios and C-scenarios. Inscribed circle radius, splitter island width and circulating roadway width are the variables of each scenario respectively, while traffic flow, approach speed and time gap are imposed as parameters for each scenario. Overall, 432 scenarios were analyzed. Based on statistical evaluations, the impact of individual factors on simulation stop-line delay for each set of scenarios was investigated in this study. Several of the geometric and driver behaviour parameters were found to exert significant individual influence on roundabout performance.

2. Literature review

Several software packages provide roundabout analysis capabilities using various theoretical methods requiring a variety of input parameters (Gallelli, Vaiana 2008). However, only a few of these parameters have significant effects on analysis results (Nikolic et al. 2010). Therefore this part of the research focuses on previous studies that examined the influence of these factors in different roundabout simulation models.

The NCHRP (Rodegerdts 2004) presented a study that compared capacity and delay estimates produced by RODEL and aaSIDRA in different roundabouts situated in the USA: 10 single-lane and 6 multilane sites. The analysis of results showed that, with queues under a minute, RODEL's delay was excessive, whereas aaSIDRA estimates were lower; instead, with queues persisting for over the minute both RODEL and aaSIDRA delays were typically low. This may be due to the fact that RODEL is based on UK empirical data whereas aaSIDRA is based on gap theory, and so they two produce different results.
different simulation models provide different sets of adjustable parameters and, generally, PARAMICS has the least calibration parameters, whereas CORSIM and VISSIM have more calibration parameters.

Therefore, after this brief digression, it is possible to conclude that it is important to understand the definition and impact of each parameter in order to obtain realistic output from the simulations.

3. Roundabout Microscopic Simulation Model

3.1. VISSIM software

The simulation of roundabout traffic operations often presents many complexities, because it is not easy to define all the geometric and user-behavioural features. VISSIM gives a flexible platform that allows the user to model a roundabout more realistically. It is based on a link-connector instead of a link-node structure which is easily able to build a complete network or, specifically, a single intersection. In addition, VISSIM is able to import CAD layout (dxf or jpg) and to set it as a background on which draw links. An appropriate scale is assigned, so that all the measurements are in the same units. In this way, for example, it allows all the geometric elements of a roundabout (splitter islands, lane width, number of lanes, entry width, etc.) to be precisely drawn (Trueblood, Dale 2003). There are three principal features which are very important to be set for a correct simulation:

- vehicle speeds (approach speed, circulatory speed and reduced speed zones);
- priority rules;
- traffic assignment.

Furthermore, the driver behaviour is also important: VISSIM uses a psycho-physical car-following model and a rule-based algorithm for lateral movements realized by Wiedemann (1974).

3.2. Vehicle speeds: approach speed, circulatory speed and reduced speed zones

An accurate definition of vehicle speeds is very important to achieve a good simulation of a roundabout.

VISSIM allows the desired speed of every type of vehicle when the said vehicle enters the network to be defined. The approach speed of every leg of the roundabout is taken in a range defined by an empirical speed curve which is created by the user: this curve usually presents an S-form (normal distribution). As reported in the VISSIM manual user, the vehicles maintain the desired speed until traffic conditions or geometric features require them to change it. VISSIM uses reduced speed zones in order to change the desired speed: these zones have been used to set the influence of roundabout entry geometry on the approach speed. The reduced speed zones assign a new speed distribution to the vehicles which begin to decelerate ($a = 2.0 \text{ m/s}^2$) before the start of the same areas. After the end of these zones the vehicles begin to accelerate in order to reach the previous desired speed if the user does not set a new one. Specifically, for roundabouts, after the
reduced speed area at entry, a circulatory speed distribution is set which is derived from vehicle radial dynamics equilibrium:

\[ V = \sqrt{127R(q + f_t)} \]  

(1)

with these assumptions: \( q = 0 \) (transverse inclination); \( f_t = 0.23 \) (side friction factor),

\[ R = R_i - \left( \frac{C_i}{2} \right) \]  

(2)

where \( R_i \) – the inscribed circle radius, m; \( C_i \) – the circulat- 

ing roadway width, m.

This equation allows the average speed (\( V_m \)) of the circulating vehicles into the roundabout to be obtained and the range of the circulatory speed distribution to be set. In fact, considering this as a normal distribution and considering standard deviation \( \sigma = 5 \) km/h (this is derived from field data), it is possible to define the extreme values of the range as \( V_m \pm (1.96\sigma) \) in order to consider the 95th percentile of the circulatory speed (Capiluppi et al. 2006; Praticò et al. 2012; Vaiana, Gallelli 2011).

3.3. Priority rules

The most important aspect of roundabout modelling in VISSIM is the correct definition of the priority rules for entering and exiting movements (for a one-lane-round-about there are only priority rules for entering vehicles). These rules are based on two fundamental parameters: min gap time and min headway.

A vehicle, which is standing at the stop-line, enters the circulatory roadway only when the time gap and headway measured from the conflict markers are greater than the relative min values. A priority rule is usually composed of a stop line and one or more conflict markers.

It is possible to set different values of headway for any type of vehicle or of min gap (this parameter is very important in VISSIM, as it will be shown in experimental results), but in this case only traffic flows measured in “equivalent vehicles per hour” are considered.

3.4. Traffic assignment

As traffic input data, VISSIM uses only an O/D matrix, which contains the number of movements for each origin/destination (space distribution of traffic flows) during a specific time range. The flow-time curve is fixed by the operator.

4. Experimental planning

The study proposed was conducted through the use of the VISSIM micro-simulator (release 4.3).

The Software requires specification of many input parameters (Tables 1 and 2 in particular):

- distribution and assignment of traffic flow in time and space. In the experimental planning introduced in this paper, four separate traffic flows \( TF_i \) (with \( i = 1, \ldots, 4 \) – only motorcars) were considered (Table 1). They were distributed in time according to a flow-time curve of traffic demand obtained from a theoretical curve (Vaiana, Gallelli 2011; Vaiana et al. 2007). \( TF_i \) is the total entering flow of an approach during an hour. For each traffic flow, four different O/D matrixes were created: one for every quarter of an hour. This entering flow was distributed as follows: first quarter: \( TF_{15min} = 0.3TF_i \); second quarter: \( TF_{30min} = 0.4TF_i \); third quarter: \( TF_{45min} = 0.2TF_i \); fourth quarter: \( TF_{60min} = 0.1TF_i \). Space distribution of traffic flows was completely represented by means of O/D matrixes with a balanced traffic flow distribution;

- implementation of circulation rules: approach speed, reduced speed zones, circulatory speed zones and priority rules;

- setting up of scenarios to be analyzed (choice of geometric and traffic variables).

Recorded outputs are represented by the average stop-line delay. The stop-line delay is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. According to the VISSIM manual user, the theoretical travel time is the time that would be reached if there were no

| Parameters | Traffic flow | Approach speed | Time gap |
|------------|-------------|----------------|----------|
| Identification | Value, vph | Identification | Value, km/h | Identification | Value, s |
| \( TF_1 \) | 350 | \( S_1 \) | 30–40 | \( TG_1 \) | 3.0 |
| \( TF_2 \) | 500 | \( S_2 \) | 40–50 | \( TG_2 \) | 3.5 |
| \( TF_3 \) | 600 | \( S_3 \) | 50–60 | \( TG_3 \) | 4.0 |
| \( TF_4 \) | 650 | – | – | – | – |

Notes: Only motorcars

- For circulatory speed 15–50 km/h:
  - critical gap = \( TG_i \) with \( i = 1, 2, 3, \)
  - headway = 5 m.
- For circulatory speed < 15 km/h:
  - critical gap is ignored;
  - headway = 5 m.
5. Scenarios development

Three separate sets of scenarios for single-lane roundabouts were developed and analyzed (Fig. 1), in total 432 scenarios:

- **R-scenarios** have the following variables: traffic flow \((T_{Fi})\), approach speed \((S_i)\), inscribed circle radius \((R_i)\), time gap \((T_{Gi})\);

- **I-scenarios**. They have the following variables: traffic flow \((T_{Fi})\), approach speed \((S_i)\), splitter island width \((I_i)\), time gap \((T_{Gi})\);

- **C-scenarios**. They have the following variables: traffic flow \((T_{Fi})\), approach speed \((S_i)\), circulating roadway width \((C_i)\), time gap \((T_{Gi})\).

Fig. 2 shows a VISSIM screenshot of the modelled roundabouts. The Fig. 2 highlights particular features (with different colours) such as: desired speed sections; reduced speed areas; conflict markers and stop lines (Vaiana et al. 2012).

6. Experimental results and ANOVA of operational parameters

VISSIM, as all micro-simulation software programs, simulates traffic in a one-shot simulation, therefore, ten simulations were made for each set of scenarios (multiple-run
simulations with running time of one hour for each simulation) in order to provide a 95% confidence in stop-line delays with a confidence interval of ± 1.00 s.

A travel time route was coded for each approach in order to obtain delay (data collection points placed on the stop line of the entries). Having considered only balanced traffic flow distributions the final value of delay for each scenario is the average of all the values calculated for the multiple-run simulations and for all the four legs of the roundabout. Furthermore, for each set of scenarios, an analysis of variance was conducted in order to identify model inputs whose impact on stop-line delay is statistically significant.

6.1. Main results and analysis of variance for R-scenarios

The R-scenarios are characterized by the following geometric variable: inscribed circle radius \((R_i)\). An Analysis of Variance (ANOVA) realized with MINITAB 15.0 (Ryan 2007) was performed to determine which factors (inscribed circle radius \((R_i)\), critical gap \((T_{Gi})\), approach speed \((S_i)\) and traffic flow \((T_{Fi})\)) significantly affect the measured stop-line delay \((W_s)\). These results are presented in Table 3.

Based on the results, only three factors and three interactions had a significant effect on the stop-line delay (only second order interactions were considered as reported in the literature) (Cunto, Saccomanno 2008). Therefore, between the first order factors only speed was found to be not statistically significant at the 5% level.

Stop-line delays are shown in Fig. 3 as a function of \(R_i\), \(T_{Gi}\), \(S_i\), and \(T_{Fi}\).

![Fig. 2. VISSIM screenshot of the modelled roundabout](image1)

![Fig. 3. Main plots for stop-line delays in R-scenarios](image2)

It follows from these plots that:
- for all the considered R-scenarios, the approach speed shows no specific influences on stop-line delay;
- if critical gap increases, stop-line delay increases;
- if traffic flow increases, stop-line delay increases;
- when the inscribed circle Radius grows, stop-line delays slowly increase.

Interaction plots for average stop-line delays are shown in Fig. 4.

From these plots, it is possible to make several conclusions:
- as was previously shown in ANOVA (Table 3), approach speed \(S_i\) compared to the other factors \(R_i\), \(T_{Gi}\), and \(T_{Fi}\) seems not to influence the stop-line delays;
- considering the effect of the combined interaction between \(T_{Gi}\) and \(T_{Fi}\) on stop-line delay, it is possible to note that, for \(T_{Gi} = 3.0\) s, the growth of \(T_{Fi}\) begins to influence appreciably stop-line delay only for \(T_{Fi} = 650\) vph, whereas for \(T_{Gi} = 3.5\) s and

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Sign. |
|--------|----|--------|--------|--------|---|---|-------|
| \(R_i\) | 3  | 4190.9 | 4190.9 | 1397.0 | 48.38 | 0.000 | Yes |
| \(T_{Gi}\) | 2  | 94 278.7 | 94 278.7 | 47 139.4 | 1632.50 | 0.000 | Yes |
| \(S_i\) | 2  | 172.7 | 172.7 | 86.3 | 2.99 | 0.055 | No |
| \(T_{Fi}\) | 3  | 123 230.6 | 123 230.6 | 41 076.9 | 1422.54 | 0.000 | Yes |
| \(R_i\), \(T_{Gi}\) | 6  | 2531.8 | 2531.8 | 422.0 | 14.61 | 0.000 | Yes |
| \(R_i\), \(S_i\) | 6  | 52.3 | 52.3 | 8.72 | 0.30 | 0.935 | No |
| \(R_i\), \(T_{Fi}\) | 9  | 2731.5 | 2731.5 | 303.5 | 10.51 | 0.000 | Yes |
| \(T_{Gi}\), \(S_i\) | 4  | 82.3 | 82.3 | 20.6 | 0.71 | 0.585 | No |
| \(T_{Gi}\), \(T_{Fi}\) | 6  | 50 889.3 | 50 889.3 | 8481.5 | 293.73 | 0.000 | Yes |
| \(S_i\), \(T_{Fi}\) | 6  | 105.3 | 105.3 | 17.6 | 0.61 | 0.723 | No |
| Error | 96 | 2772.1 | 2772.1 | 28.9 | | | |
| Total | 143 | 281 037.3 | | | | | |
TG_3 = 4.0 s, an increase of TF_i involves a great increase of W_s; 
still considering the effect of the interaction between TGi and Ri on the stop-line delay, it is possible to underline that, for T Gi = 3.0 s, the increase of Ri has no noticeable influence on W_s; instead for T Gi = 3.5 s and T Gi = 4.0 s, when Ri increases, stop-line delay increases too. All this seem a contradiction, but it is necessary to consider that, in general, in accordance with Eq (1) when Ri increases, circulatory speed increases as well (max ΔSpeed ≈ 9 km/h). Even more important is that when Ri increases, the length of circulatory roadway increases (average ΔLength ≈ 95 m).

What was stated above implies that there is a greater rate of vehicular occupation of the circulatory roadway, if combined both with the increase of traffic and the car-following model (not modified by the authors with respect of default parameter). As a direct consequence of this it happens that the average spacing among the vehicles is the smallest (Montgomery 1997). In fact, considering the effect of the combined interaction between TGi and TF_i on stop-line delay, it is possible to point out that when Ri grows together with TF_i, the stop-line delay, on the whole, increases.

6.2. Main results and analysis of variance for I-scenarios

The I-scenarios are characterized by the following geometric variable: width of splitter island (Ii). An Analysis of Variance (ANOVA) was performed to determine which factors (width of splitter island (Ii), critical gap (T Gi), approach speed (Si) and traffic flow (TF_i)) significantly affect the measured stop-line delay (W_s).

Based on the results, only three factors and three interactions had a significant effect on the stop-line delay (it was only considered second order interactions as reported in the literature) (Cunto, Saccomanno 2008). Therefore, between the first order factors, only speed was found to be not statistically significant at the 5% level.

Stop-line delays are shown in Fig. 5 as a function of Ii, T Gi, Si, TF_i.

From these plots, it is possible to make the following considerations:
for all the considered $I$-scenarios, the approach speed shows no particular influences on stop-line delay;

− if critical gap increases, stop-line delay increases;

− if traffic flow increases, stop-line delay increases;

− when the width of splitter island grows, stop-line delays decrease appreciably.

Interaction plots for average stop-line delays are illustrated in Fig. 6. The interaction plots graphically show how the factors affect the stop-line delay. The observation of the interaction plots leads to the several conclusions:

− as showed before in ANOVA (Table 4), the effect of approach speed $S_i$ with respect to the other factors ($I_i$, $TG_i$, and $TF_i$) show no kind of influence on stop-line delay;

− considering the effect of the combined interaction between $TG_i$ and $TF_i$ on stop-line delay, it is possible to note that if $TF_i$ increases then $W_s$ also increases; in particular, for $TG_2 = 3.5$ s and for $TG_3 = 4.0$ s, the increase of $W_s$ is more marked when traffic flow varies from 500 vph to 650 vph;

− considering the effect of the combined interaction between $I_i$ and $TF_i$ on stop-line delay, if $TF_i$ increases then $W_s$ also increases; in particular, for each value of $I_i$ the increase of $W_s$ is more marked when traffic flow passes from 500 vph to 600 vph;

− considering the influence of $TG_i$ combined with $I_i$ on stop-line delay, it is possible to underline that when $I_i$ increases, $W_s$ decreases; this decrement is more evident with $TG_2$ and $TG_3$.

In brief, for $TF_i$ (with $i = 1, 2, 3$) and for $TG_i$ (with $i = 1, 2, 3$) the stop-line delay values seem to converge to a value for $I_4 = 15$ m: the simulation model seems to interpret well some "historic" and consolidated indications in the literature (Louah 1987).

However, it is important to emphasize that in the design practice, if the splitter island is excessively great, it is possible to involve risky shortenings of waving section along the circulatory roadway.

According to the Rodegerdts et al. (2010), more roundabouts have also been used successfully at the interface between rural and urban areas where speed limits change. In these applications, if the splitter island is excessively great, the traffic calming effects of roundabouts are minimized (Isebrands, Hallmark 2012).

### 6.3. Main results and analysis of variance for $C$-scenarios

The $C$-scenarios are characterized by the following geometric variable: width of circulating roadway ($C_i$). An ANOVA was performed to determine which parameters (width of circulating ($C_i$), critical gap ($TG_i$), approach speed ($S_i$) and traffic flow ($TF_i$)) significantly affect the measured stop-line delay ($W_s$). Results from the ANOVA are presented in Table 5.

The results show that three of the four factors and three interactions have a significant effect on $W_s$. Traffic flow has the most impact followed by time gap and width of circulating roadway, based on the F-statistic (Ryan 2007). Therefore, approach speed has no significant effect on the average of stop-line delay. This means that the variation of $S_i$ will produce no increase or decrease of stop-line delay.
Stop-line delays are shown in Fig. 7 as a function of $C_i$, $TGi$, $Si$, $TFi$.

From these plots, it is possible to affirm that:

− for all the considered $C$-scenarios, the approach speed exhibits no particular influences on stop-line delay;
− if critical gap increases, stop-line delay increases;
− if traffic flow increases, stop-line delay increases;
− when the width of circulating roadway grows, stop-line delays slowly decrease.

The results reported are correlated with some important parameter settings used in VISSIM: only one lane in circulatory roadway, vehicle in free flow in middle position within the lane, no overtaking in the same lane.

Interaction plots for average stop-line delays are shown in Fig. 8.

From the observation of the interaction plots, it is possible to draw several conclusions:

− as showed before in ANOVA (Table 5), approach speed $S_i$ compared to the other factors ($C_i$, $TGi$ and $TFi$) exhibits no kind of influence on stop-line delay;
− considering the effect of the combined interaction between $TGi$ and $TFi$ on stop-line delay, it is possible to note that, if $TFi$ increases then $W_s$ also increases; in

| Source     | DF | Seq SS  | Adj SS | Adj MS  | F      | P      | Sign. |
|------------|----|---------|--------|---------|--------|--------|-------|
| $TGi$      | 2  | 89 945.5| 89 945.5| 44 972.8| 3040.03| 0.000  | Yes   |
| $C_i$      | 4  | 3576.8  | 3576.8 | 894.2   | 60.45  | 0.000  | Yes   |
| $S_i$      | 2  | 67.0    | 67.0   | 33.5    | 2.26   | 0.108  | No    |
| $TF_i$     | 3  | 223 891.6| 223 891.6| 74 630.5| 5044.82| 0.000  | Yes   |
| $TGiC_i$   | 8  | 316.0   | 316.0  | 39.5    | 2.67   | 0.010  | Yes   |
| $TGiS_i$   | 4  | 9.8     | 9.8    | 2.4     | 0.17   | 0.955  | No    |
| $TGiTF_i$  | 6  | 42 089.6| 42 089.6| 7014.9  | 474.19 | 0.000  | Yes   |
| $C_iS_i$   | 8  | 74.5    | 74.5   | 9.3     | 0.63   | 0.752  | No    |
| $C_iTF_i$  | 12 | 1276.7  | 1276.7 | 106.4   | 7.19   | 0.000  | Yes   |
| $S_iTF_i$  | 6  | 64.4    | 64.4   | 10.7    | 0.73   | 0.630  | No    |
| Error      | 124| 1834.4  | 1834.4 | 14.8    |        |        |       |
| Total      | 179| 363 146.3|        |        |        |        |       |

Fig. 7. Main plots for stop-line delays in $C$-scenarios

Fig. 8. Interaction plots for stop-line delays in $C$-scenarios
particular, for $TG_2 = 3.5\ s$ and for $TG_3 = 4.0\ s$, the increase of $W_i$ is more marked when traffic flow varies from 500 vph to 600 vph;

– considering the effect of the combined interaction between $C_i$ and $TF_i$ on stop-line delay, if $TF_i$ increases then $W_i$ also increases; but in this case, for each $TF_i$, the increase of $W_i$ is the same for each values of $C_i$;

– considering instead the influence of $TG_i$ combined with $C_i$ on stop-line delay, it’s possible to note that when $C_i$ increases, $W_i$ slowly decreases; in particular this decrease is really low for $TG_1 = 3.0\ s$.

7. Conclusions

In this paper different geometric and behavioural parameters in the simulation of roundabouts were compared: an analysis of variance has shown which factors were statistically significant. In this way ANOVA represents a good statistical methodology that allows the evaluation of the influence of several control factors with different levels on a response variable. Therefore, three different sets of scenarios for single-lane roundabouts were analyzed by a micro-simulator: $R$-scenarios, $I$-scenarios and $C$-scenarios. Inscribed circle radius, splitter island width and circulating roadway width respectively represented the variables of each scenarios, while traffic flow, approach speed and time gap were imposed as parameters for each scenario. Overall, 432 scenarios were analyzed.

The statistical interpretation of results has allowed interesting correlations to be obtained between stop-line delay, geometric variables and parameters of simulation coding, such as:

– $R_i$, inscribed circle radius has no noticeable influence on stop-line delay, $W_i$;

– the dimension of the splitter island, $I_p$ significantly affects the measured stop-line delay, in particular for high traffic flows;

– when the width of circulating roadway $C_i$ grows, stop-line delays slowly decrease;

– for all the three sets of scenarios it is possible to note a strong dependence of the $W_i$ on the value of the time gap assumed, especially for high traffic flows;

– at last, for all the three sets of scenarios the approach speed seems to have no particular influences on stop-line delay. This consideration is probably due to the use of a fixed distribution of traffic flow in time and space with theoretical curves based on balanced O/D matrices. In fact, in a recent studies using experimental real O/D matrices measured minute by minute, the vehicle speeds (approach speed, reduced speed zones and circulatory speed zones) seemed to be a highly significant parameters in the simulation procedure. This is why the comparison among field and micro-simulation data resulted very important. In fact, this evaluation allows the setting of the micro-simulator inputs to be adequate.

References

Bared, J.; Edara, P. K. 2005. Simulated Capacity of Roundabouts and Impact of Roundabout within a Progressed Signalized Road, in Proc. of the TRB National Roundabout Conference. May 22–25, 2005, Vail, Colorado.

Capiluppi, G. F.; Gallelli, V.; Vaiana, R. 2006. Interezioni a Raso con Soluzione a Rotatoria Dissimmetrica: Un Caso Di Studio, in Proc. of 16th National SIIV Congress. September 20–22, 2006, Rende, Italy. ISBN 88-7458-051-7.

Cunto, F.; Saccomanno, F. 2008. Calibration and Validation of Simulated Vehicle Safety Performance at Signalized Intersections, Accident Analysis and Prevention 40(3): 1171–1179. http://dx.doi.org/10.1016/j.aap.2008.01.003

Gagnon, C.; Sadek, A. W.; Touchette, A.; Smith, M. 2008. Calibration Potential of Common Analytical and Micro-Simulation Roundabout Models: a New England Case Study, Transportation Research Record 2071: 77–86. http://dx.doi.org/10.3141/2071-10

Gallelli, V.; Vaiana, R. 2008. Roundabout Intersections: Evaluation of Geometric and Behavioural Features with VISSIM, in Proc. of TRB – National Roundabout Conference 2008. Kansas City, Missouri.

Kinzel, C.; Trueblood, M. 2004. The Effects of Operational Parameters in the Simulation of Roundabouts, in The ITE 2004 Annual Meeting and Exhibit. August 1–4, 2004, Lake Buena Vista, Florida.

Isebrands, H.; Hallmark, S. 2012. A Statistical Analysis and Development of a Crash Prediction Model for Roundabouts on High-Speed Rural Roadways, Transportation Research Record 2312: 3–13. http://dx.doi.org/10.3141/2312-01

Louah, G. 1987. Capacite des carrefours giratoires interurbains. Documentation Technique 44, Ministere de l’Equipement du Logement, de l’Amenagement du Territoire et des Transports, Paris.

Montgomery, D. C. 1997. Design and Analysis of Experiments. NewYork: Wiley & Sons. 752 p. ISBN 1118146921.

Nikolic, G.; Pringle, R.; Bragg, K. 2010. Evaluation of Analytical Tools Used for the Operational Analysis of Roundabouts, in The 2010 Annual Conference of the Transportation Association of Canada. June 8–10, 2010, Halifax, Nova Scotia.

Park, B.; Qi, H. 2004. Development and Evaluation of a Calibration and Validation Procedure for Microscopic Simulation Models. Final Contract Report VRTC 05-CR1, Virginia Transportation Research Council, Charlottesville, Virginia.

Praticò, F. G.; Vaiana, R.; Gallelli, V. 2012. Transport and Traffic Management by Micro Simulation Models: Operational Use and Performance of Roundabouts, WIT Transactions on The Built Environment 128: 383–394. http://dx.doi.org/10.2495/UT120331

Rodegerdts, L. 2010. Roundabouts: an Informational Guide. 2nd Edition. Publication NCHRP Report 672. Transportation Research Board 2010 Executive Committee, Washington, D.C.

Rodegerdts, L. 2004. Applying Roundabouts in the United States. Publication NCHRP 3-65, Committee on Highway Capacity and Quality of Service, Washington, D.C.
Ryan, T. P. 2007. Modern Engineering Statistics. 1st edition. John Wiley & Sons, INC., Acworth, Georgia. 608 p. ISBN 0470081872.

Stanek, D.; Milam, R. 2005. High-Capacity Roundabout Intersection Analysis: Going Around in Circles, in Proc. of the TRB National Roundabout Conference. May 22–25, 2005, Vail, Colorado.

Trueblood, M.; Dale, J. 2003. Simulating Roundabouts with VIS-SIM, in The 2nd Urban Street Symposium. July 28–30, 2003. Anaheim, California. Available from Internet: <http://www.urbanstreet.info/2nd_sym_proceedings/Volume%202/Trueblood.pdf>

Vaiana, R.; Gallelli, V.; Iuele, T. 2012. Simulation of Observed Traffic Conditions on Roundabouts by Dedicated Software, Procedia - Social and Behavioral Sciences 53(3): 742–754. http://dx.doi.org/10.1016/j.sbspro.2012.09.924

Vaiana, R.; Gallelli, V. 2011. The Calibration of Traffic Microscopic Simulation Models: Kinematical Approach to the through Movement on Roundabouts, in Proc. of Transportation Research Board 90th Annual Meeting. January 23–27, 2011, Washington, D.C.

Vaiana, R.; Gallelli, V.; Capiluppi, G. F. 2007. Roundabout Intersections: Analysis for Scenarios by Micro-Simulation, in Proc. of 4th International SIIV Congress – Advances in Transport Infrastructures and Stakeholder Expectations. September 12–14, 2007, Palermo, Italy.

Wiedemann, R. 1974. Simulation des Straßenverkehrsflusses. Schriftenreihe des IV, 8, Institut für Verkehrswesen. University of Karlsruhe.

Received 1 June 2011; accepted 23 November 2011