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SAFETY EVALUATION OF TURBO ROUNDABOUT CONSIDERING AUTONOMOUS VEHICLES OPERATION

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A microsimulation approach was carried out in this paper to evaluate the safety performance of turbo roundabouts in which the "CAVs" of connected autonomous vehicles are mixed with the "CVs" of conventional vehicles the research aims to evaluate the advantages in terms of safety and performance of turbo roundabouts. The paper shall also lead to describe the methodological path followed to build VISSIM models of turbo roundabout changing O-D matrix as real case applications, to calibrate the simulation models, and to estimate the potential conflicts when the percentages of CAVs are introduced into the traffic mix. The results, in accordance with the existing bibliography, have shown that the safety levels and the parameters that determine an improvement in the service level in a turbo roundabouts are significantly influenced not only by the geometric characteristics, but also by the distribution of vehicular flows. Therefore, it follows that in absence of crash data including CAVs, the surrogate measures of safety must be considered a strong approach to evaluate the safety performance of a roundabout so far, any road entity.

Keywords: turbo-roundabouts, surrogate measures, traffic conflicts

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1 INTRODUCTION

The paper presents a microsimulation approach for assessing the safety performance of turbo-roundabouts where Connected Autonomous Vehicles "CAVs" are mixed with conventional vehicles "CVs". Based on the analysis of vehicle trajectories from Blumenthal (1968) [1], the find of a more recent bibliography [2] [3] [4] has underlined the usefulness of adopting a general Systems Theory as an approach to the scientific and methodological study of "traffic safety". According to the Systems Theory introduced by Von Bertalanffy [5], traffic can be considered as an "open system". This perspective can be applied to describe and explain the main properties, the hierarchical structure and the set of dynamic and interactive processes that altogether form the traffic system. Systems Theory also constitutes a tool for the detailed systematic analysis and identification of properties and mechanisms, such as "the emergency", that exist as a result of the interconnectivity and relationships between the system components at different structural levels.
The results of this research would provide indications regarding:

- Impact of technology on traffic flow and operations;
- Rules on the use of technology;
- Further research on autonomous and semi-autonomous technology.

The approach used to model traffic simulations allows two different types of analysis: simulation, which consists in observing how the model behaves if stimulated by particular conditions without these necessarily having to happen in reality (for example, the temporary closure of a lane of a road section);
Forecasting, i.e. a tool that allows you to formulate transport demand forecasts for future scenarios in the context of transport planning; this type of analysis requires continuous monitoring of vehicle traffic conditions in order to draw important indications regarding its possible evolution in the short future.
Traffic analysis and simulation models allow:

1. reducing cost: experiments carried out directly on the real system can be very expensive. A simulation study, on the other hand, drastically reduces costs because it allows to evaluate in advance the economic consequences linked to the assumed management choices, often linked to many factors that cannot be easily evaluated. It is therefore possible to identify errors before they are committed, thus avoiding costs generated by non-optimal choices;
2. greater understanding of the phenomenon and repeatability: in reality, it is impossible to experiment the system more than once without there being variations in the initial parameters. In a

simulation, instead, the same sequence of events can be repeated under the same initial conditions but starting from different inputs: the results of the same problem are this way directly comparable and therefore allow to select the optimal solution. Furthermore, the experiment being repeatable, allows more chances to collect data, unlike the real case;

3. time reduction: the execution of an experiment on a real system can take a long time while the simulation requires a shorter period to obtain the same results;
4. risk reduction for the most innovative ideas: many times, for fear of failure, too innovative ideas (the riskiest) are not even tried. With simulation, all this is made possible given the low risk, thus encouraging innovations and improvements. Being able to dynamically study a system without really disturbing it offers the opportunity to test the hypothesized management choices safely and at low cost.

2 GOALS OF RESEARCH

Blumenthal (1968) [1] the discovery of the most recent bibliography stressed the usefulness of adopting a general systems theory as a scientific and methodological approach for the study of "road safety". According to the Systems Theory introduced by Von Bertalanffy [5], traffic can be considered as an "open system".

Taking advantage of the aforementioned theory, this research will try to find the traffic conditions that determine the maximum performance if the vehicle flow is composed simultaneously of conventional vehicles (CV) and connective and autonomous vehicles (CAVs) 75% and 25% respectively. For this it was analyzed, the impact that CAVs technology determines on vehicle flow and on any change in the performance level of turbo-roundabouts will be analyse, checking the variations that this technology determines on the safety levels.

The approach used for traffic simulation modelling allows two different types of analysis [6]:

Simulation, which consists in observing how the model behaves if stimulated by particular conditions without these necessarily having to happen in reality (for example, the temporary closure of a lane of a road section);

The approach used by traffic analysis and simulation models allows to reduce the costs and times of validation of the models. A simulation study, on the other hand, drastically reduces costs because it allows to evaluate in advance the economic consequences linked to the assumed management choices, often linked to many factors that cannot be easily evaluated. It is therefore possible to identify errors before they are committed, avoid costs generated by non-optimal choices and reduce processing times.

Many times, the risk reduction that comes from innovative ideas is not achieved due to the fear of failure, and those ideas that are too innovative (the most risky ones) are not even experimented. With simulation, all this is made possible given the low risk, thus encouraging innovations and improvements.

The power of dynamically study a system without disturbing it offers the opportunity to test the assumed management choices safely and at low cost.

The simulation of a transport system can be done with the use of various models, both as regards their nature and for the results they allow to obtain. Thanks to specific guidelines published by the Federal Highway Administration (FHWA, Traffic Analysis Toolbox Volume II) [7] they can be grouped in: macroscopic models; microscopic models; mesoscopic models.

Macroscopic models are usually continuous in time and space, and they are based on equations that take into account the average quantity of properties such as vehicle density and average flows.

Micro-simulation models reproduce the motion of individual vehicles, giving information on flows, tail lengths, travel times, speeds, and number of stops.

Mesoscopic or mixed models focus their attention on the behaviour of sets of users, and the outputs that are obtained refer precisely to these groups and not to individual vehicles.

In this study a micro-simulation model has been adopted, along with a psycho-physiological approach based on the study of the human behaviour. This approach is based on Wiedemann's model of psychophysical perception and its consequent Car-Following and Lane-Changing logics.

One of the main debates about microscopic vehicle flow models concerns their level of abstraction to represent the real phenomenon, in relation to the purpose for which they must be integrated. Beyond that, it is possible to define some basic behaviours that should be well represented in order for the model to be coherent enough with reality.

As is often reported in the literature [8], the determination of the number of run "R" in microsimulation is of fundamental importance, as it allows to take into account the variation of driving behavior of users in traffic conditions (instantaneous speed, queue length, number of stop, etc.). This consideration derives from the fact that the vehicles are inserted into the network in a random way following different dynamics to each simulation, as happens in reality. To this end, in order to obtain a more precise precision in the estimation of the results, it needs to increase the number of R [8]. The first step in assessing the reliability of the model and possibly proceeding with the calibration of the same is the determination of the minimum number of R to be carried out on which results base the verification.

Based on what is proposed To determine the minimum number of R, Federal Highway Administration guidelines [9], also taken as a reference by the Virginia Transportation Research Council, were used in this research."

The minimum number of simulations is estimated by an iterative process, in which a first set of simulations is assumed, which will then determine the average value of the variable and the relative standard deviation. These last parameters are used to estimate the minimum number of repetitions as shown in the equation below.

$$s^2 = \frac{\sum(x - \bar{x})}{N - 1} \tag{2.1}$$

$$CI_{1-a\%} = 2 \cdot t_{(1-a/2),N-1} \cdot \frac{s}{\sqrt{N}} \tag{2.2}$$

Below is shown the procedure to estimate R.

As a first hypothesis it is considered:

N = number of initial runs hypothesized;

x = variable of the model for which the sample variable is required;

$\bar{x}$ = arithmetic average;

s = standard deviation;

$CI_{1-a\%}$=interval of confidence, that is, the range of values within which the real average value can reside. The size of the interval is at the discretion of the analyst and may vary according to the purposes for which the results will be used.

$t_{(1-a/2),N-1}$ =represents the quantile of the T-Student distribution, it is set according to the value of a and the number of runs R.

Considering the turbo-roundabout having the following design parameters" use "Turbo-roundabout, considered for this paper, has the following design elements: outer diameter 40.00 m; width of traffic lane on the main road east-west 3.50 m; Width of the traffic lane on the secondary road north-south 3.00 m; width of the circulatory roadway 7.00 m.

Considering the Origin - Destination matrix that best approximates the distribution of traffic in the case where two road infrastructures of different levels intersect

Table 1. It will not take into account the maneuvers of come-backs, linked to errors of travel, when this maneuver is linked to a very low percentage of turning that does not influence the final result.

Table 1. O/D Matrix

	a	**b**	**c**	**d**
a	0.00	0.15	0.70	0.15
b	0.45	0.00	0.45	0.10
c	0.70	0.15	0.00	0.15
d	0.45	0.10	0.45	0.00

Taking into account as variables: the average speed in the input section of the legs A, B, C and D; the average duration of queue in the entry section of the legs A, B, C and D. Then, assuming an initial number of R * runs equal to 12, the mean values of the variables for each run and the relative standard deviation are determined by means of a PTV-VISSIM Table 2.

It is possible to see in the Table 2. that: setting the ratio between the "CI" confidence interval and the "DS" standard deviation equal to 1.5; considering a desired 95% confidence, the calculated value is obtained CI calculated using the (Equation (2.2)), therefore the value of N° run assumed initially can be considered statistically exact. It follows that on all the schemes considered 12 runs will be performed and the final result will be linked to the average values of the variables considered.

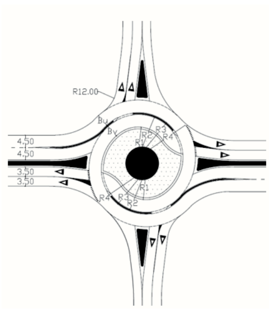
Table 2. Determination of minimum number of simulation

	Section	N° run	Ave. Value	S. Deviation		$t_{(1-a),R-1}$	$CI_{ipotesis}$=S*1.5	$CI_{calculated}$	CI_{ipot}>CI_{calc}
T_queue [s]	A1	12.00	13.44	3.23	95.00%	1.796	4.85	3.35	TRUE
	B1		107.13	10.91			16.36	11.31	TRUE
	C1		10.66	3.51			5.27	3.64	TRUE
	D1		95.51	7.33			11.00	7.60	TRUE
speed [km/h]	A1		19.21	0.58			0.88	0.61	TRUE
	B1		8.93	0.80			1.20	0.83	TRUE
	C1		19.59	0.78			1.17	0.81	TRUE
	D1		10.32	0.81			1.21	0.84	TRUE

3 CALIBRATION OF CV TO THE TURBO ROUNDABOUT MODEL

The calibration process applied consists in reporting the traffic conditions of the turbo-roundabout in VISSIM [10] using the predefined parameters. Vehicle traffic flows were assigned by all entries; it was assumed that the eastbound approach was the subject entrance for observing the capacity of each access lane. Therefore, the O / D matrices were assigned to the roundabout built in a virtual environment with due consideration of the direction of turn, in order to reproduce a circulating flow (facing the subject's entrance) from 0 veh / h to 1,400 veh / h, with a step of 200 veh / h. A saturated condition has been reached in each entrance lane; the corresponding maximum number of vehicles approaching the roundabout indicated the capacity of the entrance lane. The layout of the turbo roundabout model is shown in Fig. 1, where priority was given to approaching traffic from the left. Priority rules have been established to model the right of way and reduce the opportunities for collisions between cornering vehicles.

According to the schemes of conflict at entries, it is established that in both the left and right lanes, the flow in conflict refers to a single lane in the ring, therefore for both lanes of entry the estimate of the capacity has been carried out considering the Equation (3.1) of Hagring's theory, operating according to how right-handed for single roundabout



Element	Normal
R1	11.00
R2	15.60
R3	16.30
R4	20.80
r 1	11.00
r 2	15.60
r 4	16.30
r 4	20.80
Bv	4,60
Bu	4,60
bv	4,60
bu	4,60
Dv	4,60
Du	4,60

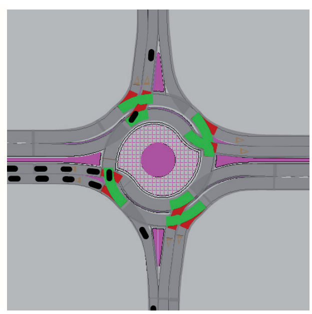


Fig. 1. layout of the turbo roundabout

According to the schemes of conflict at entries, it is established that in both the left and right lanes, the flow in conflict refers to a single lane in the ring, therefore for both lanes of entry the estimate of the capacity has been carried out considering the equation (3.1)

$$Q_i = Q_{c,i} \cdot \left(1 - \frac{\Delta \cdot Q_{c,i}}{3600}\right) \cdot \frac{e^{\left[-\frac{Q_{C,i}}{3600}(T_c - \Delta)\right]}}{1 - e^{\left[-\frac{Q_{C,i}}{3600} T_f\right]}} = \left[\frac{veh}{h}\right] \qquad i = a, b, c, d \tag{3.1}$$

of Hagring's theory, operating according to how right-handed for single roundabout wools.

Therefore by varying the calibration parameters of the Wiedemann 74 until the capacity deriving from equation (3) and leaving the VISSIM determines a GEH [11] greater than 85%. This index is a global indicator widely used in practice for the validation of traffic simulation models, especially when only aggregate values such as traffic flow counts in time-based detection stations and input capacity are available [12].

The results of the sensitivity analyses and manual calibration are shown in Table 3

Table 3. Default and set values of parameters used in manual calibration for the turbo roundabout

VISSIM Parameters W74	*Default values*	*Set Value*
Average Standstill Distance	2,00	1,20
Additive Part Of Desired Safety distance	2,00	1,80
Multiplicative Part Of Desired distance	3,00	3,60

4 Carfollowing model Calibration “Wiedemann 99” for CAVs operation

To be able to model as faithfully as possible, the behavioural model of the CAVs when they interact with all the users present in a network, it was decided to use the preloaded car-following model W99 in VISSIM, modifying it in order to adapted to the technical characteristics of driving an CAVs.

- CC0 is the front-to-rear spacing between stationary vehicles. In the case of classis vehicles, this parameter assumes an average value of 1.2 m (as per calibration) but in the case of CAVs it can be set to 1.00m when the magnetic or ultrasonic sensors on the market guarantee high efficiency and determine a risk of minimal contact due to distances between 1.00 and 1.5 m.
- CC1 is the time gap that a following vehicle wants to keep behind the lead vehicle. In the case of CV the differences in the front-to-rear time gaps of cars and heavy vehicles are illustrated by Durrani et al [13] in Fig. 2. For each 5-km/h speed interval of the following vehicle speed, the mean gap was computed. The curves on **Błąd! Nie można odnaleźć źródła odwołania.** are local polynomial regression which was fit to the observed data for each vehicle following case. For all cases, the gap was generally longer at very low speeds and decreased as the speed of the following vehicle increased. These values were 1.5, 2.7 and 1.2 s for cars, heavy vehicles and motorcycles, respectively. In the case of CAVs, the LIDAR sensors allow to keep

this distance constant regardless of the type of vehicle that follows and their speed, therefore, in agreement with the bibliography you have chosen to set this parameter to 0.5s.

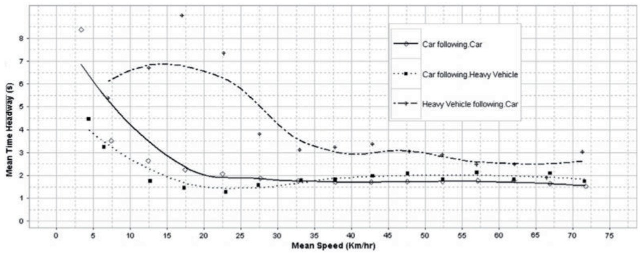


Fig. 2. Comparison of time gaps among different vehicle-following cases.

- CC2 is the spacing that the following vehicle keeps in addition to the minimum safety distance before it intentionally accelerates. This additional safety distance (X) for the CVs was estimated based on the spacing between two vehicles during the unconscious following process. Menneni et al. [14] estimated it as the difference between maximum and minimum spacing on the oscillation loop in the relative speed-spacing plot (i.e., unconscious following process) as shown in (Fig. 3). The distribution of X for each vehicle-following case is shown in (Fig. 4). The figure suggests that there were large variations in these additional distances for each vehicle-following case. The dashed line shows the mean value. This mean distances in addition to safety distance for cars, heavy vehicles and motorcycles are 11.6 m, 14 m and 9.1 m, respectively [13]. The mean value of X can be considered smaller for the CAVs case than the cases indicated above. This is because the CAVs, thanks to its sensors, are attention and conscious at 100% when they follow vehicles. Furthermore, they are able to maintain constant speed and distance avoiding the typical oscillations of the CVs. In function of this consideration the parameter X, for the CAVs, has been set to 1m.

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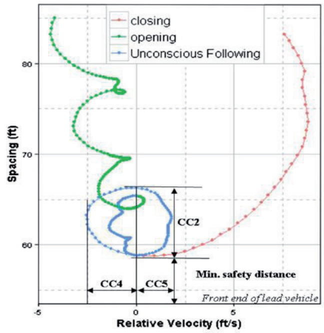


Fig. 3. CC2, CC4 and CC5 parameters from vehicle trajectory data

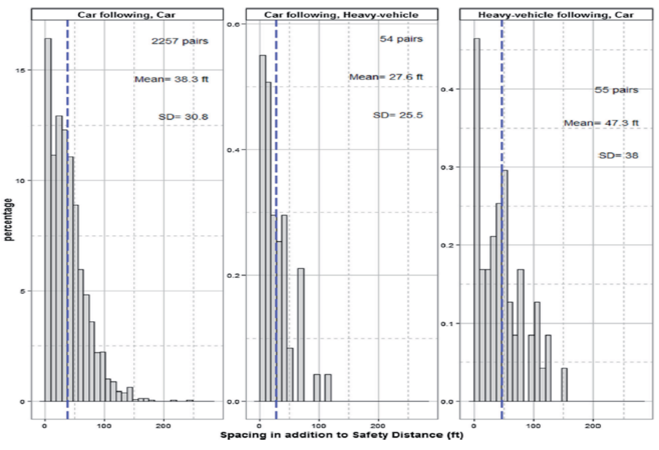


Fig. 4. Comparison of spacing in addition to safety distance among different vehicle-following cases

- CC3 is a measure of number of seconds before reaching the safety distance when a vehicle starts decelerating while perceiving a slower vehicle ahead. It was estimated for each vehicle pair based on the duration of the closing process. It was assumed that the closing process starts when the deceleration is less than or equal to -0.31 m/s2. (Fig. 5) shows the distributions of duration of the closing process for each vehicle-following case. Higher mean values of CC3 for the heavy vehicles case than the CVs case suggest that the following heavy vehicle drivers recognize slow-moving lead cars and decelerate sooner than the following car drivers. This is because heavy vehicle drivers' sight distance is longer than car drivers' due to higher position of driver's seat. Similarly, higher mean values of CC3 for the heavy vehicles case than the CVs case indicate that the following car drivers recognize the lead heavy vehicles sooner than the lead cars because of larger size of heavy vehicles than cars. On average, car drivers start decelerating for about 6 and 4 s before reaching the minimum safety distance behind the lead heavy vehicle and the lead car, respectively (i.e., when the unconscious following process starts). The estimated values of CC3 for cars, heavy vehicles and motorcycles are 4.00, 4.55 and 4.20 s, respectively.

- CC3 in the case of CAVs equipped with Lidar sensors, CACC, breaking emerging systems, allow to recognize the vehicles that precede them regardless of their size and speed, therefore, the CAVs allow a quick recognition of all users present in its trajectory, starting the deceleration process at a greater distance. In the case of CAVs this parameter has been set equal to -6s.

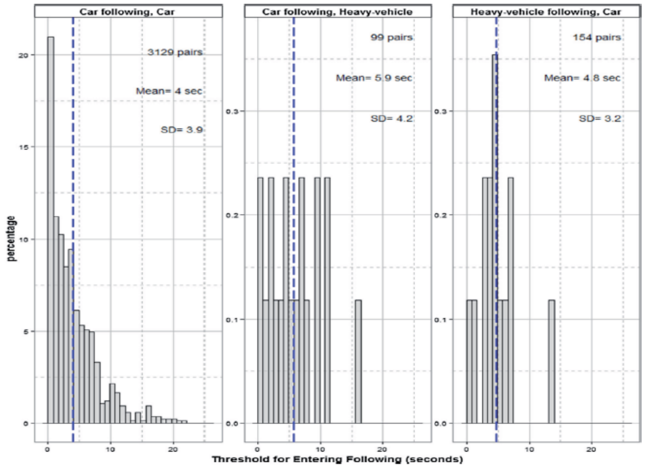


Fig. 5. Comparison of duration of the closing process among different vehicle-following cases

- CC4 and CC5 control the variation in relative velocity around zero during the unconscious following process. Because positive relative velocity could not be identified for some vehicle pairs, the absolute value of negative relative velocity was assumed to be values of both CC4 and CC5. The estimated absolute values of relative velocity are 1.65 m/s, 2.07 m/s and 1.86 m/s for cars, heavy vehicles and motorcycles, respectively. For the CAVs the variation in relative velocity between two vehicles not change it does not change much because in this type of vehicles the acceleration and deceleration process typical of a human driver is lost, this because the motion sensors of which the CAVs are equipped, like the CACC, estimates the speed of the vehicle that follows determines the distance and in the case of queuing maintains these two variables constant over time. For this reason the parameters CC4 and CC5 for the CAVs have been set equal to 0.1.

- CC6 represents how the following vehicle's speed oscillation varies as the distance to the lead vehicle changes. However, although CC6 is used to estimate CLDV and OPDV in a mathematical function [15], no study has clearly explained how to estimate CC6. In fact, the effect of changing the value of CC6 on the capacity was not significant in past studies e.g., [16]. This is because the impact of larger speed oscillation with longer spacing (i.e., higher CC6) is not likely to be significant in congested conditions. Nevertheless, in the case of CAVs this parameter can be set to 1 when the speed variation, thanks to the automatic control of the driving system.
- CC7 is the following vehicle's acceleration during the unconscious following process. It was found that there was not much difference in CC7 among the three vehicle classes. Both car and heavy vehicle drivers apply low acceleration/ deceleration during the unconscious following process because they try to maintain the ideal gap at zero relative speed. The suggested values for cars, heavy vehicles and motorcycles are 0.090 m/s2, 0.097 m/s2 and 0.085 m/s2, respectively. In the case of autonomous driving, the vehicle can maintain this variation equal to 0,1.
- CC8 desired acceleration when starting from standstill (limited by maximum acceleration defined within the acceleration curves) In the case of autonomous driving, it has been defined according to the technical characteristics of the CACC which determines an average acceleration of 3 m/s2.
- CC9 is the following vehicle's acceleration rate at speed of 80 km/h. Umair Durrani in her work have showed that the mean values of acceleration cars, heavy vehicles and motorcycles, at speed bigger of 80 km/h, were 0.45 m/s2, 0.25 m/s2, and 0.41 m/s2, respectively. In the present thesis work this parameter for the CAVs has been set at 0.5 m/s2 it does not in any way influence the simulations, since in the roundabout taken into consideration the speed of 80 km/h is never reached, as they are located in urban areas where the maximum speed limit is set at 50 km/h.

Table 4. Default and set values of parameters used for car-following model Wiedemann 99

VISSIM Parameters W99	*Default values*	*Set Value*
CC0	1.50	1.00
CC1	0.90	0.50
CC2	4.00	1.00
CC3	-8.00	-6.00
CC4	-0.35	-0.10
CC5	0.35	0.10
CC6	11.44	1.00
CC7	0.25	0.10
CC8	3.50	3.00
CC9	1.50	0.50
Reaction time [s]	1.20	0.00
Standstill distance [m]	2.00	1.00
Maximum waiting time [s]	120.00	0.00
Look ahead distance min	0.00	20.00
Look ahead distance max	250.00	200.00
Look back distance min	0.00	20.00
Look back distance min	150.00	100.00
Observed vehicles	4.00	10.00
Temporary lack of attention: Duration (sec)	0.00	0.00
Temporary lack of attention: Probability (%)	0.00	0.00
Desidered position ad free flow	Any	Middle of lane

Fig. 6. W99 Car Following Model - How It Works for CVs

The Fig. 6 shows the link between the safety distance and the vehicle speed defined by the car-following model Wiedemann 99 not calibrated for CAVs, in particular

Fig. 6. W99 Car Following Model - How It Works for CVs

show the 30 'second of a simulation that evolves into a circular path within which there are 12 CVs.

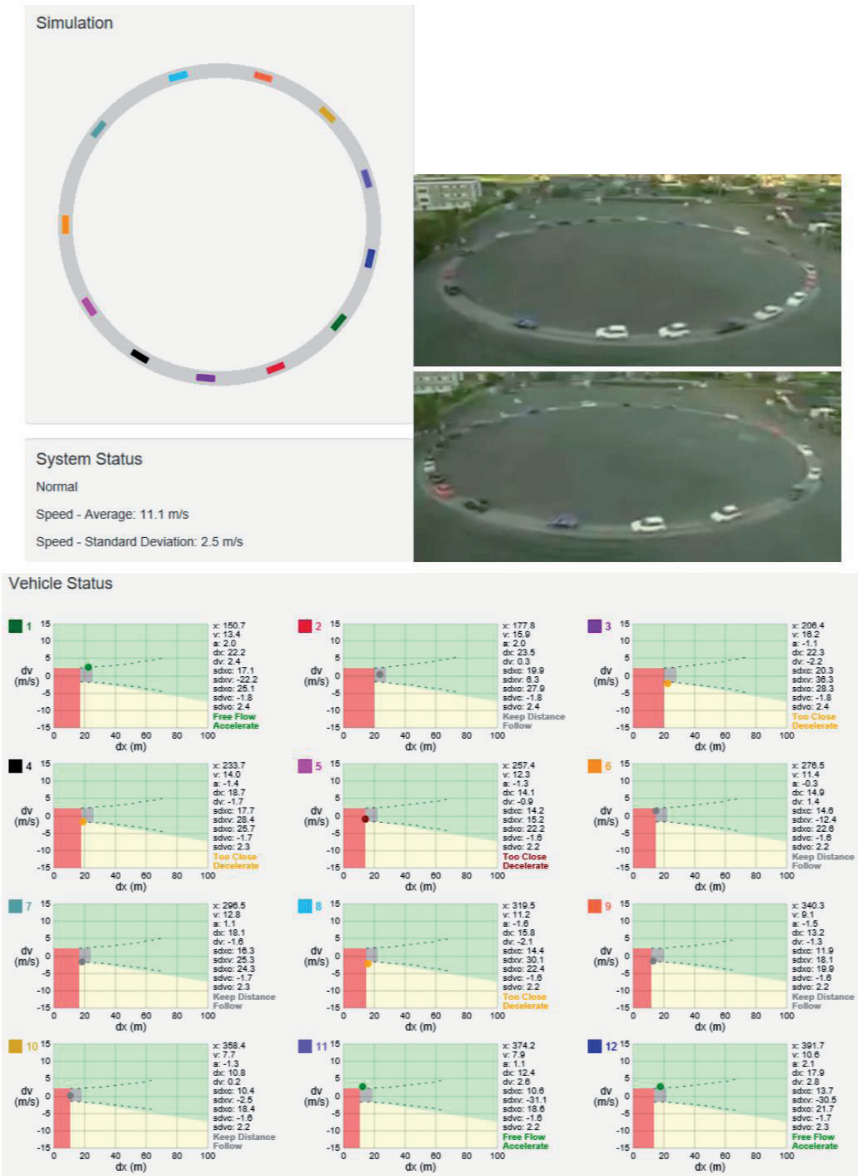


Fig. 6. W99 Car Following Model - How It Works for CVs

The obvious inability of a human user to maintain the speed constant, this determines the following consideration: the average speed of the vehicles due to the continuous phases of acceleration and deceleration is extremely low $\bar{v}$= 11.1 m/s and very variable σ = 2.5 m/s, a condition that involves a high heterogeneity in the distances between the vehicles in the queue. Therefore, this condition determines a reduction in the capacity of the considered element.

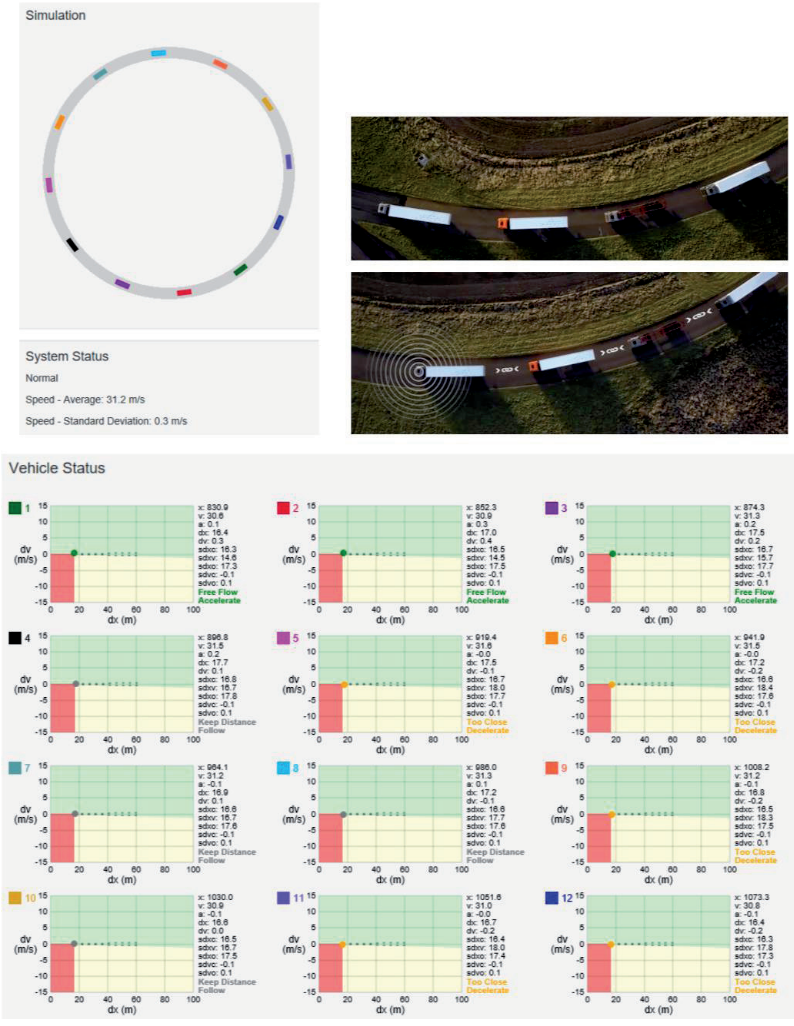


Fig. 7. W99 Car Following Model - How It Works for CAVs

Fig. 7 shows the connection between the safety distance and the vehicle speed defined by the Wiedemann car-following model 99 calibrated for CAVs, it shows the ability of a CAVs to keep the speed constant and therefore the safety distance, this determines the following consideration: the average speed of the vehicles thanks to the reduced and limited accelerations / decelerations is equal to $\bar{v}$=31.2 m/s, σ=0.3 m/s, a condition that determines a significant increase in the capacity of the considered element while maintaining a high LOS.

5 METHOD AND RESULTS

This analysis considered a turbo roundabout where have been performed 10 distribution matrices with various traffic flows, in order to establish traffic flows that identify maximum capacity and minimum conflicts. In particular, these matrices were defined as follows:Table 5. O/D Matrix

Matrice	Crossing [%]	Turn right [%]	Turn left [%]	go back [%]
A1	70	15	15	0
A2	55	30	15	0
A3	55	15	30	0
A4	33	33	33	0
A5	25	15	60	0
A6	25	60	15	0
A7	50	25	25	0
A8	65	15	15	5
A9	50	15	30	5
A10	19	40	40	1

Considering that, the Turbo-roundabout has an estimated capacity of approximately 4,100 to 4,600 veh/h, and imposing a value reduced by 50% into the system to make sure that the traffic condition was much distant from saturation conditions.

The simulated traffic flow data for the analyzed intersections were managed to calibrate the parameters of the micro simulation models, trying to obtain reliable and realistic results. The simulated intersection schemes consider a four-arm Turbo-roundabout with an outer diameter ring of 56 m, an internal diameter of 46 m and a width of the two lanes of 5 m each.

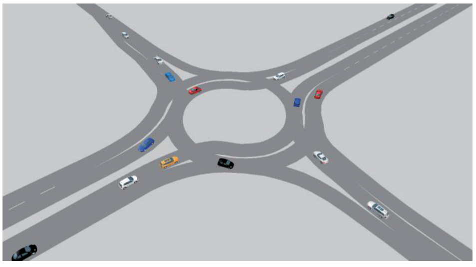


Fig. 8. Simulation scheme of turboroundabout.

Thanks to the numerous simulations performed for the distributions of the 10 O/D matrices and for the different traffic flows, very significant results were obtained, considering the following parameters: average speed; average tail length; maximum tail length; number of vehicles; number of stops.

The comparison between the different parameters of the O / D matrix obtained through Vissim with reference to the average speed at the entrance of the ring (km / h). Table 6 shows that the traffic flows of the different matrices determine an almost constant average speed value, but reaches a peak of about 38,5 km/h in the A6 matrix and a minimum of (22 km/h) in the A8 matrix. A condition that is also confirmed with a mixed flow, composed of 75% CVs and 25% CAVs respectively. In fact, the Table 6 shows that the flows relating to the matrices 6 and 8 determine the average speeds respectively of 47,0 and 23,0km / h. This condition determines an average length of the queue minimum at the traffic flow A6 (0,3m) and maximum for the flow A8 (39,1m) respectively 0,2m and 33,2m for mixed flow CVs/CAVs

Table 6. Simulation results of Vissim

O/D	**Average Speed [Km/h]**		**Average queue length [m]**		**Max queue length [m]**		**Number of Stop [n°]**		**Time Wasters [sec]**
	CVs	***CAVs***	**CVs**	**CAVs**	**CVs**	**CAVs**	**CVs**	**CAVs**	**CVs**
A1	29,3	32,8	11,2	9,0	62,1	49,7	1	0	13,2
A2	32,2	36,7	2,9	2,6	42,8	38,5	6	1	0,3
A3	28,5	37,1	13,7	10,3	65,6	49,2	16	3	1,2
A4	32,7	43,2	2,2	2,1	37,9	36,4	6	1	1,30
A5	28,3	32,5	14,6	12,8	64,2	56,5	19	6	1,4
A6	38,5	47,0	0,3	0,2	19,2	15,0	0	0	2,43
A7	31,1	34,2	4,1	3,1	47,5	35,6	1	0	7,70
A8	22,7	23,0	39,1	33,2	97,5	82,9	4	0	49,10
A9	23,3	25,2	35,1	29,5	90,7	76,2	4	0	45,7
A10	25,5	30,9	12,2	9,9	72,1	58,4	2	0	19,9

Table 6 shows the trend of the maximum tail length of the maximum queues. In the Turbo roundabout, each traffic flow has a maximum tail length value ranging from a maximum of 97,5 m in the A8 matrix to a minimum value of 19,2 m in the A6 matrix. Condition which is confirmed also for the mixed flow CVs-CAVs, in fact, the maximum lengths of the tails are respectively 15.00m and 82.9m. Moreover the Table 6 shows the trend of the variable number of stops, with jumps ranging from a maximum value of 18 in the A5 matrix to a minimum value of 1 in the A6 matrix, condition confirmed also in the case of mixed flow.

The corresponding output files produced by Vissim (i.e. TRJ files) have then been imported into

SSAM for the identification of conflicts and the calculation of surrogate security measures for each conflict event.

SSAM has been configured to use conflict identification threshold values; that is, the TTC and PET values used are 1.5 seconds and 2.5 seconds respectively.

The results of the SSAM analysis consist of the number of potential total conflicts and the number of conflicts of each type of interaction between vehicle and vehicle; in particular, they are of three types:

- rear end;
- lane changing;
- crossing.

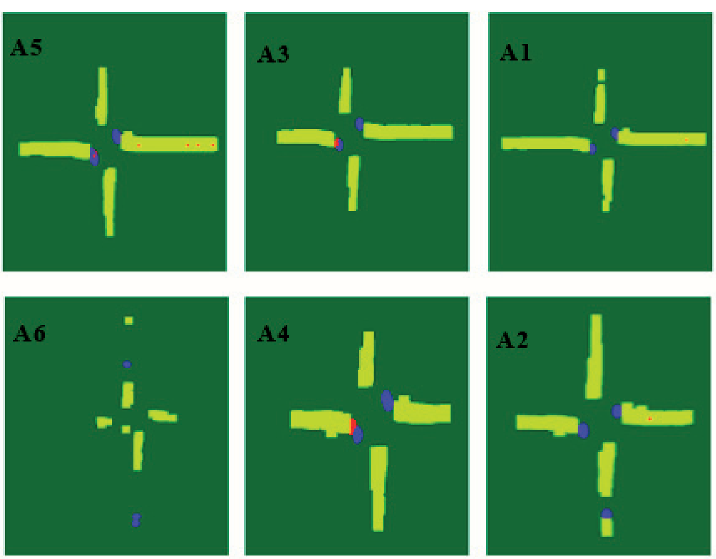
Crash counts were derived from certain filter values with TTC 0.1 and 1.5 seconds, and PET 0.5 and 2.5 seconds.

Fig. 9, instead, highlights the potential conflicts in a roundabout obtained from SSAM

- in yellow: rear end;
- in blue: lane change;
- in red: crossing.

Conflicts related to the CVs and CAVs flows were determined by applying a reduction of the TTC and PET trhough the equations shown below.

Considering that TTC increases linearly as the percentage of CVs increases, for %XCVs of 75% one can obtain $0.72 + 0.78 \times 0.75 = 1.26\ s$, while for %XCVs of 90% it results $0.72 + 0.78 \times 0.90 = 1.42\ s$.



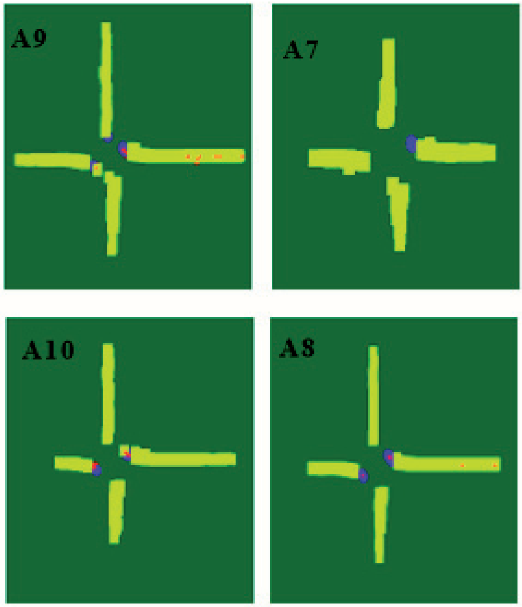


Fig. 9. Maps of potential conflicts in a Turbo roundabout created with SSAM

Table 7. conflict results of SSAM

O/D	Crossing		Lane change		Rear end
	CVs	CAVs	CVs	CAVs	CVs
A1	9	3	15	5	25
A2	12	4	11	3	32
A3	25	8	18	5	33
A4	34	10	19	6	25
A5	27	8	10	3	18
A6	18	5	8	2	12
A7	15	5	7	2	24
A8	12	4	8	2	34
A9	20	6	12	4	24
A10	29	9	15	5	16

Table 7 shows a varying average Crossing value in the Turbo roundabout, with jumps ranging from a maximum value of approximately 34 in the A4 matrix to a minimum value of approximately 9 in the A1 matrix. This condition is also confirmed in the case of mixed flow with a reduction of conflicts from 10 to 3. In case of Lane Change, the maximum conflict values are obtained in correspondence to the A4 flows, whereas the minimum from the A7 matrix. In case of Rear End, the highest values correspond to A3 flows, and the lowest to A6.

6 CONCLUSIONS

The results of this paper emphasize the importance of the impact of intersections as a crucial part of the network. Therefore, they represent the critical areas where vehicle trajectory conflicts can take place. Hence, poorly designed intersections can easily lead to congestion phenomena (with the consequent formation of vehicle queues), and in several cases even to serious or very serious accidents.

Therefore, the right choice of the intersection layout (such as Turbo-roundabout) becomes fundamental to offer a better level of service to users, giving them the opportunity to travel in the shortest time possible on the route of road they have chosen. The method of this article concerned the use of simulations of the road environment through the application of Vissim software, and the use of simulations of potential traffic conflicts through the application of SSAM software, which respectively reproduce the behaviour of the vehicles inside a Turbo roundabout.

Some fundamental parameters represented in the 10 O/D matrices were analysed through Vissim, such as average speed, average tail length, maximum tail length, number of vehicles, number of stops, time wasters. As a result of this analysis it has been possible to identify those O/D matrices that determine maximum dynamic performances and minimum conflicts. Specifically, the maximum performance values are obtained from matrices A6 and A7. In terms of conflicts, the best values are obtained from matrix A6, whereas the worst from matrices A3 and A4.

moreover, above cited results indicate that traffic distribution which determines the best performance both in terms of LOS and conflicts matrix is A6 distribution defined as follow: 25% crossing, 60% right turning and 15% left turning.

In this view, the methodological approach presented in this paper through a several case studies and its application to more complex scheme of intersections and roundabouts can contribute to address further problems that transportation engineers - which usually apply microsimulation for real world case studies in the professional context - have to solve. Future developments also include that the criterion should be specified to consider more classes of heavy vehicles and explore further mixed traffic conditions. At the last, the analysis should also be extended to other geometrical configurations in order to evaluate the impact of geometric variables (such as the width of the circulating lanes, entry and exit lanes, etc.) on the determination of potential conflict and the consequent operational level-of-service.

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