Micro-simulation effectiveness in predicting operating speed profiles in a roundabout

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subm. 15th October 2014 *approv. after rev. 12nd March 2015*

Abstract

Roundabouts affect operating speeds depending on a number of parameters. Consequently, their performance affects urban transport systems (safety, environmental and operational impacts) and tools are needed to carry out operating speed predictions. To this end, note that roundabout traffic management and control can be carried out by using road traffic micro-simulation models when a calibration is provided. As a result, the objects of the paper are: i) to use micro-simulation and experimental investigations to analyse operating speed vs. geometry relationship in a roundabout; ii) to calibrate a micro-simulation model; iii) to assess micro-simulation effectiveness in predicting operating speed profiles approaching a roundabout. Driver speed profile was studied and a procedure to predict the operating speed-profile was developed. The data derived from traffic micro-simulation were compared with experimental data. The study permitted to derive several conclusions about operating speed-profiles, micro-simulation effectiveness. Furthermore, it permitted to assess the relevance of a number of parameters in terms of speed prediction and software calibration.

Keywords – operating speed, calibration, safety, roundabout, micro-simulation models

1. Introduction

As is well-known, roundabouts performance depends on both traffic and geometric features (entry angle, lane width, external diameter, splitter island width, [10, 23]).

To estimate the safety of roundabouts, research has focused on operational indicators, including operating speeds, which represent the speed at which drivers are observed operating their vehicles during free-flow conditions [1]. A vehicle is considered to be operating under free flow conditions when the preceding vehicle has at least six seconds headway and there is no apparent attempt to overtake the vehicle ahead. Car speeds are observed in free-flow conditions and the 85th percentile speed is derived on a section-by-section basis. Note that operating speed-profiles can be seen as a surrogate measure in evaluating roundabouts safety performance (see also Praticò et al. [21] and Trueblood et al. [25]). Existing microscopic traffic simulation models for intersections can be helpful in the process of computing the measures in the simulation and extracting the required data. In more detail, microscopic and more traditional simulation models require a variety of input parameters through which driver behaviour and traffic control operations can be described. Traffic and more general issues are often involved (Park et al. [16], Praticò et al.[19], Bared and Edara, [4], Nikolic et al. [15], Kinzeland Trueblood [13], Eisenman et al. [8]). Several previous studies show that speed distribution is the most important parameter in roundabout geometric design and plays a fundamental role in micro-simulation models (Persaud et al. [17], Isebrandsand Hallmark [11], Johnson and Flannery [12], Arndt [3]; Gallelli et al. [9]). Geometry-speed relationship was the main object of several authors [5, 6], who investigated the effects of the main geometric parameters on operating speed and acceleration. Anyhow, studies on model calibration under various operating conditions are still required in order to investigate on model reliability and effectiveness [14]. Consequently, the objects of the paper are: i) to use micro-simulation and experimental investigations to analyse operating speed vs. geometry relationship in a roundabout; ii) to calibrate a micro-simulation model; iii) to assess micro-simulation effectiveness in predicting operating speed profiles approaching a roundabout. Section 2 illustrates research tasks and describes case study, while section 3 focuses on data collection in the field. Micro-simulation studies are described in sections 4 and 5, while conclusions are drawn in section 6.

2. Case study description

The roundabout studied in this paper lies at the intersection of two local roads in a suburban residential area in the south of the city of Reggio Calabria (ITALY, see Figure 1). Traffic volumes fluctuated greatly during the day, especially for the proximity to the airport, making this intersection a suitable case study. This is a single-lane, compact roundabout (inscribed circle diameter equal to 34.00 m) with three entries not equally spaced (Figure 1, Table 1).

Figure 2 summarizes the research carried out. Data gathered through the experimental investigation were used for both the calibration of Vissim parameters and the successive analyses.

Fig. 1 - General view of the roundabout

Tab. 1 - Roundabout geometric properties

	Entry		*Exit*		*Splitter Island*		
	Radius	*Width*	*Radius*	*Width*	*Width*	*Central Island Radius*	9.40 m
Approach A	347.50 m	3.50 m	395.20 m	3.50 m	15.00 m	*Inscr. Circle Diameter*	34.00 m
Approach B	60.50 m	3.50 m	347.50 m	3.50 m	13.00 m	*Circulatory Roadway Width*	7.60 m
Approach C	48.70 m	3.50 m	48.50 m	3.50 m	10.00 m		

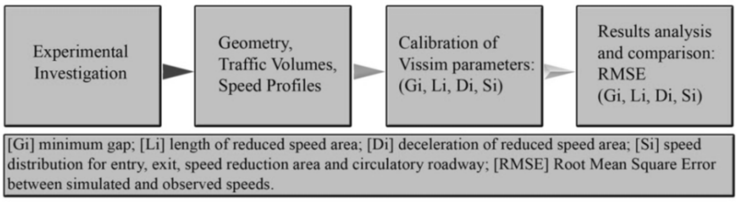


Fig. 2 - Research main tasks

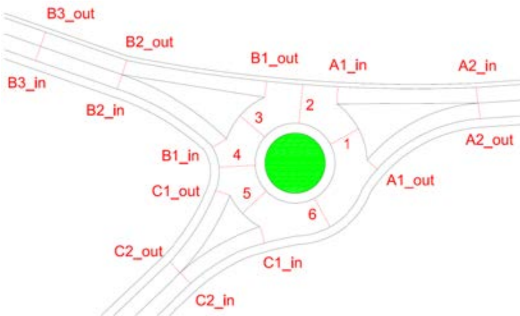


Fig. 3 - Location of some measuring sections used for the speed profiles

3. Data collection

The site was investigated during different days. Peak volumes occurred from 8:00 am to 9:00 am and from 1:00 pm to 2:00 pm. A survey of 15 hours (only working days) took place during almost 3 weeks and the following data were extracted:

- the volume of traffic entering, exiting and circulating for each approach during peak and off-peak periods;
- the profiles of the desired speed (speed a vehicle "desires" to travel at if it is not hindered by other vehicles [16]). Low traffic periods in all the sections were used (see Figure 3).

3.1. Volumes of traffic

The O/D matrices were obtained from this data collection and homogenized in vehicle per hour by using coefficients reported in the Highway Capacity Manual 2010[24]: for this case study we used the coefficients 2 for all the trucks and 0.5 for cyclists. Data are summarized in Table 2 (a: peak period; b: off-peak period). Note that entry capacity was estimated for each entry lane as follows (HCM 2010 [24]): $Q_{A,max}$=1107 veh/h; $Q_{B,max}$ =1017 veh/h;$Q_{C,max}$=1000 veh/h.During off-peak flow conditions, the following capacity reserves were derived: RC_A=85%; RC_B=89%; RC_C=87%.Car speeds were observed in free-flow conditions.

3.2. Speed profiles

The survey, carried out during off-peak period, allowed obtaining helpful information about speed distribution.In order to gather speed data, five measuring sections for the entry A, five for the entry B, seven for the entry C, and six in the circulatory roadway were considered (Figure 3).

A laser speed gun was used to collect the speeds. Speed measurements were performed point after point. The minimum size of the sample (95) was derived according to Pignataro [18]. The accuracy and precision of this device was investigated by Praticò and Giunta [20].

Tab. 2 - Volume of traffic for peak and off-peak period

(**a**)	*A*	*B*	*C*
A	0	164	119
B	160	0	49
C	468	21	4

(**b**)	*A*	*B*	*C*
A	0	81	88
B	81	0	30
C	112	17	0

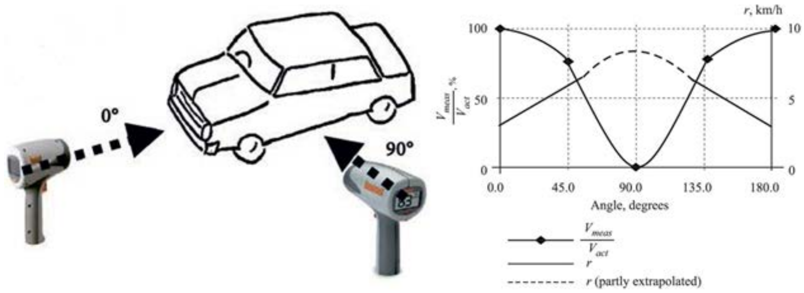


Fig. 4 - Accuracy (% of true speed) and repeatability (*r*)

Tab. 3 - Summary of experimental approaching, circulatory and exiting speeds

	A		*B*		*C*		*Circulatory Roadway*
	Entry	Exit	Entry	Exit	Entry	Exit	
85th Speed (km/h)	54.54	48.00	40.08	42.72	50.08	46.77	30.26
Av_Speed (km/h)	46.84	40.58	32.70	36.60	43.92	43.48	25.79

Figure 4 illustrates how the error depends on the angle. The ratio V_{meas}/V_{act} (in percentage, where V_{meas} is the measured speed and V_{act} is the actual speed) is plotted against angles (degree, x-axis). Right y-axis refers to repeatability, r. V_{85} and average speeds are summarized in Table 3. These data were the basis for the implementation of microsimulation scenarios. V_{85} and average speed have been determined for all the movements: they will be the benchmark for outputs' scenarios.

4. Scenarios design

Experimental data are of great importance to provide reasonable estimates for Vissim parameters. Starting from the data collected during the surveys, a calibration procedure of the microsimulation tool was carried out. 72 different scenarios were considered for the evaluation of the speed profiles (all the movements in the roundabout). Note that critical headway (or critical gap), follow-up headway (or follow-up time) and space headway are important parameters to perform design and operational analyses at a roundabout [29]. Critical gap at roundabouts represents the minimum time interval in the circulating flow when an entering vehicle can safely enter a roundabout. It depends on local conditions such as geometric layout, driver behaviour, vehicle characteristics, and traffic conditions. It is expressed in seconds. Averages are around 4.1-5.2s [2, 24]. The follow-up time (2.2-3.2 s) is the time between the entry of one vehicle into the roundabout and the entry of the next vehicle using the same gap in circulating traffic, under a condition of continuous queuing on the roundabout approach. The space headway refers to the "clear" distance for which motorists would wait before entering the Roundabout (for example: 15feet≈5m). The minimum headway refers to the case of circulating speeds lower than 15 km/h, while, for circulating speeds higher than 15 km/h, the minimum gap is used [25].

Therefore the following parameters were considered for the calibration:

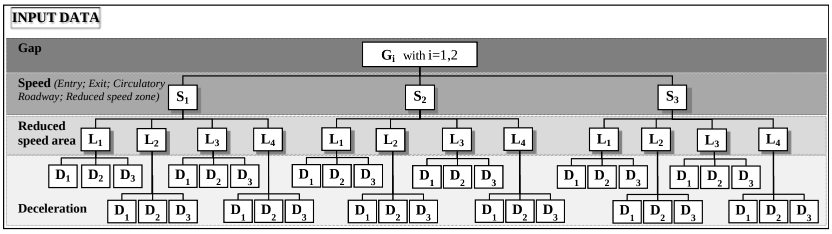
- traffic assignment: O/D matrix related to off-peak traffic conditions (Table 2a);
- speed distribution for entry, exit, reduced speed area and circulatory roadway (Figure 5, data reported in Table 3);
- minimum gap and minimum headway of the priority rules;
- driver behaviour elements: Vissim uses a the car-following model set out by Wiedemann '74 [22]. As regards the Wiedemann model, the default settings, reported by the software and shown in Table 4, were used.

The variables for the setting up of scenarios were chosen as summarized in Figure 5 [26, 27].

Tab. 4 - Default parameters of Wiedemann '74 model

Car-following model	*Look-ahead distance (*)*	0.00 m - 250.00 m	
	Average standstill distance (**)	2.00 m	
	Additive part of desired safety distance	2.00	
	Multiple part of desired safety distance	3.00	
Lane Change		*Own*	*Trailing Vehicle*
	Max Deceleration	-4.00 m/s²	-3.00 m/s²
	Accepted Deceleration	-1.00 m/s²	-1.00 m/s²
General behaviour	Free lane selection		
Lateral behaviour	Desired position at free flow: middle of lane		

(*) sight distance; (**) Average standstill distance defines the average desired distance between stopped cars and also between cars and stoplines, signal head [16].



Symbols: *[G_i]* is minimum gap; *[S_i]* is speed distribution for entry, exit, speed reduction area and circulatory roadway; *[L_i]* is length of reduced speed area; and *[D_i]* is deceleration of reduced speed area).

Fig. 5 - Summary of input data

Note that the following input data were set out (see Figure 5 and 6):

i. minimum gap [G_i], two levels;
ii. length of reduced speed area [L_i], four levels;
iii. deceleration of reduced speed area [D_i], three levels;
iv. range of speeds distribution [S_i], three levels. In particular each speed level considered four different areas in the roundabout simulated: entry and exit (for all legs), speed reduction area and circulatory roadway from the values reported in Table 3.

Note that the subscript refers to the level of the variable. For example, the deceleration length, L_i, ranged from 10m to 16m (four different levels: L_1=10m; L_2=12m; L_3=14m; L_4=16m, see Figures 5, 6, and 7). As for the gaps, note that G_1=3.0s and G_2=3.5 s were used, due to the fact that they represent a minimum gap and not a critical gap. In Vissim, for free flow traffic on the circulatory roadway, the minimum gap time is the relevant condition. If the current gap time is lower than the minimum gap time (defined for the conflict marker) the corresponding stop line stops any approaching vehicle (as a red signal). In particular, the 85th percentile speed was considered to define the upper limit of the speed range (adding, for each level, respectively, the following amounts: 1km/h, 2km/h and 3km/h). Furthermore, the average speed was used to fix the lower limit of the speed range (subtracting for each level, respectively, the following amounts: 6 km/h, 7km/h and 8km/h). Figure 6 shows a Vissim screenshot of the modelled roundabout, pointing out particular features such as: desired approach speed sections, length of reduced speed areas, stop lines, desired exiting speed and measuring sections.

5. Results and ANOVA of calibration ability

The simulation results were analysed in terms of average speed for the different movements and compared with the experimental data collected along the same paths during the lowest traffic period. The measuring sections along each movement described in Figure 3 and the calibration parameters summarised in Figure 5 were considered. The Root Mean Square Error (RMSE) was derived for each simulation as follows:

$$RMSE = \frac{\sum_{j=1}^{K}\left[\sum_{i=1}^{N}\sqrt{\frac{(S_{Si}-S_{Oi})^2}{N}}\right]_j}{K} \quad (1)$$

where

S_{Si}=Speed obtained from the simulation on the section "i"; S_{Oi}=Speed observed on the section "i"; N=Number of speed sections for each path; K= Number of paths considered in the analysis.

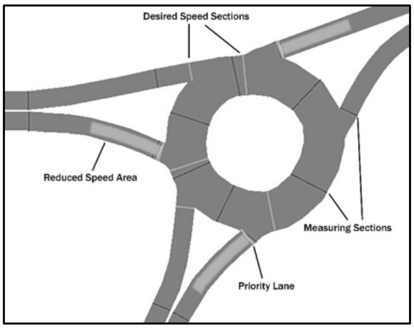


Fig. 6 - A Vissim screenshot of the modelled roundabout used for simulations

Tab. 5 - ANOVA results for the RMSE between simulated speed and observed speed along the different paths in the roundabout

Variables	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*	*Signif*
G_i (Minimum Gap,)	1	0.000045	0.000045	0.000045	1.92	0.174	**No**
L_i (Length of reduced speed area)	3	0.133380	0.133380	0.044460	1889.13	0.000	**Yes**
D_i (Deceleration reduced speed area)	2	0.018308	0.018308	0.009154	388.95	0.000	**Yes**
S_i (Speed distribution)	2	0.480760	0.480760	0.240380	10213.91	0.000	**Yes**
*G_i*L_i*	3	0.000223	0.000223	0.000074	3.16	0.035	**Yes**
*G_i*D_i*	2	0.000006	0.000006	0.000003	0.14	0.873	**No**
*G_i*S_i*	2	0.000044	0.000044	0.000022	0.93	0.405	**No**
*L_i*D_i*	6	0.001492	0.001492	0.000249	10.57	0.000	**Yes**
*L_i*S_i*	6	0.002926	0.002926	0.000488	20.72	0.000	**Yes**
*D_i*S_i*	4	0.000129	0.000129	0.000032	1.37	0.262	**No**
Error	40	0.000941	0.000941	0.000024			
Total	71	0.638254					

Symbols:
DF: degree of freedom; *Seq SS*: sequential sum of squares; *Adj SS:* adjusted sum of squares; *Adj MS:* adjusted mean square; *F:* F-statistic; *P:* p-values; *Signif.*: statistical significance.

Each scenario was run 10 times in order to provide a 95% confidence in reported speed with a confidence interval of ± 0.50 Km/h. Furthermore, an Analysis of Variance (ANOVA) was performed to determine which factors (minimum gap [G_i], length of reduced speed area [L_i], deceleration of reduced speed area [D_i] and speed distribution for entry, exit, speed reduction area and circulatory roadway [S_i]) significantly affect the average speed (response variable) along the different paths in the roundabout. Results are presented in Table 5. Note that the only factor which did not result statistically significant was the minimum gap G_i. As for the interactions, G_i*L_i, L_i*D_i and L_i*S_i were significant. Note that, as reported by Cunto and Saccomanno [7], only two-way interactions were considered (Table 5). Figure 7a shows the main results in terms of RMSE of Gap (G_i), L_{dec} (L_i), Dec (D_i), Speed (S_i, see Figure 5). Y-axes refer to speed errors (RMSE), while x-axes refer to one of the four considered parameters (G_i, minimum gap, [s]; L_i, deceleration length, [m]; D_i, deceleration, [m/s^2]; S_i, speed distribution, [km/h], see Figure 5). Note that in the interaction plots (Figure 7b), for a given x-axis (for example, L_i), several different values of another parameter (for example G_i) are considered, while the y-axis still represents the RMSE. It is possible to observe what follows:

- There is no difference between the values of 3.0 and 3.5 seconds for the minimum gap used in the definition of the priority rules. This consideration confirms what Vaiana et al. [28] highlighted.
- In order to obtain the best fit (observed data vs. simulated data) the consideration of a reduced speed zone for each entry is needed. In particular, in this case, the higher the length of reduced speed zone the lower the error.
- The three values of deceleration (D_i) used to set-up the scenarios don't yield appreciable differences in terms of RMSE. D_3=1.80 m/s^2 yields the best results.
- The speed distribution S_3 yields the best fit among the six speed profiles considered.

Figures 8 and 9 show the comparison between the six profiles of the experimental and the simulated average speed for the best scenarios. Y-axes refer to speed (km/h), while x-axes refer to the different measuring sections.

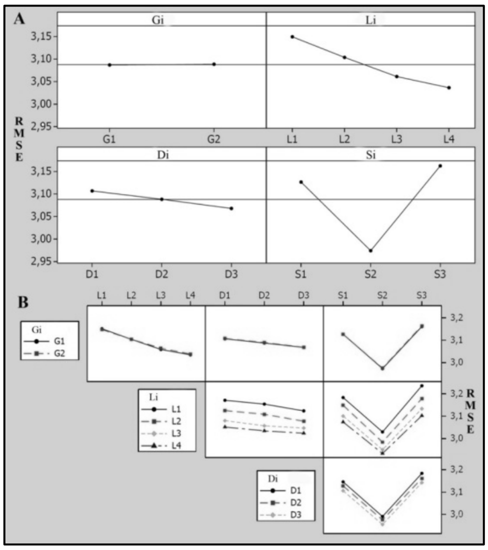


Fig. 7 – RMSE vs. G_i, L_i, D_i, S_i and interaction plots

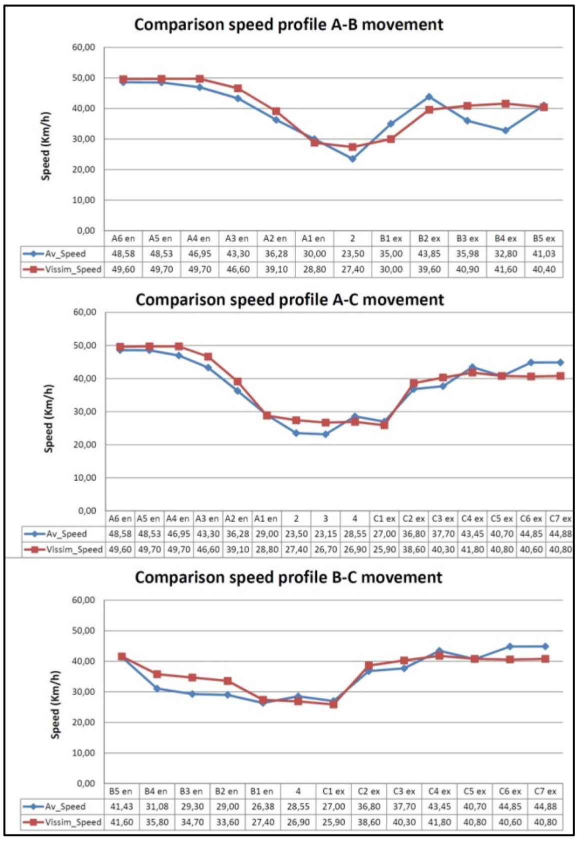


Fig. 8 – Comparison of speed profiles for three of the best scenarios

6. Conclusions

Roundabout intersections have an outstanding diffusion across Europe. Their design is carried out according to design guides but research is needed to better assess and evaluate the dependence of operating speeds and safety on design features. To this end an experimental investigation was carried out on a roundabout (asymmetrical, three-leg, located in South Italy) and Vissim simulations were carried out. Once the micro-simulation model was calibrated and implemented, the sensitivity to four main parameters was tested: i) minimum gap [G_i], two levels; ii) length of reduced speed area [L_i], four levels; iii) deceleration of the reduced speed area [D_i], three levels; iv) speed distribution for entry, exit, speed reduction area and circulatory roadway [S_i], three levels. The following conclusions may be drawn for the case under examination: i) the minimum gap G_i doesn't affect significantly operating speeds (in the range tested). This result calls for further research. Indeed, values of 3.0 and 3.5 seconds for the minimum gap did not affect Vissim simulation; ii) the interactions, G_i*L_i, L_i*D_i and $L_i*S_i$are significant; iii) the best fit (observed data *vs.* simulated data) is obtained by considering reduced speeds (one for each entry). Length of reduced speed zone between 14 and 16 meters result to better fit data; iv) decelerations slightly affect results and behaviours; v) micro-simulation program for studying the operating speed of roundabouts proved quite effective.

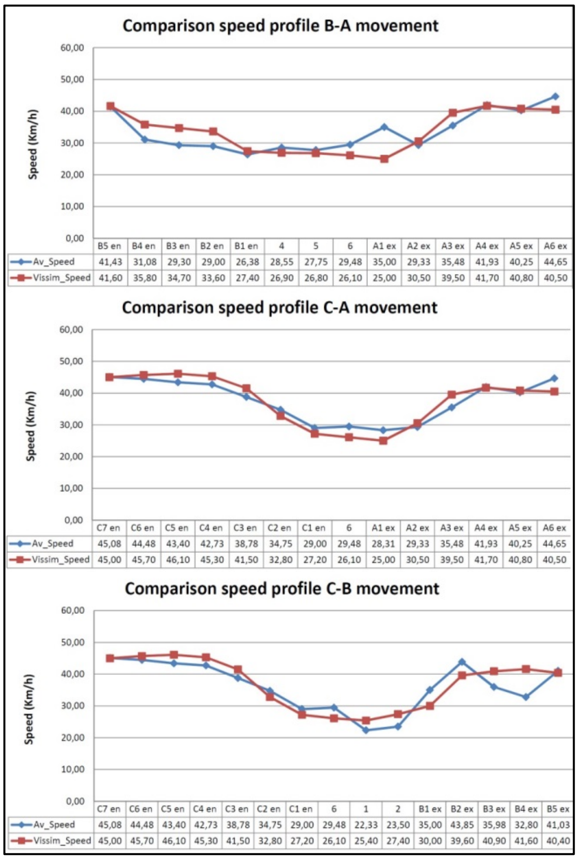


Fig. 9 – Comparison of speed profiles for the other three best scenarios

Method set up allows calibrating microsimulation software and considering both performance-related and safety-related issues. Future research will address the validation of the calibrated model and its transferability to different case-studies. Outcomes of this study are expected to benefit both practitioners (functional requirements estimate) and researchers (method statement and synergistic consideration of safety-related and functional requirements).

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