Driver Behaviour At The Roundbouts: Analisys And Simulation.

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ABSTRACT
Traffic congestion in the intersection is a major problem. Congestion during peak hours extends for longer periods each day. Congestion adversely affects mobility, safety and air quality. These cause direct economic losses due to delay and accidents, and indirect economic losses due to environmental impact. In most cases, the capacity of the existing intersection systems cannot be incresed by adding additional lanes due to the space, resource, or environmental constraints. Potential ways to address the congestion problem are to improve the utilization of the existing systems through better traffic management and operations strategies, and improve the geometric design of the intersections. Traffic operations at the non signalized intersections is very complex, since different drivers employ different techiques to travel through such sections while interacting with other drivers. To understand the occurrence of bottleneccks and to device solutions for it, a comprehensive analysis of vehicle to vehicle interactions is essential. This requires the development of traffic theories to explain driver behaviour at the microscopic level [3, 19].
In this research, the data required to estimate driver behaviour models at roundabouts and the data that was obtained from real traffic are presented. In addition, a methodology for estimating istantaneous speed and acceleretaions that are required for model estimation from discrete trajectory data to the lane changing at the roundabouts, that can be obtained from the field is developed [1]. Data required to esimate the models that reproduce the circulation at the roundabouts include the position, speed, acceleration, time interval rejected and accepted at the entry of the roundabouts, length of a subject vehicle and the vehicles ahead of and behind the subject in the current lane as well as in ajacent lanes, relative speed and acceleretion in the lane changing behaviour, etc. Data on gap lenghts , headways, density of traffic, etc. can be extracted from the above mentioned data by simple operations. Typically, such data is collected using photografic and video equipment.
In general, the experimental analysis is distinguished in three phases:
- project of the research;
- information and variables acquisitions, useful to explain driver behaviour in the various manoeuvre at the roundabouts;
- data processing.

The definition of the driver behaviour parameters is complicated, in several operative conditions and in several socio –economic reality [27]. However, there is another complication relative to the definition optimal condition of survey: adequacy of the intersections with reference to geometric and circolation conditions, adequacy of the analysis points.
They have been characterized 6 roundabouts, three in the territories of Quarto and Villaricca, in province of Naples, others three to Foggia, in the north periphery. However, only three of these have turned out adapted to the scope of the present analysis. Infact three of these, not offering, adapt survey points. The data collected through such devices is processed to obtain useful information such as vehicle location at discrete points in time. Istantaneous speed and acceleretion data, that is required for estimation of the models, have to be inferred from the trajetcory data.

1 PROBLEM FORMULATION
Experimental analysis has represented the most greater part of the research. The acquisition of the drivers' behavior data to the intersection to the definition and the calibration model simulation of the vehicular circulation has been essential [2, 4].
The drivers' behaviors in the roundabouts have been analyzed.
It is possible to distinguish the experimental analysis in different and consecutive operational phases:
- Design of investigation;
- The acquisition of data and parameters to the modeling of the vehicular circulation;
- The evaluation, in the laboratory, of the acquired data.

The choice of the data to be surveyed, according to one determined methodology, has been in continuous evolution and it is tied to the following phase of the model construction. For these reasons, it is essential to know the model that reproduce the phenomenon to analyze.
Before analyzing the particular operation of the roundabouts experimentally observed, it needs to remember, shortly, what the principal types of regulation [2, 24, 25, 26, 30].
Up to the eighties the operation of a rotatory has been considered as a succession of zones of exchange among two adjacent accesses; this was due, mainly, to the rule of circulation that was in force: the vehicles coming from the arms had the precedence on the circulating flow.
This type of operation involved the demand to proportion the speed in the roundabouts with the confluent roads, to avoid high decelerations in the immission. In fact there isn't some obligation of Stop or precedence to the circulating vehicles; to such end it was necessary to develop wide zones to lane cahanging. With this rule of circulation it occurred the autosaturation of circulatory roadway; in fact the capacity of the intersection, in this case, essentially depend on the length of the zones of lane changing [15].
This rules induced the construction of roundabouts with an elevated diameter, with enough long distances among two following immissions.

Changing rules of circulation, it is possible to think the roundabout functioning like a sequence of T intersections. The actual rules, in fact, assert that “the vehicle that circulate in the ring to have priority over vehicle in immission”
This fact has involved a substantial change of the operation in the roundabout. The capacity, in fact, is function of the entering vehicle flow now.
Moreover it is not necessary to maintain in the ring vehicle speed close to those along the arm. The roundabout is understood as an “element” that has the tendency to reduce the speed of the vehicles getting into roundabout, with an increase of the safety of the intersection both to reducing speed, for the crossing vehicles, and for the most greater attention that the veicles have in the immission.
In the roundabout that we analyzed, one to Villaricca (near Naples) and two in Foggia, contrasted tendency has been found. This intersections has been suitable in the following way:
1. "VILLARICCA": it is the intersection in Villaricca;
2. "FOGGIA 1": it is the first roundabout analyzed in Foggia;
3. "FOGGIA 2": it is the second roundabout analyzed in Foggia.

Villaricca

The roundabouts in Villaricca are distant among them of some kilometer, along a principal road that is interested from an elevated vehicle flows. The transversal roads are smaller importance.
Probably the necessity of redesign the old intersections, with some schemes to rotatory, was born more for safety reasons than to discipline the traffic. In fact, in these intersections, today the old rule of the precedence of the principal road has still been maintained on the smaller roads.
The Villaricca roundabout is characterized by stop signals in correspondence of the immissions of the smaller roads, while for those of the principal roads there is no type of signaling.
This regulation involves the following operation: the vehicles that originate from the principal road (“A” traffic flow) have the precedence on the vehicles that circulate. There isn’t some signal, so it is valid the right rule of precedence; the vehicles that originate from the secondary road (“B” traffic flow), instead, must stop and to give the precedence to the vehicles that circulate in the ring.

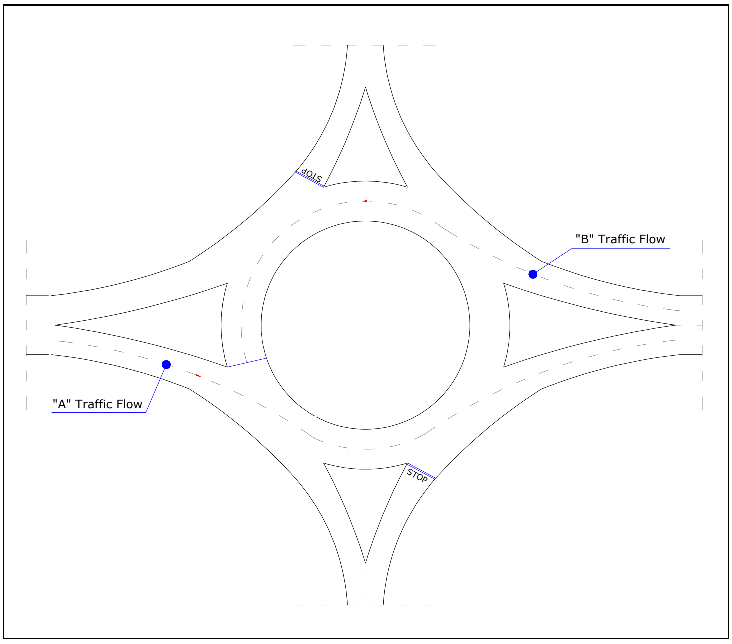

Figure 1: Precedence Rule (Villaricca)

If the traffic became more intense, a wrong operation in the roundabout is noticed: the vehicles in the ring have to give the precedence to those are introduced. To increase the flow, therefore, an accumulation of vehicles is verified, saturating the circulatory roadway.
Changing the rule of circulation (precedence to the ring) it would probably maintain a correct circulation in the circulatory roadway avoiding the saturation of the intersection.

Foggia

In the Foggia roudabouts the operation results completely different. In this case the precedence rule was in force to the ring unlike the common practice adopted in other Countries. Instead of the system of give way signs, to the immissions there are stop signals: the vehicle arrived in the approach link was forced, always, to stop and to waited an enough interval to complete the manoeuvre. The vehicles once to enter into roundabout approaching the inner lane as far as the arm of exit. If however this last exit was immediately following to the immission, the vehicle to go through external lane. The behavior of the drivers results therefore, similar to that in literature.

2 THE DESIGN OF ANALISYS

The determination of the drive behavior parameters depends on numerous factors: the operational conditions, the socio-economic reality, the necessity to determine optimal conditions of survey, the adequacy of the intersections with reference to geometric and circulation conditions, the suitability of the observation points. Results therefore necessary to organize a plan of work for the activity of experimental analysis.

2.1. Determination of the observation places.

For the experimental phase different roundabouts are been analyzed, particularly 6 intersections are been individualized, three of which in the territories of Quarto and Villaricca, near Naples and three in the Foggia, in the suburban area.

Nevertheless, only three of these result suitable to the experimental analysis.

One is situated in the Villaricca and the others two in the Foggia, the adopted denomination is the following:

- "VILLARICCA";
- "FOGGIA 1";
- "FOGGIA 2".

The choice of such roundabouts has been conducted, verifying the correspondence of some characteristics relate to the operational conditions, to the geometry of the intersection and the site orography, carried afterwards:

- diameter neither too much great neither too much small, in the order of the 50 meters;
- two lane circulatory roadway;
- nonmountable central island;
- nothing inclination of the confluent roads;
- roundabouts location in the suburban areas; note that separate categories have not been explicitly identified for suburban environments. Suburban settings may combine higher approach speeds common in rural areas with multimodal activity that is more similar to urban settings. Therefore, they should generally be designed as urban roundabouts, but with the highspeed approach treatments recommended for rural roundabouts.
- possibility to individualize a suitable live points.

2.2. Determination of the Shot Points.

The determination of suitable shot points conditioned the choice of the roundabouts to be analyzed.

Every position has been select, in line with the characteristics of the disposition instrumentations, in this way to be been able to include at least an arm of approach and the adjacent parts to it: exit and entry, with relative zones of circulation. Bibliography examined, these points have been looked for height, could compensate the lack of longitudinal distance with the distance in elevation.

In this way it is possible to measure through the same shot, not only the parameters connected to the phase of approaching and immission, but also the parameters related to the vehicles in circulation.

In general we choice the shot points so that:

- a position has been select that gave the widest vision of the intersection, so that to be able to contemporarily observe all the phases in which it is possible to divide the mechanism of circulation in the roundabouts;
- a small distance has been select from the roundabout, in this way we haven't many difficulties in obtaing parameters in examination;
- a view has been selected how much possible in plant, so that to avoid excessive distorsions that derive from perspective sights.

For those reasons the shot points, for everybody roundabouts, have been fixed on the roofs of buildings that rise behind the intersections.

The photographic investigations are been performed with a digital camera of with focal objective of 50mm. The video - camera analisys are been performed with a digital video - camera provided, besides, of pantoscope.

From photographic survey the number and typology sections of control, in comparison to which to perform the calculation of the parameters of speed, acceleration and time separation, have been determined.

The principles followed in the choice of the sections of control can be characterized in this way:

- The number of the sections has been established equal to four so that to be able to get, for every vehicle, three values of speed and two of acceleration;
- The spacing among the sections has been determined in operation of the consequential perspective distorsion from the videocamera. For the couple of sections, that resulted to be more distant from the point of shoting, we have been assumed spacing equal to 10 mt or 15 mt, while it is assumed for the remaining couples equal to 5 mt. This spacing has been valued as measured curvilinear length on the circumference that delimits the central island of the roundabout;
- The sections are all convergent in the center of the central island.

To the goals of the data acquisition, it is possible to distinguish two principal typologies of parameters: those related to the vehicles circulation, defined parameters of flow and those related to the geometry of the roundabouts.

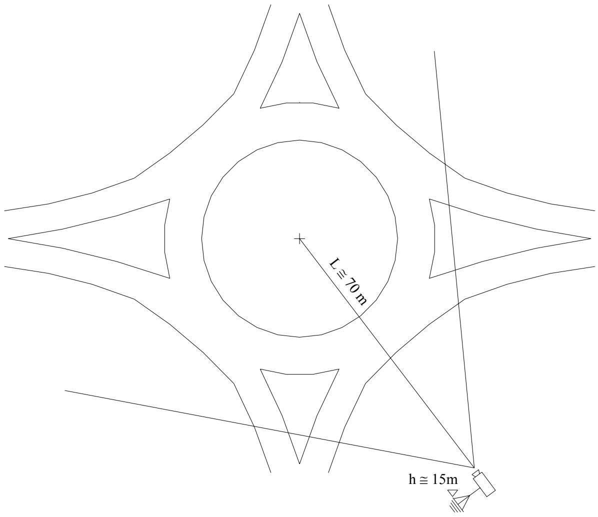

Figure 2*:* Shot Point - "Villaricca"

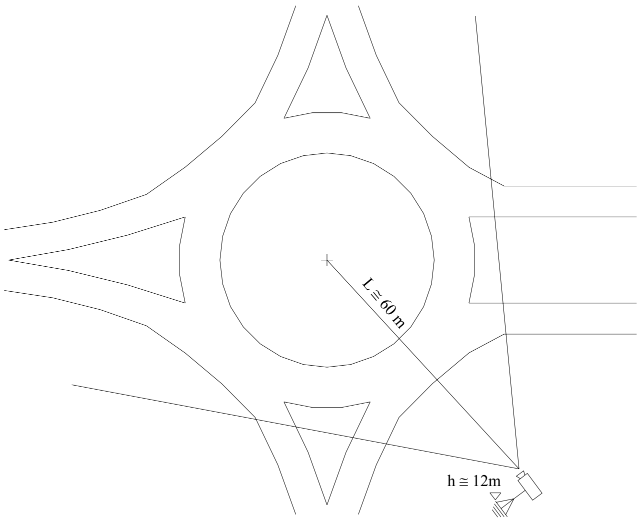

Figure 3: Shot Point - "Foggia 1"

2.3. Determination of the traffic flow

The observation points chosen allowed the observation of the principal manoeuvres: approach, enter, and travel through a roundabout.

Fixed the videocamera, during the recording, it has been signaled, in correspondence of every intersection, some points of the circular crown, to the purpose to determine the sections of survey. Operationally the points have been signalled with colored flags to a variable relative distance.

With reference to the immission, the relief on road has concerned: the individualization of the approaching line and the determination of the considered "conflict" section between the entry flow and circulating flow.

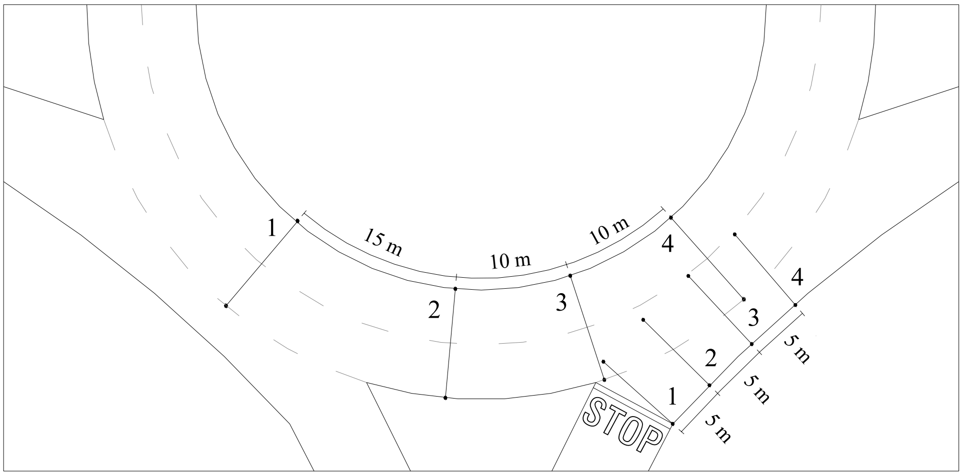

Figure 4: Control Sections in the Villaricca Roudaubout.

Subsequently in the laboratory the following parameters are determined:

- rejected and accepted time interval for entering vehicles;
- vehicle queue lenght, that waiting to entering in the roundabout;
- waiting time for every vehicle that is introduced;
- entering flow;
- time gap among vehicles that reaching the entry lane;
- the acceleration of the vehicles that start from stop or give way line.

In relationship to the circulatory flow, for every lane, the following parameters has been determined:

- the speed;
- the acceleration and the deceleration;
- gap time and gap space among the vehicles;
- traffic flow;
- the density, for every way, among two consecutive sections.

The phase of investigation has been conducted in different temporal periods, according to different conditions of traffic: the end of July, hypothesizing a smaller load of the network road in reason for the work exodus from the cities; the end of September, considering the complete return to the ordinary working activities. The data acqiusition in the two periods, have operationally been conducted in the following days and times:

- Thursday 18 July from the 15:30 to 17:30, for the intersection of "VILLARICCA";
- Monday July 30 th, from the 13:30 to 15:30, for the intersection of "Foggia 1", in the first condition of traffic; Monday 23 September from the 10:50 to 12:50, for the second condition of traffic;
- Wednesday September 02 th, from the 13:15 to 15.15, for the intersection of "Foggia 2".

2.4. Geometric Parameters

The principal geometric parameters for three intersections are been measured. These are:
D: the diameter of the central island;
c: the width of circulatory roadway;
L,L' s,s': the elements of the splitter islands;
e: entry width;
u: exit width;
Le: approach width;
Lu: exit width.

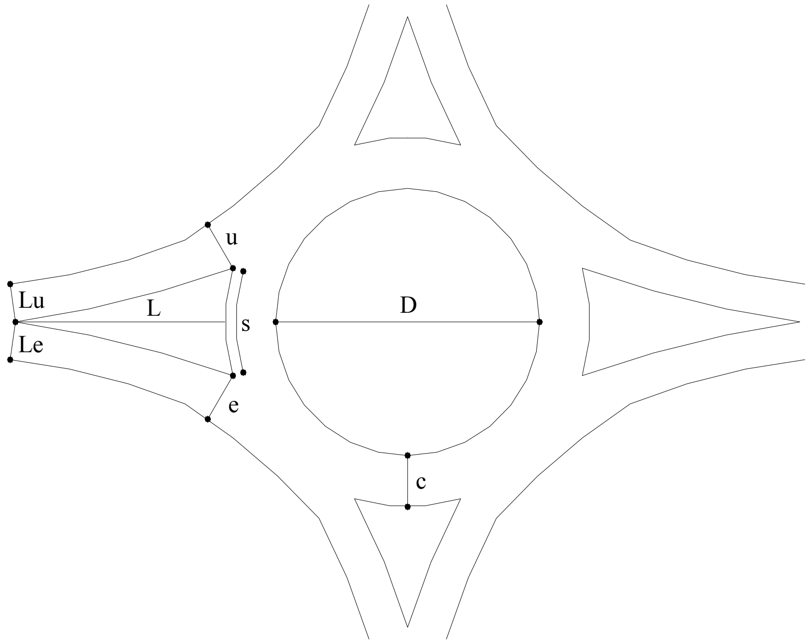

Figure 5: Represenattion of Geometric Parameters.

	Villaricca	Foggia 1	Foggia 2	
D	49	50	52	meters
c	9,4	11	8	meters
Nc	2	2	2	lanes
L	38	38	-	meters
s	20	26	101	meters
L'	22	19	24	meters
s'	17	20	14	meters
e	7,5	11,5	11,8	meters
u	9,2	11,5	7	meters
Le	7,7	10	8,3	meters
Lu	7,7	10	7	meters

Table 1: Explititation of Geometric Parameters.

3. DATA ANALISYS

The phase of tis research indicated as data analisys, carried out in the Department of Transportation Engineering of University of Naples "Federico II", has been separate in two principal moments: the data reading and the statistic elaboration of these.

3.1. The Data reading

To be able to obtain all the useful parameters to the goals of the elaboration has been necessary to perform some preliminary operations:

- The images transfer: the recorded images on digital tapes have been transferred on definitive tapes with the aid of two VCRs and a timer, situated among the same.
- The impression of the control sections to the video images.
- The reading of the transit times: the transit vehicles time in correspondence of the control sections have been inserted in date-base realized with spreadsheets Excel.

In the following figure it is relate data base used to estimate parameters related to the circulatory roadway. This spreadsheet is analogous to that adopted for the evaluation of the accelerations of the approaching vehicles.

Vehicle		Transit time in the reference section								Section distance			Speed			Acceleration	
n	Type	T1	C1	T2	C2	T3	C3	T4	C4	Δ1	Δ2	Δ3	V1	V2	V3	a1	a2
1	A	6,18	2	8,56	2	10,02	2	11,26	2	16,44	10,96	10,96	6,91	7,51	8,84	0,31	0,99
2	A	8,56	2	10,6	2	11,68	2	12,70	2	16,44	10,96	10,96	8,06	10,15	10,75	1,34	0,57
3	A	10,68	2	13,28	2	14,58	2	15,76	2	16,44	10,96	10,96	6,32	8,43	9,29	1,08	0,69
4	A	11,92	2	14,66	2	16,00	2	17,17	2	16,44	10,96	10,96	6,00	8,18	9,37	1,07	0,95
5	P	15,12	1	18,37	1	19,88	1	21,16	1	19,32	12,88	12,88	5,94	8,53	10,06	1,09	1,10
6	A	16,55	2	18,07	2	18,99	2	19,95	1	16,44	10,96	12,81	10,82	11,91	13,34	0,90	1,52
7	A	17,45	2	20,22	2	21,52	2	22,8	2	16,44	10,96	10,96	5,94	8,43	8,56	1,23	0,10
8	A	18,9	2	22,12	2	23,63	2	24,94	2	16,44	10,96	10,96	5,11	7,26	8,37	0,91	0,79
9	A	29,26	2	31,9	2	33,49	2	34,9	1	16,44	10,96	12,81	6,23	6,89	9,09	0,31	1,46
10	A	30,73	1	33,27	1	34,59	1	35,97	1	19,32	12,88	12,88	7,61	9,76	9,33	1,11	-0,31

Table 2: Circulation parameters data base.

The symbols used in table 2 have the following meaning:

- n: progressive number that denote the vehicle in the roundabout;
- Type: typology of vehicle. Particularly: A define the vehicle; M the motocycle; P the truck and PR the articulated lorry;
- Ti (i= 1,…,4): time to cross a i control section;
- Ci (i=1,…,4): lane occupied by the generic vehicle when it transits for the section i. This value is equal to 1 if the vehicle occupied external lane, 2 if the vehicle occupied the inner lane;
- Δi (i = 1,…,3): length of the inclusive lines among two consecutive sections. These values are reported to curvilinear lengths in meters measured along the road axis.
- V_i (i=1,…,3): mean speed in Δi:

$$v_i = \frac{\Delta_i}{T_{i+1} - T_i}$$

- a_i (i=1, 2): istantaneus acceleration:

$$a_i = 2 * \frac{v_{i+1} - v_i}{T_{i+2} - T_i}$$

Auto	T_i	Δt_i	Rejected	Accepted	$\Delta t_{Rejected}$	$\Delta t_{Accepted}$
1	96,03					
	96,67	0,64	1	0	0,64	
	97,89	1,22	1	0	1,22	
	102,17	4,28	0	1		4,28
2	102,17					
	103,55	1,38	1	0	1,38	
	104,13	0,58	1	0	0,58	
	105,71	1,58	1	0	1,58	
	106,95	1,24	1	0	1,24	
	111,79	4,84	0	1		4,84

Table 3: Rejected and accepted gap times data base.

Table 3 shows the Excel spreadsheet relate to rejected and accepted gap on the secondary road. The adopted simbology has the following meaning:

- Auto: progressive number that denote the vehicle in the entrance;
- Ti: time in correspondence of which the circulatory vehicle transits in front of the vehicle waiting for to immission. This time is valued making reference to the so-called section of conflict, that is that section in which is hypothesized that the two stream, entering and circrculatory stream, intersects;
- Δti: time interval between two consecutive vehicles that cross entering vehicle:

$\Delta t_i = T_i - T_{i-1}$

- Rejected: binary code equal to 1 if the time interval is rejected, 0 otherwise;
- Accepted: binary code equal to 1 if the time interval is accepted, 0 otherwise;
- $\Delta t_{Rejected}$: it is the value of the rejected gap;
- $\Delta t_{Accepted}$: it is the value of the accepted gap.

3.2. The Statistic Processing

The result parameters, derived by data bases just explained, are:

- V1: the circulatory speed in lane 1 (external lane);
- V2: the circulatory speed in lane 2 (inner lane);
- A_{lane1}: the acceleration in lane 1;
- A_{lane2}: the acceleration in lane 2;
- $\Delta t_{Rejected}$: the maximum rejected time interval by the vehicle in entrance;
- $\Delta t_{Accepted}$: the accepted time interval by the vehicle in entrance;
- $\Delta t_{critical}$: critical gap assessment obtained as difference to maximum rejected gap and accepted time interval;
- $A_{approach1}$: the entering vehicle acceleration in the first line (7,5 mt.) beginning from the stop line;
- $A_{approach2}$: the entering vehicle acceleration in the second line (7,5 mt.);
- $\Delta T_{circulatory\ roadway}$: time interval in the curculatory roadway;
- $\Delta T_{approaching}$: time interval in the secondary road.

The parameters above listed are subject to a strong variability that can be attributed to the different behavior of the users and the different degree of roundabouts congestion.
They appears, therefore, as the aleatory variable and it is important to know the laws of probability. These last ones have been determined through the techniques of the statistic inference [9].
As a random sample of the different aleatory variable in examination is tried to reconstruct its probability density function (pdf) drawing the distribution of the densities of frequency of it.
Being aleatory continuous variable we proceeds to the collection of the respective experimental determinations in groups, according to the belonging to intervals of predetermined values. These intervals have been select of equal width, contiguous, closed to the right and in number neither too much great, to avoid to have empty intervals, neither too much small not to lose information around the form of the pdf.
To choose the correct number of intervals in which to divide the range of observed values is made reference to the k number obtained by the following empirical formula [17]:

$$k = 1 + 3{,}3\log_{10}(n)$$

$$\Delta x = \frac{x_{\max} - x_{\min}}{k}$$

where:

- N is the sample dimension;
- Δx is the width interval;
- xmax [xmin] is maximum [minimum] value in the aleatory distribution.

The number of values n_i in every interval divided up n and the width of the interval determined the density of frequency f_i that insists (middly) on the i generic interval.
For the f_i the followings relationships are equal to:

$$f_i = \frac{n_i}{n \times \Delta x}$$

$$\sum_{i=1}^{n} f_i \times \Delta x = 1$$

the histogram of the f_i constitutes image of the pdfs aleatory variable. The tests of hypothesis will confirm or less such affirmation.
From the values of the experimental determination they have been valued some characteristics of the sample that constitute esimates of the corresponding characteristics of the aleatory variable. In fact, the assessment of mean and standard deviation of the single variable have been effected achieved to the following formulation:

$$\hat{\mu} = \frac{1}{n} \times \sum_{i=1}^{n} x_i = \bar{x}$$

$$\hat{\sigma}^2 = \frac{1}{n} \times \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2$$

In the formulation of standard deviation, showing up "n" to the denominator to the place of "n-1", could be considered not "correct". The dimension, sufficiently ample, of the sample it eliminates this problem.
The models of aleatory variable that, for the different parameters in analysis, reproduce better the empirical distributions are:

- Normal variable;
- Exponential variable;
- Gamma varible.

The Gamma function is, in general, the model of aleatory variable that better interpolates the empirical distribution of haedways.
In the following figure it is possible to notice as Gamma function changes with reference to your characteristic parameters (k and λ):

- in the first case λ is constant (=1) and k vary from 1 to 4. So that also the average varies from 1 to 8;
- in the second case we maintain constant the average, equal to 4, and we make vary both k, from 1 to 4, and λ.

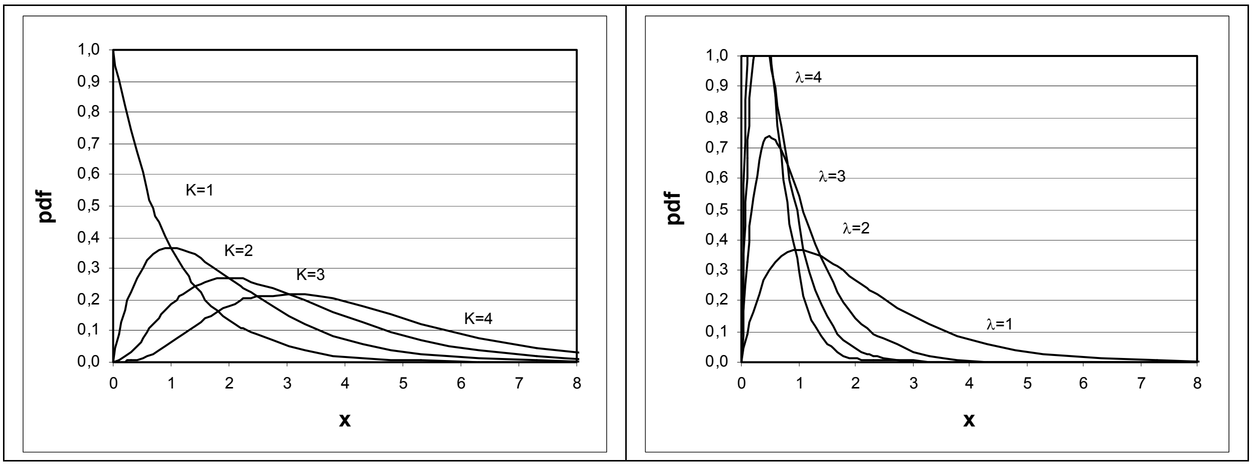

Figure 6: pdf variations in relation of k and λ parameters.

The hypotheses effected around the adaptability of the statistic models to the distributions of empirical frequency are been verified through the aid of the tests of hypothesis of "Kolmogorov-Smirnov".

3.3. The Statistic Processing outcome

The observed cases are the followings:

- only one traffic flow condition for "Villaricca";
- two traffic flow conditions for "Foggia 1": the distinction has been made in reference to the two different conditions of traffic that are noticed, one to free flow and the other more congested, respectively these conditions are suitable with "Foggia 1-1" and "Foggia 1-2";
- one traffic condition for "Foggia 2".

3.3.1 Traffic Volumes

For each cases studied we show, in first place, the volumes of traffic measured in the reference period. Keeping in mind that the measurement of the data covers a period of one hour.
In the following section we carried, for every examined condition, not only the tables, but also the graphic representation of traffic volumes in the roundabouts.
"Villaricca"
With reference to the approaching phase, the traffic volumes are two, circulating flow that has the precedence and the entering flow, that is the secondary. This vehicles are forced to stay stanstill to the Stop line. For the "Villaricca" roundabout these volumes corresponds the following values:

- Circulating flow: 834 vehicle per hour;
- Entering flow: 810 vehicle per hour.

To attribute the value to the principal flow, has been observed that the vehicles that interact with the vehicles that are introduced are those of the exeternal lane, particularly those that transit for the section 4.

	Vehicle/hour			
	sez 1	sez 2	sez 3	sez 4
Q_{lane1}	657	504	507	834
Q_{lane2}	972	1125	1122	795
$Q_{circulatory\ roadway}$	1629			
$Q_{immission}$	810			

Table 4: Traffic volume in the Villaricca Roundabout.

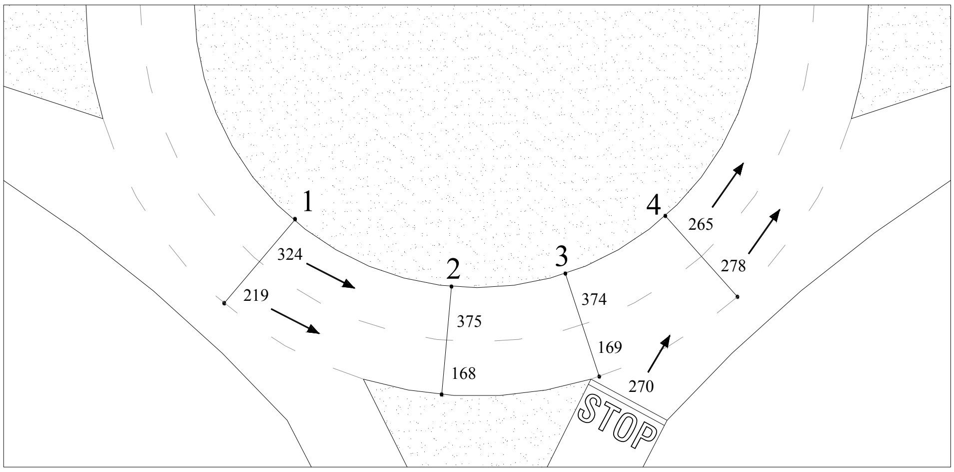

Figure 7: Traffic volume in the reference section.

In the next figure the flow circulating rates and flow entering rate showed.

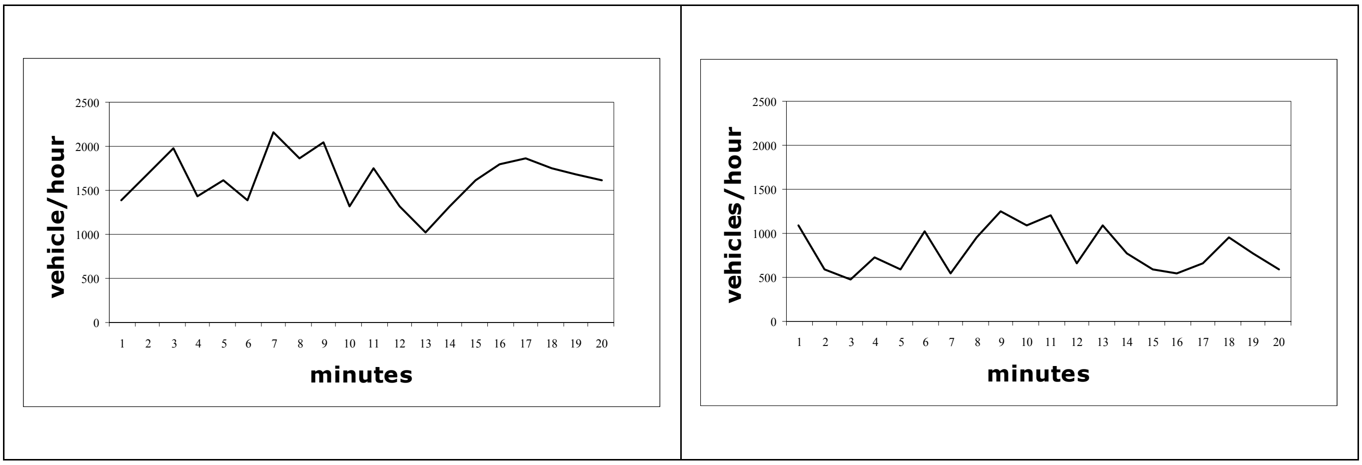

Figure 8: Traffic flow circulating rates.

"Foggia 1-1"

- Circulating flow: 405 vehicle per hour;
- Entering flow: 186 vehicle per hour.

The flow rates in the period of analisys are represented in the figure 9, also in this case it is possible to notice an oscillating trend around to a constant value (middle), that represent traffic volume in this reference period.

	Vehicle/hour			
	sez 1	sez 2	sez 3	sez 4
Q_{lane1}	9	9	381	405
Q_{lane2}	543	543	171	147

$Q_{circulatory\ roadway}$	552
$Q_{immission}$	186

Table 5: Traffic volume in the Foggia 1 Roundabout.

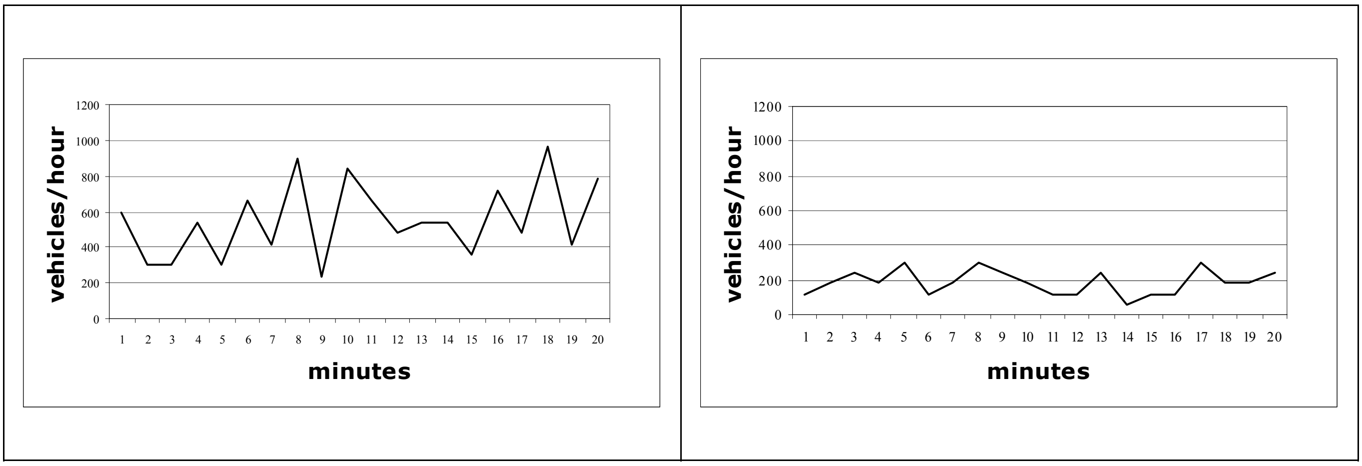

Figure 9: Traffic flow circulating rates.

"Foggia 1-2"

- Circulating flow: 1176 vehicle per hour;
- Entering flow: 438 vehicle per hour.

	Vehicle/hour			
	sez 1	**sez 2**	**sez 3**	**sez 4**
Q_{lane1}	336	540	1116	1176
Q_{lane2}	1128	924	348	288
$Q_{circulatory\ roadway}$	1464			
$Q_{immission}$	438			

Table 6: Traffic volume in the Foggia 1 - 2 Roundabout.

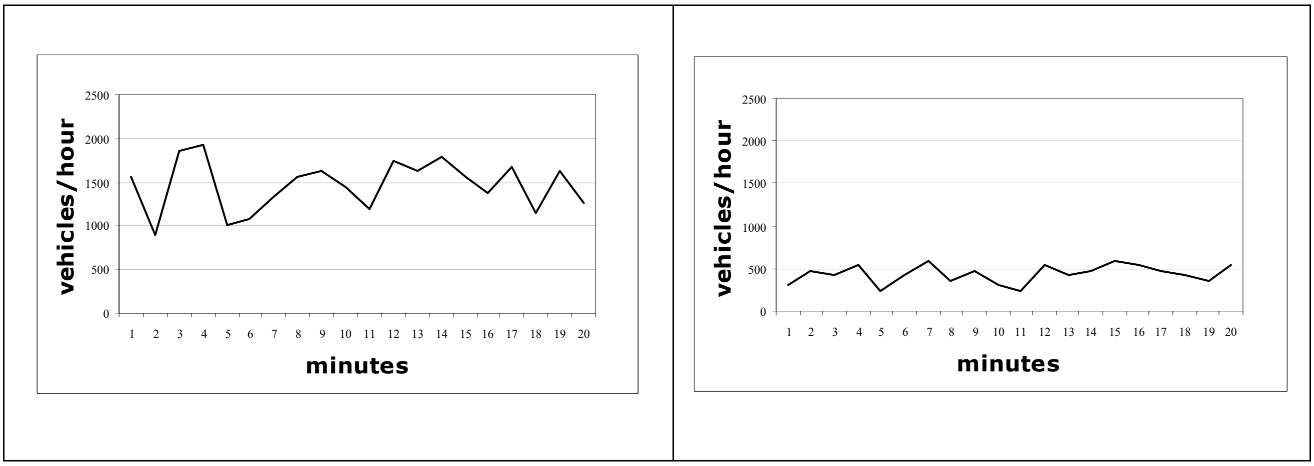

Figure 10: Traffic flow circulating rates.

"Foggia 2"

- Circulating flow: 1110 vehicle per hour;
- Entering flow: 798 vehicle per hour.

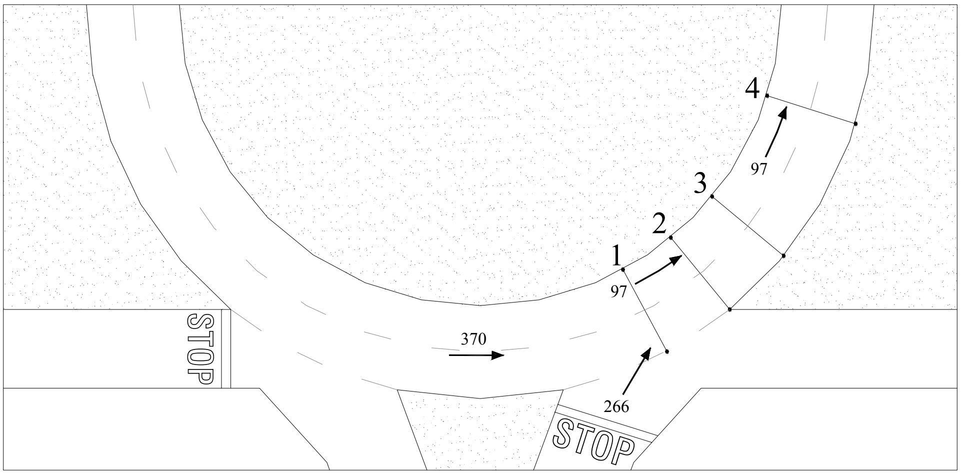

Figure 11: Traffic volume in the reference section.

3.3.2 Traffic Flow Diagram

The flow diagrams allow to define the conditions of traffic in which the roundabout works. In reference to the circolatory road, we can be gone a condition of free flow, if density is low, to one of saturation, if the circulating flow approach the capacity of the infrastructure. The diagrams have been built dividing the whole period of observation of one hour, in intervals of 1 minute. In every interval the average of the speeds of the vehicles is calculated in each reference section [14].

The diagrams are described in the figures 12, 13. It is possible to distinguish two different situations:

- for "Villaricca" and "Foggia 1-2" roundabouts the conditions of circulatory road are near to the saturation (about 2500 veic. per hour);
- for "Foggia 1-1" and "Foggia 2" raundabouts the cloud of points assembles in the tall part of the diagram: the conditions of traffic are to free flow.

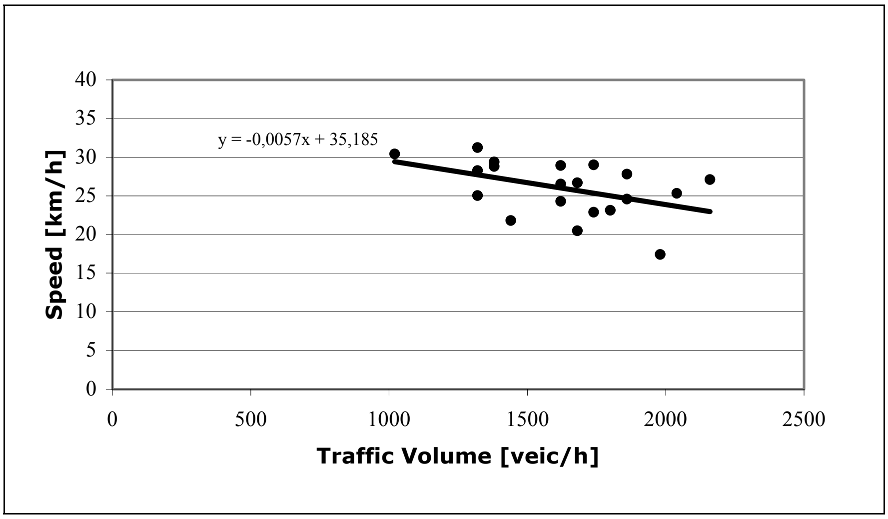

Figure 12: Traffic flow diagram - "Villaricca"

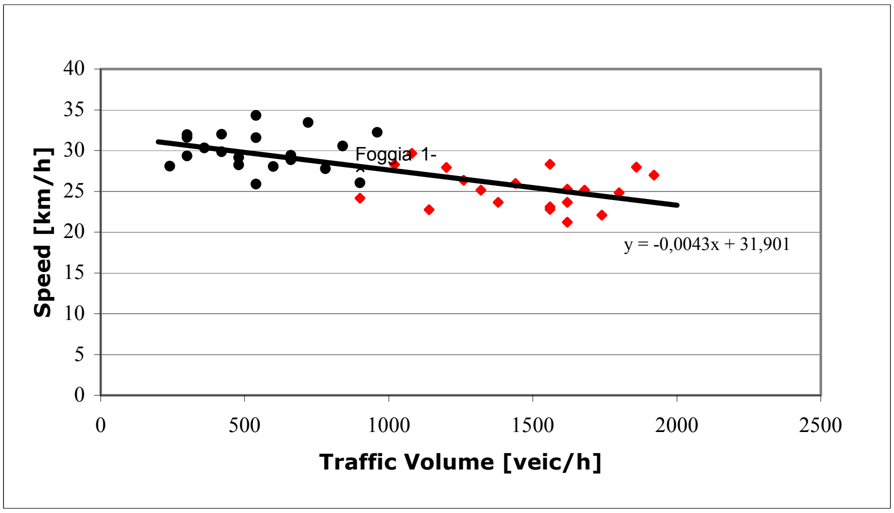

Figure 13: Traffic flow diagram – "Foggia 1-1" e "Foggia1-2"

3.3.3 The Speed in the Circulatory Road

The speeds of circulating vehicle have been diversified in relation of lane belonging. Particularly have been separate the vehicles that proceeded always on the same lane from those that instead carried a merging or diverging manoeuvre or a exit manoeuvre. In the tables 7 and 8 shows the parameters of the speed distributon:

μ: it is the average of the observed sample;
σ: it is the standard deviation of the same sample;
min: it is the minimum speed value observed;
max: it is the maximum speed value observed;
n: it is the number of the elements of sample;
pdf: it is the model of aleatory variable that better interprets the empirical distributions.

	μ	σ	**min**	**max**		**n**	**pdf**
Villaricca	26,9	9,0	4,5	53,9	[km/h]	488	*normal*
Foggia 1-1	-	-	-	-		-	-
Foggia 1-2	27,0	4,8	15,4	36,0	[km/h]	300	*normal*

Table 7: Speed in the lane 1.

	μ	σ	min	max		n	pdf
Villaricca	23,5	6,9	4,3	45,9	[km/h]	717	*Normal*
Foggia 1-1	26,7	3,6	13,1	37,0	[km/h]	147	*Normal*
Foggia 1-2	24,4	5,4	7,3	36,0	[km/h]	276	*Normal*
Foggia 2	25,8	4,1	16,2	42,3	[km/h]	291	*Normal*

Table 8: Speed in the lane 2.

As can be seen by the mean values, the differences of speed among the roundabouts are least. They mainly depends on the values of volumes observed: to increase the flow for "Villaricca" and "Foggia 1-2" roundabouts correspond smaller mean speed in comparison to those of "Foggia 1-1" and "Foggia 2".
Also the differences of speed between two lanes are negligible, as soon as of 3 km/h. Such difference is related to the different values of volume that interest the two lane.

3.3.4 The Acceleration in the Rotatory Roadway

For the accelerations processing likewise proceeds to that for the speeds in circulation: it has been select only the accelerations of the vehicles that proceeded always on the same lane.

	μ	σ	min	max		n	pdf
Villaricca	0,28	0,68	-1,731	2,11	[m/s^2]	328	*normal*
Foggia 1-1	-	-	-	-		-	-
Foggia 1-2	-0,14	0,56	-1,513	1,14	[m/s^2]	280	*normal*
Foggia 2	-	-	-	-		-	-

Table 9: Acceleration in the lane 1.

	μ	σ	min	max		n	pdf
Villaricca	0,24	0,60	-1,777	2,36	[m/s^2]	582	*normal*
Foggia 1-1	0,04	0,70	-1,916	1,91	[m/s^2]	104	*normal*
Foggia 1-2	0,01	0,63	-2,004	1,19	[m/s^2]	200	*normal*
Foggia 2	0,07	0,51	-1,053	1,14	[m/s^2]	194	*normal*

Table 10: Acceleration in the lane 2.

From the analisys of mean values we deduce invariable accelerations in different traffic condition. The only case that is different from the other ones it is Villaricca roundabout in which a mean is few greater. This is justifiable in relationship to the traffic flow conditions that characterize the roundabout in Villaricca: the traffic volume is near saturation condition. We can use these data to calibration and validation of car following and lane changing behavior [1, 33]

3.3.5 The Distribution of Rejected, Accepted and Critical Gap Times

Critical gaps are the variables that mainly interest the gap acceptance model [7]; it is necessary, therefore, to specify better the concepts of rejected, accepted and critical gaps [12].
A minor street vehicle can only enter in the roundabout if the next major vehicle is far enough away to allow the minor vehicle safe passage of the whole conflict area. “Far enough" is defined as: The next major street vehicle will arrive at the intersection at an instant that will happen t_c seconds after the previous major stream vehicle or t_c seconds after the minor vehicle's arrival. This value t_c is called the critical gap, which is the

minimum time gap in the priority stream that a minor street driver is ready to accept for crossing or entering the major stream conflict zone [13].
Another limiting factor for the minor street vehicles is the fact that they cannot enter the conflict area during a short while after the previous minor street vehicle has entered, owing to the physical length of the vehicles and the necessary safe headways. Thus, as the second variable for the characterization of minor street driver's behavior we use the follow-up time, t_f, where is the time gap between two successive vehicles from the minor street while entering the conflict area of the intersection during the same major street gap. It is obvious that t_c and t_f changes from driver to driver, from time to time, and between intersections, types of movements, and traffic situations. Due to this variability, there is no doubt that the gap acceptance process is a stochastic process. Thus t_c and t_f can be regarded as random variables. Moreover, the parameters of the distribution functions for these variables may be subject to different external influences. Consequently, it is necessary to define some type of representative characteristics to model the usual behavior of drivers [20, 21]. Therefore, the estimation of critical gaps and follow-up times tries to find out values for the variables tc and tf, as well as for the parameters of their distributions, which represent typical driver behavior at the investigated intersection during the period of observation [16].
Considered for every user the critical gap proceeds to the statistic elaboration. Particularly we have been determined, for every roudabout, three models of random variable: one for the rejected gap, one for those accepted and one for the critical gaps. The tables 11, 12, 13 show the relative characteristic parameters to every type of interval.

	μ	σ	min	max		n	pdf
Villaricca	1,77	0,58	0,86	3,40	[seconds]	120	*gamma k=2*
Foggia 1-1	2,06	0,82	0,54	3,74	[seconds]	37	*gamma k=2*
Foggia 1-2	2,27	0,83	1,10	5,18	[seconds]	114	*gamma k=3*
Foggia 2	2,35	0,71	0,65	3,73	[seconds]	170	*gamma k=3*

Table 11: Maximum rejected gap.

	μ	σ	min	max		n	pdf
Villaricca	3,46	1,10	1,58	7,12	[seconds]	168	*gamma k=4*
Foggia 1-1	5,06	1,92	2,38	9,94	[seconds]	43	*gamma k=5*
Foggia 1-2	4,24	1,58	1,86	9,46	[seconds]	158	*gamma k=4*
Foggia 2	5,37	1,56	2,5	9,68	[seconds]	202	*gamma k=6*

Table 12: Accepted gap.

		μ	σ	min	max		n	pdf
Villaricca	classe1= 62%	2,03	0,24	1,34	2,5	[secondi]	75	*normale*
	classe2= 38%	3,18	0,41	2,51	6,4	[secondi]	45	*normale*
Foggia 1-1		3,56	1,45	1,60	9,59	[secondi]	37	*gamma k=4*
Foggia 1-2		2,93	0,76	1,68	8,93	[secondi]	114	*gamma k=3*
Foggia 2		3,69	1,00	1,97	9,51	[secondi]	170	*gamma k=4*

Table 13: Critical gap.

You can be observed that to Villaricca roundabouts we have found two behavior classes:

- the first one includes the drivers whose critical interval is very low, varying from a minimum 1,34 second to a maximum of 2,5 seconds with mean equal to 2,03; an aggressive so-called attitude has been attributed to such users: they are prepared to accept intervals lower part with a greater risk [22];

- the second class includes those people that can be defined more prudent, their critical interval varies between the values of 2,5 and 6,4 seconds with mean of 3,18.

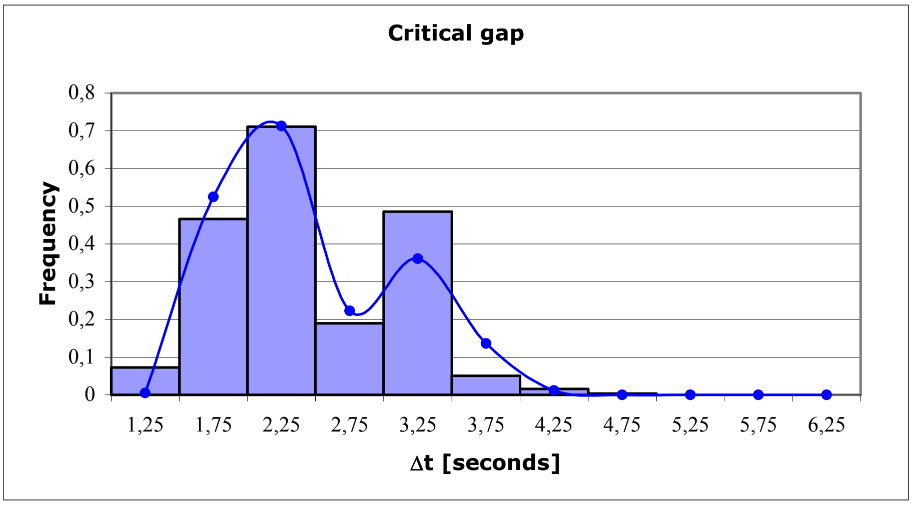

Figure 14: Critical gap distribution in the villaricca roundabout.

Such distinction has emerged to building the empirical distribution of critical gap: as you note from the figure 14, the histogram of the relative frequencies introduces two peaks, that characterizes a double line of behavior. Verified the existence of two classes, the problem is introduced to define an opportune random model. In this step we choose the model denoted "miscellany" that it consists in a double normal aleatory variable whose mean respectively coincide, with the present peaks in the empirical distribution. To building this model proceeds in the following way:

- the sample has been separated in two classes in relation to that seemed to be the value of border from the observation of the histogram;
- for every class the normal random model has been determined also;
- the model of distribution "miscellany" has been obtained adding the correspondents values of normal variable of the first and second class weighted through the numerousness of every class.

For the other roundabouts the situation results more homogeneous. In these cases the model, select to interpret the empirical distributions, results to be gamma function.

The classes adopted for determining the histograms result equal to 0,5 seconds for the rejected interval and 1 for those accepted and critical. Only for the critical intervals of "Villaricca" such indication has not been respected. Choosing this width there isn’t a lot of values, therefore, it has been necessary to decrease the class.

It is possible to make some observations about characteristic statistic model:

- note that the mean of critical gap is higher for "Foggia 1-1" and "Foggia 2" than "Villaricca" roundabouts. There are different factors that explain it. However the discriminating element can mostly seek in the circulating vehicular flow: if it is elevated as to Villaricca, the drivers that are introduced will have to choose among smaller gaps in the circulatory flow, with consequent reduction of the rejected, accepted and critical gaps. Besides under conditions of elevated flow, the elevated waiting time before introducing contributes to increase the aggressiveness of the driver. Such phenomenon of "impatience" distorts the driver behavior that is inclinable to accept a greater risk and smaller gaps. This tendency is evident in the diagrams that follow (figures 15, 16, 17). You see that in all the studied cases, to increase traffic volume, the critical gap decreases. The diagrams have been built through the measurement, for every introducing driver, its critical gap and the vehicle traffic flow. You can see how exist for everybody diagrams a line of well defined inferior tendency: its points represent the respects of critical gaps. The superior points are more dispersed. They represents higher estimates of accepted gaps and therefore far of critical gap [18].

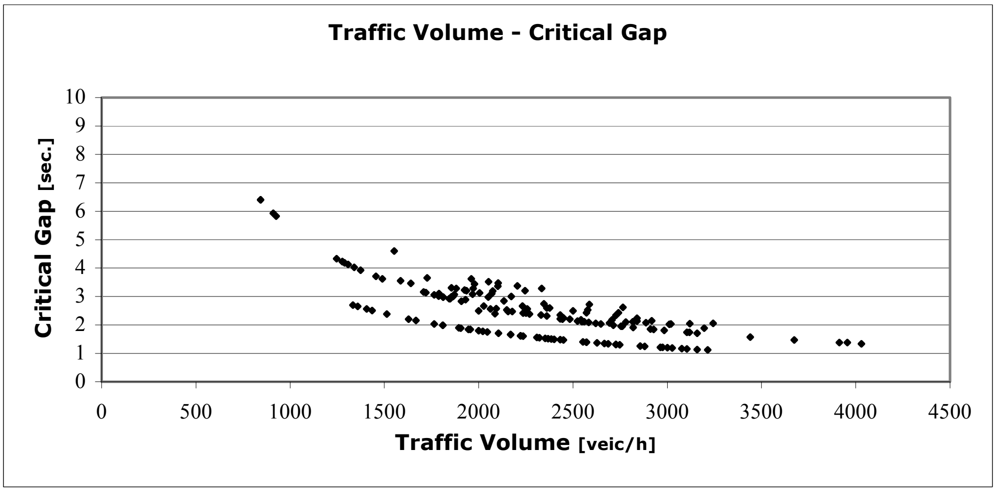

Figure 15: Traffic flow vs critical gap diagram in the Villaricca Roundabout.

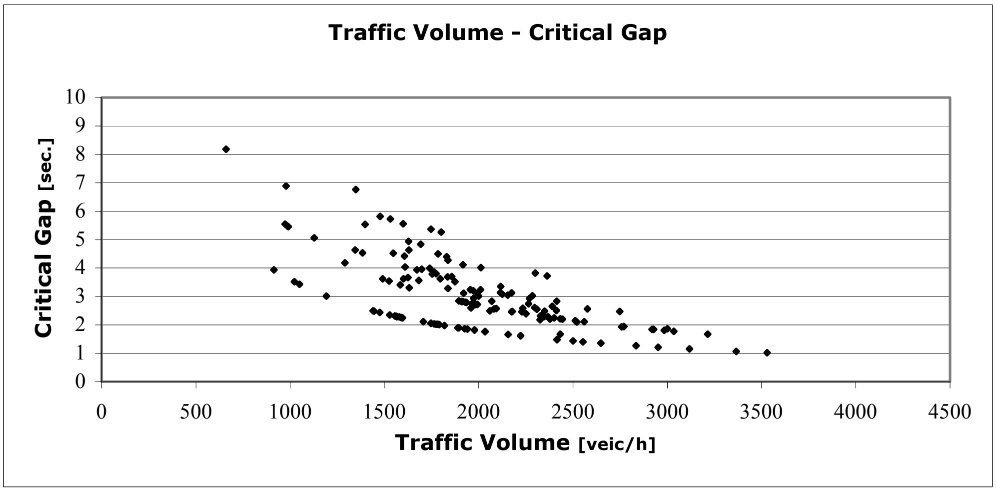

Figure 16: Traffic flow vs critical gap diagram in the Foggia 1 Roundabout.

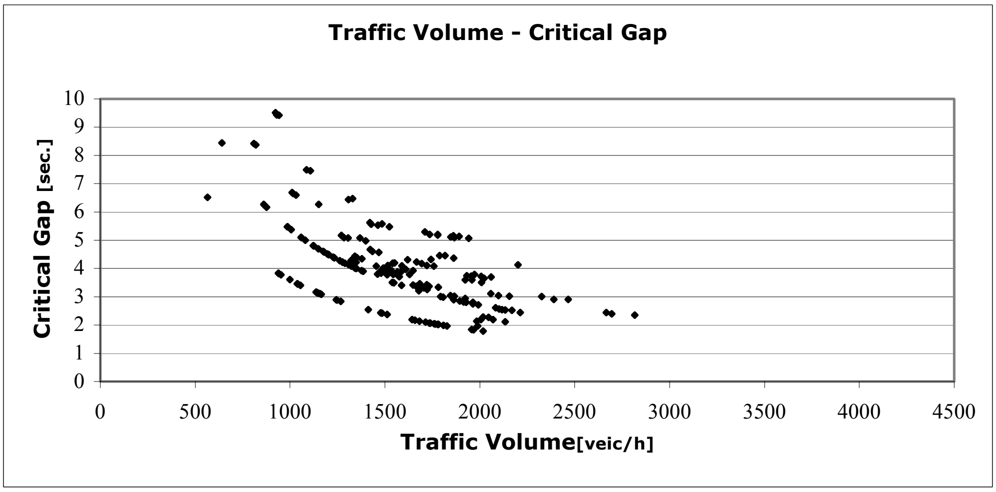

Figure 17: Traffic flow vs critical gap diagram in the Foggia 2 Roundabout.

- Also the geometric characteristics contribute to modify the behavior of the driver. In the "Foggia 2"roundabout, in fact, despite the principal flow is greater of that of "Foggia 1-2" the critical gap results greater. The motivation is due to the particular configuration of rondabout, that have a configuration analogous to that of a T intersection;
- Other geometric characteristics in "Foggia 2" roundabout, that affect on the mean critical gap, it is the width of the splitter island that is a raised area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road in two stages. From the comparison with "Foggia 1" (figure 18), it is possible to see that both for small dimensions of splitter island and for the different direction of the principal flow, the separation among exiting and entering traffic it is more clear in the "Foggia 1" roundabout than in "Foggia 2" roundabout.

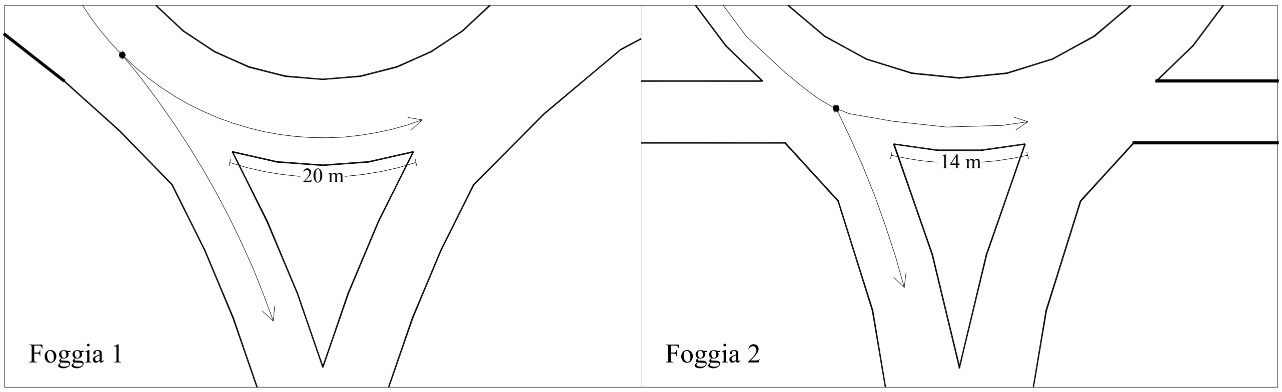

Figure 18: Comparison of splitter island in the roundabouts.

- Often the distinction among circulating vehicle in the inner lane and external lane is not perfectly clear. When the flows around two lanes increase, the two stream are confused and the entering vehicles have small critical gap avilable.

3.3.6 The Acceleration in the Entering Flow

The driver's behavior in the immission, in literature, it always foresees that the vehicle was stop and subsequently accelerate. In the reality it doesn't always occur this circumstance: some vehicles decelerates in correspondence of the stop line, for then to accelerate overcome the same one.
The sections where the transit times have been measured are four, and they have been situated beginning from Stop line to intervals of 5 meters. It has been possible to measure two accelerations: the first one related to the following line immediately to the Stop signal, the second to the following lines, everybody around 7,5 meters long.
For every line the statistic elaboration of the measured accelerations has been performed. The characteristic parameters are presented in the following tables.

	μ	σ	min	max		n	pdf	% of vehicles acceleration
Villaricca	-0,81	0,80	-2,48	1,79	[m/s^2]	270	*Normal*	16
Foggia 1-1	0,80	0,54	-0,36	2,30	[m/s^2]	61	*Normal*	92
Foggia 1-2	0,02	0,90	-2,06	2,14	[m/s^2]	146	*Normal*	56
Foggia 2	1,37	0,65	-0,33	3,25	[m/s^2]	266	*Normal*	99

Table 14: Acceleration in the entering traffic stream (line 1).

	μ	σ	min	max		n	pdf	% of vehicles acceleration
Villaricca	0,33	0,74	-1,95	2,65	[m/s^2]	270	*Normal*	70
Foggia 1-1	0,70	0,67	-1,19	2,32	[m/s^2]	61	*Normal*	81
Foggia 1-2	1,48	0,54	-0,75	2,43	[m/s^2]	146	*Normal*	99
Foggia 2	0,94	0,77	-1,90	2,73	[m/s^2]	266	*Normal*	88

Table 15: Acceleration in the entering traffic stream (line 2).

As it regards the mean of the accelerations, we are seen by the tables 14 and 15, that, for the first and second line, these vary a lot in relation of roudabouts. This fact is true in relation to the percentage of drivers accelerate. When in fact the acceleration is low, also the average of the accelerations is such, so much that to "Villaricca" in the first line the average have a negative value; if this percentage increases it also increase the average. Particularly it is essential to point up the first line, because it is clear that in the second line the general tendency is to accelerate.

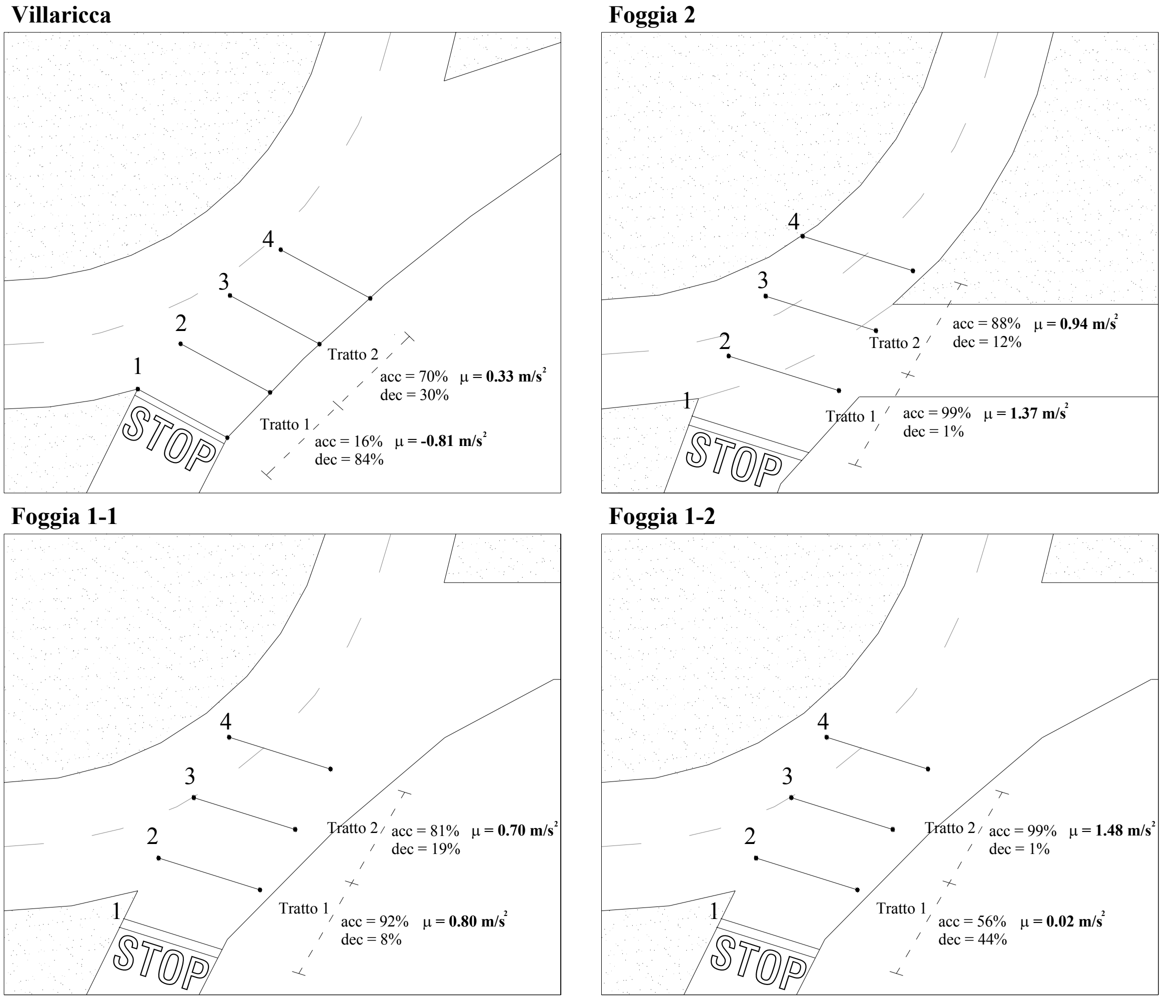

Figure 19: % of acceletrating vehicle in the every line.

The driver's tendency to stop and then acclerate, or to continue in deceleration depends from many factors. First there is the natural propensity of whom drives to be more prudent or more agressive, second there are the external factors what the conditions of traffic, the geometry of the intersection, the guaranteed visibility.
In the cases of study it is possible to show as follows:

- to "Villaricca" the low percentage of vehicles that accelerate to the Stop line reports both the propensity of the drivers to undertake a greater risk and the general behavior of the driver in the congested roundabout: reached the Stop line verified the presence of circulating vehicles, it decelerates and it begins to start gap acceptance behavior. If the first gap is accepted the driver entering in the roundabout and therefore accelerates, otherwise he stops and in this case the stop line seems to step forward. This is the consequence of a more aggressive attitude, typical of the driver that entering in congested traffic situation.
- to Foggia 1, the behavior emerged to "Villaricca" it is evident even more in two traffic conditions (Foggia 1-1, in free flow condition, Foggia 1-2 in saturated condition): in fact under conditions of low flow, the percentage of vehicles that immediately accelerate after the Stop is elevated, while when the flow increases the vehicles that accelerate they decrease showing the attitude first described.
- to "Foggia 2" it is evident a particular situation in relation to the geometric configuration of the immission, assimilable to a T intersection. The circulating stream continue in straight line forcing the entering vehicles to stop. The phenomenon is evident in figure 20.

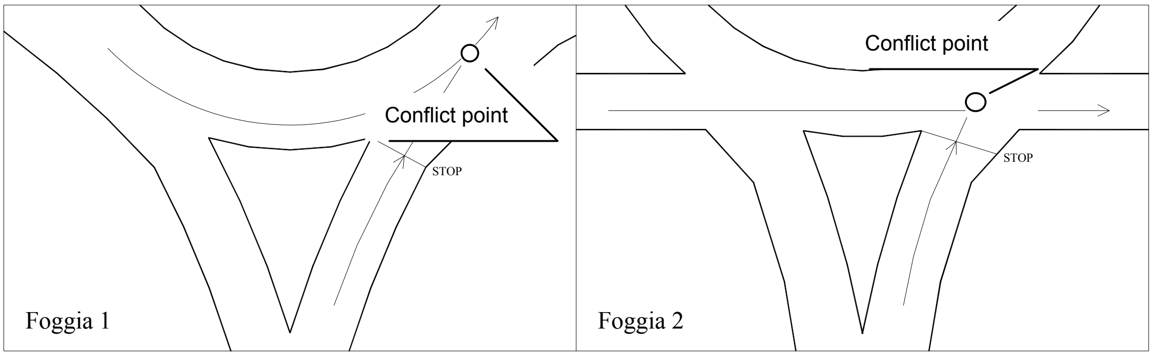

Figure 20: Comparison of approaching roadway.

Close to these considerations, related to the differences about different roundabouts, there are other factors that, directly influence behaviour's entering vehicles.
The acceleration of each vehicle that is introduced it is conditioned from the distance and from the speed of the first vehicle that arrives in the principal traffic flow (circulating traffic).
Entering vehicle will decelerate if will see to arrive any circulating traffic coming from the left to a small distance.
This distance can assume equal to the critical gap of the driver. When the vehicle that circulates is found to a greater time distance of the critical interval, it will force the vehicle that is introduced to accelerate for immediately taking up the intersection.
This is alone however a general tendency, in the sense that however there will be drivers that, in every way, they stop at yeld line or stop line and therefore they decelerate.
The behavior is show in the following diagram in which you can be remarked that in the field of the accelerations the experimental points are collected all in the superior part: nothing vehicle accelerates when sees to arrive another vehicle to a smaller distance of the critical interval.
In the field of the decelerations the points are collected in the lower part of the diagram: when the vehicle that circulates is next to what has to introduce it will have the tendency to decelerate, and it is seen that there are however, also vehicles that decelerate even if the vehicle that arrives is enough distant.
As it regards the speed of the circulating vehicle, the influence is smaller, but however a certain dependence is noticed: if the vehicle of the principal stream has a high speed, the tendency of the introducing vehicle is to decelerate even if the distance between them is enough to the immission manoeuvres. From the figure 21 are noticed that if speed is high (greater of around 32 km/hs), the vehicles almost always to decelerate, if speed is low (smaller of 25 km/hs) they accelerate.

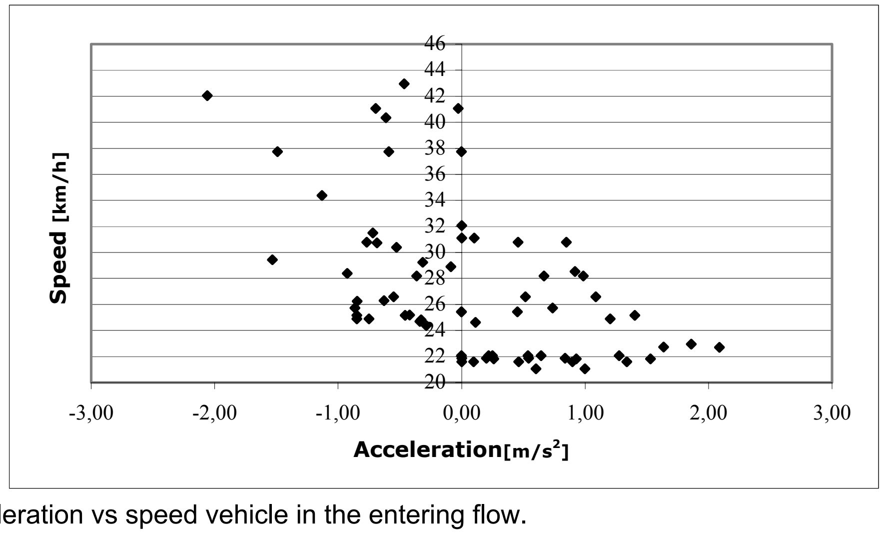

Figure 21: Acceleration vs speed vehicle in the entering flow.

3.3.7 Headway Distributions in the Circulating and Entering Stream

The statistic models of headway provide, through a probability density function, a description of the random variable τ that is the "time interval from two following transit in the considered section."
Under stationary flow conditions, the description of the vehicular time distance τ as random variable with different laws according to the characteristics of the traffic can achieve. Pointing out with μ and σ^2 the average and the standard deviation of the sample, the random models used in this applications are:

$$f_\tau(\tau) = \frac{1}{\tau\beta\sqrt{2\pi}} \exp\left(-\frac{(\ln\tau - \alpha)^2}{2\beta^2} \right); \quad \text{with} \quad \alpha = \ln\left(\frac{\mu}{\sqrt{1 + c_\tau^{\,2}}} \right); \quad \beta^2 = \ln\left(1 + c_\tau^{\,2}\right); \quad c_\tau^{\,2} = \frac{\sigma^2}{\mu^2};$$

- Exponential distribution;
- Erlang or Gamma distribution;
- Log-normal distribution.

For every roudabout and for every flow the time interval among the vehicles have been collected and, subsequently we have also been elaborated this values, as done for the other parameters.

The model that approximate random sample is always an exponential distribution. It is possible to show that if the transits are distributed according to a Poisson model, the time distance among vehicle is an exponential variable. In the studied cases time distance and the arrivals between two consecutive vehicles are distributed rispectively as exponential and Poisson models, also when the flow is equal to 1000 veic/hs. This correspondence is confirmed by the comparison among the mean and standard deviation of the sample: for an exponential model distribution mean and standard deviation are assimilable and as we are seen by the determined values, such circumstance is always verified.

	μ	σ	**min**	**max**		**n**	**pdf**	**Traffic Flow** [veic/h]
Villaricca	4,33	4,33	0,22	35,00	[seconds]	277	*Exponential*	834
Foggia 1-1	8,30	8,08	0,36	44,30	[seconds]	134	*Exponential*	405
Foggia 1-2	3,06	3,40	0,26	24,66	[seconds]	391	*Exponential*	1176
Foggia 2	3,24	2,92	0,56	26,60	[seconds]	369	*Exponential*	1110

Table 16: Headway in the circulatory roadway.

You can also be verified as the mean of time distance is equal to the inverse of the volume of traffic $\mu = 1/Q$.

4. Conclusion

This study represents an intermediary phase of a search regarding the determination of a model to simulate traffic in intersection without traffic signal. Particularly the problem of the roundabouts circulation has been, individualizing and schematizing the principal aspects of operation, through the photographic and video investigation, and the statistic elaboration. For this last phase of work the principal statistic distribution inherent behavior parameters of roundabouts circulation are been individualized: immission, circulation in car-following regime, lane changing, exit [8, 28, 29, 32]. The statistic elaboration carried out from sample investigations and using the statistic inference techniques to deduce the "general" distribution.

According to the formalities exposed in the preceding paragraphs the statistic distribution of the principals behavioral aspects in circulation are been extracted. Beginning from the geometric Villaricca intersection configurations we have been specified and implemented, with Visual basic 6.0 language [34], the single manoeuvres' models: immission, circulation, external lane changing, internal lane changing, exit.

Every model can be specified using the sample determination deduced in this search, through iterations like "*Monte – carlo simulation*". The future development of this search is the calibration, using the same logical sequence previously exposed, as well as the calibration of the complete roundabout model simulation, linking opportunely the single forms.

The intersections analysis depends on drivers behavioral parameters, just it was been necessary to investigate, experimentally, on the local conditions user's guides.

The objective of this search is to define some tools of intersections planning or change all existing [31]. One of these tools, is the coding of simulation programs for different typologies of intersection studied.

The innovative contributions of the search can synthesize in the definition of the circulation simulation models for intersection without signals:

- according to a user behavior logic;
- flexible and modifiable;
- calibrating with behavioral parameters setting experimentally with statistical analysis.

REFERENCES

[1] Ahmed K.I. (1999), Modeling drivers' acceleration and lane changing behavior, PhD Thesis, Transportation System and Decision Sciences at the Massachusetts Institute of Tecnology.

[2] AA.VV. (2000), Roundabouts: an informational guide, Federal Highway Administration publication n° FHWA-RD-00.067.

[3] Barcelò J., Bernauer E. et al. (1999), Smartest (Simulation Modelling Applied to Road Transport European Scheme Tests). Smartest Project. Project part funded by the European Commission under the Transport RTD Programme of the 4th Framework Programme.

[4] Brilon W. (1988), Intersection without traffic signals, Ed.Springer- Verlag. Vol 1 e Vol 2.

[6] Brilon W., Koenig R., Troutbeck R.J. (1999), Useful estimation procedures for critical gaps, Trasportation research Part A 33 pp. 164-186.

[7] Daganzo C.F. (1981), Estimation of gap acceptance parameters within and across the population from direct roadside observation, Trasportation research Part B 15 pp. 1-15.

[8] De Luca M., Grossi R., Petitto S. (2001), Studio della circolazione nelle rotatorie mediante la tecnica della simulazione. Convegno Input2001. Isole Tremiti. 2001.

[9] Erto P. (1999), Probabilità e statistica per le scienze e l'ingegneria, Ed.McGraw-Hill.

[10] Gipps, P. G. (1986), A model for the structure of lane changing decisions, Transportation Research 20B(5), pp. 403-414.

[11] Grossmann M. (1988), KNOSIMO – A praticable simulation model for unsignalized intersections, Intersection without traffic signals, Ed.Springer- Verlag. Vol 2. pp.263-274.

[12] Hagring O. (2000), Estimation of critical gaps in two major streams, Trasportation research Part B 34 pp. 293-313.

[13] Hamed M.M. et al. (1997), Disaggregate gap-acceptance model for unsignalized T- intersections, Journal of transportation engineering vol. 123 n°1 pp. 36-42.

[14] HCM Highway Capacity Manual (2000), TRB Special Report 209 Washington D,C. : Office of Research, FHWA.

[15] Hossain M. (1999), Capacity estimation of Traffic circles under mixed traffic conditions using micro – simulation technique, Transportation Research, Vol. 33 B.

[16] Mahmassani H.,Sheffi Y., (1981), Using gap sequences to estimate gap acceptance functions, Trasportation research Part B 15 pp. 143-148.

[17] Mood A.M., Graybill F.A., Boes D.C. (1988), Introduzione alla statistica, Ed.McGraw-Hill.

[18] Pollatschek M.A., Polus A., Mosche L. (2002), A decision model for gap acceptance and capacity at intersection, Trasportation research Part B 36 pp. 649-663.

[19] Ran B. et al. (1999), A microscopic simulation model for mrging control on a dedicated-lane automated highway system, Trasportation research Part C 7 pp. 369-388.

[20] Teply S. et al. (1997), Gap acceptance behaviour aggregate and logit perspectives: Part 1, Traffic engineering and control vol 38 n°9 pp. 474-482.

[21] Tian Z. et al.(1999), Implementing the maximum likelihood methodology to measure a driver's critical gap, Trasportation research Part A 33 pp. 187-197.

[22] Wilde J.S.G. (1990), Target Risk, PDE Pubblications, Toronto – Ont., Canada M2N 6M2.

[23] Adams J. (1995), Risk, University College London Press, London.

[24] AA.VV. (2000), Road User Rule – Consulattion paper: Traffic Law for Roundbouts, Land Transportation Safety Authority, Welligton.

[25] AA.VV. (1999), Australian Road rules, part 9, Approved by Australian Transport Council, National Road Transport Commission.

[26] AA.VV. (2001), Road Users' Handbook, Amendments to jan and june 2001 versions.

[27] Groeger J.A., Rothengatter J.A: (1998), Traffic is psycology and behaviour, Transportation Research, part F1.

[28] Chin H. C. (1985), SIMRO: a model to simulate traffic at roundbouts, Traffic Engineering and Control.

[29] Salter R. j., Okezue O. G. (1998), Simulation of traffic flow at signal – controlled roundbouts, Traffic Engineering and Contreol.

[30] Taetarouk T. (1998), Modern Roundbouts for Oregon, Oregon Department of Transportation, Research Unit (#98-SRS-522), Salem Or.

[31] Van As S. C. (1979), Traffic signal optimisation procedures and tecniques, PhD Thesis, Departmrnt of Civil Engineering, University of Southampton.

[32] Varol Y. L., Kaufman A. A., Hanani M. Z. (1977), Applying simulation to highway intersection design, Simulation, 28(4), pp. 97 – 105

[33] Ozaki H. (1993), Reaction and anticipation in the car – following behavior. In C.F. Daganzzo (Ed.), Proceedings of the 12th International Symposium on the Theory of Traffic Flow and Transportation, New York, pp. 349 – 366. Elsevier.

[34] Bradley J. C., Millspaugh A. C. (1999), Visual Basic 6.0, Guida alla programmazione, McGraw – Hill.