Modeling Drivers' Roundabout Behavior

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Synopsis

This work contributes to the development of microscopic traffic performance models in the roundabout. It enhances the existing models and develops new ones. An important contribution of this research is the empirical work, i.e. estimating models using statistically rigorous methods and microscopic data collected from real traffic.

To develop a roundabout simulation model it is necessary to examine drivers' behavior. Therefore can be useful to define trajectory "type" from the entry up to the exit arms.

In this research it is been individualize the elementary drivers' behavior that will characterize every trajectory (e/o manoeuvres), trying to determine a mathematical formalism (model) that reproducing them.

The connection among the models that reproduce different drivers' roundabout behavior it will allow to simulate the manoeuvres according to the sequence:

approach;
circulation;
lane changing to the lane inside;
lane changing to the external lane;
exit.

The purpose of this paper, in the approach manoeuvre, is to present a microscopic decision model for driver gap-acceptance behavior when waiting at an intersection on the secondary road. Critical gap is one of the major parameters for gap acceptance models. The accuracy of capacity estimation is mainly determined by the accuracy of the critical gap. This paper focuses on the implementation of the maximum likelihood technique to measure a driver's critical gap using field data. A methodology to define gap events is proposed, so that the accepted gaps and maximum rejected gaps required by the maximum likelihood technique could be obtained.

The model takes into account individual preferences by defining individual critical gap, which is different from the traditional macroscopic critical-gap approach. The latter estimates the critical gap for the entire population of drivers.

The acceleration model (reproducing some circulation behavior) defines two regimes of traffic flow: the car - following regime and the free -flow regime. In the car - following regime, a driver is assumed to follow his/her leader, while in the free - flow regime, a driver is assumed to try to attain his/her desired speed. A probabilistic model, that is based on a time headway threshold, is used to determine the regime the driver belongs to. Heterogeneity across drivers is captured through the headway threshold and reaction time distributions.

The parameters of the car - following and free - flow acceleration models along with the headway threshold and reaction time distributions are jointly estimated using the maximum likelihood estimation method.

The lane changing decision process is modeled as a sequence of three steps: decision to consider a lane change, choice of a target lane, and gap acceptance. Since acceptable gaps are hard to find in a heavily congested traffic, a forced merging model that captures forced lane changing behavior and courtesy yielding is developed. A discrete choice model framework is used to model the impact of the surrounding traffic environment and lane configuration on drivers' lane changing decision process.

The models are estimated using actual traffic data collected from Foggia and Naples roundabouts. In addition to assessing the model parameters from statistical and behavioral standpoints, the models are validated using a microscopic traffic simulator. Every model are implemented in Visual basic 6.0 language and next we are connected them in a single simulation model, implemented in Visual Basic language that reproduce circulation in the real roundabouts. This model is calibrated using real data collected in the Foggia and Naples reality and regards time spends in queue for every secondary street, gap acceptance behavior, speed in the circulation and capacity of two real roundabout intersection.

Overall, the empirical results are encouraging, and demonstrate the effectiveness of the modeling framework.

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The objective of the present research is that to get some tools of planning of the intersections or change of those existing, that are function of the circulation. One of these tools, are the coding of simulation programs for the two roundabouts studied.
The innovative contributions of the research can synthesize in the definition of the circulation simulation models for the intersections:
- according to a logic vehicular behavior;
- flexible and modifiable;
- experimentally set with measurable values of the behavioral characteristics.

Data required to estimate the models that reproduce the circulation at the roundabouts was obtained from real traffic and 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 adjacent lanes, relative speed and acceleration in the lane changing behaviour, etc. Data on gap lengths , headways, density of traffic, etc. can be extracted from the above mentioned data by simple operations. Typically, such data is collected using photographic and video equipment.

1. FIELD STUDIES ON THE VEHICLE INTERACTIONS AT ROUNDABOUT

To develop a roundabout simulation model it is necessary to examine drivers' behavior. Therefore can be useful to define trajectory "type" from the entry up to the exit arms.
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1.1. A decision model for gap acceptance

The purpose of this paper is to present a microscopic decision model for driver gap-acceptance behavior when waiting at an unsignalized intersection on the secondary road.
Many studies have been conducted on gap acceptance and critical gaps. For example, an early approach suggested by Greenshields et al. (1947), used the definition of the ''acceptable average minimum time gap'' for the critical gap. Ra. and Hart (1950) defined the critical lag as the size of the lag for which the number of accepted shorter lags is equal to the number of rejected longer lags. A similar, widely accepted, definition, proposed by Drew (1968), suggested that the critical gap is that for which an equal percentage of traffic will accept a smaller gap as will reject a larger one. Kremser (1962a,b) provided models to estimate delay for both vehicles at the head of the queue and vehicles arriving at the back of the queue. A recent study by Brilon et al. (1999) described estimation procedures for critical gaps at unsignalized intersections.
A recent thought, absent from earlier studies, stipulated that not all gaps presented to the driver should be considered in the process while waiting at an intersection. Kittelson and Vandehey (1991) showed that nearly all gaps longer than 12 s are accepted and, therefore, should not be considered when determining the critical gap. Teply et al. (1997) similarly suggested that drivers facing gaps greater than 13 s had a ''no choice'' situation because all greater gaps were accepted. Polus and Shmueli (1999), who studied gap acceptance at roundabout intersections, suggested a threshold gap, values above which would not be relevant for the determination of the critical gap and, consequently, for the capacity analysis. The threshold gap was shown to be dependent on the local conditions: the radius of the roundabout, the speed of vehicles around the central island, and a coefficient representing mainly the impact of visibility across the circle. They arrived at threshold-gap values of 8–9 s for the sites studied. Several researchers have discussed the issue of risk impact on drivers' decision-making. Adams (1995) modified the risk ''thermostat'' that was earlier devised by Wilde (1990). Adams' model postulates that every driver has a propensity to take risk; this inclination varies among individuals and is ''influenced by potential rewards of the risk-taking''. Based on Adams' thermostat, a driver's modified ''risk–reward loop process'' is suggested for drivers who wait at a stop-line for an appropriate gap. The thermostat stipulates that drivers' delay at a busy intersection is the catalyst for their propensity to take a risk when entering the main road. This may result in a reward in the form of an entry into the intersection and travel-time saved, which in-turn may lead to risk aversion that causes a new delay.
In the traditional gap acceptance theories, it has been commonly assumed that the major stream vehicles have absolute priority over the minor stream vehicles. The minor stream vehicles are assumed to accept any

gap greater than critical gap and reject any gap smaller than the critical gap. All delays at an a intersection are experienced by the minor stream vehicles whilst the major stream vehicle suffer no delays.

1.2. Acceleration model: background study

The models capturing drivers' acceleration behavior can be classified as:

Car - following models,

General acceleration models.

The car - following models capture acceleration behavior in the car - following regime. In this regime, the drivers are close to their leaders and follow their leaders. The general acceleration models capture acceleration behavior in both the car - following and free - flow regimes. In the free - flow regime, drivers are not close to their leaders and therefore, have the freedom to attain their desired speed. Drivers' acceleration behavior, when they are in the car - following regime, has been studied extensively since the 1950s. Estimation of these models using microscopic data, for example, speed of a subject and its leader, gap length, acceleration applied by the subject, has not received much attention. Simple correlation analysis was used to estimate the models in most cases. Researchers started paying attention to the acceleration behavior in the free – flow regime in the early 1980s as microscopic simulation emerged as an important tool for studying traffic behavior and developing and evaluating different traffic control and management strategies.

The general form of the car- following models developed in the late 1950s is as follows:

$$response_n(t) = sensitivity_n(t - \tau_n) \times stimulus_n(t - \tau_n)$$

where,

t = time of observation,

τ_n = reaction time for driver n,

response(t) = acceleration applied at time t.

The reaction time, τ_n, includes the perception time (time from the presentation of the stimulus until the foot starts to move) and the foot movement time. The front relative speed is generally considered as the stimulus and sensitivity is a proportionality factor that may be a function of factors such as subject speed, space headway. Chandler et al. (1958) developed the first car - following model that is a simple linear model. Mathematically, the model can be expressed as

$$a_n(t) = \alpha \Delta V_n^{front}(t - \tau_n)$$

where,

$a_n(t)$ = acceleration applied by driver n at time t,

α= constant,

ΔV^{front}: stimulus,

A driver responds to the stimulus at time (t - τ_n) by applying acceleration at time t. The same sensitivity terms are used for both the acceleration and deceleration situations. They estimated the model using the correlation analysis method and microscopic car - following data. For each driver, the data included discrete measurements of the acceleration, speed, space headway, and relative speed over the time of observation. For different values of τ and α, correlations between the observed and the estimated accelerations were computed. The values of τ and α that yielded the highest correlation were used as the estimates of τ and α for each driver. A major limitation of the above model is the assumption of a constant sensitivity for all situations. Gazis et al. (1959) address it by incorporating the space headway between the two vehicles in the sensitivity term. Their model is as follows:

$$a_{n(t)} = \frac{\alpha}{\Delta X_n(t - \tau_n)} \Delta V_n^{front}(t - \tau_n)$$

where, $\Delta V_n^{front}(t - \tau_n)$ denotes the space headway at time (t - τ_n). The model was estimated using microscopic data collected from the car - following experiments in the Holland Tunnel and the Lincoln Tunnel in New York and at the General Motors test track. The parameters τ and α were estimated for each driver of each data set using correlation analysis.

The mean reaction time measured at the test track varied from 1.0 to 2.2 seconds. Edie (1961) pointed out that, the model given by previous equation suffers from two limitations. First, from a behavioral standpoint, the follow – the leader theory is not applicable at low densities. Second, the macroscopic speed - density relationship derived from previous equation yields infinite speed as the density approaches zero.

Edie addressed the above mentioned limitations by changing the sensitivity term and the model is as follows:

$$a_n(t) = \alpha \cdot \frac{V_n(t - \tau_n)}{\Delta X_n(t - \tau_n)^2} \cdot \Delta V_n^{front}(t - \tau_n)$$

Sensitivity is now proportional to the speed and inversely proportional to the square of the headway. The previous equation can be integrated to obtain a model that yields free - flow speed as the density approaches zero. This model performed better than the model proposed by Gazis et al. (1959) at low densities. However, the stimulus term is still a function of the front relative speed, which is not realistic at low densities, in particular, when the headways are high. Instead of using the sensitivity - stimulus formulation to explain the car – following acceleration decision, Newell (1961) suggested the following relationship between the speed and the headway:

$$V_n(t) = G_n \cdot \Delta X_n(t - \tau_n)$$

where, G_n is a function whose form determines the specification of the car – following models that are presented above. Different forms of G_n were assumed for the acceleration and deceleration decisions. Although, the model had the advantage of integrability to obtain different macroscopic speed – flow - density relationships, no attempt was reported to obtain a quantitative result to validate the model. The car - following model developed by Gazis et al. (1961), known as the General Motors Nonlinear Model, is the most general one. The model is given by:

$$a_n(t) = \alpha \cdot \frac{V_n(t)^\beta}{\Delta X_n(t - \tau_n)^\gamma} \cdot \Delta V_n^{front}(t - \tau_n)$$

where, α, β and γ are model parameters. The sensitivity is proportional to the speed raised to the power γ and inversely proportional to the headway raised to the power. The parameter α is a constant and the front relative speed is the stimulus. The models developed earlier by Chandler et al. (1958) and Gazis et al. (1959) can be derived from this model as special cases. It should be mentioned that the macroscopic flow - speed relationship developed by Greenshields (1934) can be derived from the GM Model by setting $\beta = 0$ and $\gamma = 2$. No rigorous framework for estimating the model was provided.

Ozaki (1993) estimated the GM Model parameters. He used regression analysis to estimate a model for drivers' reaction time and correlation analysis to estimate parameters α, β and γ.

Aycin and Benekohal (1998) developed a car{following model which estimates the acceleration rate at any instant of time. Acceleration for the next time instant is then computed by adding the product of the acceleration rate estimate and the time difference to the current acceleration. This guarantees continuity in the acceleration profile for a given driver. Equations of laws of motion are used to compute the acceleration rate required for a driver to attain its leader's speed while maintaining a preferred time headway. The preferred time headway is defined as a headway the driver wants to maintain under steady{state car{following conditions. For each driver in the car - following data set that travelled at speeds within ± 5 ft/sec of its leader's speed, the discrete time headways measurements over time were averaged. Then, the average was taken as the driver's preferred time headway. The preferred time headway values ranged from 1.1 to 1.9 seconds with a mean of 1.47 seconds. The effect of reaction time is explicitly modeled. According to this model, drivers are assumed to be in the car - following regime if the clear gap is less than 250 feet. This rule ignores variability between drivers. The reaction time was not estimated using a rigorous method. It was assumed to be 80% of the estimated preferred time headway.

The models presented above apply to the car - following regime only. When the headways are large, drivers do not follow their leader, instead they try to attain their desired speeds. Developing an appropriate acceleration model for the free - flow regime is important for microscopic simulation models. Gipps (1981) developed the first general car - following model that is applicable to both the car - following and free - flow regimes. This model calculates a maximum acceleration for a driver such that the speed would not exceed a desired speed, and the clear gap would be at least a minimum safe distance. Mechanical limitations of vehicles were captured by using the parameters maximum acceleration and most severe deceleration. The parameters of the models were not estimated rigorously and the reaction time was set arbitrarily for all drivers.

Subramanian (1996) developed a general acceleration model that captures drivers' acceleration behavior in both the car - following and free - flow regimes. A space headway threshold distribution was assumed that determines which regime a driver is in at any instant of time. In the car{following regime, drivers are assumed to follow their leader, and in the free - flow regime, they are assumed to try to attain their desired speed. He, however, estimated only the car{following model parameters using data that was collected in 1983 from a section of Interstate 10 Westbound near Los Angeles. His specification of the car - following model is an extension of the GM Model and is given by:

$$a_n(t) = \alpha \cdot \frac{V_n(t - \tau_n)^\beta}{\Delta X_n(t - \tau_n)^\gamma} \cdot \Delta V_n^{front}(t - \tau_n) + \varepsilon_n^{cf}(t)$$

where, $\varepsilon_n^{cf}(t)$ is the random term associated with driver n at time t. He modeled the reaction time as a random variable to capture the variability within driver and between drivers. Variables $\varepsilon_n^{cf}(t)$ and τ_n are assumed to be distributed normal and truncated lognormal respectively. He estimated separate models for acceleration and deceleration observations. The estimation results are:

Tab 1.1.: Estimation results of the GM Model by Subramanian (1996).

Parameter	Model for acceleration estimate
α	9.21
β	-1.67
γ	-0.88
Std. dev. $\left(\varepsilon_n^{cf}\right)$	0.78
Mean (τ), sec.	1.97
Std. dev. (τ)	1.38

1.3. Lane changing model: the state of art

In this section, a literature review of the lane changing models is presented followed by a literature review of the gap acceptance models. The principal focus of research in modeling drivers' lane changing behavior has been on modeling the gap acceptance behavior at stop controlled T - intersections.
The gap acceptance phase is a part of the lane changing process Gipps (1986) presented a lane changing decision model to be used in a microscopic traffic simulator. The model was designed to cover various urban driving situations where traffic signals, obstructions, and the presence of heavy vehicles (for example, bus, truck, semi - trailer) affect a driver's lane selection decision. Three major factors were considered in the lane changing decision process: necessity, desirability, and safety. Different driving conditions were examined including the ones where a driver may face conflicting goals. However, different goals were prioritized deterministically, and inconsistency and non - homogeneity in driver behavior were not modeled.
The terms inconsistency implies that a driver may behave differently under identical conditions at different times, while the term non{homogeneity implies that different drivers behave differently under identical conditions.

2. MODEL FORMULATIONS

In this chapter we present a rigorous framework to reproduce local behavior by model simulation is presented. The proposed models consists in three components: the gap – acceptance model; the car – following and free – flow acceleration models; the lane – changing model.
The free - flow acceleration model is applied when a driver tries to attain its desired speed and is not following its leader.
This chapter starts with a presentation of the conceptual framework and specification of the model. Next, the likelihood function that is necessary for estimating the model is formulated.

2.1. Gap – Acceptance Model

This section discusses the development of a new gap acceptance model which assumes limited priority for the minor stream vehicles. The major stream vehicles are assumed to be in the circulatory roadway. In this step we have assumed that a single-lane exit ramp terminates in a two-lane street (circulatory roadway) at a stop sign as shown in Figure 1.1. The two integer variables that reflect the state of the system are the presence or absence of a vehicle at Point A and the number of vehicles in queue at Point B on the approach. The three possible events are as follows: a vehicle arrives at A, a southbound vehicle arrives at B, and this vehicle accepts or rejects a gap between vehicles arriving at A and executes (or does not execute) a right-turn maneuver. The time-step logic can be discrete steps of variable size with the simulation model stepping from one event to the next (event-based) since no modeling of the vehicle dynamics (i.e., vehicle accelerations and decelerations) is involved. Three elements of the processing logic are setting the gaps between arriving vehicles at A, setting similar gaps for arriving vehicles at B, and having the vehicles at B determine whether gaps between successive vehicles at A are large enough for them to execute their turning maneuver (i.e., if the gap is large enough, to turn, otherwise to wait). To set the gaps between vehicle arrivals and the minimum gap that the vehicles at B will accept, three probability distributions are needed. We have assumed that the following probability distributions pertain (this means that the model is stochastic):

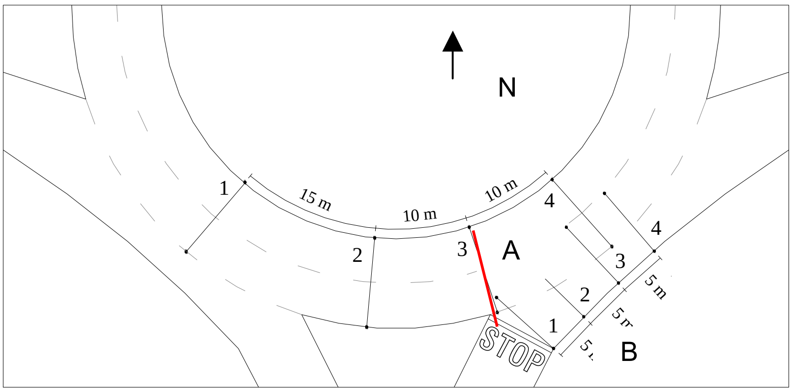


Figure 2.1.: An exit arm in the Villaricca (NA) roundabout with conflict section for gap acceptance behavior.

The model reproduces gap – acceptance process: it compares major stream time gap with those critical. The vehicle behavior and the variable on which it depends are "condensed" all in the distribution of the critical interval. Following the numerical approach the probability of acceptance is already provided as a input through the probability distribution, from the observed data, of this last.
The proposed model has been implemented through a program of software compilation. The used programming language is the Visual Basic, the software has been adopted, more precisely, related to the Visual Basic version 6.0. This model run the probability distribution obtained by the experimental elaboration:
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:

$$f_\tau(\tau) = \frac{1}{\tau\beta\sqrt{2\pi}} \exp\left(- \frac{(\ln\tau - \alpha)^2}{2\beta^2} \right)$$

with

$$\alpha = \ln\left(\frac{\mu}{\sqrt{1 + c_\tau{}^2}} \right)$$

$$\beta^2 = \ln\left(1 + c_\tau{}^2\right)$$

$$c_\tau{}^2 = \frac{\sigma^2}{\mu^2}$$

For Villaricca Roundabout 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 respectively 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.

Tab. 2.1.: Time Headway in the circulatory roadway.

	μ	σ	min	max		n	pdf	Traffic Flow [veic/h]
Villaricca	4,33	4,33	0,22	35,00	[seconds]	277	Exponential	834

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

Considered for every user the critical gap proceeds to the statistic elaboration. Particularly we have been determined, three models of random variable: one for the rejected gap, one for those accepted and one for the critical gaps. The tables 2.2., 2.3., 2.4. show the relative characteristic parameters to every type of interval.

Tab. 2.2.: Maximum rejected gap.

	μ	σ	min	max		n	pdf
Villaricca	1,77	0,58	0,86	3,40	[seconds]	120	gamma k=2

Tab. 2.3.: Accepted gap.

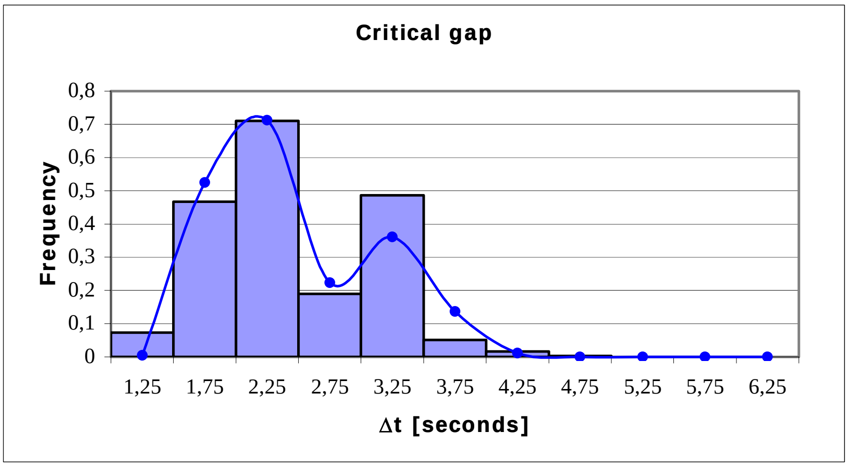
	μ	σ	min	max		n	pdf
Villaricca	3,46	1,10	1,58	7,12	[seconds]	168	gamma k=4

Tab. 2.4.: Critical gap.

		μ	σ	min	max		n	pdf
Villaricca	class1= 62%	2,03	0,24	1,34	2,5	[seconds]	75	normal
	class2= 38%	3,18	0,41	2,51	6,4	[seconds]	45	normal

You can be observed that 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; 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.

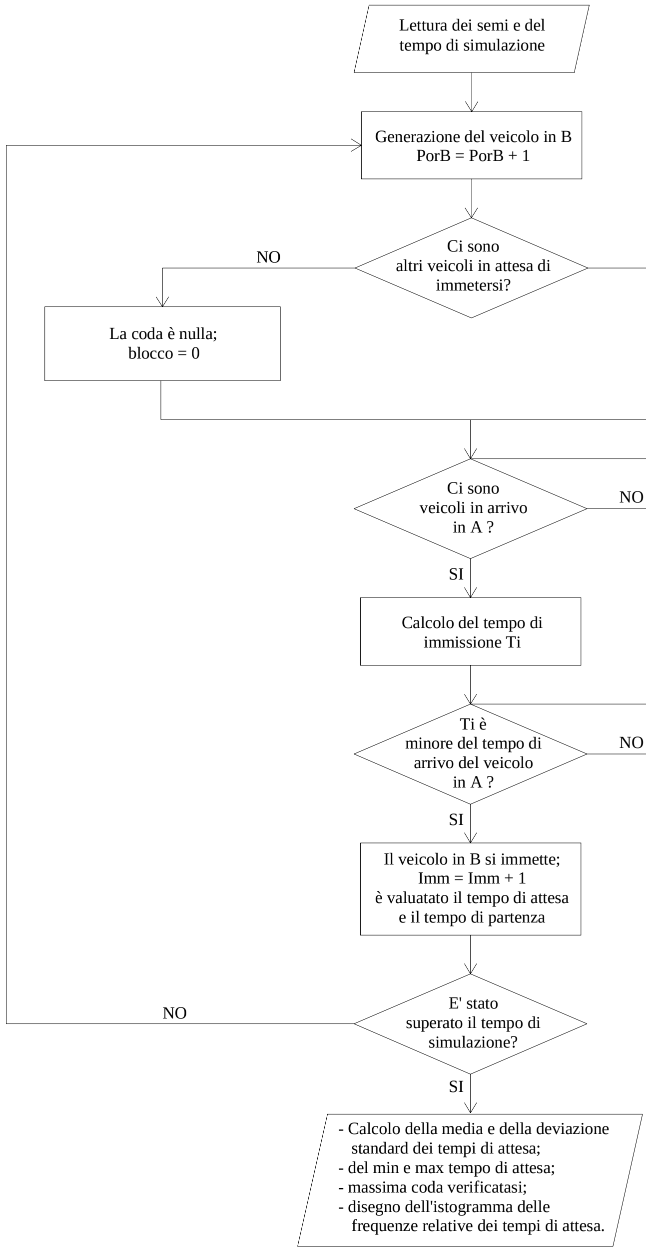
Figure 2.2.: Critical gap distribution in the Villaricca roundabout.



Such distinction has emerged to building the empirical distribution of critical gap: as you note from the figure 2.2., 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 random 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.

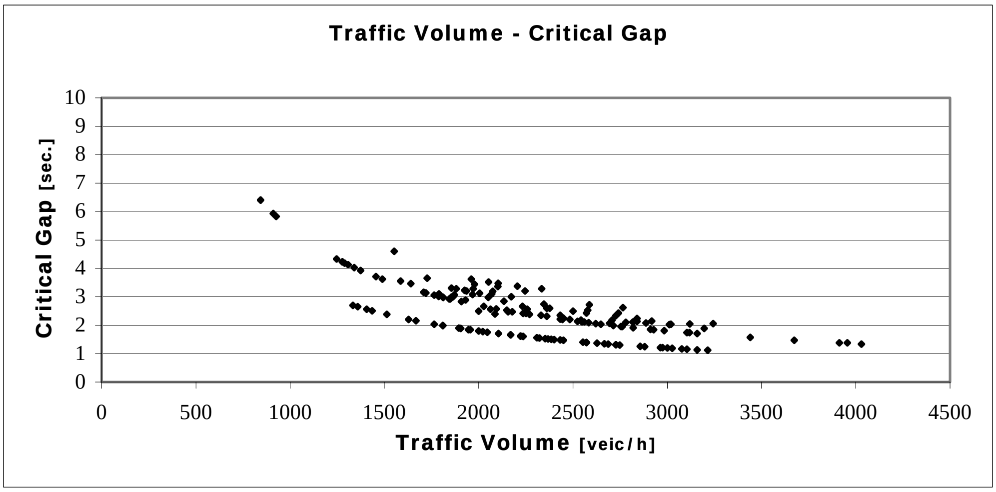
In the next figure we show the flow chart related to the gap acceptance model implemented.

Figure 2.3.: Flow chart of gap acceptance model.



A further change of the implemented model has been studied for trying to make to derive you critical time gap, not directly from experimental distributions but from the motion characteristic parameters.
The critical interval depends on numerous factors what the vehicular flow on the ring, the speed of the circulating vehicles, the vehicles mechanical characteristics, the geometry of the entry arms, the environmental conditions, etc. particularly from the figure 2.4. (critical gap time vs. traffic volume) a correlation is noticed between the critical interval and the conditions of traffic in the roundabout. Through the flow diagram it is been possible to deduce a dependence between the critical interval gap time and the vehicular circulation speeds.

Figure 2.4.: Traffic flow vs. critical gap diagram in the Villaricca Roundabout.



For this reason if it was used a model that determines the critical interval through the casual extraction from an experimental distribution, as described, we would neglect the correlation, shown, between critical intervals and the traffic conditions in the roundabout, important to the goals of the operation of the gap acceptance mechanism.

The change has consisted of determining through a directed proportionality relationship the critical gap time interval and the major stream vehicle speed. In such way, to increase traffic volume, because of lower circulation speeds, we'll have a smaller critical gap time interval. In this way we will be made the hypothesized correlation. The mathematical relationship for the determination of the critical interval gap time has been, in first approximation, hypothesized with the following hypotheses:

the vehicle in the minor stream start to STOP line with motion uniformly accelerated;

the vehicle in the major stream, that circulating on the ring, proceeds with constant speed;

in the time in which the secondary stream vehicle is introduced, it reaches the speed of that follows; the following vehicle, will have to be in a safety distance to the preceding vehicle: in other words, the vehicle that arrives doesn't have to be forced to slow down.

Under such conditions a vehicle that is introduced, will have reached the speed v after a time t=v/a, and in this time interval will have crossed a space $s=v^2/2a$. This same space will have been crossed by the vehicle that follows, that proceed to a constant speed v, in a time gap interval given by s/v = v/2a. If a δt the major stream vehicle had reached that departed by the STOP line it would transit a time interval (t - v/2a = v/2a) after the entry of the first vehicle. Also considering the safety distance from the vehicle that precedes and that follows, the critical interval is:

$$I_c = \frac{v}{2 \cdot a} + 2 \cdot \delta$$

Applying the formula to the studied intersection and hypothesizing the following values for the independent variables:

δ = 1 sec.;

a = 1,2 m/s^2;

v = 27 km/h (mean speed relieved in the Villaricca Roundabout)

a value of the critical gap time interval is gotten I_c = 5,12 seconds. It rather results distant from that middle measured equal to 2,46 seconds. Particularly observing the guide behavior in correspondence of the analyzed intersection, some hypotheses can be seen again done for its formulation.

To the speed v that is reached by the vehicle that start to the STOP line, the difference of speed ($v - v_{imm}$) has been replaced, where v_{imm} is the speed of the secondary vehicle, that entry in the roundabout, when the tail of the preceding vehicle transits along the entry arm. This speed can be determined in consideration of the acceleration *a* of the entering vehicle and of the time *t'* of advance with which it begins to accelerate. This time *t'*, it will be equal to that obtained from the vehicle that "it opens" the gap acceptance mechanism to cross a distance equal to his length L.

The expression of the v_{imm} is:

$$v_{imm} = \frac{a}{v_{pre}} \cdot L$$

with:

a entering acceleration;

L length of the vehicle;

V_{pre} speed of the vehicle that precedes.
Therefore, we have, a new expression of the critical gap time interval:

$$I_c = \frac{v - v_{imm}}{2 \cdot a} + 2 \cdot \delta$$

This consideration to be derived from *non correct* gap acceptance behavior that entered in a local intersection with smaller accepted intervals and therefore with that smaller critical gap time.

2.2. Acceleration Model

The guide of a vehicle can be schematized as a succession of phases:
Phase 1: Perception in which the driver visually acquires the stimuli that originate from the external environment;
Phase 2: Decision in which, interpreted the above-mentioned stimuli the driver elaborates the strategy of guide to adopt in operation of his experience and of the knowledge of the vehicle;
Phase 3: Reaction in which the driver translates in the operations of guide the elaborate choices, in relation of the performances of the vehicle in the environment in which is found.
The car-following models cannot logically interpret the complexity of the "human factor", they describe, through a simple relationship of behavioral reciprocity, the interaction among two vehicles: the vehicle that follows tries to maintain your position in proximity of the vehicle that precedes preserving a safety distance to avoid the collision, also in correspondence of the emergency braking of the preceding vehicle.
The model that we have used in this research overcomes the limits of the models adopted in some microsimulation software: the sequential approach in the updating of the vehicles, the discontinuity of the acceleration profile, etc. This model, in fact, simultaneously updates the characteristics of vehicles motion and assess, step by step, the counterblow, guaranteeing in such way the continuity of the profile of acceleration function. This shape guarantees the followings benefit:
the accelerations calculated in one "simulation step" are correlated to those of the preceding step;
the solutions result to be continuous in the time;
the model of linear acceleration describes well the behavior of the drivers.
We consider in this work the desired space in car – following. This variable is given from:

$$D_s = V \cdot t_p$$

where
V is the follower vehicle speed
T_p is the preferred time headway: desired gap time to follower vehicle when circulate with the same speed of the leader vehicle and it represents the ability to develop the same deceleration rate of the vehicle "leader" when this last brakes. In other words *Ds* represents the maximum reaction time of the follower driver.
The model formulation predict the updating of the position and the speed of the vehicles through the following equations:

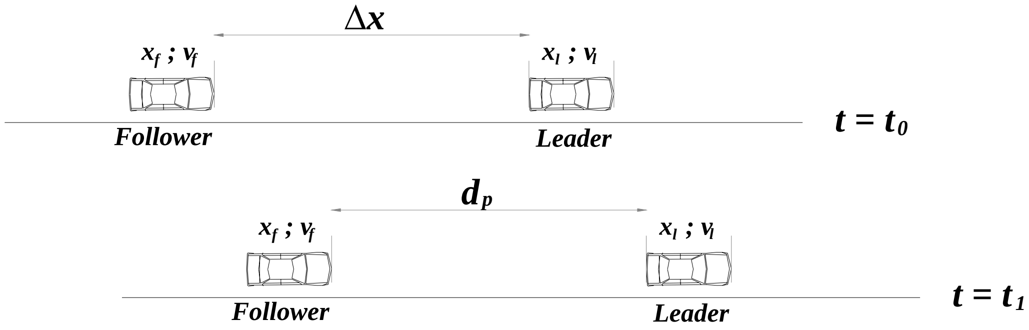
$$a_{t_1} = a_{t_0} + s \cdot T$$

$$V_{t_1} = \int_{t_0}^{t_1} a(t) \cdot dt = V_{t_0} + a_{t_0} \cdot T + 0.5 \cdot s \cdot T^2$$

$$x_{t_1} = \int_{t_0}^{t_1} V(t) \cdot dt = x_{t_0} + V_{t_0} \cdot T + 0.5 \cdot a_{t_0} \cdot T^2 + 0.167 \cdot s \cdot T^3$$

where
a = acceleration;
s = acceleration rate;
v = speed;
x = position;
t_1, t_0 = final and initial time of the considered step of simulation ($T = t_1 - t_0$).
Particularly the desired space to the time [$t_1 = t_0 + T$] is calculated through the procedure that follows:

Figure 2.5.: Schematic procedure of the car – following model.



to the time t_0 $V_f > V_l$; $\Delta x = (x_l - x_f)_{t0} - L_l$;

to the time t_1 the condition of stability is, instead, the following:

$V_f = V_l$; $d_P = (x_l - x_f)_{t1} - L_l$

where d_p is the desired space by the "follower" in the car-following condition. The two vehicle positions at t_1 are calculated in accord with the equations:

$$(x_l)_{t_1} = (x_l)_{t0} + V_l \cdot T + 0{,}5 \cdot a_l \cdot T^2;$$

$$(x_f)_{t_1} = (x_f)_{t0} + V_f \cdot T + 0{,}5 \cdot a_f \cdot T^2 + 0{,}167 \cdot s_f \cdot T^3$$

Deducting the first equation to the second it is drawn the expression that allows to calculate the desired space by the "follower"

$$(d_P)_{t_1} = \Delta x - \Delta V \cdot T - 0{,}5 \cdot \Delta a \cdot T^2 - 0{,}167 \cdot s_f \cdot T^3$$

in this equation, however the terms s_f and T are unknown; it need, therefore, further two equations to resolve the problem: the speed difference calculated to the time t_1 has to be zero

$$(\Delta V)_{t_1} = (\Delta V)_{t_0} + (\Delta a)_{t_0} \cdot T + 0{,}5 \cdot s_f \cdot T^2 = 0 \Rightarrow s_f = -\frac{2 \cdot \left[(\Delta V)_{t_0} + (\Delta a)_{t_0} \cdot T\right]}{T^2}$$

the desired space is:

$$(d_P)_{t_1} = (V_f)_{t_1} \cdot t_P = (V_l)_{t_1} \cdot t_P = \left[(V_l)_{t_0} + a_l \cdot T\right] \cdot t_P$$

replacing the expressions (7.15.) and (7.14.) in (7.13.) the principal equation is drawn of according to degree in the unknown T whose positive root, replaced in (7.14.), it will allow to calculate the acceleration rate of the "follower" and accordingly the desired space ***(d***$(d_p)t_1$.

2.3. The lane changing model

The study of the lane changing manoeuvres in the roundabouts start from the examination, even though schematic, of the reality driver behavior.

It is essential to individualize, first of all, the elementary behaviours that determine every trajectory to try to use a mathematical formalism (model) that reproducing them. The mutual connection among the model that reproduce the different drivers behaviours will allow to simulate the development of the manoeuvres in the roundabouts intersection: the generic vehicle enter in the circulatory roadway and crosses it up to the desired exit way. In this run, the vehicle that doesn't have necessity to go out to the first possible occasion, performs in succession, the following manoeuvres: the entry manoeuvre; the circulation along the external lane; exchange toward the inside lane; the circulation along the inside lane; exchange toward the external lane; the circulation along the external lane; the exit. In particular the observation of the vehicular circulation along roundabout allows to affirm that: the vehicle that enter in the *i* arm and that have to go out in that following (*i+1*) it doesn't effect any lane changing. It crosses the roundabout in the external lane up to reach own destination (trajectory in green in the figure). In the other situations the vehicle will have the tendency to go on the inside lane not to be conditioned from the manoeuvres of entry and exit in the roundabout; it will stay on this lane to return, to a certain distance from own destination, on the external lane to effect the manoeuvre of exit (trajectories in red and in blue in the figure).

Figure 2.6.: Trajectories followed by the circulating vehicles in the roundabouts

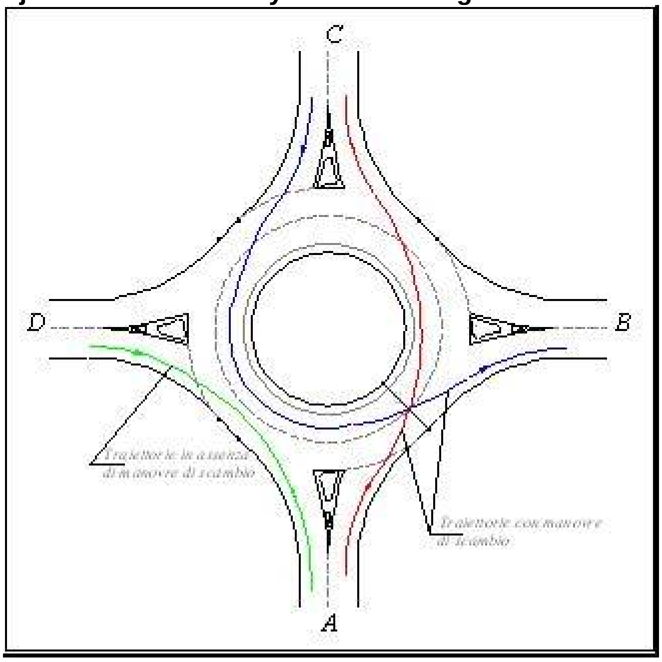
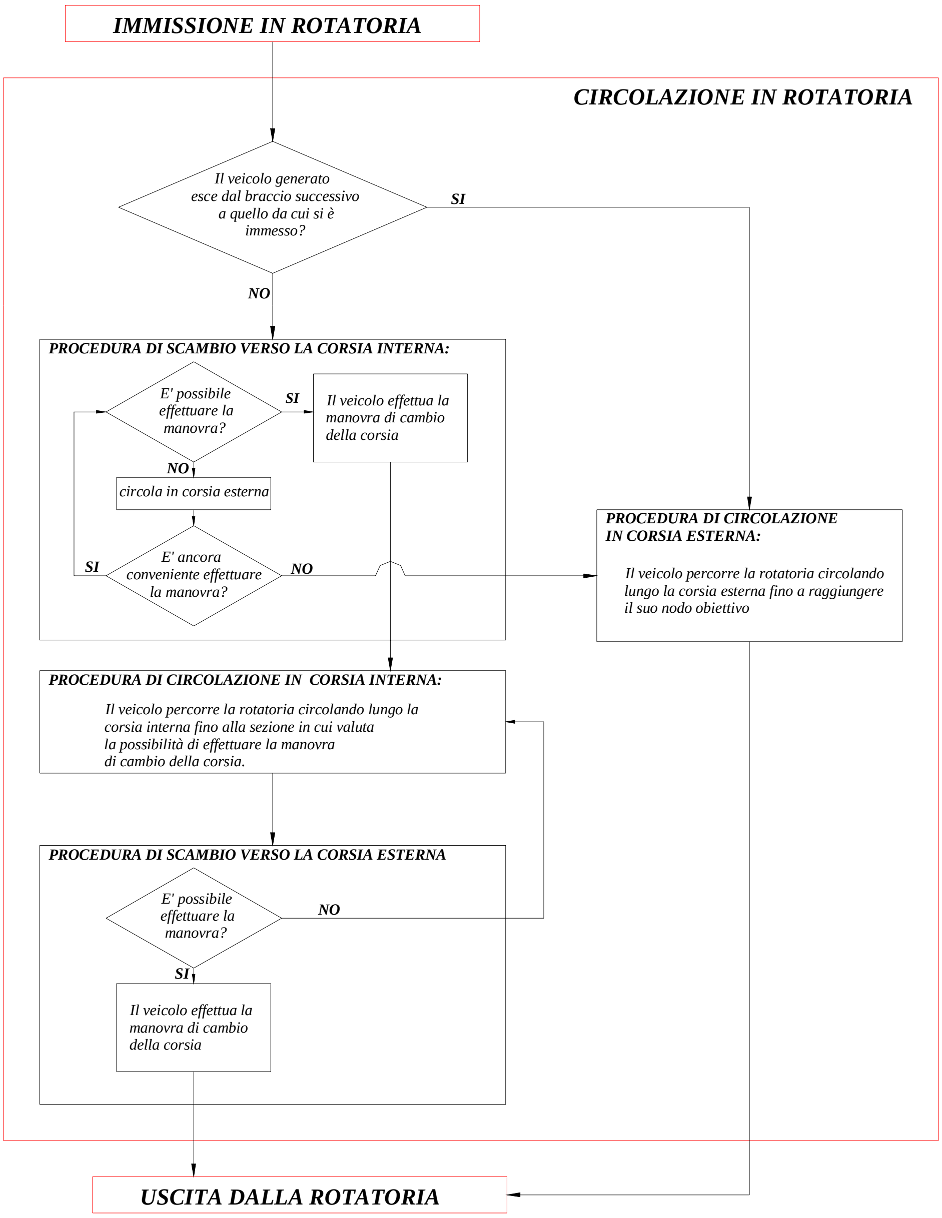


Figure 2.7.: Model circulation flow chart



In first approximation, a model of simulation has been implemented that checks the possibility of the lane changing maneuvers based on gap acceptance behavior with the relative speed among the vehicles that intend to effect the maneuver and those that circulate along the circulatory roadway. The experimental determination of critical gap interval doesn't result of easy realization: it is not possible, in fact, to know the time in which the driver decides to effect the maneuver. A technique used for the respect of such parameter implies, in fact, the knowledge of the accepted interval and of that maximum reject for every vehicle that intends to effect lane change. In other words, during the experimentation can be analyzed only that parameters related to the maneuver already carried out (accepted intervals).
It is possible to use the following formulation to determine critical gap time:

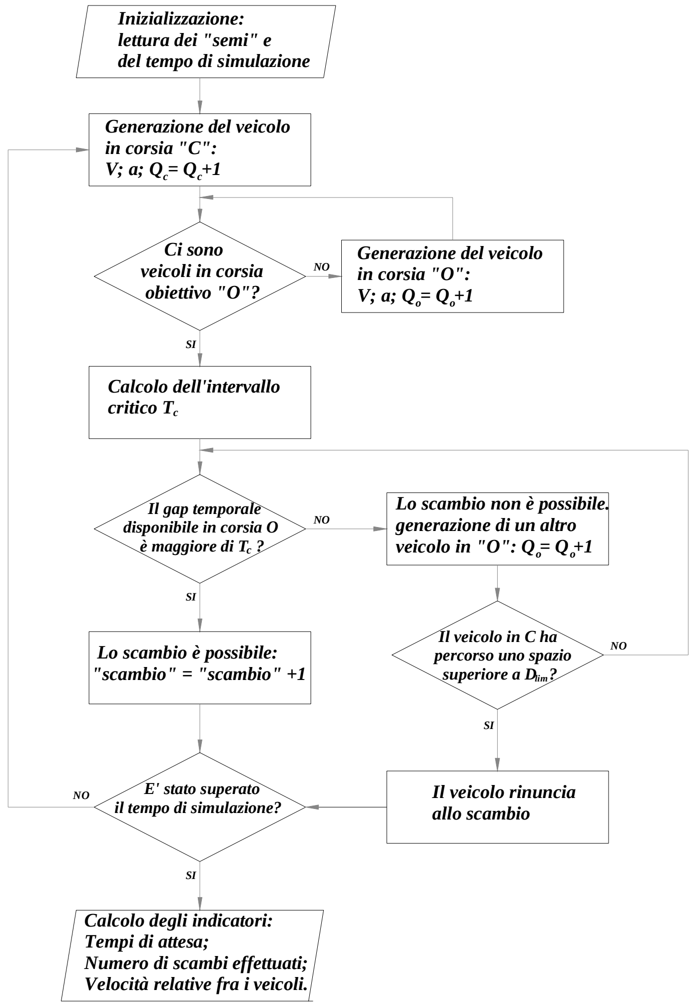
$$T_c = \frac{V_c - V_o}{2 \cdot a_c} + 2 \cdot \delta$$

where
V_c is the vehicle speed that intends to realize the maneuver;
V_o is the vehicles speed, hypothesized constant, that circulate along the ring road;
a_c is the vehicle acceleration in maneuver;
δ is the safety time distance among two vehicles of the objective lane, or destination lane (this distance is held equal to the perception and reaction time and is equal to around 1s).

The logic of the simulation process implies to determine the time of circulating vehicles arrival and those that, circulating on that adjacent lane, intends to change lane. The input data are of three types:
the time headway among the vehicles on the objective lane;
the time headway among the vehicles that have to change lane;
the kinematics parameters: speed and accelerations.
To every parameter it will correspond a distribution of probability experimentally determined [1].
In conclusion a vehicle will effect the lane change maneuver if along the destination lane a time gap greater than critical gap time is available. In the case in which this verification doesn't result satisfied the driver will try the maneuver to when he has crossed roundabout inclusive among two consecutive accesses.

2.4. The implemented lane changing model

The model has been implemented using a software program in Visual Basic (version 6.0) language. The different model phases can synthesize as it follows:
the simulation starts with the reading of the input data: integers numbers (seeds of generation) which corresponds a generation of pseudo-casual numbers and the time of simulation;
the of generation of a vehicle in the external lane "C". The vehicle is identified through its time of generation calculated t_{gen} adding instantly temporal t, related to the precedent step of simulation, the value of time headway *t* extracted by the cumulated distribution frequencies (Cdf) note from the experimental analysis. For every produced vehicle it is updated the Q_c variable that counts the number of vehicles that intends to change lane. Finally, to the produced vehicle, a value of speed and acceleration associates him (from normal Cdf with average and standard deviation known [1]) through which the critical interval T_c is calculated;
the possibility of the lane change maneuver checks, at first, the presence of vehicles on the objective lane *O*. If this verification doesn't result satisfied he proceeds, likewise to the lane "C", to the generation of the vehicles along the objective lane;
to this point, identified the follower and leader vehicles, the model checks if the lane changing is possible or less comparing the critical gap time to the vehicle in the lane "C" with that available on the destination lane "O". If the maneuver doesn't result possible the control will repeat up to when the vehicle has not crossed a line of roundabout inclusive among two consecutive accesses D_{lim}. Carried out the maneuver it is adjourned the variable "exchange" that it counts the number of the effected maneuvers;
last control is performed on the time of simulation. If the generation time is greater than simulation time the process of simulation stops and the model calculates some parameters that they point out the correspondence of it with the observed in the reality.
In the case of external lane change the simulation procedure is analogous to that just described. You will reverse however the destination lane with that objective. In the next figure we show the flow chart that exemplifies the simulation process described.



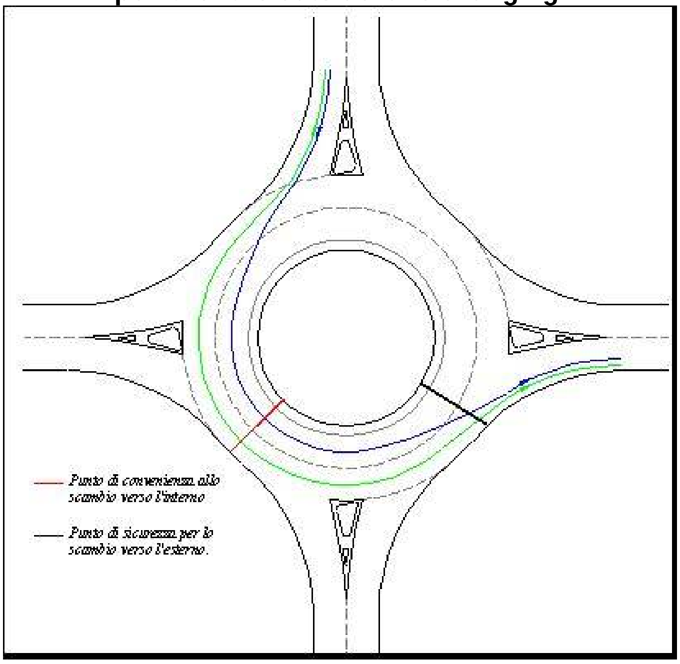
Simulating the lane changing maneuvers with the described model the behavioral characteristics of the single driver are not considered. The longitudinal interactions among consecutive vehicles (car-following process) are not analyzed. In the following paragraphs we will analyze a first attempt of resolution of such problems through the interaction between the car-following and lane changing process.
Before the lane changing maneuver the follower driver circulates adopting a distance from the vehicle that it precedes (leader) equal to desired speed; at the end of the maneuver this interval will result reduced and the car-following model also will calculate an emergency deceleration of the vehicle that follows. Under the real traffic conditions, however, there is not necessary an emergency braking but simply a gradual deceleration from the vehicle that follows for adjusting the lane change maneuver and, accordingly, to increase the distance with leader vehicle.
This trial produces an important connection between the lane changing model and the car-following model.

2.5. A new lane changing model

The model must be described answering, in sequence, to the two questions: whether and in this way to carry out maneuver.
In the internal lane change the driver is motivated from the alone desire to adjust your speed of the desired one. This motivation will be very greater as greater it is the difference of speed with the leader vehicle. The operation is called a discretionary lane change (DLC). When a lane change is required due to, for example, a lane drop, or to go out of the intersection to the arm of destination, the operation is called a mandatory lane change (MLC). Under these conditions the driver will check the possibility of exchange to a point that can be defined of convenience over which he will force to remain on the current lane up to the exit arm. The definition of this point of convenience to internal lane change can be critical for the model operation, but in this phase it is hypothesized that for the driver this section is positioned in the middle point among two consecutive accesses before exit arm (figure 2.9.).
This is congruent with the observed behavior: the driver that immediately goes out to the following arm to that of entrance doesn't exchange. If the driver has not changed the lane after the entry arm he will prepare

to cross the circular link of exit updating own speed to that a safety and “comfortable” deceleration proportional to maximum deceleration.
If the driver crosses in the inside lane close the exit arm it will have to try changing lane up to a section that can be defined safety point over which he can’t turn and he will complete another circle in the roundabout. Also the definition of this safety point can be critical for the model operation and, in this phase, it is hypothesized that this section is situated near of the exit line (figure 2.9.).

Figure 2.9.: Representation of the convenience section to the inside changing lane and the safety point for the outside lane changing.



The maneuvers of immission toward the inside lane happen under safety conditions checking the vehicle that precedes and what follows in the destination lane (left lane). Not having necessity to effect the maneuver, but only desire, the driver will control your current speed (Car-Following speed), without variations, to adjust your speed to that the destination lane with positive acceleration. Controls will be repeated up to the convenience point. The external lane change maneuver will happen in safety conditions checking the preceding vehicle and that following on the right lane (destination lane). The mechanisms of control and maneuver are identical to those described for the left change (to exception of the acceleration sign). But, remembering that the maneuver is not motivated only from desire but from necessity, in case of failure of the first attempt the driver will be induced to anticipate the maneuver of lane change making to transit the vehicles on his right up to find a distance among theirs that the maneuver can allow, in deceleration. To do this the following controls to the first one don’t happen to the current speed in the lane (what in this case can be the desired speed or C.F. speed) but a progressively lower speed (the vehicle slow down with the maximum rate deceleration) to look for the necessary space.
Following the different components of the proposed model will be analyzed:
the generation of the vehicles;
the vehicles speed;
the verification of feasibility of the lane change maneuver;
the trajectory of lane change.
To every step of the simulation program, in operation of the volume circulating, it occurs if in the two lanes there is or less a vehicle. To every vehicle it will be in join a vector of "parameters" through which the single vehicle can easily be identified during the lane changing simulation.
Operationally the generation of the vehicles develops through following the pseudo-casual number extractions, compared with the relative values of probability, they allow to verify the presence of a vehicle in the lane changing zone. Particularly, to every simulation step (0,5 seconds), two pseudo-casual numbers are extracted: C_1, C_2. If it occurs that:
$C_1 \le P_1$; or $[C_2 \le P_2]$
then a vehicle will be generated in the lane 1 [2]. Besides if it occurs that:
$C_1 \le F_{s1,2}$; $[C_2 \le F_{s2,1}]$
then the vehicle generated in the lane 1 [2] will have to change in the lane 2 [1].
To the action of the generation, for every vehicle, it is necessary to define the characteristic values for the maneuvers in the roundabout, what:

- the speed along the external lane (hypothesized equal to the desired speed);
- the speed along the inside lane;
- the maximum acceleration available;
- the minimum deceleration available;
- the action and reaction time;
- the time headway from the preceding vehicle.

The values of the descriptive statistic distributions of all these parameters are known from the carried out local experimentation [1]. The hypothesis is that they are all "linked" as general expression of the guide behavior of the single driver.

In this phase we have been select to make to derive all the parameters from a single casual extraction of a parameter defined principal that allows the definition of the others correlated. To define the logic of correlation is necessary to re-examine both the parameter distributions and the driver behavior that will extend to the desired speed in line with the circulation conditions. You observes that the desired speed it is also function of the environmental conditions (geometry, atmospheric conditions, etc.). Desired speeds are been defined as principal parameter and from them derive the remainders.

The casual extraction of a desired speed value by a normal distribution, with average and standard deviation known, defines the behavior of the single driver: he will be as weapon as extract speed value approach maximum experimental value. The speed on the inside lane will proportionally be more elevated in operation of the desired speed and drawn by a uniform distribution, with values minimum and maximum known, for scale change. Also the accelerations and the desire maximum decelerations are drawn through a correspondence with the desired speed. For these the minimum value is that correspondent to the 50° percentile of the experimental distributions.

Particularly we present below the principal variable, necessary to the simulation, what:

the *desired speed*: a driver, is able not to want to reach the limit of speed allowed him by possible conditions of free flow. The process of generation of the desired speeds is type pseudo-casual and reported to a function density of Normal probability of average equal to 25,8 Km/hs and standard deviation equal to 4,1 Km/hs (V_{max}=42,30 km/h; V_{min}=16,20 km/h). Extracting a random number V_i in an interval [0,1] from the cumulated frequencies distribution (Normal) we read the desired speed to associate to the single vehicle and characterizing the driver behavior;

the speed along the inside lane: from the value of the relationship

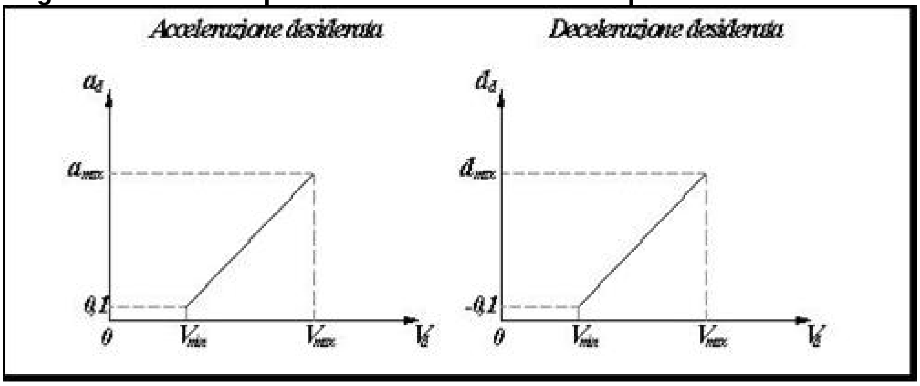
$$R = V_{d(estratta)} / V_{d(max)}$$

we determine the value of the speed on the inside lane

$$V_i = R \cdot V_{i(max)}$$

the acceleration and the desired maximum deceleration: those are hypothesized correlated to the desired speed. The user that driving with relatively low speed preserve your style of guide "moderate" varying a few the speed in the time unit; opposite, the user that driving with elevated speed will proportionally accept higher acceleration and deceleration values. The accelerations (positive and negative), measured under the same conditions of free flow, they result distribute as Normal variable of average equal to 0,07 m/s^2 and standard deviation equal to 0,5 m/s^2. Those last functions between desired speed and acceleration is brought in the next figure.

Figure 2.10.: Correspondence between desired speed and acceleration



$$a_d = \frac{a_{max} - 0{,}1}{V_{max} - V_{min}} \cdot (V_d - V_{min}) + 0{,}1$$

$$|d_d| = \frac{d_{max} - 0{,}1}{V_{max} - V_{min}} \cdot (V_d - V_{min}) + 0{,}1$$

the perception and reaction time and the headway time distance from the leader vehicle: those parameters are hypothesized correlated to the desired speed according to a relationship of inverse proportionality

$$T_{p,r} = T_{min} + T_{max} \cdot (1 - R); \qquad \Delta T = \Delta T_{min} + \Delta T_{max} \cdot (1 - R)$$

In conclusion to every vehicle produced in the exchange zone will be join the following vector of parameters:

Lane 1 (external) vehicle= $\{N_V ; t_g ; P(t_g); V_d ; a_d ; d_d ; L_V\}$

Lane 2 (internal) vehicle= $\{N_V ; t_g ; P(t_g); V_d ; a_d ; d_d ; L_V\}$

where

N_v is a progressive number that identifies the vehicles in the two lane;

t_g is the time in which the vehicle has been generated;

$P(t_g)=[r(t),\Theta(t)]$ is the position of the vehicle to the time t_g;

F_s is the binary variable that points out if the vehicle has to effect (1) or less (0) the lane change.

Under free flow circulation conditions a driver moves with own desired speed function of the geometric characteristics of the roundabout and your degree of aggressiveness. However if the same driver is preceded by another vehicle it will circulate adapting your speed in comparison with leader calculated through the formulation of proposed Car – Following Model. It needs, therefore, to individualize the limit distance (D_{lim}) below which the follower vehicle beginnings to be influenced by preceding:

$$V(n, t + T) = V_b(n, t + T) \quad \text{if} \quad D < D_{lim}$$

$$V(n, t + T) = V_{desiderata} \quad \text{if} \quad D \geq D_{lim}$$

where D is the current distance between two consecutive vehicles and $D_{lim} = \frac{2\pi R}{4}$.

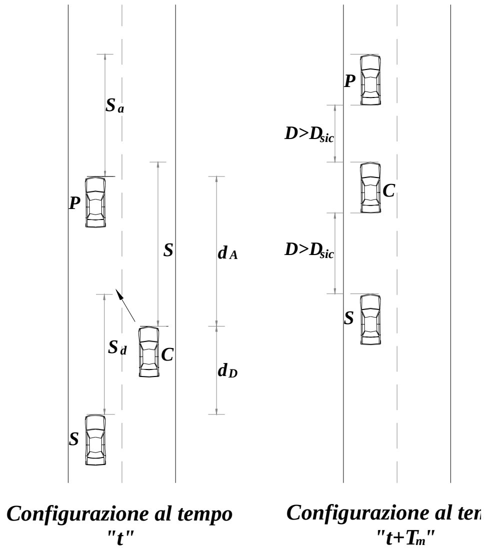
The feasibility of the lane changing manoeuvre has been valued comparing the deceleration (d_c) imposed by the vehicle "P" that it precedes in objective lane to the vehicle "C" in manoeuvre and that (d_s) imposed by this last to the vehicle "S" that it follows with the desired decelerations by the vehicles "C" and "S" respectively.

The vehicle "C", therefore it will effect the lane change manoeuvre if, having found a safety distance between vehicles, results verify the following inequalities:

$$d_c = \frac{V_c(t + T) - V_c(t)}{T} \geq d_d(c)$$

$$d_s = \frac{V_s(t + T) - V_s(t)}{T} \geq d_d(s)$$

Figure 2.11.: Initial and final vehicle configuration in lane changing manoeuvre.



Verified the possibility of lane changing execution it has been necessary to know the trajectory followed by the vehicles. The performed experimental observation, has addressed the choice toward a sine curve characterized by the following equations:

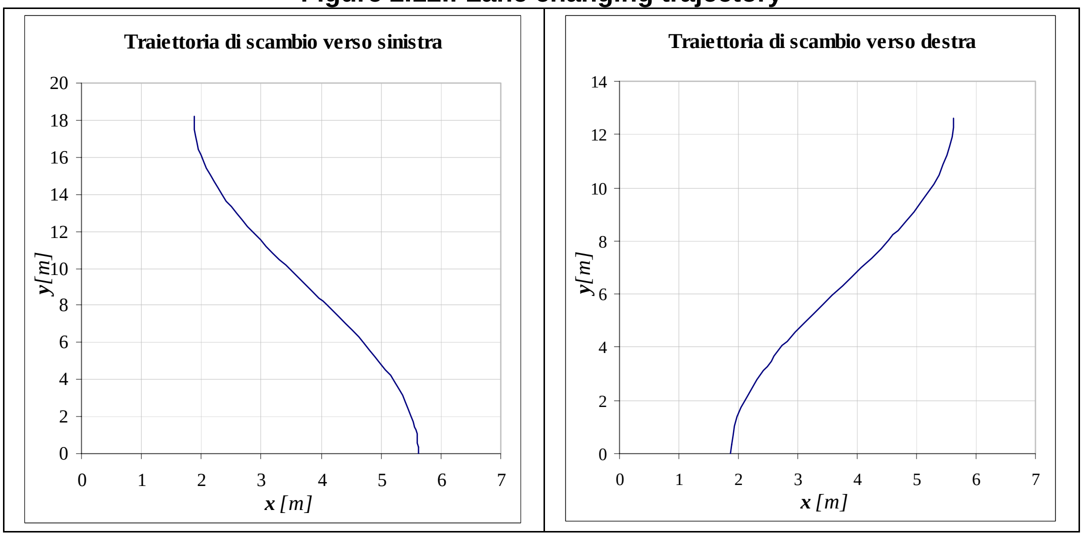
$$y = y_0 + v \cdot t$$

$$x = x_0 \pm sen\left[\left(\frac{t}{T_m} \cdot \pi\right) - \frac{\pi}{2}\right] \cdot \frac{c}{2} \pm \frac{c}{2}$$

to use with the first sign (+) for the exchange toward right manoeuvres and with the second sign (-) for those toward left. The used symbols point out:

x_0, y_0: the initial position of the vehicle in manoeuvre;
v: the speed of the vehicle to the time t;
T_m: the necessary time to perform the manoeuvre;
c: the lane width.

Figure 2.12.: Lane changing trajectory



3. SIMULATION PROCESS

In this paragraph the logical trial is described through which the manoeuvres in the roundabouts. The operation of the simulation model is type "Step-by-Step": it analyzes the configuration of the roundabouts for following time intervals (steps) and it is characterized by the succession of the following operations: data entry, analysis and results.

The data entry is composed from the geometric and flow conditions. The necessary geometric data to the model operation are:

R: the inscribed circle radius;
c: the circulatory roadway width;

α : the angle formed by the lines connects the centre of the roundabouts with the inside edges of the islands divider of two consecutive accesses;
As it regards the data related to the flow conditions it is necessary to know:
Q_i: the circulating direct volume around two lanes;
$Q_{s\ 1,2}$; $Q_{s\ 2,1}$: the volumes of exchange.
The analysis phase regards the application and controls realized through simulation process implemented connecting the behavior model schematized in the previous paragraphs:
the generation vehicles;
the lanes position control;
the trajectory and speed vehicles control;
the updating lanes vehicle configuration.

4. RESULTS

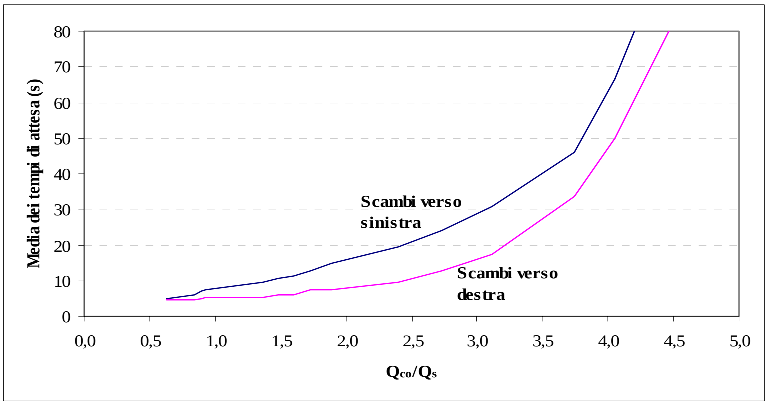
The results of the model implementation are the followings: for the lane changing manoeuvre founded on the critical interval concept of are the followings:
for a first verification around the correspondence of the model to the observed reality the distributions of frequency are proposed related to the speed differences calculated between the lane changing vehicle and the follower in the objective lane (V_{lag}). The comparison among the parameters of dispersion (average and standard deviation) of the experimental frequency distributions and the model distribution are brought in the following table:

Tab. 4.1.: Comparison of the dispersion values of the ΔV_{lag}

	Sperimentazione		*Simulazione*	
	Villaricca	Foggia 1	Villaricca	Foggia 1
pdf	Normale	Normale	Normale	Normale
media	2,67	2,38	2,44	2,21
dev.std.	4,09	4,31	6,09	5,9

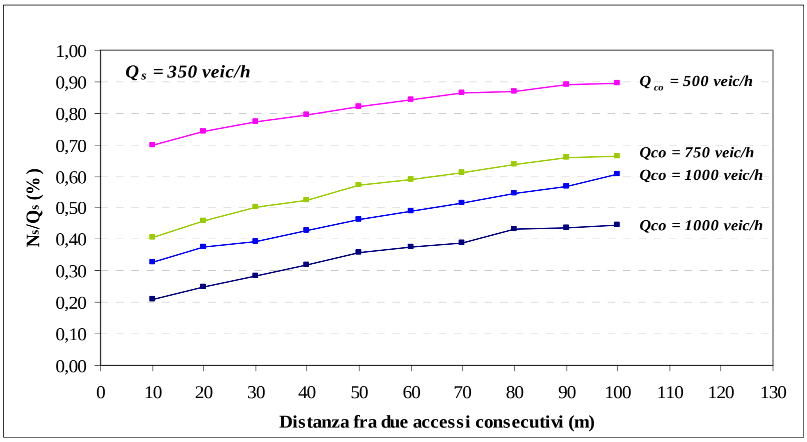
Subsequently the variation of the mean waiting time has been analyzed related to the two typologies of manoeuvre of exchange (toward left and toward right) in operation of the relationship among the vehicular volume on the destination lane (Q_{co}) and the volume of the exchange (Q_s). From the figure 4.1. are noticed as the two curves is increasing to increase volumes on the destination lane. The waiting time for the right lane change are lower in comparison to those left lane changing to confirmation of the different motivation that induces the drivers to effect the two types of manoeuvres.

Figure 4.2.: Average waiting time variation



We are also investigated on the variation of the manoeuvre vehicles number compared to the lane changing volume (N_s/Q_s) related to the distance between two consecutive accesses (D) and of the vehicular volume in the destination lane. The vehicular volume in the destination lane results to be the parameter that mostly influences the possibility of the lane changing manoeuvres. In fact, to parity of vehicular volume circulating (Q_{co}), widening the distance between two consecutive accesses from 20 to 80 meters, the percentage of succeeded manoeuvres increases of around the fifteen percent. Opposite, fixing the distance D, for a vehicular volume in the destination lane that varies from 1250 to 500 veic/hs, the percentage of manoeuvres of lane changing results increases of around the forty percent. Nevertheless, not to consider the relative position between two roundabout arms is an error, infact, it determines the so-called zones of exchange, that, as it is deduced by the simulation, they have an important relief in to determine the quality of the circulation in the roundabout together whit the other factors.

Figure 4.3.: Variation of the number of left lane changing in operation of the distance between two consecutive accesses



CONCLUSION

The final result of the present search can synthesize in the determination of a simulation program to roundabout in the Naples, characterized by an architecture modular able to schematize the whole the circulation behaviors guide in, as noticed from a careful country of experimental investigations.
A further characteristic of the final product of the present search is that to be able to be considered flexible. In other words it is possible to make to vary the variables and to get a program that simulates the circulation of a different intersection: we think about the variation of the principal geometric variables (central island radius, inscribed circle diameter, circulatory roadway width, entry width, exit and entry radius, etc.), but also to the introduction of further functions of measured and measurable experimentally behavioral parameters (distribution of critical gap times; distribution of the speeds and accelerations, etc.).
The reproductive ability of the phenomenon also in one or more different configurations from that of Villaricca it will allow to generalize the program to the various geometric - behavioral contexts. What constitutes the realization of a further phase of verification, defined of validation of the circulation model for which it is necessary to intensify the activity of experimental analysis, individualizing others roundabouts, it will allow to determine the final and ambitious product of the search: the determination of a program, modular and flexible, to reproduce the reality of behavior in the non signalized intersections, for such reason, usable in the planning phase and/or in management phase, seeking the condition of optimal circulation in the respect of the level of service of the arteries that meets in the intersection. In conclusion we reported simulation process, with typical form in Visual Basic (Ver. 6.0) and the calibration results.

Tab. 5.1.: Relived O/D Matrix

O/D (veic/h)	1	2	3	4
1	0	420	708	72
2	198	0	330	182
3	900	300	0	450
4	483	132	195	0

Tab. 5.2.: Simulated O/D Matrix

O/D (veic/h)	1	2	3	4
1	0	400	718	82
2	140	0	370	200
3	908	270	0	477
4	400	202	190	0

Figure 5.1.: User Form in simulation process of Roundabout in Villaricca (Naples)

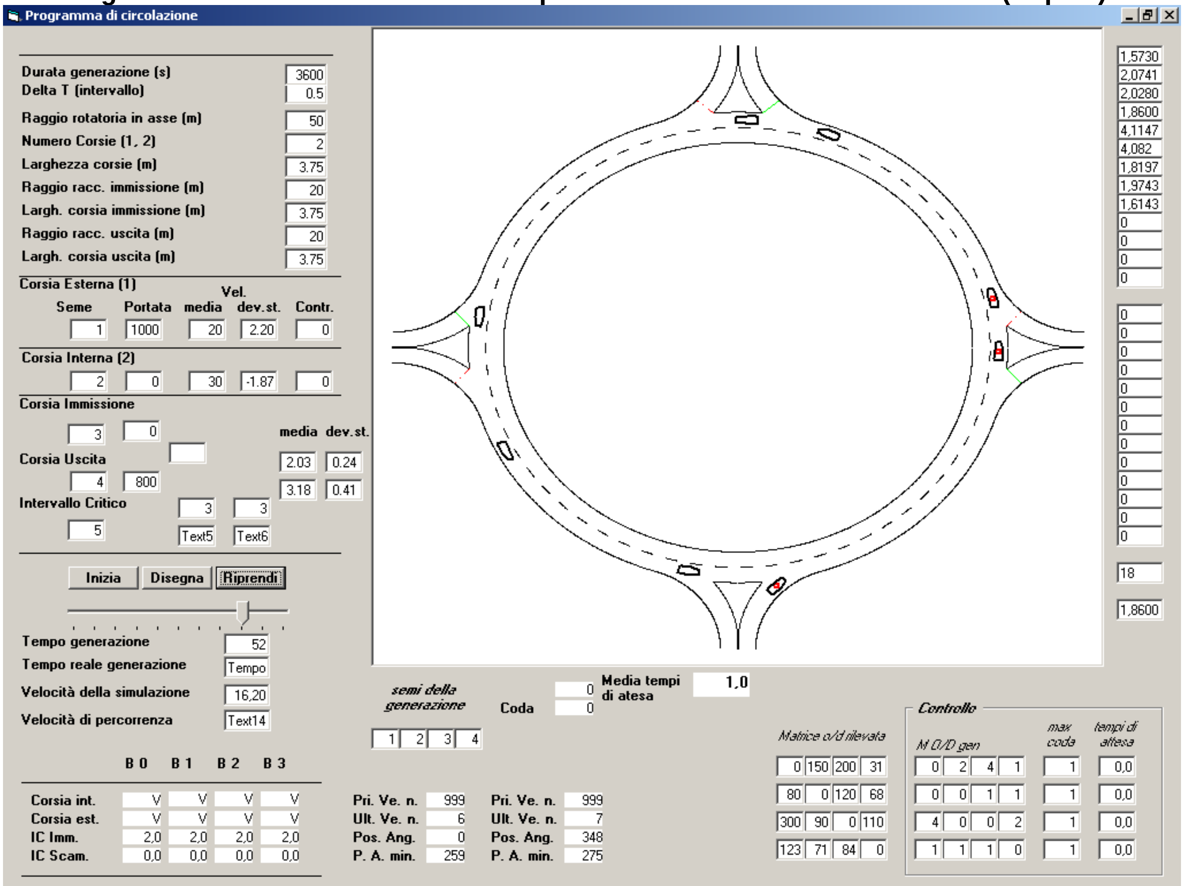


Figure 5.2.: Comparison among the middle waiting times in the entry volume

<table>
<tr><th>Arm</th><th>Relieved (min.)</th><th>Simulation results (min.)</th><th>Variations (%)</th><th>Middle Value(%)</th></tr>
<tr><td>1</td><td>1,7</td><td>2,4</td><td>17</td><td rowspan="4">17,5</td></tr>
<tr><td>2</td><td>5,8</td><td>6,9</td><td>25</td></tr>
<tr><td>3</td><td>1,2</td><td>0,8</td><td>13</td></tr>
<tr><td>4</td><td>4,7</td><td>6,4</td><td>15</td></tr>
</table>

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