ANALYSIS AND COMPARISON BETWEEN TWO-LANE ROUNDABOUTS AND TURBO ROUNDABOUTS BASED ON A ROAD SAFETY AUDIT METHODOLOGY AND MICROSIMULATION: A CASE STUDY IN URBAN AREA

Lenin A. Bulla
Associated Professor, Faculty of Engineering, Universidad Militar Nueva Granada
Bogotá, Colombia, e-mail: lenin.bulla@unimilitar.edu.co

William Castro
Associated Professor, Faculty of Engineering, Universidad Nacional de Colombia
Bogotá, Colombia, e-mail: wcastrog@unal.edu.co

Submitted to the 3rd International Conference on Road Safety and Simulation, 14 September 14-16, 2011, Indianapolis, USA

ABSTRACT

Turbo roundabouts are a type of intersection with an increased use in Holland during the last ten years, and since its invention in 1996, more than 130 of these have been built in this country. Recently, one was built in Germany and three in Spain. A field study has shown that turbo roundabouts have helped reduce accidents by a significant 80% in comparison to intersections regulated by roundabouts. In the same way, its new geometry has restricted weaving and persuaded drivers on the road to yield to a maximum of two lanes, providing an additional capacity of 12% to 20% of the rotating roadway.

In order to implement the first turbo roundabout in Bogotá, a research was developed to compare the two-lane roundabouts and basic turbo roundabouts to different aspects of capacity, level of service, and road safety. During this research, micro simulation was used to determine the performance of road capacity by implementing a basic turbo roundabout as a control mechanism within an intersection, currently regulated by a conventional roundabout.

The benefits in relation to road safety and traffic indicators were analyzed to allow a feasible implementation of these new intersections, generating a preliminary design criterion that can be reevaluated. To compare the two types of intersections in terms of road safety, a methodology of road safety audits (RSA) is proposed and applied.

Keywords: roundabout, turbo roundabout, micro simulation, road safety, traffic engineering.

INTRODUCTION

The developed project will lead to the formulation of a methodology of RSA to compare roundabouts and turbo roundabouts in design stage, looking for advantages and disadvantages in its operation. On the other hand, basic methodologies of design and micro simulation of turbo roundabouts were formulated from the benefits that these have shown in the Holland. As a result strategies for their implementation in Bogotá will be considered. Models of micro simulation of same road intersection with roundabout and turbo roundabout were constructed to characterize the performance of turbo roundabouts in technical and operative aspects, obtaining indicators of comparison with the traditional roundabouts based on the growth of the demand in time and the evaluation of future scenarios.

RESEARCH COMPONENTS

The following sections will present the different stages and components that were sequentially developed during the research.

State of the art

The turbo roundabout is a multilane roundabout with spiral lane demarcations, separated by raised dividers in which road users must select a lane before entering the roundabout, in order to leave in the desired direction. Main geometric characteristics of turbo roundabouts are:

- Turbo roundabouts have more than one turning lane.
- The right lane must be selected before reaching the intersection.
- Incoming volumes must yield to the users turning in order to limit to two lanes the maximum number of turning lanes in all cases.
- Weaving movements are not possible in turbo roundabouts.
- Left movements in turbo roundabouts are prioritized.

These characteristics make turbo roundabouts safer for operational turns and allow an increased capacity in traffic flow than roundabouts. The following European countries confirm that turbo roundabouts are a better solution according to their research studies:

<u>Holland</u>

Lambertus Fortuijn (2009a), who developed turbo roundabouts in 1996, presented a paper titled “Design Principles and Safety Performance” which explained restrictive weaving and the purpose of limiting yield to a two lane maximum. Holland has built 170 turbo roundabouts since 2000, based on the 80% accident reduction rate that these offer, compared to classical roundabouts.

The Practical Manual of Roundabouts - Application and Design (2009) dedicates a chapter to turbo roundabouts. This Manual specifies than in Holland conventional roundabouts will no longer be constructed, and turbo roundabouts will replace them gradually.

Fortuijn's designs of turbo roundabouts can turn more complex according to volume and specific needs of each case. Planning a first turbo roundabout in Bogotá is considered for this project the simplest version of the intersection, named *basic turbo roundabout*, shown in Figure 1.

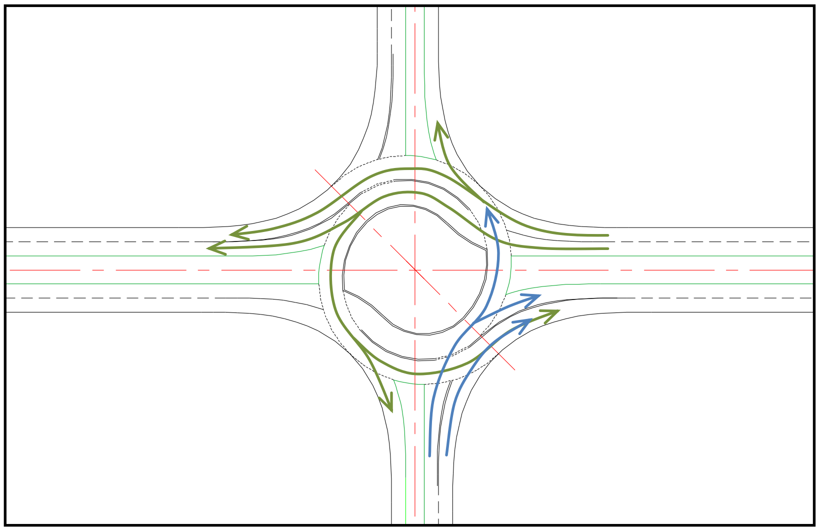

Figure 1 Basic turbo roundabout scheme

Belgium

Yperman and Immers (2003) determined the capacity of a two-lane turbo roundabout using Paramics, finding an increase of 12% compared to a two-lane classical. They used the Bovy´s formula corresponding to Cetur method.

South Africa

Engelsman and Uken (2007) presented a paper in which they explained the possible impact of turbo roundabout implementation in South Africa. The research supports that turbo roundabouts are an efficient solution, better than two-lane roundabouts, single-lane roundabouts, yield intersections and some signalized intersections, as long as the volume will not be higher than 3500pcu.

Germany

Brilon (2008) presented his experiences based on observations of the first turbo roundabout in Baden-Baden, Germany. His conclusions included:

- Turbo roundabout work in a good level.
- It is capable of admitting large volumes of through-traffic under lower demand on the side it approaches.

This research is based on just one case with low volumes.

Spain

In the city of Grado (Asturias) two turbo roundabouts were constructed and opened on 2009. Through a micro simulated analysis including alternative roundabouts, turbo offered the best results. During the first days of operation, users were skeptical because of this new way of control, but with the support of traffic police they gradually realized the benefits.

Fieldwork at an intersection in Bogotá

Good indicators of traffic and road safety are the motivation to consider the possibility of implementing turbo roundabouts in Bogotá, taking into account that the city needs a better intersection management. The project began with the selection of an intersection that is currently regulated by a two-lane roundabout. After a search of three months a place was finally found (shown in Figure 2). The basic requirements for this selection were:

- An area big enough to implement a turbo roundabout without affecting sidewalks or private properties.
- A place without access to houses, buildings or properties that may affect the operation of the intersection.

Fieldwork includes current geometrical design, vehicle volumes, directionality, variation in time, speeds, critical gaps and other necessary information to develop micro simulation models. This information was gather through video analysis during peak hours and field visits.

Figure 2 Aerial view of the intersection from the filming location

Critical gap is the minimum time between two consecutive vehicles of the same main stream that drivers of a minor stream accept to merge on the main stream, used in the capacity evaluation of unsignalized intersections. Information analysis allowed to find values of the critical gap in a two-lane roundabout discriminated by origin lane of the approach and destination lane of the roundabout. These values are shown on Table 1.

Table 1 Critical gap values

	Left lane of main road to	Right lane of main road to	Only lane of minor road to
Inner lane of roundabout	2.0 s	1.8 s	2.0 s
Number of data	31	6	9
Outer lane of roundabout	2.0 s	3.6 s	2.0 s
Number of data	11	48	15

It is important to specify that these gaps were obtained based on video recordings; therefore the values are not rigorously exact. The values correspond to the peak hour of the intersection, found on a Saturday morning (07:15 to 08:15).

Geometric design of a proposed turbo roundabout

A turbo roundabout has been proposed for the selected intersection in the city of Bogotá based on field and video information, applying a geometric design methodology formulated in the project. The result of the information analysis generates the design shown in Figure 3. This geometry is the base of the turbo roundabout microsimulation model, as well as, the model with the current roundabout situation.

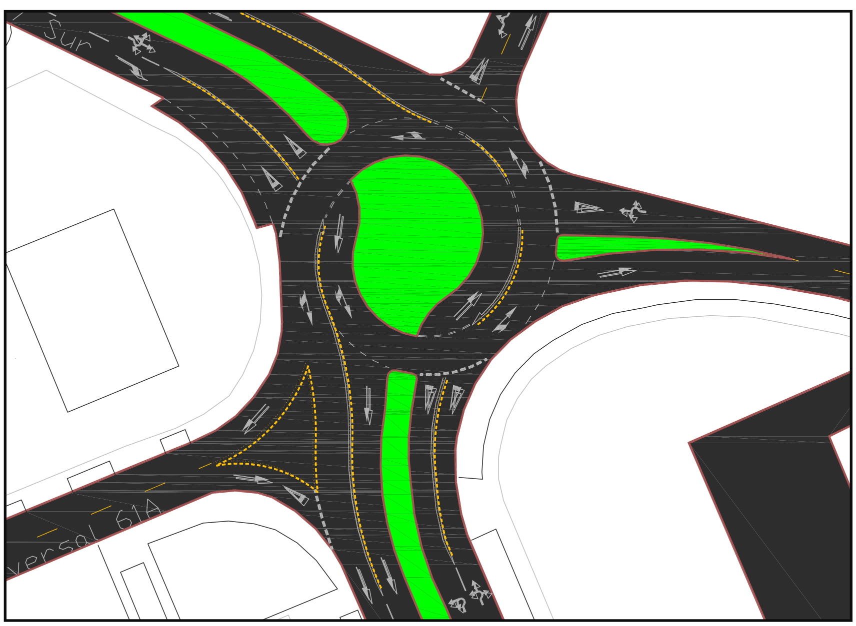

Figure 3 Proposed turbo roundabout

There are some marks in the design that are not included in the Colombian Manual of Signalization and need to be studied a reevaluated by national entities in case of future implementation of turbo roundabouts in the country. Likewise, it is necessary to implement a field research to choose the right raised canalization materials according to the local driving behavior. Fortuijn's design principles and safety performance (2009b) was a support for the proposed geometry.

Road safety audit methodology and results

A RSA methodology is proposed to compare classical and turbo roundabouts. The procedures followed by the RSA do not correspond to a globally standardized methodology. As a matter of fact, it is constantly changing due to the growing importance of the global trend towards the reduction of accidents, prevention, correction of human behavior; vehicle performance and specifications of the roads leading to improve and reevaluate the design and construction of infrastructure to encourage a safer human behavior. As a first step it is necessary to establish the danger level of all road users (vehicles, pedestrians, cyclists, etc...), which can be determined as hazard to others due to an inadequate behavior with the real operation on the road. To assess the risk at every area of conflict three aspects are taken into account: the time of exposure of users to hazards, the probability of an accident seen from the auditor's perception of risk, and consequences measured from the type of accident that could occur due to a typical activity in the area. The sum of these three parameters measures the degree of danger, under the following scale of values in Table 2.

Table 2 Values for score of level of danger

Scale	Consequence	Time of exposure	Probability	Sum
Low	1	1	1	Different for each point
Medium	3	3	3	
High	5	5	5	

The sum of the score of the three parameters leads to the final value of the level of danger, and according to the level the hazard it could be measured as high, medium or low. A value will be assigned according to Table 3.

Table 3 Values for score hazard

Hazard	Level of danger	Score
Low	1 To 5	1
Medium	6 to 10	3
High	11 a 15	5

To evaluate vulnerability it is necessary to measure what percentage of users will be susceptible to the hazards identified in point during a predefined period. This is mainly achieved through a field measure; depending on the resulting percentage it is appropriate to assign a score to the vulnerability according to Table 4.

Table 4 Values for score vulnerability

Vulnerability	Percentage of exposed	Score
Low	1 to 30	1
Medium	30 to 60	3
High	60 to 100	5

Finally, the risk is rated based upon the principle of geotechnical risk, as the product of hazard and vulnerability. For illustration purposes a color is assigned to each risk level (high, medium and low). The risk score ranges are presented in Table 5.

Table 5 Values for score risk

Risk	Hazard x Vulnerability	Color
Low	1 to 4M5	Green
Medium	5 to 14	Yellow
High	15 to 25	Red

Based on a checklist the main critical points (aspects of operation) were determined, presenting major risks in both intersections: roundabout (R) and turbo roundabout (TR). Since the list is really long, Table 6 has been reduced to show only eight critical points.

Table 6 Evaluation of hazard, vulnerability and risk

Aspect	Danger evaluation								Hazard		Vulnerability		Risk	
	Consequence		Exposure time		Probability		Total							
Kind	R	TR	R	TR	R	TR	R	TR	R	TR	R	TR	R	TR
Intersection configuration	3	1	5	3	1	1	9	5	3	1	3	5	9	5
Motorcycles operation	3	3	1	1	3	3	7	7	3	3	5	3	15	9
Uniform cross section	3	1	5	1	3	1	11	3	5	1	5	1	25	2
Distances of cross section changes	1	3	5	3	1	1	7	7	1	3	5	5	5	15
Pedestrian canalized flows	5	5	1	1	3	3	9	9	3	3	1	3	3	9
Pedestrian infrastructure	3	3	5	5	1	1	9	9	3	3	5	5	15	15
Visibility of pedestrian refuges	5	3	3	3	1	1	9	7	3	3	1	1	3	3
Pedestrian crosses	5	5	3	3	1	3	9	11	3	5	3	3	9	15

Other aspects evaluated are: volumes, intersection design, global visibility, signals, sections, speeds, pedestrian facilities, and human behavior.

Basically, turbo roundabouts offer lower exposure time than roundabouts due to the raised dividers for many aspects of the operation. In the city of Bogotá the use of motorcycles is a critical aspect because of its hazardous driver behavior and the significant increase it has have. In both cases, the pedestrian operation can prove to be risky due to the geometric layout and the dangerous behavior shown by drivers of passengers and larger vehicles.

An overview of the risk values allows to conclude that operation in a turbo roundabout is safer, validated by field observations in Holland. However, taking into account local driving, the risk level for pedestrians and cyclist is high, which results in the recommendation to move the location of the crossings for non-motorized users away from the area of direct influence of the intersection.

At the roundabout, the lack of uniformity of the section generates a high risk because the output leg does not have the same number of lanes as the road of rotation. This creates a bottleneck effect where users need to yield, making the probability of conflict very high. This situation can be overcome by configuring a turbo roundabout.

Microsimulation comparison: two lane roundabout vs. two lane turbo roundabout

With known geometry, volumes, traffic composition, directions, speeds, gaps, etc. both model, the two-lane roundabout and the two-lane turbo roundabout were micro simulated and calibrated, generating models for 2010 year basis and for 5, 10 a 15 years in the future. Figure 4 shows both models using VISSIM software.

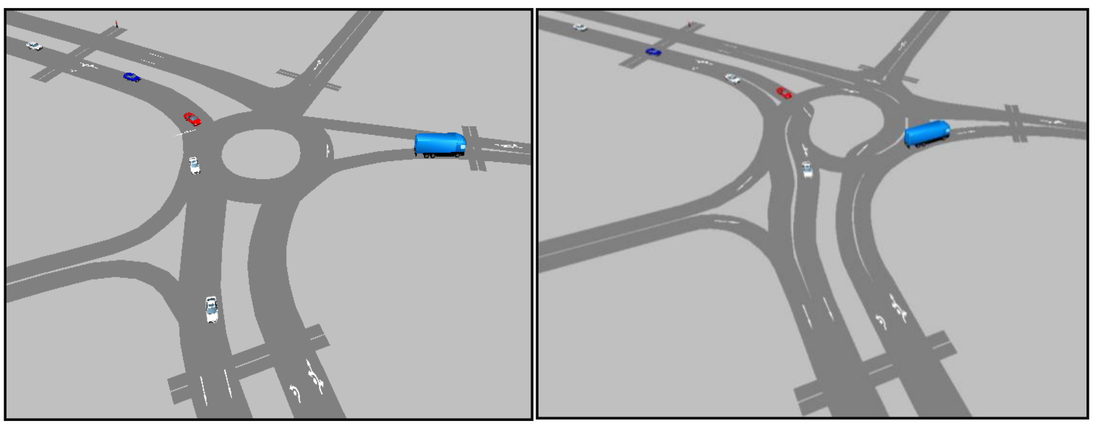

Figure 4 Microsimulation in the current situation (left) and proposed turbo roundabout (right)

Model calibration and validation

Models were calibrated by GEH Index. The averaged delay per approach and maximum queue distance observed, helped obtain the next results:

- Fellendorf (2004) exposes that GEH Index was proposed by Geoffrey E. Havers (UK, 1970). The proposed equation (see Equation 1) allows to compare two different volumes of the same network (real vs. simulated), under the next parameters:

GEH<5	volumes satisfactorily calibrated.
5<GEH<10	additional adjustment is required.
10<GEH	volumes are not correctly adjusted.

$$GEH = \sqrt{\frac{(observed\ volume - simulated\ volume)^2}{0.5(observad\ volume + simulated\ volume)}} \quad (1)$$

According to the pick hour volume of the base model GEH is:

$$GEH = \sqrt{\frac{(2486-2458)^2}{0.5(2486+2458)}} = 0.56 \quad (2)$$

GEH Index= 0.56 concludes that the calibrated volume validates the base of the 2010 year model.

- Average delay per approach determined by observing videos, and compared with reports from the micro simulation software. Values shown on table 7 were used to produce a calibration curve of R^2=0.64.

Table 7 Comparison between field and model average delay

Approach	Number of data	Field average delay (sec./vehicle)	Model average delay (sec./vehicle)	Difference
North	38	5.43	4.5	0.93
South	203	3.96	3.06	0.90
West	317	2.23	3.3	-1.07
East	72	1.73	0.47	1.26

- Maximum queue distance determined for each approach by field and video measures using real queue length and average vehicle length. This parameter produced a R^2=0.97 in a calibration curve.

Figures 5 and 6 show calibration curves of average delay and maximum queue distance per approach.

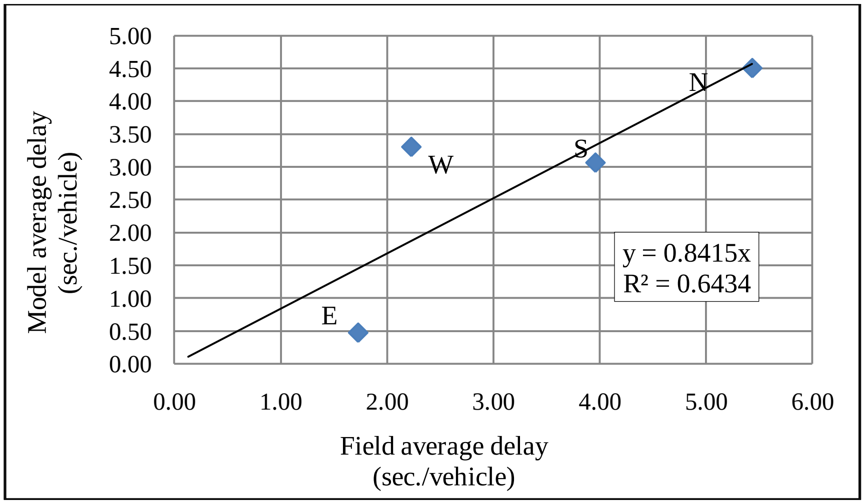

Figure 5 Model calibration based on average delay

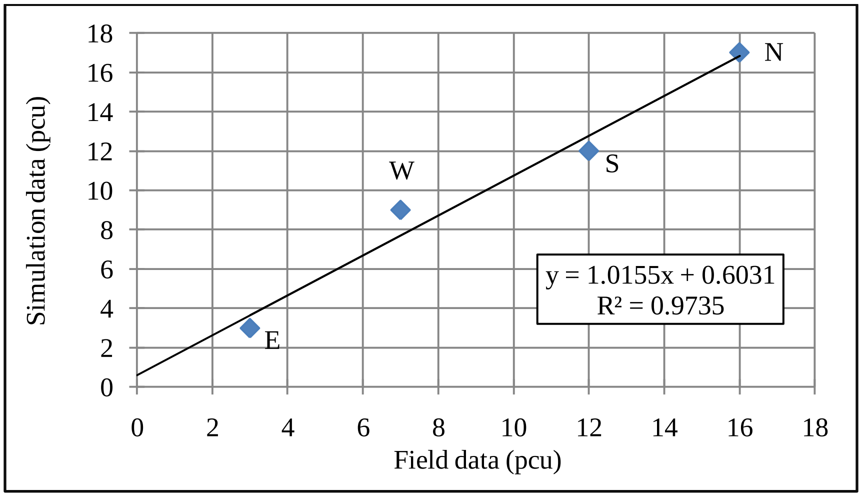

Figure 6 Model calibration based on maximum observed queue distance

The three parameters selected for the calibration of the models proved to be a reliable data. After generating, calibrating, and validating models for the year 2010, additional models were generated projecting vehicular volumes with an annual growth rate of 1.1% for the next 5, 10 and 15 years. This percentage was drawn by governmental agencies to validate the plan for land use in Bogotá and it is specific to the sector of the city where the intersection under study is located.

After generating multiple runs of the model, it was possible to analyze and compare operational indicators. Turbo roundabout model presents better indicators in all assessments, and will help postpone the traffic saturation that will increment as time goes by.

Table 8 shows the values of delay and speed average for the intersection. As noted, the turbo roundabout has lower values and as time passes the volume increases and the difference between the two types of intersection increases as well.

Table 8 Performance of operational indicators in time

Parameter (all vehicle)	2010		2015		2020		2025	
	Base year		Annual growth: 1.1%		Annual growth: 1.1%		Annual growth: 1.1%	
			Total growth: 6%		Total growth: 12%		Total growth: 12%	
	R	TG	R	TG	R	TG	R	TG
Simulated vehicle	2486	2486	2633	2634	2705	2779	2773	2917
Average delay (sec./vehicle)	12.849	9.155	34.487	11.351	42.772	17.059	54.891	27.743
Average speed (Km/h)	28.777	33.470	19.266	31.606	17.107	27.662	14.734	22.393
LOS HCM 2010	B	A	D	B	E	C	F	D

Aiming to establish Level of Service (LOS) for multilane roundabouts, the criteria set by the National Cooperative Highway Research Program (2007) was used. Table 9 shows the LOS parameters based on the average delay.

Table 9 Level of service in multilane roundabouts

Average delay	LOS due to V/C	
Seconds/vehicle	V/C≤1	V/C>1
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	F
>50	F	F

CONCLUSIONS

Three components were used to achieve acceptable levels of road safety: engineering associated to design and logical programming of infrastructure, displacements, and regulations. Configuration of turbo roundabouts represents an ingenious design that controls vehicle movement and speed, and help promote driver awareness to street signage when they encounter risky overtakes on the road.

In a particular case of this research a capacity increase of 7% difference was found between roundabout and turbo roundabout; however, it is emphasized that critical gap parameters used in micro simulation models of a turbo roundabout were taken from a field study in Holland. Dutch gaps results were smaller than the calibrated gaps in Bogotá. Once a turbo roundabout is available for calibration it is thought to generate a greater capacity to the intersection.

The RSA developed a process that allowed concluding and ratifying the road safety benefits in turbo roundabouts. There was a 22% reduction found in overall risk assessment obtained by the comparison of the average risk of both intersection.

The main contribution of this research is found on the generation of a technical document that validates the feasibility of implementing turbo roundabouts in Bogota, seen from the operating indicators. At the same time, a methodological guide was generated to design the basic type of turbo roundabout, including step-by-step instructions on how to divide in half the central island in a turbine shape, as well as the joints.

ACKNOWLEDGEMENTS

Thanks to Professor Carlos Moncada of the Universidad Nacional de Colombia, who reviewed the wording and presentation of this document and made valuable conceptual contributions.

REFERENCES

Brilon, W. (2008) Turbo-Roundabout - An experience from Germany. *In Transportation Research Board, National Roundabout Conference*, Kansas City, Missouri.

Engelsman, J.C. & Uken, M. (2007) Turbo roundabouts as an alternative to two lane roundabouts, *Paper presented to the 26th Annual Southern African Transport Conference*, South Africa, 9 - 12 July 2007. 8p.

Fellendorf, M. (2004) Calibration of VISSIM. *14th ptv vision User Group Meeting*. Karlsruhe, Germany. 22p.

Fortuijn, L. G. H. (2009a) Turbo Roundabouts: Design Principles and Safety Performance. *In Transportation Research Record: Journal of the Transportation Research Board*, 2096**,** pp. 16-24.

Fortuijn, L. G. H. (2009b) Turbo Roundabouts: Estimation of Capacity. *In Transportation Research Record: Journal of the Transportation Research Board*, 2028, pp. 83-92.

NCHRP, (2007) National Cooperative Highway Research Program. *Roundabout in the United States*. *Report 572*, Transportation Research Board, 125p.

Yperman, I. & Immers, B. (2003) Capacity of a turbo-roundabout determined by micro-simulation. *In proceedings of the 10th World Congress on ITS***,** 10p.