THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2013
8(3): 174–183

SENSITIVITY ANALYSIS IN TRAFFIC MICROSCOPIC SIMULATION MODEL FOR ROUNDABOUTS

Rosolino Vaiana[1], **Vincenzo Gallelli**[2]✉, **Teresa Iuele**[3]

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

ISSN 1822-427X print / ISSN 1822-4288 online doi:10.3846/bjrbe.2013.22
http://www.bjrbe.vgtu.lt

Instead, Kinzel and Trueblood (2004) made a comparison and sensitivity analysis for operational parameters related to roundabouts (such as critical gap, headway, follow-up time and speed) considering different models: HCS, Synchro, aaSIDRA, SimTraffic and VISSIM. This study, simulating a hypothetical roundabout under three volume scenarios (balanced, unbalanced and congested), led to several conclusions: the parameters used in aaSIDRA (critical gap, follow-up headway, intra-bunch headway and O/D factor) had a marked effect on the results; the effect of adjusting headway in SimTraffic was appreciable with lower-flow, but not dramatic, while, in case of congestion, this effect was much more significant; in VISSIM delay was much more sensitive to variations in the gap-acceptance parameters.

Bared and Edara (2005) modelled two high-capacity roundabouts and their integration into smart signalized streams using VISSIM. Then these simulation results were compared to the results of RODEL and aaSIDRA. Finally, the comparison with real data collected from various sites in the USA showed that VISSIM outputs were closer to real data than the RODEL and aaSIDRA results.

The sensibility of several software models is also discussed by Stanek and Milam (2005). They compared the capacity of roundabouts with flared entry and double lanes (a five-legged roundabout and a diamond interchange with roundabouts) obtained from RODEL, aaSIDRA, VISSIM and PARAMICS. The conclusions of this study pointed out that RODEL and aaSIDRA must be used to analyze high-capacity roundabouts only for unsaturated conditions or for isolated locations with standard geometry. Instead, PARAMICS and VISSIM should be used when oversaturated conditions are present in the study area or unique roadway geometry features are present.

Gagnon *et al.* (2008) presented a study where different roundabout models were considered: aaSIDRA, RODEL, PARAMICS, SimTraffic and VISSIM. In this paper, model evaluation was based on comparing approach delay values to actual field delays of two modern roundabouts in New Hampshire (USA). The main conclusions of the research were: among the models considered, VISSIM appeared to be the most versatile, and RODEL seemed to be the least; for aaSIDRA the Environment Factor (EF) appeared to have the most significant impact on the results, whereas for VISSIM, adjusting the minimum acceptable gap was a very powerful tool in calibrating the model; PARAMICS offered a number of calibrating factors, but, in this case, some of these parameters did not impact on the results.

Still considering the effect of operational parameters in the simulation of intersections, Park and Qi (2004) realized a study in which three microscopic traffic simulation models, VISSIM, PARAMICS and CORSIM, were selected for model review and practice of model calibration and validation. The simulation results were compared with the field data of two actuated signalized intersections in the USA to determine the performance of the calibrated models. The final considerations of this work were that 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 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:

$$V = \sqrt{127R(q + f_t)}, \tag{1}$$

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

$$R = R_i - \left(\frac{C_i}{2}\right), \tag{2}$$

where R_i – the inscried circle radius, m; C_i – the circulating 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 σ = 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-roundabout 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,…,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

Table 1. Summary of the imposed values for traffic flow, approach speed and time gap

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.	

Table 2. Summary of the imposed values for the geometric features of the scenarios

Parameters	Inscribed circle radius		Splitter island width		Circulating roadway width	
	Identification	Value, m	Identification	Value, m	Identification	Value, m
	R_1	15.0	I_0	6.0	C_0	6.0
	R_2	20.0	I_1	8.0	C_1	7.0
	R_3	25.0	I_2	10.0	C_2	8.0
	R_4	30.0	I_3	12.0	C_3	9.0
			I_4	14.0	C_4	10.0
Notes:	Only single-lane roundabouts		–		–	

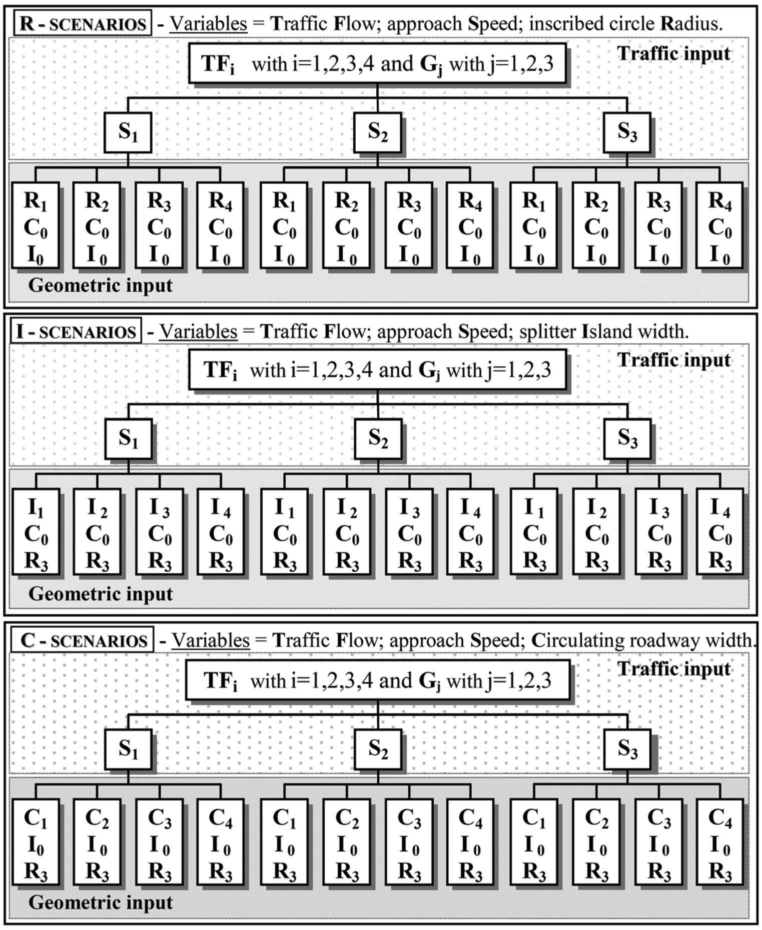

Fig. 1. Sets of scenarios analyzed (Gallelli, Vaiana 2008)

other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account).

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 (TF_i), approach speed (S_i), inscribed circle radius (R_i), time gap (TG_i);

- *I*-scenarios. They have the following variables: traffic flow (TF_i), approach speed (S_i), splitter island width (I_i), time gap (TG_i);
- *C*-scenarios. They have the following variables: traffic flow (TF_i), approach speed (S_i), circulating roadway width (C_i), time gap (TG_i).

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

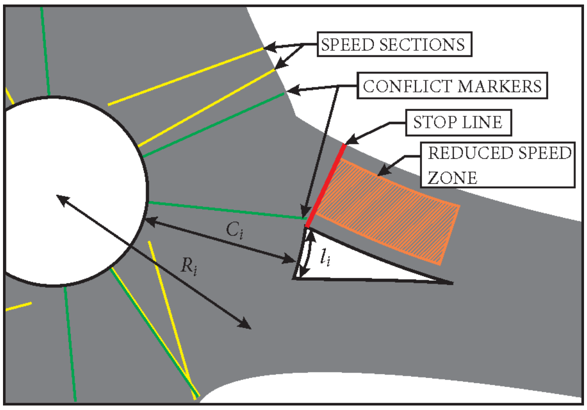

Fig. 2. VISSIM screenshot of the modelled roundabout

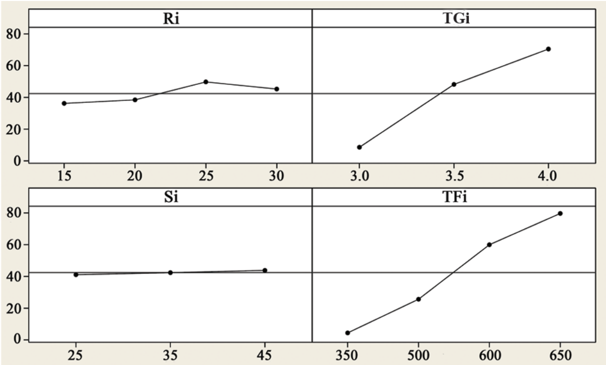

Fig. 3. Main plots for stop-line delays in *R*-scenarios

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 (TG_i), approach speed (S_i) and traffic flow (TF_i)) 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, TG_i, S_i, TF_i.

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, TG_i, and TF_i) seems not to influence the stop-line delays;
- considering the effect of the combined interaction between TG_i and TF_i on stop-line delay, it is possible to note that, for TG_1 = 3.0 s, the growth of TF_i begins to influence appreciably stop-line delay only for TF_4 = 650 vph, whereas for TG_2 = 3.5 s and

Table 3. Anova for stop-line delays in *R*-scenarios

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
TG_i	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
TF_i	3	123 230.6	123 230.6	41 076.9	1422.54	0.000	Yes
$R_i\,TG_i$	6	2531.8	2531.8	422.0	14.61	0.000	Yes
R_iS_i	6	52.3	52.3	8.72	0.30	0.935	No
R_iTF_i	9	2731.5	2731.5	303.5	10.51	0.000	Yes
TG_iS_i	4	82.3	82.3	20.6	0.71	0.585	No
TG_iTF_i	6	50 889.3	50 889.3	8481.5	293.73	0.000	Yes
$S_i\,TF_i$	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					

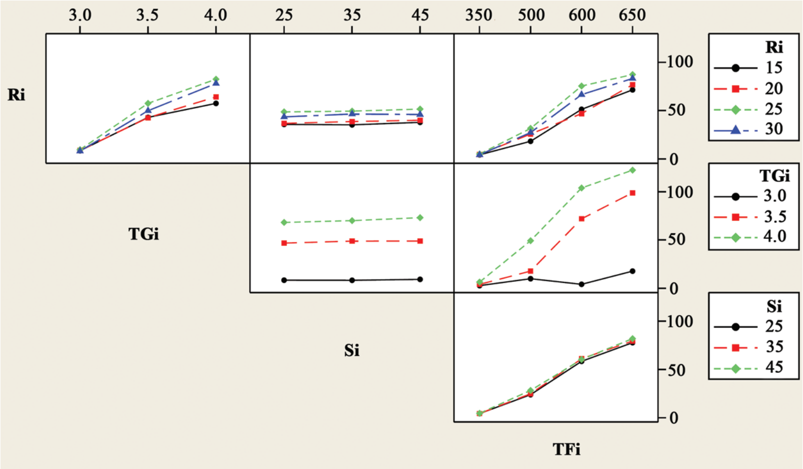

Fig. 4. Interaction plots for stop-line delays in *R*-scenarios

Table 4. Anova for stop-line delays in *I*-scenarios

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*	Sign.
TG_i	2	46 963.7	46 963.7	23 481.9	408.54	0.000	Yes
I_i	4	29 850.1	29 850.1	7462.5	129.83	0.000	Yes
S_i	2	31.2	31.2	15.6	0.27	0.763	No
TF_i	3	111 439.7	111 439.7	37146.6	646.29	0.000	Yes
TG_iI_i	8	6644.8	6644.8	830.6	14.45	0.000	Yes
TG_iS_i	4	218.4	218.4	54.6	0.95	0.438	No
TG_iTF_i	6	25 602.2	25 602.2	4267.0	74.24	0.000	Yes
I_iS_i	8	25.1	25.1	3.1	0.05	1.000	No
I_iTF_i	12	15 086.7	15 086.7	1257.2	21.87	0.000	Yes
S_iTF_i	6	155.9	155.9	26.0	0.45	0.842	No
Error	124	7127.2	7 127.2	57.5			
Total	179	243 145.0					

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 TG_i and R_i on the stop-line delay, it is possible to underline that, for TG_1 = 3.0 s, the increase of *Ri* has no noticeable influence on W_s; instead for TG_2 = 3.5 s and TG_3 = 4.0 s, when R_i 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 R_i increases, circulatory speed increases as well (max ΔSpeed ≈ 9 km/h). Even more important is that when R_i 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 TG_i and TF_i on stop-line delay, it is possible to point out that when R_i 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 (I_i). An Analysis of Variance (ANOVA) was performed to determine which factors (width of splitter island (I_i), critical gap (TG_i), approach speed (S_i) 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 I_i, TG_i, S_i, 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).

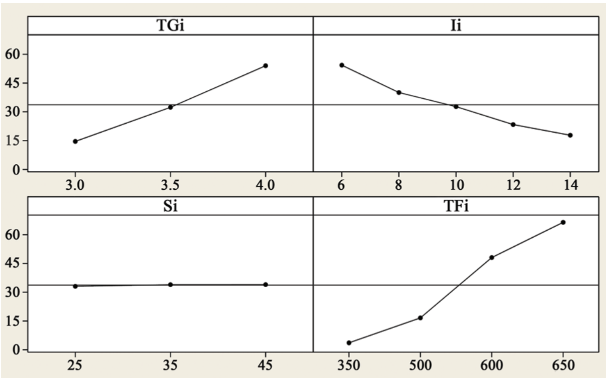

Fig. 5. Main plots for stop-line delays in *I*-scenarios

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.

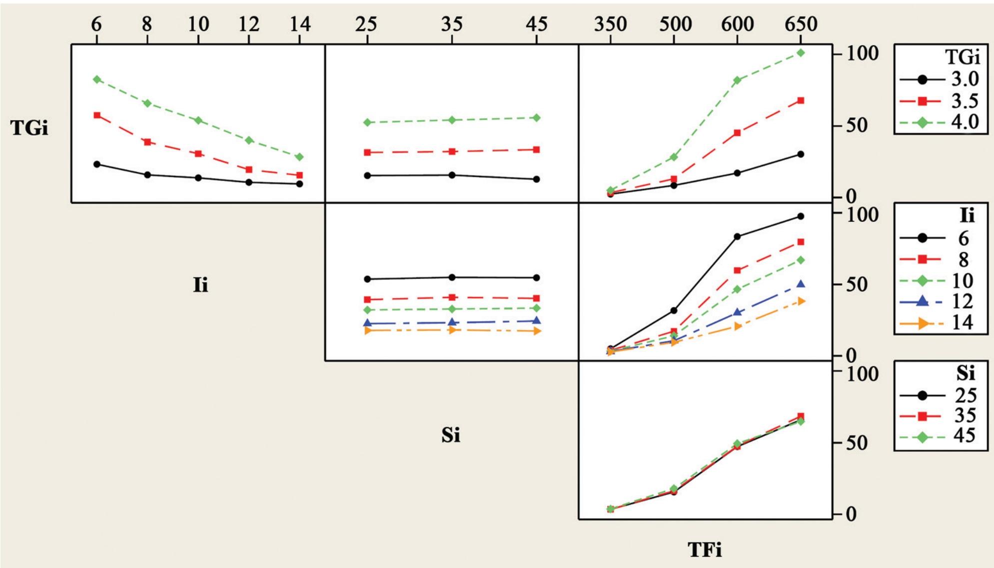

Fig. 6. Interaction plots for stop-line delays in *I*-scenarios

Table 5. Anova for stop-line delays in *C*-scenarios

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*	Sign.
TG_i	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
TG_iC_i	8	316.0	316.0	39.5	2.67	0.010	Yes
TG_iS_i	4	9.8	9.8	2.4	0.17	0.955	No
TG_iTF_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					

Stop-line delays are shown in Fig. 7 as a function of C_i, TG_i, S_i, TF_i.

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.

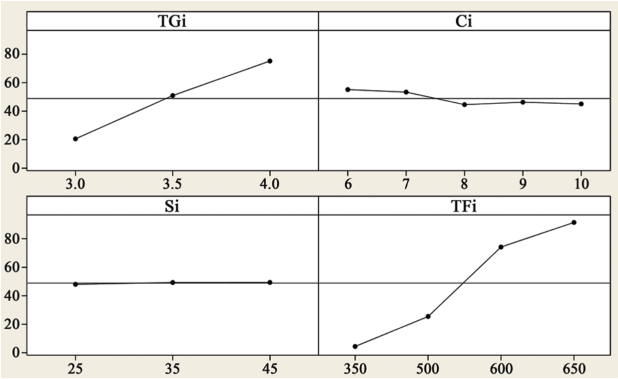

Fig. 7. Main plots for stop-line delays in *C*-scenarios

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, TG_i, and TF_i) exhibits 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

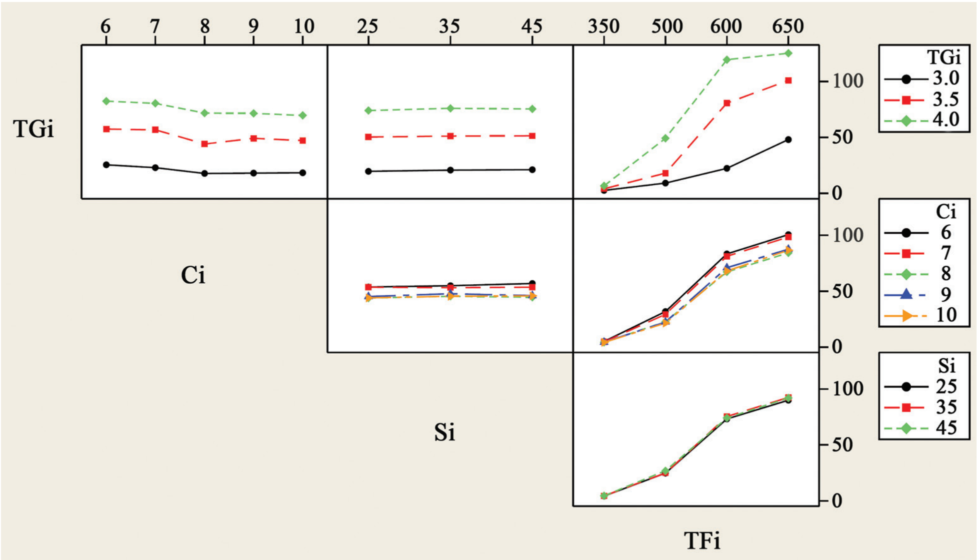

Fig. 8. Interaction plots for stop-line delays in *C*-scenarios

particular, for TG_2 = 3.5 s and for TG_3 = 4.0 s, the increase of W_s 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_s also increases; but in this case, for each TF_i, the increase of W_s 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_s 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_s;
- the dimension of the splitter island, I_i, 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_s 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 matrixes. In fact, in a recent studies using experimental real O/D matrixes 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. Intersezioni 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 VISSIM, 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 IfV, 8, Institut für Verkehrswesen. University of Karlsruhe.

Received 1 June 2011; accepted 23 November 2011