PERFORMANCE INDICES FOR THE CHARACTERIZATION OF THE SAFETY LEVEL FOR THE ROUNDABOUTS

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ABSTRACT

Rural roundabouts present an important quality: the improvement of the safety characteristics with respect to other intersection typologies of intersection at grade. With the present paper, we want to propose a general methodology which, basing on a series of inputs (geometry, vehicular flows, operative speeds), allows to characterize the performances, in terms of safety, of the roundabouts. The final objective is to determine the performance indices necessary to define the dangerousness level of the roundabouts of great diameter, typical of the rural contexts. These indices will come up to the traditional parameters (level of service, capacity), that defines the roundabout performances only in the terms of the transport service quality.

KEY WORDS

INTERSECTIONS / ROUNDABOUTS / SAFETY / PERFORMANCE / INDICES

1. INTRODUCTION

Safety evaluation of road intersections is a recurrent and determinant problem in order to establish intervention techniques for maintenance and also to make right design choices for the realization of new infrastructures.

Italian experience is still limited and cannot give a definitive judgement on the real advantages, in terms of safety, of roundabouts with respect to other typologies of intersections.

Strict before-after investigations were already carried out at international level and many data were collected. These data put in evidence that roundabouts are particularly effective for reducing the level of risk connected with their use. (AA.VV., 2000).

Roundabout literature has now available many analytical previsional models, that models may be applied to the nodes of a road network and used to foresee accidents that may occur at road intersections. Even if on the basis of different formulations, these models request two categories of input parameters: traffic-flows and geometric characteristics of the elements which define the intersection (Curti, Marescotti, Mussone, 2001).

An “historical” model to evaluate the number of accidents of a roundabout is the one proposed by Maycock and Hall in 1985.

It is an experimental model, based on the value of the average daily traffic (ADT) which allows the evaluation of the number of fatal and injured accidents (A) on every access lane to the roundabout.

The formulation proposed by Maycock and Hall is:

$$A = K \cdot Q_e^{\alpha} \cdot Q_c^{\beta} \cdot e^{\sum(b_i \cdot X_i)} \quad (1)$$

Where:

- K, b_i = coefficients to be estimated on the basis of regressions;
- α, β = coefficients to be estimated on the basis of flow;
- Q_e, Q_c = in/out flows (ADT);
- X_i = geometric variables.

The model prepared by Kennedy, Hall and Barnard (1997) is more recent and specific for accidents prevision concerning roundabouts in urban areas. This is also an experimental model and its analytical representation is formally identical to the formulation (1).

Another analytical model for the evaluation of roundabout-accidents is the Arndt and Troutbeck model (Arndt, Troutbeck, 1995), refined by Arndt after few years (Arndt, 2000).

Unlike the previous ones, this is a theoretic model and not an experimental one; the requested input data are:

- geometric layout of the roundabout;
- speed in every approach lane;
- traffic volumes necessary for all the manoeuvres.

The formulations proposed by Arndt allow the evaluation of the number of the accidents connected to everyone of the six following accident typologies, for a reference period of one year:

1) accidents related to isolated vehicle;
2) rear-crashes at access lanes;
3) crashes among entering and circulating vehicles;
4) crashes among exiting and circulating vehicles;
5) lateral crashes;
6) other types of accidents.

Even if founded on simply theoretic basis, this model, when applied, has given results very close to the real ones; this induced this research team to use it for the evaluation procedure of the Roundabouts Performance Index. It has to be underlined that since several years the authors of this paper have been studying the problems connected to the performance characteristics of urban and rural roundabouts (Canale, Leonardi, Pappalardo, 2001; Canale, Leonardi, Pappalardo, 2002; Leonardi, Pappalardo, 2002).

With the present study we want to propose a general validity methodology allowing performance characterization, in terms of safety, of wider roundabouts, on the basis of a series of input parameters (geometry, vehicular flows, operative speeds). Particularly, we will define some performance indicators which will allow the quantification of only one Performance Indicator, useful to characterize the safety level offered to the users.

2. PROCEDURE FOR THE EVALUATION OF PERFORMANCE INDEX

The first point of the procedure is the evaluation of a synthetic indicator suitable to describe the level of safety of a rural roundabout.

We deemed it was necessary to make reference to the total number of incidents expected per one year, estimated on the basis of the theoretic model elaborated by Arndt.

We have therefore defined the incidentality index (A), quantifiable through the relations proposed by Arndt (Arndt, 2000):

$$A = A_{sp} + A_{sa} + A_r + A_e + A_d + A_{SS} + A_l \quad (2)$$

We have foreseen to evaluate the incidentality index of a group of roundabouts in rural areas, in order to obtain a methodology of general validity. In particular:

- we have chosen roundabouts with four arms symmetrically disposed;
- we have adopted external radiuses with a variability between 30 and 100 meters, and intervals of 10 meters;
- we have changed the conformation of the approaches time by time according to the radius chosen for the circulatory roadway so that deflection radiuses of vehicular trajectories suitable with foreseen speed are always guaranteed;
- we have chosen two different configurations in relation with the lanes number: the circulatory roadway with only one lane and the circulatory roadway with two lanes and have adopted a minimum of 3,75 meters/lane.

For what concerns traffic data we have foreseen:

- to refer to the flow circulating on every roundabout, variable within an interval of 5000/50000 vehicles/day, with successive step of 5000 vehicles/day;
- to justly subdivide each flow on the four arms composing the intersection;
- to uniformly divide each arm flow on each of the three possible manoeuvres (crossing, right-turn and left-turn).

Finally, for what concerns operative speeds on the entry lanes:

- we have adopted values between 50 km/h and 100 km/h, with interval of 10 km/h;
- each speed value has been given, without any variation, to all the four entry lanes to the roundabout taken into consideration;

- the variations of operative speeds, starting from the entering value, have been calculated in function of the conformation of the various vehicular trajectories, accordingly with the procedure proposed by Arndt.

The results of these processes are shown in a series of 12 diagrams (figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

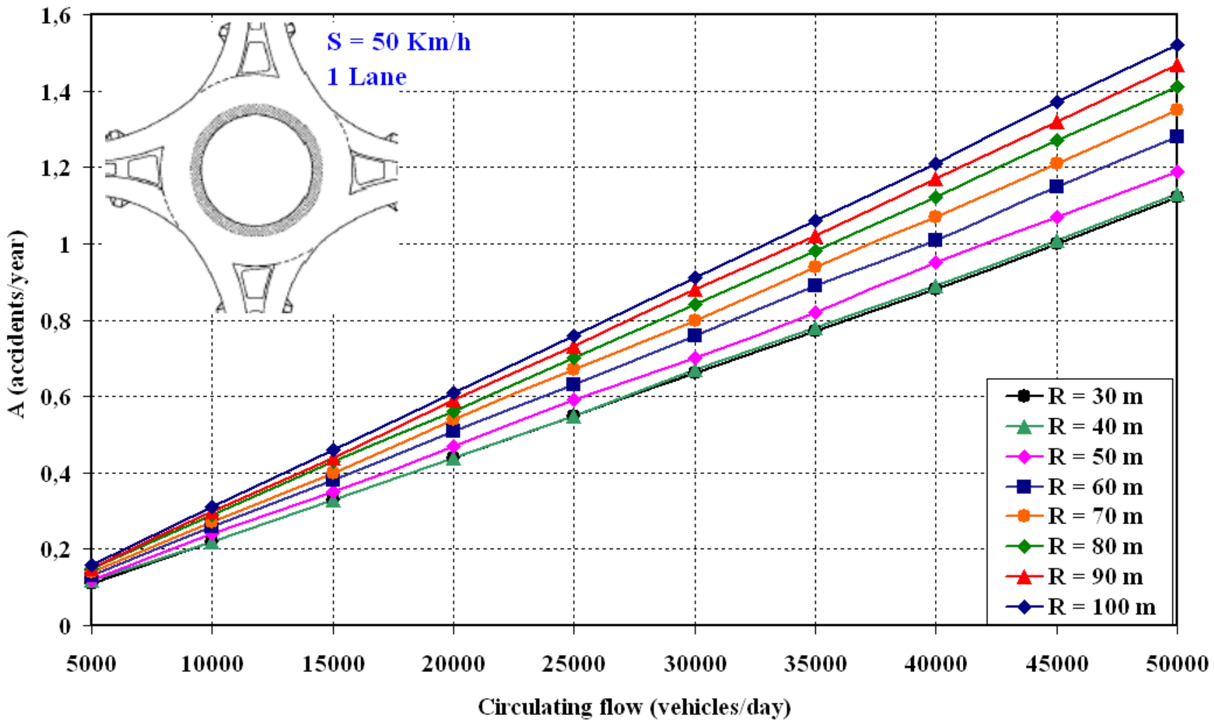

Figure 1 - Incidentality Index on the roundabouts (one lane, S=50 km/h)

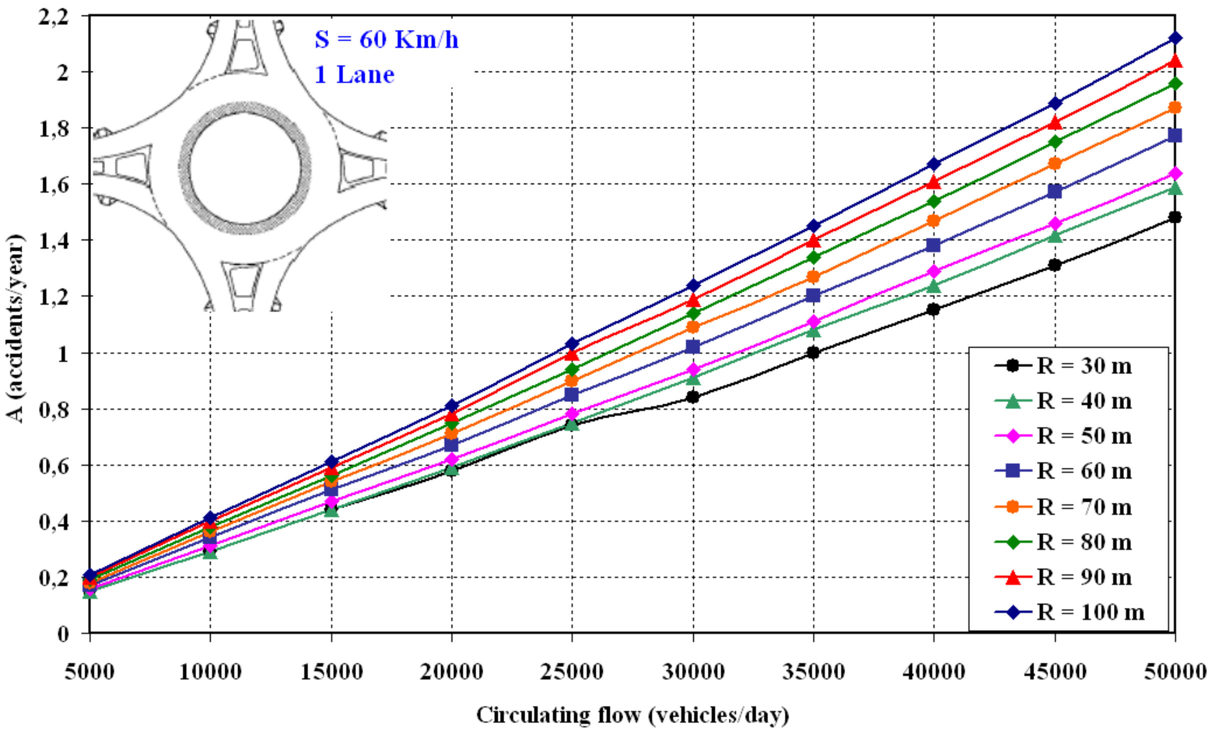

Figure 2 - Incidentality Index on the roundabouts (one lane, S=60 km/h)

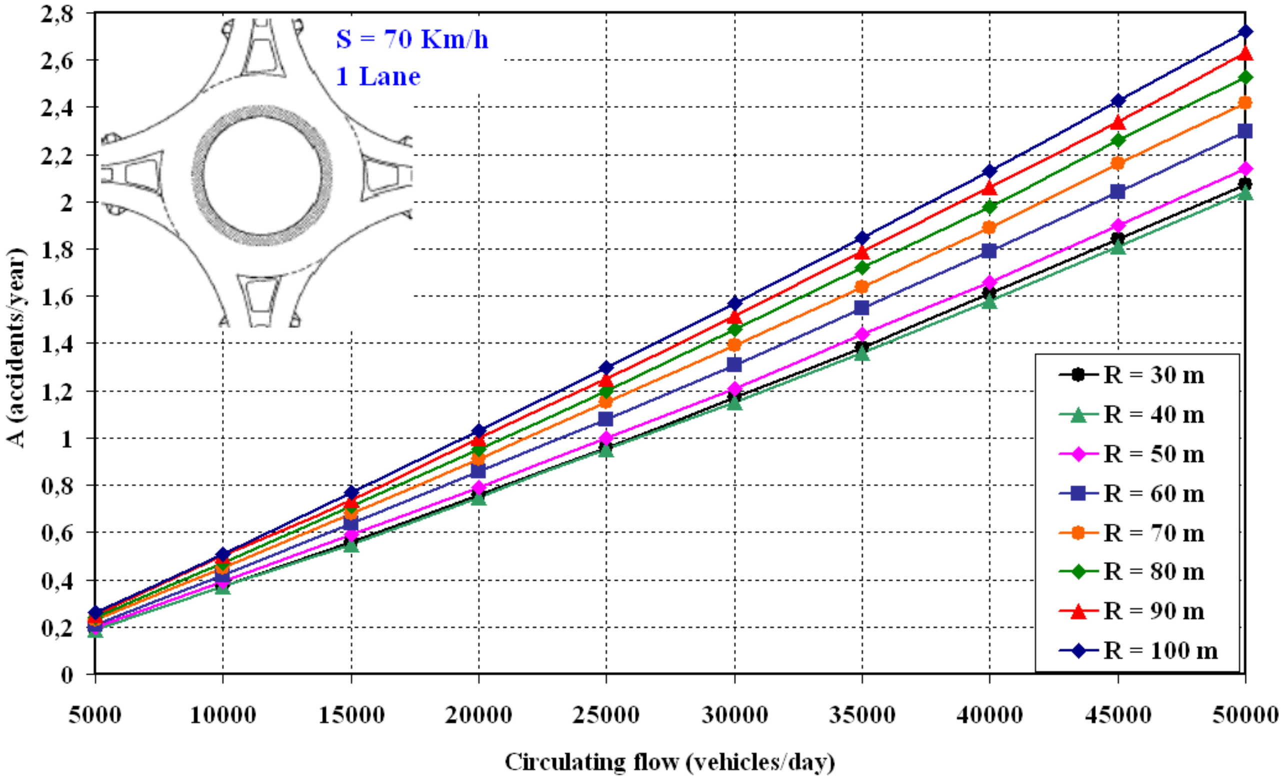

Figure 3 - Incidentality Index on the roundabouts (one lane, S=70 km/h)

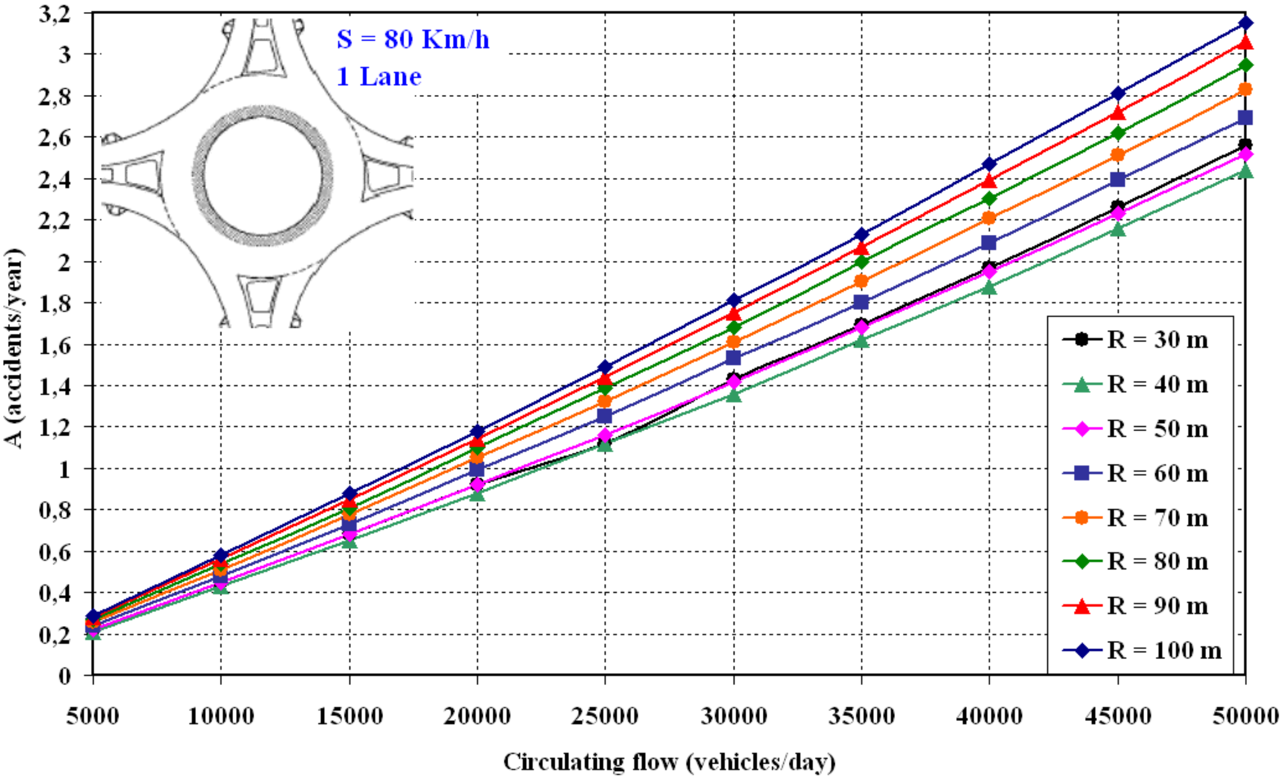

Figure 4 - Incidentality Index on the roundabouts (one lane, S=80 km/h)

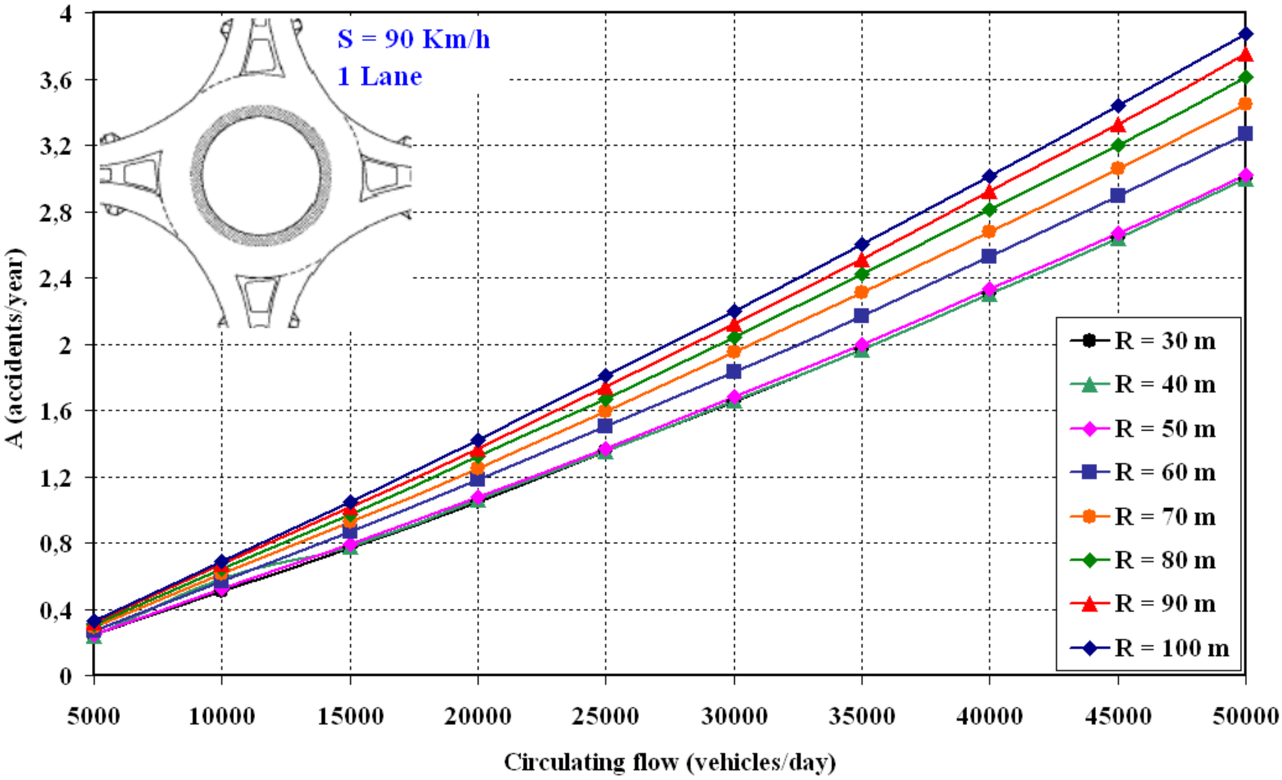

Figure 5 - Incidentality Index on the roundabouts (one lane, S=90 km/h)

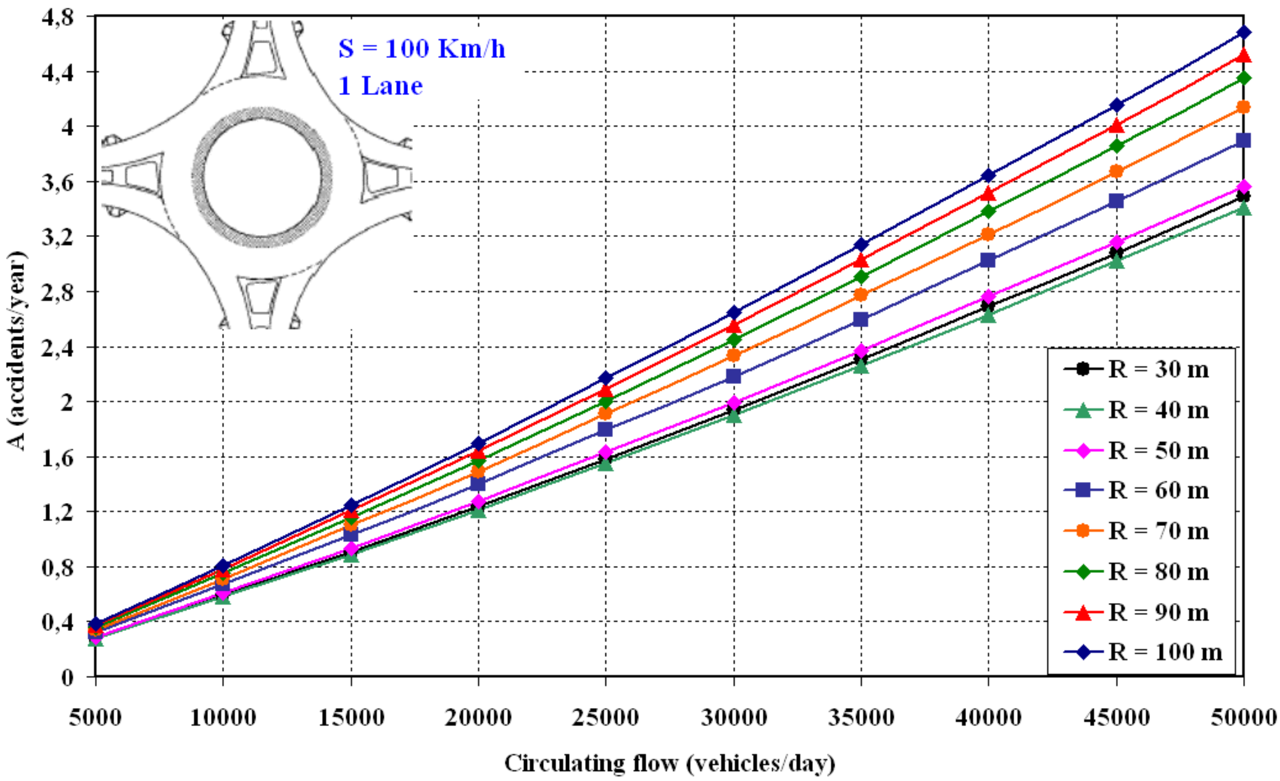

Figure 6 - Incidentality Index on the roundabouts (one lane, S=100 km/h)

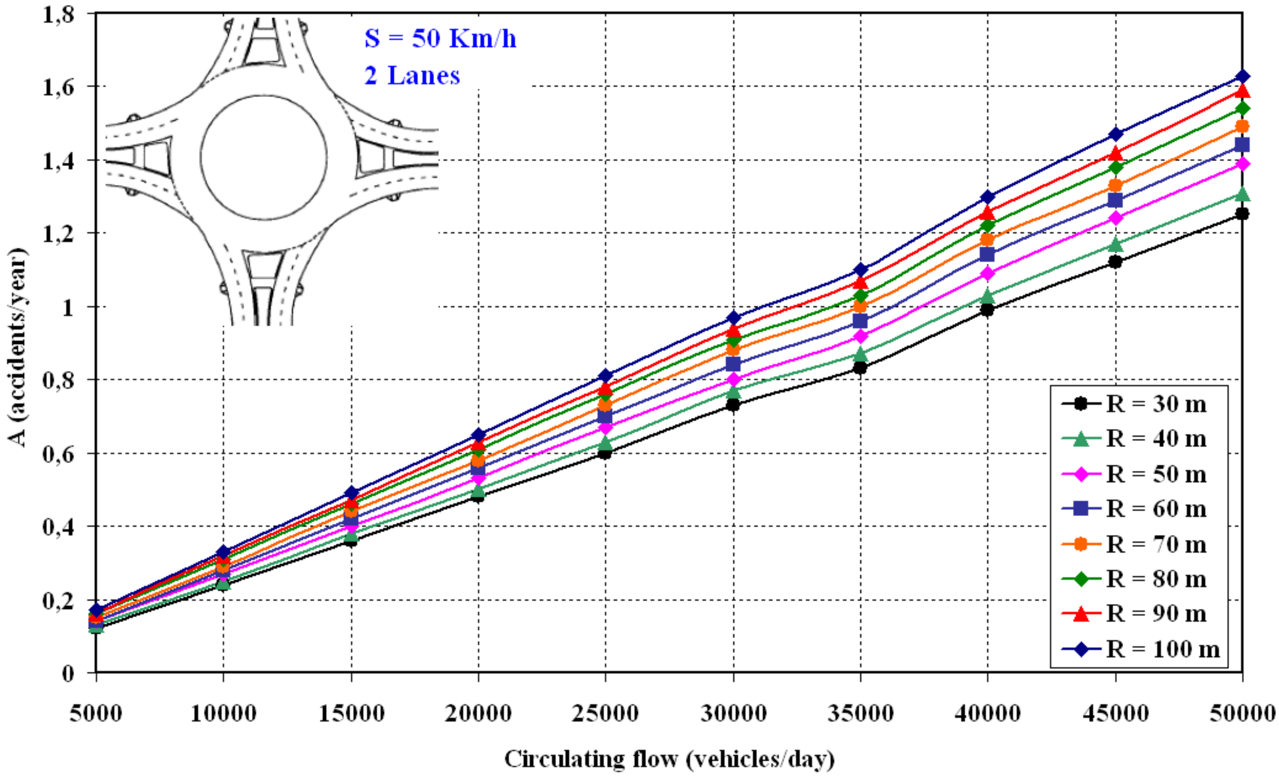

Figure 7 - Incidentality Index on the roundabouts (two lanes, S=50 km/h)

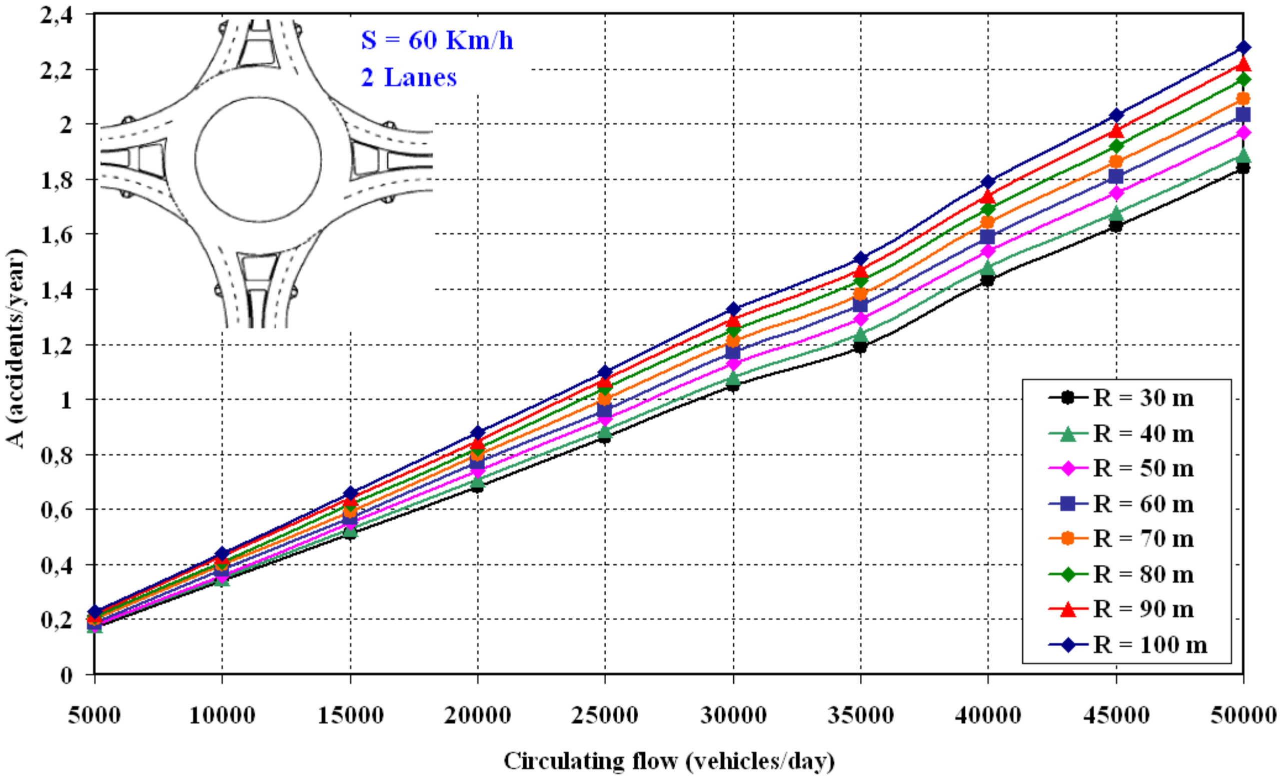

Figure 8 - Incidentality Index on the roundabouts (two lanes, S=60 km/h)

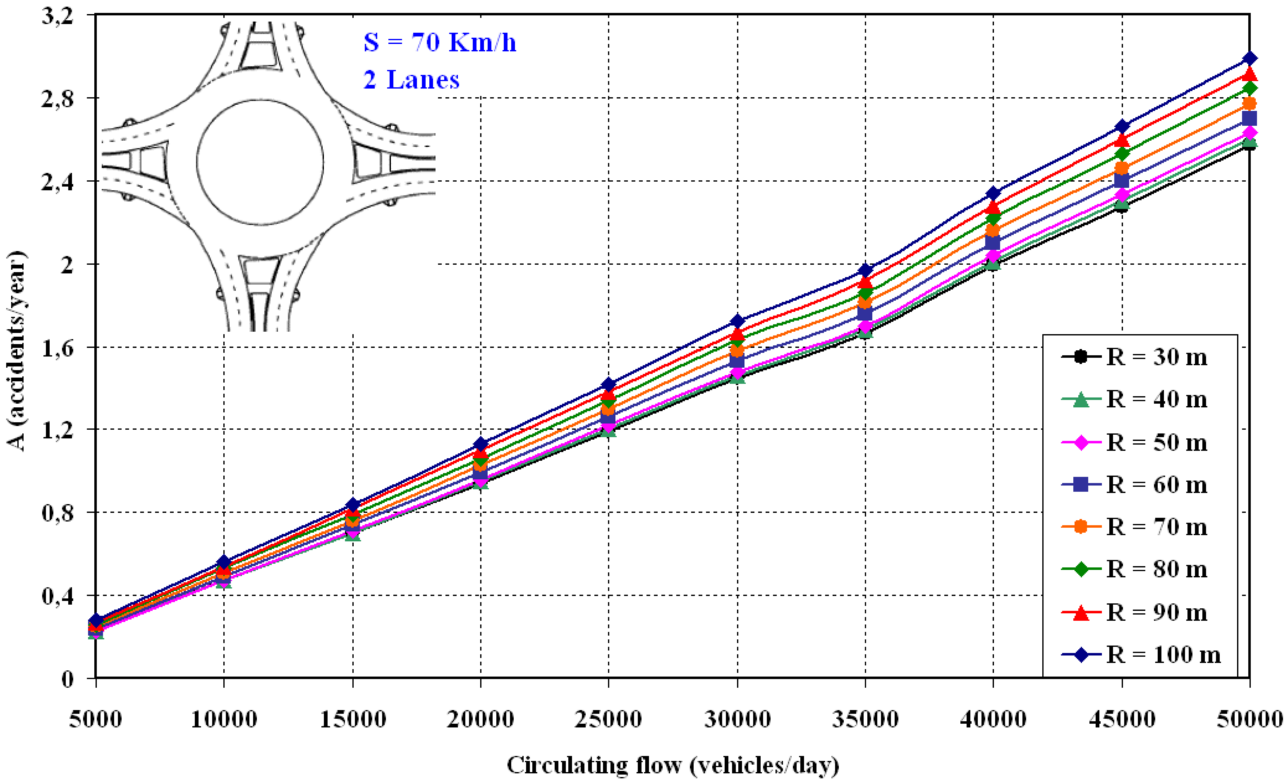

Figure 9 - Incidentality Index on the roundabouts (two lanes, S=70 km/h)

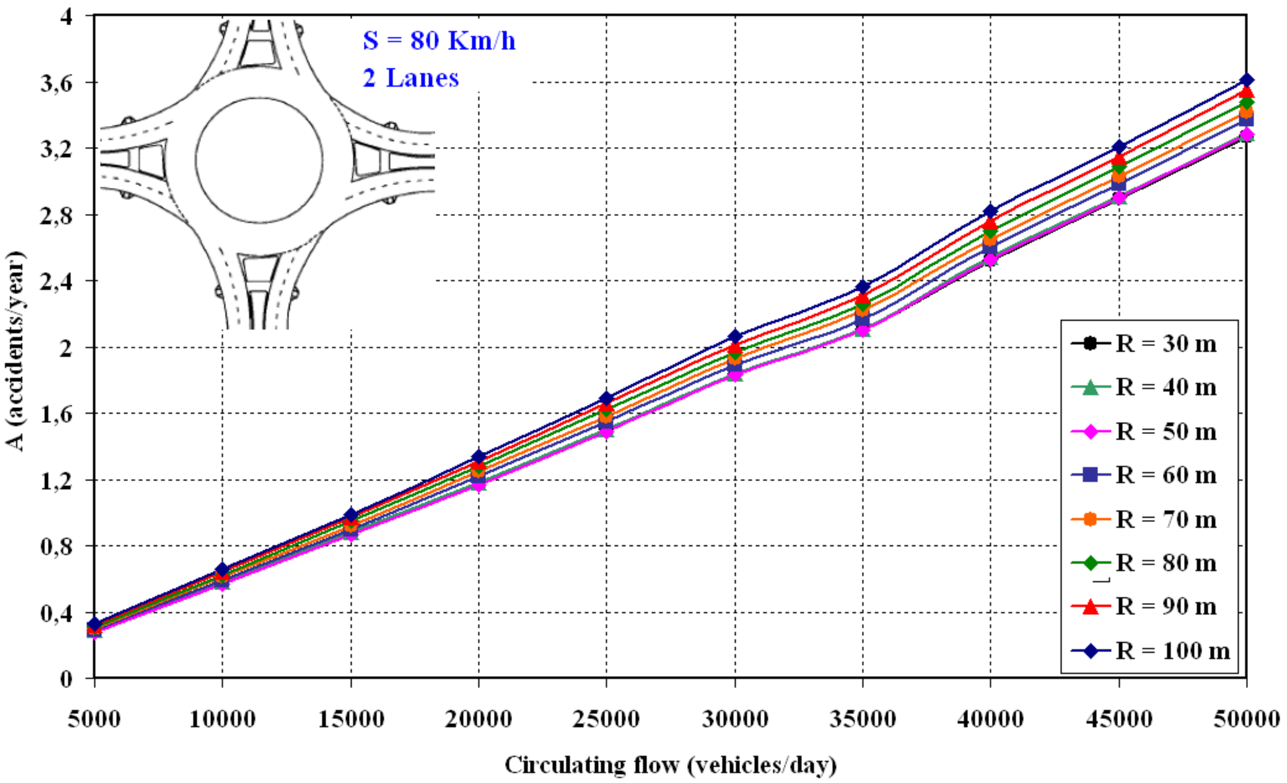

Figure 10 - Incidentality Index on the roundabouts (two lanes, S=80 km/h)

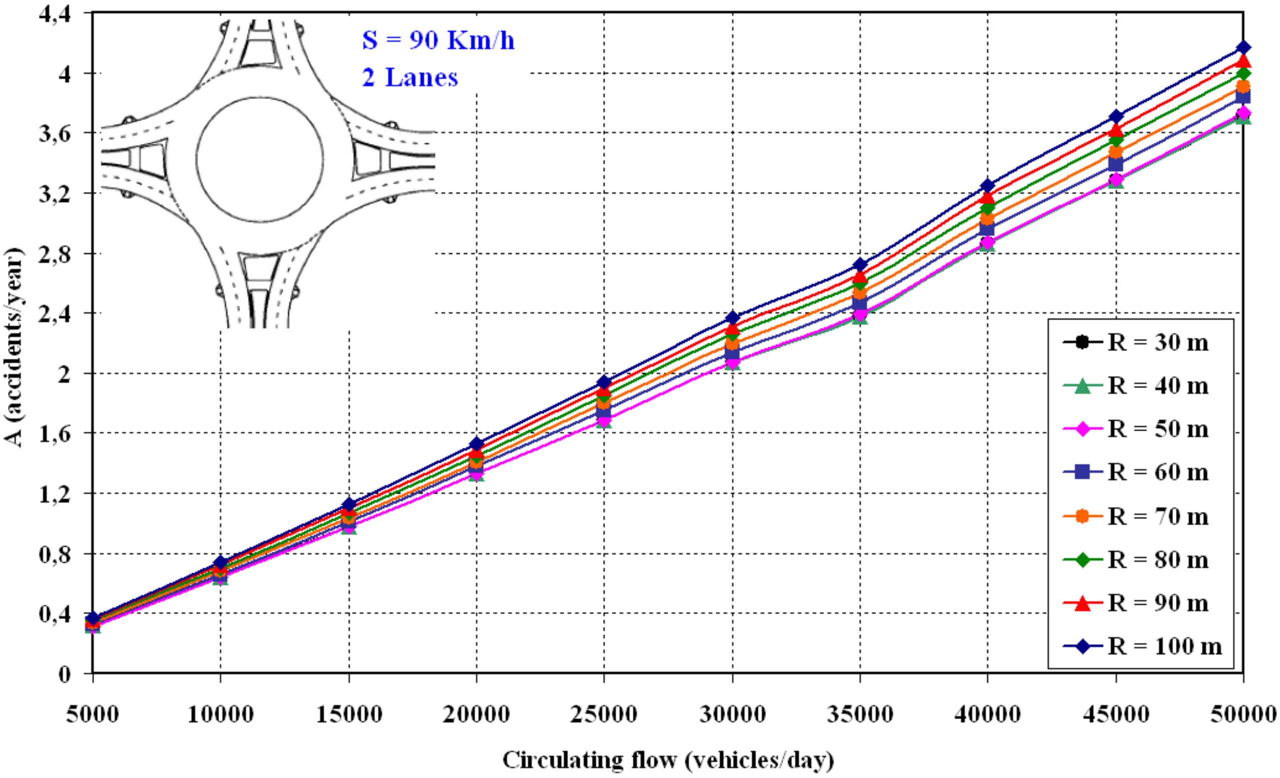

Figure 11 - Incidentality Index on the roundabouts (two lanes, S=90 km/h)

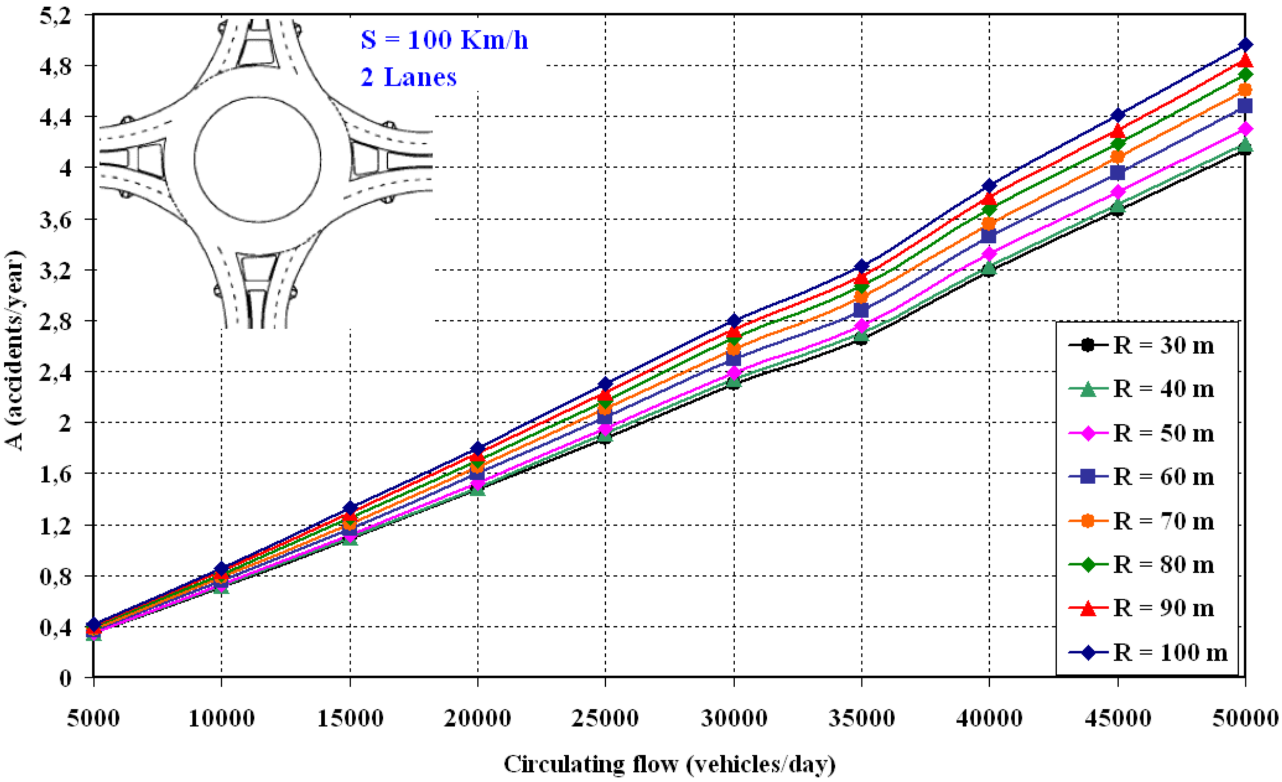

Figure 12 - Incidentality Index on the roundabouts (two lanes, S=100 km/h)

From these diagrams it is possible to immediately deduce the Incidentality Index (A) connected to everyone of the roundabout configurations and after their analysis we can obtain two important conclusions:

1) Two lanes roundabouts are more dangerous than one lane roundabouts. If we observe, for example, the configurations relevant to 90 km/h speed, we can notice that the incidentality index varies from 3.85 to 2.95 for one lane roundabout, and from 4.15 to 3.70 for two lanes roundabouts. This brings an average increase of the dangerousness level equal to 15%. If we consider the increase of conflicts on the very wide circulatory roadway, this result was to be expected.

2) The dangerousness level of the roundabouts grows according to the increase of the external radius. If we analyse for example the diagram of the figure 2, relevant to one lane roundabouts at a reference speed of 60 km/h, we can notice that incidentality index assumes the value of 1.30 when the radius of the roundabout is equal to 30 m, while the same indicator is 2.15 where the radius value is higher (R = 100 m); we have therefore an increase of the risk level equal to 60%.

We want now indicate the methodology for the determination of the Performance Index.

For what concerns the possibility to consider the passage at different speed at the entry legs of the same roundabout, we thought to repeat all the processes and make the hypothesis that speed differences from a minimum of 10 km/h up to a maximum of 50 km/h may exist between the two directions of the roundabout.

The results of these processes permitted to deduce a series of corrective factors (f_v), shown in table 1, to be applied to the incidentality indicators (A).

Table 1 - Corrective coefficients (f_v) due to speed differentiation

Speed (km/h)		**Principal direction**					
		50	*60*	*70*	*80*	*90*	*100*
Secondary direction	*50*	f_v=1.0	f_v=1.2	f_v=1.5	f_v=1.7	f_v=1.8	f_v=2.0
	60		f_v=1.0	f_v=1.15	f_v=1.3	f_v=1.4	f_v=1.6
	70			f_v=1.0	f_v=1.1	f_v=1.2	f_v=1.3
	80				f_v=1.0	f_v=1.1	f_v=1.2
	90					f_v=1.0	f_v=1.1

We must keep into account also the possibility that the entering flows may be not uniformly distributed.

In order to calculate the corrective factor, we have operated as follows:
- we have started 18 cycles of computations, characterized by different distribution of the flows, reported in table 2, only for one of the arms composing the roundabout. During the execution of each calculation cycle, we have constantly kept uniform the division of vehicular flow for the manoeuvres connected to each one of the other thee arms;

Table 2 - Flows distribution adopted for the manoeuvres on single arm

Cycle of computation	Distribution of the flow for the right turn	Distribution of the flow for crossing	Distribution of the flow for the left turn
1°	*40%*	*30%*	*30%*
2°	*30%*	*40%*	*30%*
3°	*30%*	*30%*	*40%*
4°	*50%*	*25%*	*25%*
5°	*25%*	*50%*	*25%*
6°	*25%*	*25%*	*50%*
7°	*60%*	*20%*	*20%*
8°	*20%*	*60%*	*20%*
9°	*20%*	*20%*	*60%*
10°	*70%*	*15%*	*15%*
11°	*15%*	*70%*	*15%*
12°	*15%*	*15%*	*70%*
13°	*80%*	*10%*	*10%*
14°	*10%*	*80%*	*10%*
15°	*10%*	*10%*	*80%*
16°	*90%*	*5%*	*5%*
17°	*5%*	*90%*	*5%*
18°	*5%*	*5%*	*90%*

- we have compared the values of the obtained incidentality indices with the ones corresponding to the basic situation characterized by identical flows for each manoeuvre. From this comparison it was possible to quantify the corrective factors relevant to flow distribution (f_a) in function of the flow division thought for the three possible manoeuvres (Table 3). The symbols reported in this table make reference to the diagram of figure 13.

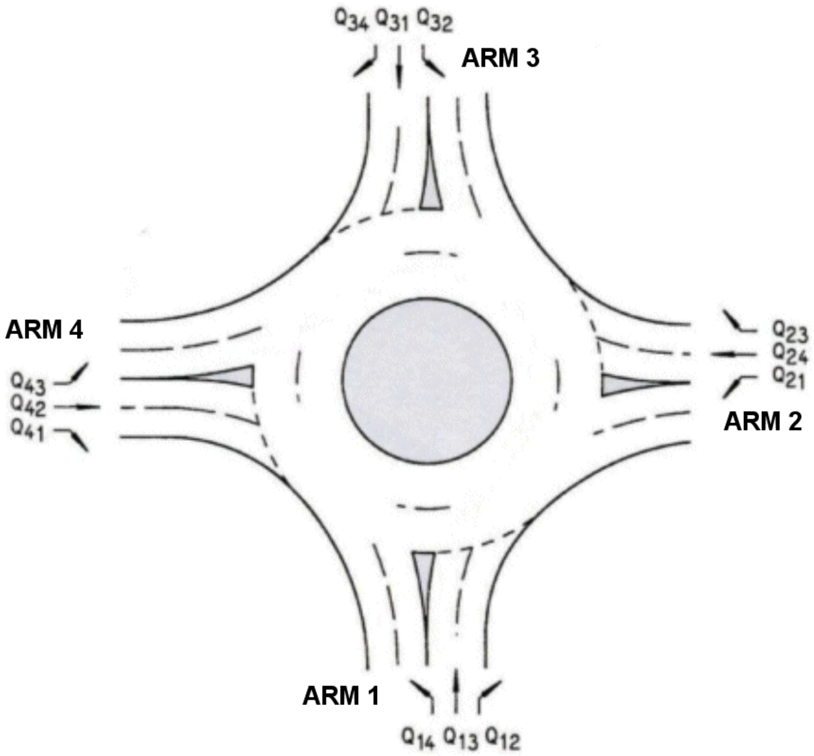

Figure 13. Diagram of a roundabout and symbols of the flows

Table 3 - Corrective coefficients (f_a) due to the different distribution of the flows

Distribution percentage of the flows			f_a
Q_{12}	Q_{13}	Q_{14}	
Q_{23}	Q_{24}	Q_{21}	
Q_{34}	Q_{31}	Q_{32}	
Q_{41}	Q_{42}	Q_{43}	
40%	*30%*	*30%*	0.99
30%	*40%*	*30%*	1
30%	*30%*	*40%*	1.01
50%	*25%*	*25%*	0.98
25%	*50%*	*25%*	1
25%	*25%*	*50%*	1.02
60%	*20%*	*20%*	0.96
20%	*60%*	*20%*	1
20%	*20%*	*60%*	1.03
70%	*15%*	*15%*	0.94
15%	*70%*	*15%*	1
15%	*15%*	*70%*	1.04
80%	*10%*	*10%*	0.93
10%	*80%*	*10%*	1
10%	*10%*	*80%*	1.05
90%	*5%*	*5%*	0.91
5%	*90%*	*5%*	1
5%	*5%*	*90%*	1.06

We have foreseen to estimate the Incidentality Indices when – on two or more arms – the flows are divided in the various manoeuvres according to the division plans reported in table 2. We have then started other computation cycles formulated in such a way to foresee that all the four arms of the roundabout have the flows not-equally divided in the three manoeuvres.

From the analyses of the obtained Incidentality Indices and from the comparison with the indicators relevant to the previous configurations (namely: the perfectly equilibrated configurations and the configurations with only one “non-uniform” arm), we have deduced that it is possible to make reference to the corrective coefficients f_a, reported in table 3, also in the cases that the not-equilibrated arms are more than one; *but we must consider time by time only one not-equilibrated arm, deduct the corresponding values f_a, and, finally, multiply by the corrective factors obtained singularly.*

In conclusion, the global corrective coefficient (f_{ag}) for the not-equal division of the flows on the single arms, may be expressed as follows:

$$f_{ag} = f_{a1} \cdot f_{a2} \cdot f_{a3} \cdot f_{a4} \qquad (3)$$

where f_{a1}, f_{a2}, f_{a3} and f_{a4} are the values of f_a connected to each one of the arms composing the roundabout.

We are able to introduce the parameter which allows the quantification of the whole safety level potentially offered by the roundabouts. It is the so-called Roundabout Performance Index (I_{PR}) defined by the following relation:

$$I_{PR} = A \cdot f_v \cdot f_{ag} \tag{4}$$

We have thought to subdivide the variability interval of the Performance Index into six functional categories; this has permitted the introduction of the Service Levels in terms of safety, that is:

- LOS_S=A (0[I_{PR}[0.33): indicates the ideal conditions, in terms of safety. The index I_{PR} rises as an incidentality indicator referred to 1 year time interval, therefore the frequency of incident is theoretically reduced to only one accident every three years, at maximum (such frequency may be normally attributed to a “physiological” component absolutely unforeseeable and practically not removable).

- LOS_S=B (0.33<I_{PR}[0.5): represents favourable conditions in terms of safety. We have at maximum, one accident every two years at the intersection.

- LOS_S=C (0.5<I_{PR}[1.0): individuates roundabout configurations moderately unsafe. In fact, the limit value of 1 accident per year is an indicator of risk conditions which cannot be imputed to physiological or causal components.

- LOS_S=D (1.0<I_{PR}[2.0): the intersection may be considered so dangerous that appropriate actions have to be taken (speed reduction, geometric variation, vehicular flows limitation, etc.) in order to minimize accidents.

- LOS_S=E (2.0<I_{PR}[3.0): describes the limit situation from the point of view of intersections dangerousness. If an intersection presents this level of service at design phase, has to be re-designed. If a roundabout in operation has the service level E, has to be urgently subjected to appropriate implementation and/or re-qualification interventions.
- LOS_S=F (I_{PR}>3.0): represents the limit threshold. From a theoretic point of view, this indicates that safety reserve is unfortunately exhausted.

3. CONCLUSIONS

The objective of the present study was to define a simply applicable procedure, able to characterize the safety level offered by wide radius roundabout (R>30 m).

The definition of the service levels in terms of safety (LOS_S) represents the achievement of the objective we had established.

Roundabout Performance Index (I_{PR}) constitutes exactly that parameter, and together with traditional transportation indicators (capacity, delay) enlarges the panorama of road intersection performance indices. This allows keeping into account also the level of safety offered by the rural wide radius roundabouts.

The obtained results encourage the authors to research for other methodologies in order to reach the characterization of safety level connected to further typologies of road intersections (both at grade and at grade separated junction intersections) which define the nodes of urban and rural road network.

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