Simulating a Three-Lane Roundabout Using SUMO

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Abstract. Transportation issues have imposed major challenges in many countries around the world, especially in large urban areas. A great deal of such challenges is related to factors such as: speed limits of particular sites, minimum safe distance between two vehicles, and the uncertainty inherent to drivers' behaviour. These apply to urban and inter-urban roads, to traffic flow models, and to traffic control at intersection points. Nowadays, there are several problems that lead to traffic congestion. Just to mention a few of them: waiting queues, drivers' increased reaction time after an accident, traffic shock waves, not abiding by intersections rules, and many others. Roundabouts are an example of spots where congestion represents a huge problem in need of a careful analysis in order to be solved. In this paper we will examine the effect of speed and acceleration reduction/increase within a roundabout, as well as the reduction of the minimum distance between vehicles, drawing conclusions about their flow throughout the roundabout. We use a method that combines several factors inherent to SUMO default car-following model (i.e. Krauss' model) in order to understand which configuration gives us higher performance in terms of throughput. Calibration was also a very important aspect to achieve good and realistic values. Future research will be needed to further study speed reduction relative to roundabouts. In addition, it will be necessary to calibrate the model, according to driver behavioural aspects of the studied region.

Keywords: Three-lane roundabouts · Simulation · Traffic · Car-following model · Speed · Gap acceptance · Acceleration · Krauss' model · SUMO · Shock wave

1 Introduction

Roundabouts are widely accepted for their safety as they are better in this aspect than traditional signal-controlled or stop-signed intersections for car drivers, as argued by Hels and Orozova-Bekkevold [10], also implying capacity and environmental advantages. They have caused fewer injury accidents for both motor car drivers and pedestrians, as reported elsewhere [11,15].

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The problem at hand is traffic congestion in roundabouts, assessing through a computer simulation whether a change in speed, acceleration and minimum distance (min gap) can result in better throughput and diminished waiting time. Congestion in roundabouts is a daily problem affecting many people, with higher incidence in the morning and late afternoon in urban centres. Moreover, the fact that many drivers do not know is that their contour rules make the circulation even more difficult. With the rush of not arriving late at work and with the worry to get home to rest after an exhausting day, drivers tend to create more traffic, even without knowing it. This happens because drivers usually change quickly to other lanes causing the so-called shock-wave effect, leading to a slowdown of all cars behind in a chain reaction. Besides all these problems, there are also an increasing number of accidents within rush hours creating even more problems by blocking an entire lane [3]. In order to improve the use of roundabouts we decided to analyze some changes relatively to speed, acceleration and minimum distance (min Gap) so as to understand the ultimate impact of doing so. We consider our approach well indicated, taking into account that there are several roundabouts recommendations regarding speed, acceleration and minimum distance [22]. It is important to determine which of them are the most effective for a better traffic circulation. From our point of view it is necessary to solve/improve this problem because it has a direct impact on people's daily lives. Thus, if we draw relevant conclusions about our Simulations, we will be able to indicate which factors are the most important and suitable for a better traffic flow in certain scenarios.

The remainder of this paper is as follows. In Sect. 2 we make an analysis on the available literature to gain a solid basis of the studies that have already been done in this area of research, from the various types of roundabouts to their inherent problems. We also look at speed and acceleration reduction approaches in order to achieve better roundabout performance. In Sect. 3 we will show our methodological approach clarifying which are our Data Requirements (input and output) as well our reference and what-if Scenarios. Specific details about each of the experiments will also be here explained. In Sect. 4 we will show the results obtained in each of our scenarios, and make a comparative analysis of them as well. In Sect. 5 we explain in detail the implementation we have done, particularly regarding the use of SUMO. Finally, Sect. 6 concludes with some discussion and notes about future development.

2 Literature Review

Shaaban and Hamad [17] present a method to analyze driver behaviour and estimate the critical gap for three-lane roundabouts. The operations of multilane roundabouts, especially three-lane roundabouts, are unique and more complicated than any other type of roundabouts. Data was collected at two roundabouts in the city of Doha, Qatar. Analysis showed that the vast majority of the vehicles accept the gap in groups and the critical gap was estimated accordingly. The overall critical gap value was 2.40 s. The critical gap for passenger vehicles was the lowest (2.39 s) compared to average (2.53 s). The study provides a new explanation for the operation of multilane roundabouts.

Guo, Liu and Wang [7] try to analyse the capacity of a roundabout based on the gap acceptance. Incoming vehicles can enter the roundabout when there is a time gap larger than the critical gap; otherwise, the vehicles need to wait until there is a large enough gap. The gap acceptance theory was used to analyze the entrance capacity of roundabouts, which can be derived from queuing theory involving two vehicle streams. They conclude, when the critical gap is constant, the deviation of the capacity model is conveniently used to obtain the equations and calculate the accurate capacity values.

Wang and Ruskin [20] propose a multi-stream minimum acceptable space (MMAS) approach based on cellular automata (CA) models to study non-signalised multi-lane (two- or three-lane) urban roundabouts. The method is able to reproduce many features of urban traffic, for which gap-acceptance models are not robust. The operations of two- and three-lane roundabouts are compared in terms of throughput. They conclude that the performance of tree-lane roundabouts is almost the same as two-lane roundabouts where left-turning (LT) vehicles use left lane only, right-turn (RT) vehicles using right lane only, and straight-through (ST) vehicles can use both lanes. The main advantage of three-lane roundabouts is not obvious for situations where LT vehicles are filtered out directly.

Silva and Vasconcelos [18] listed the roundabout types and their inherent problems in Portugal. This provided some background story to contextualize the current situation of our country concerning the problematic. They have shown that single-lane roundabouts are scarce, normally located on rural residential areas. The authors concluded that the main problems are: typical behaviours when some driver circulates inappropriately, geometrical design problems such as large roundabouts, lack of entry deflection, lack of channelisation and traffic signals, and obstructions in the central island. This work provides some useful information relatively to headway distribution models and estimation of critical headways.

Ziolkowski [23] points the fact that the high number of accidents occurring in roundabouts deserves a deeper study. This article concludes that the influence of roundabouts on drivers behaviour expressed by their speed in approach arms as well as by the manoeuvres they perform, vary depending on the geometric parameters of roundabouts, though this dependency is not uniform and so there is no direct relationship.

Al-Saleha and Bendakb [2] highlight the number of deaths and injuries due to roundabouts in Saudi Arabia over 15 years (1994–2008). For these authors it is clear from the results that many drivers do not follow traffic regulations on roundabouts and this explains the high number of accidents.

Leksono and Andriyana try to improve the traffic issues on Idrottsparken roundabout in Norrköping, Sweeden by providing an alternative model to reduce queue and travel time. They use two different simulations models: the first one adds an extra lane for right turn from East leg to North and from North leg to West; the second scenario restricts the heavy goods vehicles from passing Kungsgatan which is located in the Northern leg of Idrottsparken roundabout, during peak hours. This thesis concludes that the parameters which give more effects to calibration process in a SUMO project are the driver imperfection (σ) and the driver's reaction time (τ).

Figure 1 summarizes the contributions from the referenced authors in this section. For instance, data collection and gap acceptance to calibrate our model while SUMO gives us some insight into how microscopic roundabout simulations are done. For a further discussion on other microscopic simulation models, the interested reader is referred to [14] for an additional appraisal.

Authors/ Features	Roundabout types	Roundabout inherent problems	Gap Acceptance	Headway distribution models	Estimation of critical headways	Driver's behaviour	Data Collection	SUMO
K. Shaaban and H. Hamad	x		x	x		x	x	
Ruijun Guo, Leilei Liu and Wanxiang Wang			x	x	x	x	x	
Ruili Wang and Heather Ruskin	x	x	x			x	x	
A.Silva and L. Vasconcelos	x	x		x	x			
R. Ziolkowski						x		
K. Al-Saleha and S. Bendakb	x					x	x	
Catur Yudo Leksono and Tina Andriyana	x						x	x

Fig. 1. Related work gap analysis

3 Methodological Approach

In this section we begin by elucidating the way we develop the research presented in this paper. We present the starting point and then by describing our simulation scenarios as well as our setups for Car following-model calibrations.

3.1 Fundamentals of Roundabouts - Process Model

First of all, we start by clarifying that, by definition, a roundabout is a circular intersection (or junction) in which road traffic is permitted to flow in one direction around a central island, and priority is typically given to traffic already in the junction. Some relevant aspects are that vehicles circulate around the central island in one direction at speeds in a range of 25–40 km/h and multi-lane roundabouts are typically less than 75 m in diameter [4].

The flowchart below, Fig. 2, modelled using Business Process Model Notation, is a detailed description of a roundabout operation. This was the starting point of our research.

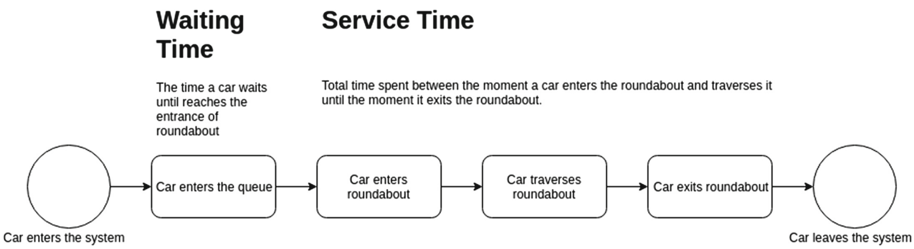

Fig. 2. Roundabout operation flowchart in Business Process Modelling Notation (BPMN)

The gap acceptance is based on the velocity of the vehicle moving in the front, and the maximum speed that can be attained by the vehicle that tries to overtake it. The entrance capacity, delay and queue length can be calculated by using the gap acceptance theory. In Germany, gap acceptance theory was well developed [21]. The base theory was proposed by Major, Buckley and Tanner [6,9]. The capacity model had been developed based on different signal timing, different lane numbers, and different vehicle traffic characteristics. After enormous amount of research, countries developed their own capacity methods for their own traffic conditions including Highway Capacity Manual in USA, Swedish CAPCAL, SETRA method, aaSIDRA, AUSTROADS and NAASRA in Australia, and CETUR method in Germany. This is very important to understand so we could achieve a gap acceptance that simulated the real case.

To understand the congestion problem, bottleneck's occurrence and to formulate solutions for it, a thorough study of vehicle-to-vehicle interactions is necessary [12]. These interactions are able to achieve with a car-following model. This brings to a common problem in traffic congestion called shock waves [13]. This are a chain reaction phenomenon which leads to traffic congestion well after the first car, the on who started the congestion, has departed [16]. Due to its perpetuation after the front car's leave it is akin to a ghost like occurrence. Shock waves happen fewer times by reducing the maximum velocity imposition within the lanes [8]. With this in mind, our main goal, is to prevent shock waves to happen so the throughput is higher by reducing the speed in case of congestion on a three-lane roundabout.

3.2 Experimental Scenario

Taking into consideration the previous subsection, now we are going to describe our particular case. It was decided to choose a roundabout that we knew well. This one is located in Ermesinde, Valongo, Porto, Portugal next to the Santa

Rita's church. To set peak hours for the roundabout saturation we decided to use traffic information made available by Google Maps. Through this information, presented in Fig. 3 we know the most critical times for congestion. Based on the color scale defined in Fig. 3 we can conclude that the critical moments (orange color) are at the end of the afternoon as predicted based on our experience and knowledge of this place.

Fig. 3. Santa Rita roundabout - color scale congestion by Google Maps (Color figure online)

These are our simulation Scenarios:

- Standard Roundabout: Base scenario which will serve as a control model in our simulation environment. It will be used to achieve the main values and the calibration setup as well as a base comparison to the other scenario;
- Standard Roundabout with maximum permissible speed variations: Similar to the standard roundabout, now with decreases in maximum speeds. This is the system we used to avoid shock waves having a better traffic flow.

3.3 Car Following-Model Calibration Setup

In this subsection we explain how was achieved, in the better way possible, the traffic situation shown in Fig. 3 by calibrating the car-following model. In traffic flow theory, car-following model is a method used to determine how vehicles follow one another on a roadway. These models describe how cars are spaced between each other and how many drivers react to changes caused by road events. Some well known models are: Krauss, Gipps and Wiedemann. Well will

Table 1. Default Krauss following-model parameters

Name	accel	decel	maxSpeed	minGap
Krauss	$2.6\,\mathrm{m\,s^{-2}}$	$4.5\,\mathrm{m\,s^{-2}}$	55.5 m/s	2.5 m

use the default modified version of Krauss Model used in SUMO as our reference. The default input parameters are defined in the Table 1.

We will focus on the following to achieve the best traffic scenario:

– Maximum Speed Imposition in indoor lanes: we evaluate the car flow of the outdoor lane and, at the same time, the effect of the overall throughput.
– Varying minGap: Here we study the effect of varying the minimum distance between two cars in terms of speeds and throughput;
– Varying minGap and accelaration: Here we study the conjugation of two of the attributes that characterise Krauss car-following model. The goal is also to understand the results in terms of speeds and throughput.

For our simulation plan we have perform around 10–12 runs per experiment. Each run lasts 2000 ms and is repeated if any of its output values is biased or unrealistic. If the warm ups prove to be long, we will use batches to only pay the warm-up price once, saving the state of the model after reaching a congested state, where the vehicles will have reached saturation speed. We end this simulation project when a satisfactory outcome is achieved or failing to fulfill it if the proposed number of runs is surpassed.

4 Implementation

The first step to implement the simulation was to export Santa Rita's Roundabout to the OSM format using Open Street Maps. From here we made the necessary changes in NETEDIT [1] so that the rules of the roundabout correspond to the existing one. Let's observe the final result obtained through NETEDIT in Fig. 4.

There are in total 28 detectors responsible for recording the velocities and the time that each vehicle pass by them. There are two detectors per entrance, one for each lane, same for the exits. Inside the roundabout there are 4 for each lane that covers the main junctions so we could collect data.

Every detector gives information about the moment each vehicle, enters, stays on and exists. Therefor, the entrance velocity can be defined as the velocity at the moment the vehicle exits the detector and the exit velocity as the given velocity when entering the detector.

RandomTrips.py, a script created by German Aerospace Center (DLR), that allowed us to populate the scenario with trips. We changed it to fit our needs, so it was possible to have a saturation point and to force every vehicle to pass through the roundabout. Also, we created a parser to collect all the data and

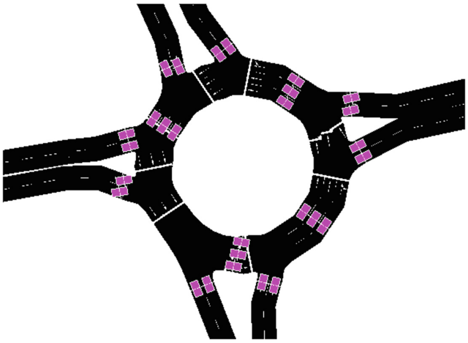

Fig. 4. NETEDIT final roundabout after subtle changes to match the real one.

manage to better understand the output information from each run and their detectors. Figure 5 represents an example of an experiment using SUMO-GUI. The roundabout is already in a state of saturation.

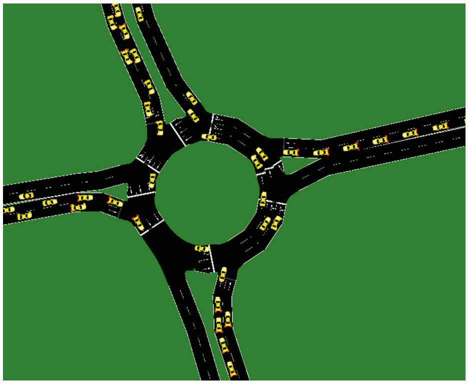

Fig. 5. Roundabout experiment, state of Saturation.

5 Results and Discussion

In this section we will explain in detail the results of our 3 experiments. The first experiment focuses on the imposition of maximum speed limits within the interior lanes of a roundabout. The second is about the krauss-following-model calibration relative to the minGap parameter. Finally the third one that combines the minGap and acceleration parameters to calibrate the same model. The discussion of experiences essentially addresses the possibilities and challenges that we find based on the results.

5.1 Experiment 1 - Speed Analysis According to Maximum Speed Impositions

No driver is perfect. Having that in mind, one of the main car traffic issues are shock waves. This happens due to a driver's reduction in speed leading to a chain reaction, where all the vehicles behind will have to stop originating congestion. In an ideal scenario, this phenomenon would not take place.

To prevent this event from happening we believe that if the vehicles circumventing a roundabout travel with a lower velocity, reaction time will increase and consequently, the vehicles entering the roundabout will be able to do it with greater ease and in a safer way. This will nullify the shock waves or at least minimise its impact in the eventuality of its occurrence.

In a three lane roundabout, in which each entrance has two lanes, generally speaking, the right most lane will always be the occupied by vehicles which will exit on the first exit. Due to this, after diminishing the maximum speed imposition in the right most lane, we observed that there were no significant results. Thus we consider that would not be relevant to reduce the maximum speed imposed on this lane.

Considering the above mentioned, we started to reduce the speed only for the middle and left most lanes. The average speed detected by the sensors at the entrances, middle and the exits of the roundabout are shown in Fig. 6 whereas in Fig. 7 the throughput results are shown.

Even after reducing the maximum speeds imposed on the innermost lanes, both entrance and exit velocities remain unchanged when compared to our base configuration. In spite of the fact, the roundabouts throughput increases, indicating that this is a promising experiment.

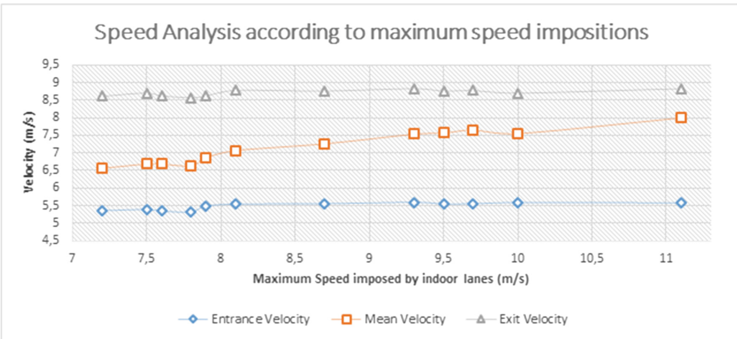

Fig. 6. Speed analysis according to maximum speed impositions.

After reducing the roundabout's maximum speed circulation following the criteria explained above, it's noticeable a higher number of cars traversing a roundabout. This way we can observe that reducing maximum speed of circulation is effective in a three lane congested roundabout.

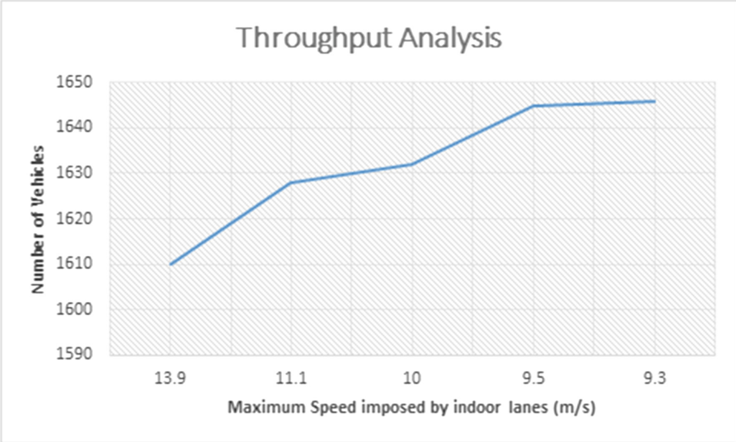

Fig. 7. Throughput analysis according to maximum speed impositions.

5.2 Experiment 2 - Calibration of the Krauss Model by Varying MinGap Parameter

The minimum safety distance between two vehicles is a very important topic in the context of car traffic. By definition we are talking about sufficient distance to avoid an accident if the front vehicle stops or reduces speed. This parameter proved to be very important in order to conclude about the impact on the roundabout throughput when its value is modified.

SUMO tracks gaps between vehicles that are on the same edge. By default, whenever these gaps are greatly reduced there is a possibility of collision between cars. Our goal was to prevent any kind of situations because this would invalidate our simulations. This way, we started by using SUMO default value (2.5 m) and from there, we added or subtracted small plots.

Comparing the graphic on Fig. 8 with the experience 1 presented on Fig. 6 we noticed that there are some similarities relative to entrance and exit mean velocities. However, there is now a significant difference, mean velocity for circulation has increased as the minGap decreases. This result is justified by the allowability of the short distances for drivers within the same lane. This gives them the possibility to maintain higher velocity values.

Concerning Fig. 9 we can observe significantly positive results regarding the throughput by decreasing the minGap between vehicles. These results were already expected but now it is necessary to discern and to decide what should be the minimum distance we could establish to maintain safety. We believe that a variation between 2.5 and 1.5 m inside a roundabout is safe but this is a debatable subject and requires more research.

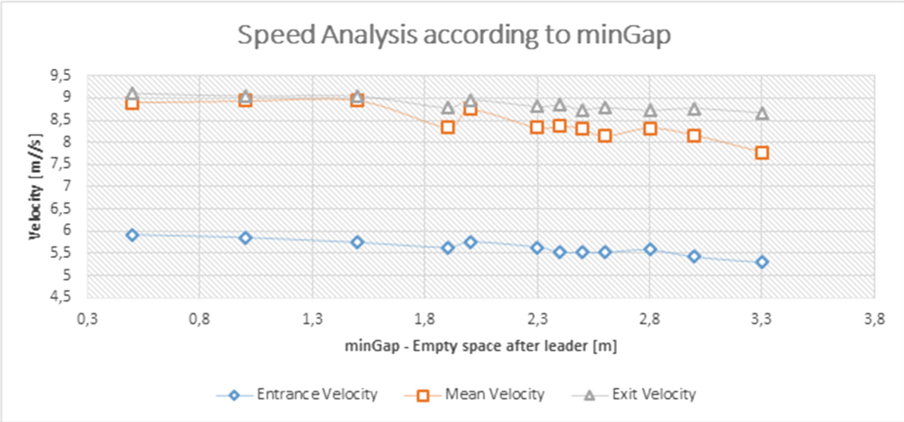

Fig. 8. Speed analysis by varying minGap.

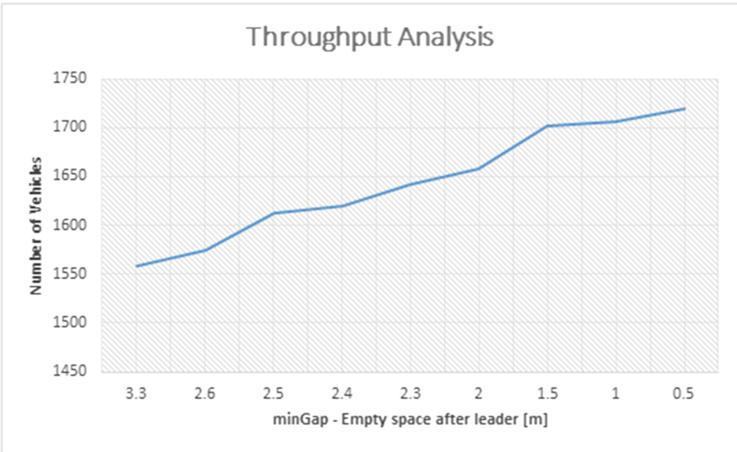

Fig. 9. Throughput analysis by varying minGap.

5.3 Experiment 3 - Calibration of the Krauss Model by Varying Acceleration and MinGap Parameters

In this experiment we try to go further in the studies of the parameters that characterise krauss car-following-model. In this case we add the acceleration to our analysis. We expect, as the acceleration is increased, the throughput will be improved. The same situation occurs for the diminution of minGap. Here we intend to find a balance between acceleration and minGap in order to find realistic and reasonable values.

If we observe the first table below we conclude that the best conjugation of values would be with minGap = 2.4 m and accel = $3.2\,\mathrm{m\,s^{-2}}$, giving us a value of 1688 vehicles that concluded the simulation with a saturated roundabout. If we look at Table 2 these values are reinforced because they allow a minimum time of circulation equal to 11.23 s.

Although these values are the best we want, as we said before, we want to find values that are more realistic and that provide equally good results. This way, we suggest using the minGap = 2.8 m and accel = 2.9 m s^{-2} configuration, since it has a result in terms of throughput equal to 1684 (less four compared to the previous one) and a circulation time of 11.84 (more 0.61) (Table 3).

For this last proposed configuration the results are very close to the previous ones with two differences to highlight. The acceleration is lower and the minGap is larger providing greater safety to the driver and all the surroundings.

Table 2. Throughput according to acceleration and minGap parameters

minGap/accel	2.4	2.6	2.9	3.2
3.3	1545	1558	1596	1643
2.8	1603	1628	1684	1681
2.4	1614	1620	1677	1688

Table 3. Recorded average times [s] of circulation according to acceleration and minGap parameters

minGap/accel	2.4	2.6	2.9	3.2
3.3	15.08	16.14	13.80	11.97
2.8	14.32	12.94	11.84	11.11
2.4	13.13	13.18	13.61	11.23

6 Conclusions

From our experiments we are able to draw some interesting inferences. Firstly, by imposing a maximum speed reduction on the two innermost routes within the roundabout, we conclude that it is possible to significantly improve throughput. In order to obtain such reduction in vehicle speed we suggest the use of speed bumps or a more rugged pavement, because solely decreasing the allowed maximum speed for the entire roundabout is not enough to enforce it. On the other hand, by studying the impact of the minimum safety distance between vehicles we also observed significant improvements in the flow of cars at the roundabout. It is important to note that safety distances must be met in the context of a particular roundabout, taking into account its characteristics. The Krauss' car-following model calibration for acceleration and minGap parameters allowed us to find a balance between minimum safe distance and adequate acceleration.

The main lesson that we draw is that some results obtained through simulation in a traffic context may not be linear. We are aware of this because there are many factors to take into account when, for example, a parameter such as the maximum speed (or acceleration) is changed. A change in one of these parameters causes a particular trip to perform in a different way and when coupled with thousands of trips the result may not be what was expected. In spite of this we believe that our efforts to make a correct calibration of the default SUMO model helped leading us to quite satisfactory conclusions.

As final remarks we would like to mention that there are several paths in order to continue this study. As future work, the procedures used in the Krauss' car-following model could be improved with more iterations and also varying other parameters such as reaction time, and driver imperfection factor. In addition, it has the potential of being extensible with other car-following models. It is also possible to continue this work by creating new geometries for such roundabouts and analyse how the new designs affect results. We also intend to enrich the behaviour of vehicles using the agent-based models through the combination of SUMO and TraSMAPI [5,19].

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