MICROSCOPIC TRAFFIC SIMULATION OF NON-CONVENTIONAL ROUNDABOUTS PERFORMANCES: A CASE STUDY

Astarita V.
Professor – University of Calabria. – vastarit@unina.it
Gallelli V.
PHD lecturer– University of Calabria. – vincenzo.gallelli@unical.it
Guido G.
PHD - University of Calabria. – guido@unical.it
Vitale A.
PHD - University of Calabria. – alessandro.vitale@unical.it

ABSTRACT

This research develops results obtained in a preceding research (Astarita et. al., 2006); the study is focused on the possibility to implement noncircular roundabouts in particular contexts, analysing their functionality levels by microscopic vehicular flow simulation.
The authors intend to validate preceding results, obtained by simulation, carrying out experimental analysis on real traffic conditions.
A survey has been set up and carried out to evaluate traffic parameters characterising vehicle flow on the analysed roundabouts; the analysed noncircular intersections have similar characteristics to those examined by microsimulation models in the previous research.
A micro simulation traffic flow model (VISSIM, PTV), was used to reproduce roundabouts geometry and to define vehicle flow parameters.
Preliminary results allow to evaluate roundabouts level of service as a function of geometric features. Finally, the limits of applicability and convenience of implementing noncircular roundabouts has been established confirming the previously obtained results.
Keywords: roundabouts, microsimulation, performance levels

1. INTRODUCTION

In the last few years the notable increase in mobility has coincided with an ever greater use of individual means of transport, causing an increase in levels of congestion on town and out-of-town transport networks, above all at junctions. These circumstances produce ever more frequent negative effects on the user both in terms of safety and of atmospheric pollution.

In Italy and in other European countries there is a growing interest in junctions regulated by roundabouts which, compared to ordinary junctions (for example, those regulated by right of way and traffic lights), assure a lower number of points of conflict, the absence of left turns, a greater ease of entry and, above all a reduced velocity of the transiting vehicles in the exchange area.

Commonly, solutions of changing flat junctions into roundabouts are adopted, where one does not want or does not have to attribute priority among any of the intersecting roads.

In this contribution, by means of the application of a traffic micro-simulation software, the authors intend to study the performances of roundabouts with different geometries and forms for vehicular flows prevalent on one route. To confirm the validity of the results obtained in previous studies (Astarita et al., 2006), the performance indicators generated by the micro-simulation are compared to those from real observations of roundabouts with different geometrical characteristics and situated in different territorial contexts.

The paper is divided into four parts: the first part defines the methodological criteria used; the second part describes the case studies examined; the third part is relative to the application of the micro-simulation to the cases described; finally, the fourth part analyses the results obtained comparing them with the predictions supplied by the previous studies.

2. METHODOLOGICAL APPROACH

In an initial phase of the study it was opportune to establish the type of junction and the study context to be represented by the micro-simulation model (Canale, 2005; FHA, 2000). With the aim of analysing one of the most widespread cases in the national context, the two-lane roundabout was considered, having four confluent town or out-of-town roads, with ninety-degree angles between one entering road and the next and a flow mainly on one traffic route.

Different geometries and shapes were defined, as a function of the ratio of the minimum to maximum radius, considering values of this ratio also less than 0.75. The first considerations for the definition of roundabout geometry of any shape emerge from an analysis of the regulations currently in force regarding “Road Geometry” (D.L. 285/1992, D.M. 05/11/2001). Having to allow the transit of vehicles belonging to any category, it is necessary to size the roundabout with determined minimum radius and width of ring values (D.P.R. 495/1992).

To simulate the roundabout’s performances of a defined geometry, supposing that the traffic routes do not have the same importance and, therefore, that the traffic volumes are greater on the entry roads placed on the main axes (larger axis of the ellipse), four hourly O/D matrices of equivalent car flows, were defined.

The matrices of traffic volumes are differentiated one from the other by the exit flow values of the secondary routes (variable from 20% to 80% of the volume assigned to the main route), whereas the exit flow values of the main route are considered constant (the crossings of weak users are neglected). The choice of these values is justified by the willingness to test the roundabouts under consideration in critical conditions and to evaluate the effects of the variation shape on the overall performances.

On the basis of what has been discussed above, in a successive phase, it was possible to define five scenarios for roundabouts with different geometries to be analysed by means of the micro-simulation, dynamically assigning the traffic volumes individuated in the O/D matrices.

Overall, therefore, twenty different configurations were analysed, combinations of the five scenarios at variable geometry and the four compositions of the hourly vehicle flow matrices. For geometries and entities of different traffic volumes, therefore, it was possible to evaluate the performance levels of the roundabouts analysed, in this way predicting any critical circumstances that can arise for specific geometrical configurations and/or flows. These preliminary phases are amply described in a previous paper by the authors (Astarita et al., 2006).

In order that this analysis technique can really constitute a valid decision support tool, it is necessary, however, that the results obtained by the micro-simulation be compared with the results from an analysis of real case studies. In this regard, two representative town roundabout case studies were chosen, having a different geometry and situated in different territorial contexts.

The performance parameters of these case studies were obtained by means of a video data acquisition technique starting from some on site recordings. In a successive phase the geometries of the two case studies were reproduced within the VISSIM micro-simulator and then the simulated parameters were obtained. Special attention was paid to the implementation of the analysed roundabouts in the micro-simulator, defining all the geometrical elements constituting the junctions, specifying the vehicle flow parameters on specific stretches of the analysed network.

The last study phase concerned the comparison of the observed to the simulated performance indicators, to test whether the theories made starting from the theoretical scenarios are valid if applied to real roundabouts and, therefore, whether it is possible to identify planning solutions that concur to optimising the performances of this type of junction in relation to traffic levels and to geometrical features.

3. CASE STUDY

3.1 Preface

Experimental analyses were carried out on two real study contexts, representative of particular geometrical configurations of roundabouts situated in a town context.

The first study case concerns a circular roundabout, situated in the centre of an Apulian town (Mottola); the second case study regards a noncircular roundabout situated near the A3 Salerno-Reggio Calabria off-ramp in the area of the municipality of Rende.

The geometrical characteristics and the volumes of traffic transiting the roundabouts under consideration were found through analyses.

To this purpose, it is necessary to specify that the observations of the traffic flows were circumscribed in defined temporal intervals, but opportunely chosen to evince peak loads.

The geometry of the roundabouts was implemented in a specific vehicular traffic micro-simulation software (VISSIM, PTV); special attention was paid to the comparison of the definition of the parameters governing the vehicle exit flow (servicing times, velocity of approach, etc.).

The measure of the performance indicators of the roundabouts analysed was, finally, obtained following the assignation of the traffic volumes recorded during the survey phase.

The authors verified that the results offered by the simulations, expressed in terms of mean driving times, mean delays, length of queues, reproduced, with an acceptable margin of error, what was predicted by the analyses carried out in a previous study (Astarita et al., 2006); the performance levels of the roundabouts analysed, for the assigned traffic volumes and for the geometries defined, were, in fact, compared to those obtained by the simulations carried out on "virtual" scenarios in similar conditions.

3.2 Mottola roundabout

The roundabout is located in the municipality of Mottola, in the province of Taranto; four roads converge on it, one being part of the provincial road linking up with the motorway artery, and three town roads.

The records and observations made in situ provided the data needed for the input to the simulations; special attention was paid to the determination of the dimensions of the entry and circulatory lanes, as well as to the recording of the velocity in some sections (tab. 1).

Table 1 Geometric features of Mottola roundabout

	Mottola
Internal radius (m)	7.15
Inscribed circle diameter (m)	24.5
Circulatory lanes	1
Average of circulatory velocity (km/h)	15.17
Entry width (m)[1]	3.81/4.51

[1] Min and max values

The geometrical configuration is shown in figure 1.

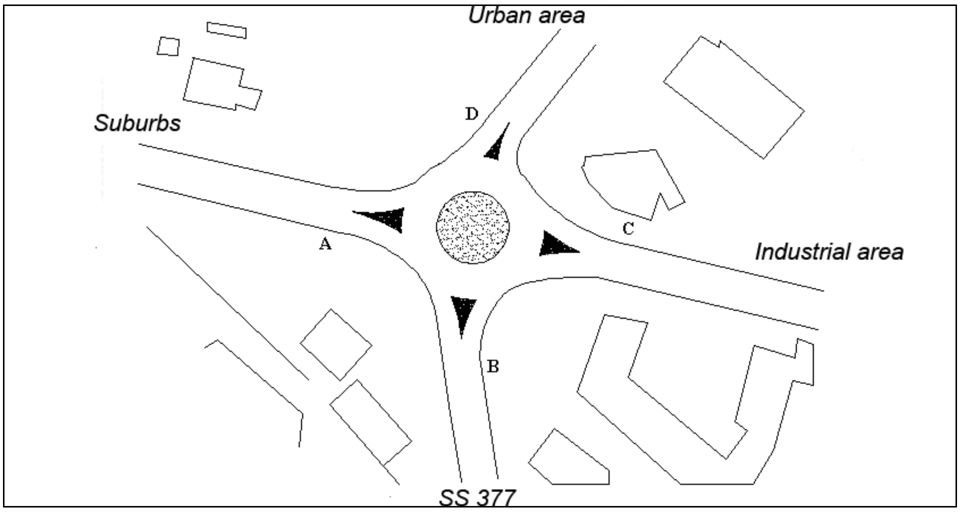

Figure 1 Mottola roundabout geometry

During the observation period, the vehicular flows entering and exiting the various roads on the roundabout at intervals of five minutes were recorded, allowing the determination of the rush hour volume.

From the analysis of the data found it can be evinced that the main traffic route is that distinguished by the axis passing through nodes B and D; the ratio of the entity of hourly vehicular flows transiting on the secondary route to the entity of hourly vehicular flows transiting on the main route is 0.30 (Q_{pr} = 1350 vehic/h, Q_{sec} = 410 vehic/h).

Table 2 O/D matrix of Mottola roundabout

Min÷Med÷Max (veic/h)	A	B	C	D	Qe (Med)
A	0÷**1**÷12	12÷**104**÷252	0÷**26**÷72	48÷**178**÷384	**309**
B	36÷**72**÷174	0÷**16**÷60	0÷**30**÷60	300÷**430**÷660	**548**
C	0÷**37**÷120	0÷**24**÷48	**0**	0÷**43**÷132	**94**
D	24÷**209**÷354	288÷**560**÷864	0÷**39**÷84	0÷**5**÷24	**813**
Qu (Med)	**319**	**704**	**95**	**646**	

3.3 Cosenza roundabout

The roundabout is located in the municipality of Rende, in the province of Cosenza, in the immediate vicinity of the Cosenza Nord off-ramp of the A3 Salerno-Reggio Calabria motorway.

For this reason, this node of the road network is particularly subjected to heavy traffic flows in many hours of the day.

Four roads converge on it, of which, one is almost tangential to the ring, in a configuration that proves to be, overall, asymmetrical (fig. 2).

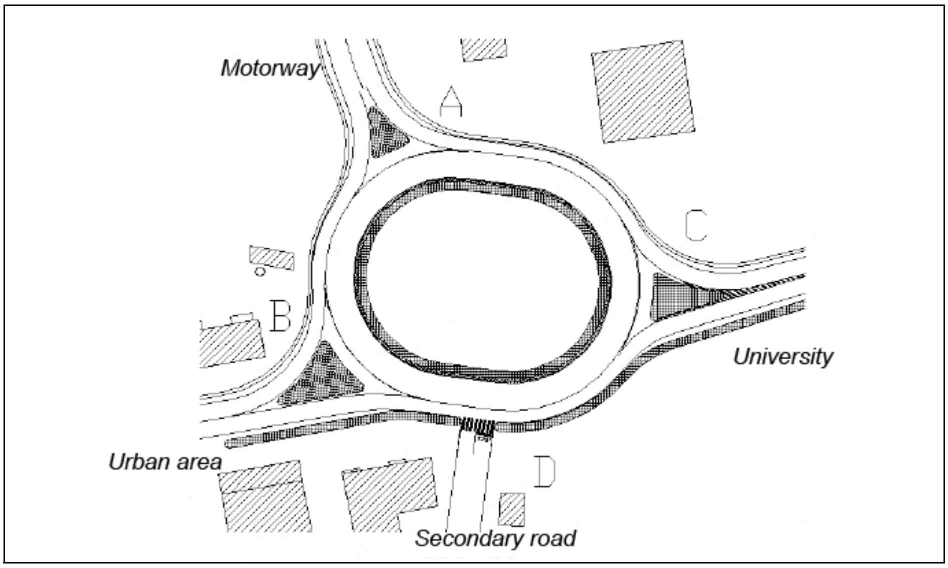

Figure 2 Cosenza roundabout geometry

The campaign of surveys carried out on the site was aimed at the geometrical survey of the roundabout which, owing to its unusual shape, necessitates, for the purpose of the performances simulation, careful evaluations of all the typifying elements (different radii of curvature, variable width of entries, layout of the splitter islands, etc.). Also in this case, special attention was paid to the determination of the profiles of the velocities in some sections, finally recording the average of circulatory velocity; table 3 summarises the data recorded.

Table 3 Geometric features of Cosenza roundabout

	Cosenza
Internal radius (m)[1]	24/31
Inscribed circle diameter (m)	68/80
Circulatory lanes	2
Average of circulatory velocity (km/h)	26.27
Entry width (m)[2]	3.99/6.00

[1]Minor and major radius
[2] Min and max values

The monitoring of the vehicular flows transiting the roundabout under consideration, carried out in repeated survey campaigns, allowed the determination of the rush hour volume. East-west transiting traffic flow proves to be particularly heavy, that is the flow of vehicles from the district of Quattromiglia di Rende (node B) and the State Road 107 (node C), presumably originating from the area of the university campus of Arcavacata.

The ratio of the entity of hourly vehicular flows transiting on the secondary route to the entity of hourly vehicular flows (at rush hour) transiting on the main route is 0.46 (Q_{pr} = 1800 vehic/h, Q_{sec} = 830 vehic/h).

Table 4 O/D matrix of Cosenza roundabout

Min÷Med÷Max (veic/h)	A	B	C	D	Qe (Med)
A	0	264÷**378**÷492	120÷**270**÷420	0÷**96**÷192	**744**
B	132÷**264**÷396	0	180÷**420**÷660	12÷**54**÷96	**738**
C	204÷**378**÷552	204÷**534**÷864	0	12÷**42**÷72	**954**
D	0÷**12**÷24	0÷**24**÷48	12÷**36**÷60	0	**72**
Qu (Med)	**654**	**936**	**726**	**192**	

4. MICROSIMULATION

4.1 General remarks

The geometry of the roundabouts described in the previous sections was reproduced and implemented in the VISSIM (figs. 3 and 4) micro-simulation software with due care, to allow a correct evaluation of the performance indicators.

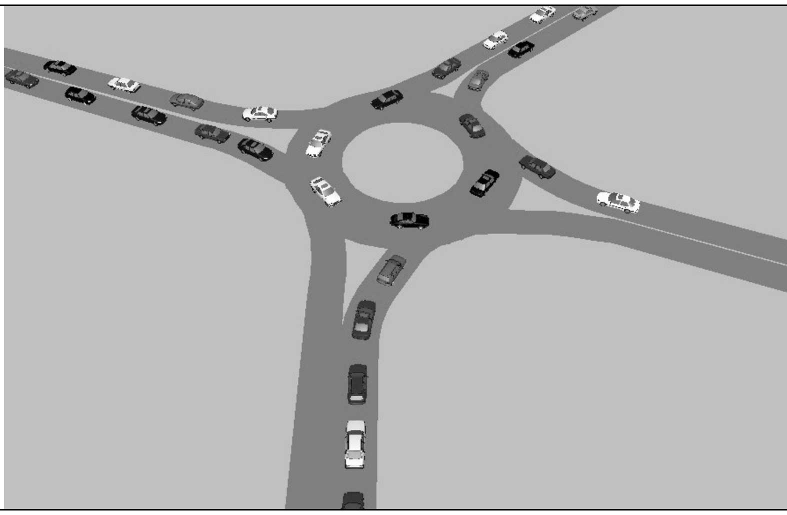

Figure 3 Mottola roundabout in VISSIM

Parallel to the implementation of the geometry in the micro-simulation software, the definition phase of the parameters governing the vehicular exit flow was carefully undertaken. Even before assigning the hourly traffic volumes, on the supply of data obtained during the survey campaign phase, it was, in fact, opportune to specify and calibrate the micro-simulation software, analysing the aspects relative to the behavioural models used and to the admissible velocity fields in the different sections of the network.

Inside the microsimulation model VISSIM, it is possible to define the users behaviour in roundabout through a car-following model and a lane change model.

The car-following model developed in the software is an adapted version of the model carried out by Wiedemann in 1974. According this model a user can reach one of the following driving methods:

- free driving mode, in which the user is not influenced by the preceding vehicles on the same lane and he tends to maintain his desired speed;
- approaching mode, in which the user has to adapt his speed at the lower speed of the preceding vehicle (the deceleration impressed by the user assumes the value that led to a null speed difference between the user's vehicle and the preceding vehicle on the same, once the desired safety distance has been reached);
- following mode, in which the user tends to maintain the desired safety distance from the preceding vehicle on the same lane more or less constant (speed difference between the vehicles assumes a value that oscillates around zero);
- braking mode, in which the user applies a medium-high acceleration if the distance from the preceding vehicle on the same lane falls below the desired safety distance.

The input parameters of the Wiedemann model that can be modified inside the software are the average standstill distance, the additive part of desired safety distance and the multiplicative part of desired safety distance.

The lane change behaviour, in VISSIM, is regulated by the following parameters:

- the maximum acceptable deceleration for the vehicle and the trailing vehicle on the new lane, depending on the distance to the emergency stop position on the next connector of the route;
- the desired safety distance of the trailing vehicle on the new lane;
- suitable gap in the destination flow.

Regarding the users behaviour in not signalized intersections, in VISSIM software three parameters can be defined for the entry manoeuvres: minimum gap time, minimum headway (distance) and maximum speed.

The values of the parameters used for the input of the performed simulations are reported in table 5.

Table 5 Simulations parameters

	Cosenza	***Mottola***
average standstill distance (m)	2.00	2.00
additive part of desired safety distance (m)	2.00	2.00
multiplicative part of desired safety distance (m))	3.00	3.00
maximum acceptable deceleration (m/sec^2)	-3.00 / -4.00[1]	-3.00 / -4.00[1]
minimum gap time (sec)	2.70 / 6.20[1]	3.20 / 7.80[1]
minimum headway (m)	5.00	6.00
maximum speed (km/h)	15.80	14.40

[1] Variation range

For every scenarios number five simulations were made in order to obtain statistically valid estimate of the roundabout's performances (delay and queue length).

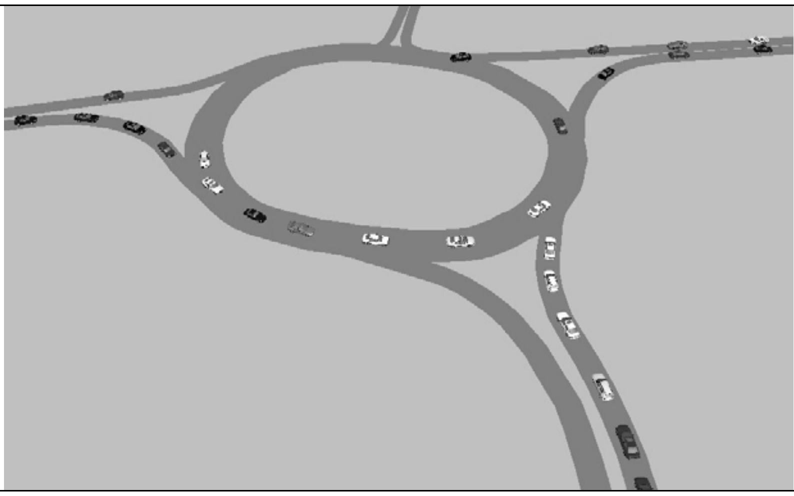

Figure 4 Cosenza roundabout in VISSIM

4.2 Circulatory and approach velocity

The definition phase of the distributions of the circulatory velocities of the roundabouts under consideration is fundamental to correct reproduction of the vehicular circulation along the arcs of the curvilinear network. VISSIM, although allowing the modelling of the curvilinear arcs, does not reproduce the interaction of the vehicle with the curve. Since roundabouts are the object of study, a precise intervention was therefore necessary: for each scenario simulated, on sections of the ring with different curvature, with the definition of the velocity distribution curves. The velocities on the ring, like those on the entries, were distributed with a normal law; the table below points out some of the main parameters found in situ and, observing the provisions of D.M. 05/11/2001, the value of the driving velocities (Vs) on the curves, for the different internal radii, in equilibrium conditions for the vehicle.

Table 6 Velocity distribution parameters

	Cosenza	***Mottola***
Average of circulatory velocity (km/h)	26.27	15.17
Standard deviation (km/h)	6.67	5.97
Crossing grade (%)	0	0
Friction coefficient	0.22/0.21	0.23
Vs = Skid velocity limit (km/h)	25.89/28.75[1]	14.45

[1] For minor and major radius

Analogously to what was done in the oft-cited previous study (theory confirmed by the experimental surveys) it was considered that the average of the circulatory velocity distributions were almost equal to the value of velocity Vs calculated analytically for the different radii of curvature.

With this presupposition, it was possible to define several velocity distribution curves in relation to the value of the curvature radii defined for the simulations, using normal distributions with media (μ) equal to Vs, for null values of transversal slope and adherence coefficient of 0.21/0.22 and 0.23, for the Cosenza and the Mottola roundabout respectively, and standard deviation (σ) of 6.67 km/h, for the Cosenza roundabout, and 5.97 km/h, for the Mottola roundabout (tab. 6).

4.3 Servicing times

To correctly define the priority rules in correspondence to the entries of the roundabouts under consideration, the servicing times values recorded during the survey phase of a study previously undertaken by other researchers (Capiluppi et al., 2006), on the same sites examined in this context, were used as input data for the simulations.

From an analysis of the above data, it was possible to define the servicing times for each of the roads of the roundabouts analysed, identifying an 85° percentile of the sample distribution.

Below is a summary of the values of the servicing times adopted during the definition phase of the priority rules implemented in VISSIM for the two case studies (tab. 7).

Table 7 Registered servicing times (seconds)

Servicing times (sec)	***Cosenza***	***Mottola***
Entry A	5.03	7.81
Entry B	3.72	5.64
Entry C	2.67	3.23
Entry D	6.25	5.77

5. RESULTS ANALYSIS

5.1 General considerations

The microsimulation model, being able to represent the interactions between different traffic streams with different priorities, evaluates increasing delays and increasing queues for secondary streams as the eccentricity of the roundabout increases (Cosenza roundabout). The same effect was not observed on the secondary approaches of the Mottola roundabout. More detailed results are presented in the following, relative to these two performance measures (queues and delays), for all the analysed case studies.

5.2 Queues

As indicated, the simulation carried out on the two analysed scenarios allowed the measurement, among the others, of a performance feature for roundabouts: queue lengths at the approaches. The 95th percentile of queue lenghts, obtained by microsimulation, are compared in table 8, with the 95th percentile of queue lengths deriving from the utilization of servicing times, separately for each leg of the roundabout under the above specified flow loads (Gallelli et al., 2007).

Table 8 Comparison between the 95th percentile of queue lengths obtained from the utilization of the servicing times and estimated by microsimulation on each leg

Mottola roundabout	***A***	***B***	***C***	***D***
VISSIM (vehic)	10	8	6	8
Queue length observed (vehic)	8	9	1	14
Cosenza roundabout	***A***	***B***	***C***	***D***
VISSIM (vehic)	12	10	7	3
Queue length observed (vehic)	12	6	13	1

A further analysis was carried out by changing the traffic streams on the secondary direction approaches and holding constant the other traffic streams (tab. 9).

Table 9 95th percentile queue length estimated by microsimulation as a function of the different ratio between secondary and main flow streams

Mottola roundabout (vehic)	***A***	***B***	***C***	***D***
$Q_{sec}/Q_{pr} = 0.20$	7	8	5	8
$Q_{sec}/Q_{pr} = 0.40$	9	8	6	8
$Q_{sec}/Q_{pr} = 0.60$	9	9	7	9
$Q_{sec}/Q_{pr} = 0.80$	10	9	7	9
Cosenza roundabout (vehic)	***A***	***B***	***C***	***D***
$Q_{sec}/Q_{pr} = 0.20$	9	9	7	2
$Q_{sec}/Q_{pr} = 0.40$	10	9	7	2
$Q_{sec}/Q_{pr} = 0.60$	14	10	7	3
$Q_{sec}/Q_{pr} = 0.80$	15	10	7	5

5.3 Delays

Average delays, relative to the analysed scenarios, were evaluated for each of the roundabout approaches (tab. 10). Moreover, again a further analysis was carried out by changing the traffic flow streams on the secondary direction approaches and holding constant the other traffic streams (tab. 11).

Similarly to what has been evidenced in the queue length analysis, the average delays do not change for different values of the ratio between main and secondary streams when all other values are kept constant on the Mottola roundabout, whereas notably different delays are obtained among the different approaches of the Cosenza roundabout and for each approach a great variability is observed connected with a variable ratio between secondary and main flow streams.

Table 10 Comparison between the average delays obtained from the utilization of the servicing times and estimated by microsimulation on each leg

Mottola roundabout	**A**	**B**	**C**	**D**
VISSIM (s)	24	20	7	16
Delays observed (s)	11	8	6	18
Cosenza roundabout	**A**	**B**	**C**	**D**
VISSIM (s)	15	6	6	13
Delays observed (s)	10	4	5	7

Table 11 Average delays estimated by microsimulation as a function of the different ratio between secondary and main flow streams

Mottola roundabout (veic)	**A**	**B**	**C**	**D**
$Q_{sec}/Q_{pr} = 0.20$	21	17	5	14
$Q_{sec}/Q_{pr} = 0.40$	26	21	8	18
$Q_{sec}/Q_{pr} = 0.60$	27	24	11	20
$Q_{sec}/Q_{pr} = 0.80$	29	27	14	24
Cosenza roundabout (veic)	**A**	**B**	**C**	**D**
$Q_{sec}/Q_{pr} = 0.20$	10	5	5	8
$Q_{sec}/Q_{pr} = 0.40$	12	6	5	11
$Q_{sec}/Q_{pr} = 0.60$	21	7	8	19
$Q_{sec}/Q_{pr} = 0.80$	30	9	9	29

6. CONCLUSIONS

The analysis carried out on the Mottola and Cosenza roundabouts has been able to indicate how for a ratio between secondary and main direction flow streams close to 50% on non-circular roundabout delays are on average high for the secondary direction approaches.

On the Cosenza roundabout, in fact, with a value of 0.46 for the above mentioned ratio, average delays for users travelling on the secondary direction extend to twice the value of user delays travelling in the main direction.

Similarly, longer queue lengths are obtained for one approach on the secondary direction (even if a normal queue length is reproduced on the other secondary direction approach due to the low value of traffic flow for that specific approach in the studied case).

In agreement with what was forecasted in a preceding work (Astarita et al., 2006) based on other analyses developed in different contexts (test case scenarios), the results of this paper indicate that delays and queues sensibly increase for secondary traffic flow streams, on eccentric roundabouts, as the ratio between secondary and main direction flow streams increases.

The interpretation of the results presented in this work suggests the use of a non-circular roundabout when the intersecting roads have a different importance and different volume of traffic streams and when it is possible to choose to favour traffic flow in one direction over secondary traffic flow streams on the other perpendicular direction. This choice would allow a considerable increase in road safety for the driver. Moreover, in this way delays could be reduced in the main traffic direction. In fact, on circular roundabouts, the delays experienced by users travelling in the main direction would reach the same level of delays experienced by travellers on the secondary approaches.

REFERENCES

ASTARITA, V., GUIDO, G., VITALE, A., (2006) – "Verifica della applicabilità di rotatorie di forma non circolare tramite simulazione microscopica del deflusso veicolare" – *Proceedings of the XVI Convegno Nazionale S.I.I.V.*, Rende (CS), Italy, Volume Sessione Adeguamento, pp. 271-285, ISBN 88-7458-051-7

CANALE, S. et al. (2005) - "Progettare le rotatorie" – EPC Libri, Roma.

CAPILUPPI, G., GALLELLI, V., VAIANA, R., (2006) - "Intersezioni a raso con soluzione a rotatoria dissimetrica: un caso di studio" – *Proceedings of the XVI Convegno Nazionale S.I.I.V.*, Rende (CS), Italy, Volume Sessione Adeguamento, pp. 405-420, ISBN 88-7458-051-7

D.L. 285/1992 – "Nuovo Codice della strada" - Gazzetta ufficiale n.114 del 18/05/1992 e successive modifiche.

D.M. 05/11/2001 – "Norme funzionali e geometriche per la costruzione delle strade" – Gazzetta ufficiale n.3 del 04/02/2002.

D.P.R. 495/1992 – "Regolamento di esecuzione ed attuazione del Codice della strada" - Gazzetta ufficiale n.303 del 28/12/1992 e successive modifiche.

FEDERAL HIGHWAY ADMINISTRATION (2000) – "Roundabout: An Informational Guide", Turner-Fairbank Highway Research Center, U.S. Department of Transportation.

PLANUNG TRANSPORT VERKEHR AG (2005) - "Manuale per l'utente di VISSIM, versione 4.00", Transport Planning Service, Perugia.

TRANPORTATION RESEARCH BOARD (2000) – "Highway Capacity Manual 2000" – TRB, National Research Council, Washington.

WIEDEMANN, R. (1974) - "Simulation des Strabenverkehrsflusses" - *Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe*, Heft 8.

WIEDEMANN, R. (1991) - "Modelling of RTI-Elements on multi-lane roads" - *Advanced Telematics in Road Transport*, Elsevier, Amsterdam, pp 1007-1019.

GALLELLI V., CAPILUPPI G.F., VAIANA R. (2007) - Roundabouts performances analysis: comparison between classical methodologies, micro-simulation and field measuring – XXII European Conference on Operational Research, Road Traffic Management Session, Prague, July 8-11.