

# Micro-simulation of the Impact of Different Speeds on Safety Road Travel and Urban Travel Time: Case Study in the City of Guimarães

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*Abstract:* In recent days, the use of micro-simulation as an additional tool for the study of the network makes this management faster and more efficient, avoiding in situ studies. However, although it is a useful tool, it is necessary that the model under study is the best represented possible in order to obtain results that best fit the reality of the road, and a poor calibration of the model can provide results that do not fit the good management of the road under study. In this sense, using micro-simulation, more precisely to the VISSIM PTV software, a road network at the microscopic level will be evaluated as well as the parameters that most influence the route of the users within that network. The parameters will be modified according to the modeler so as to obtain a model as close to reality as possible. The most appropriate criteria for the calibration and validation of the model will also be chosen. The road safety of the network will also be analyzed using the SSAM software. Here the network's points of conflict will be analyzed, characterizing them as to the type and its severity. Subsequently, a sensitivity analysis will be introduced, where some parameters will be modified individually or together, in order to assess their influence on the network, thus assessing the importance of each in the vehicles.

*Key-Words:* Traffic simulation; traffic flow; road safety; traffic conflict.

## 1 Introduction

The driver behavior is directly affected by speed, due to changes of the characteristics that occurs in the visual field, peripheral vision, in the need to search for information at greater distances and the reaction time to unforeseen events. The practice of higher speeds does not allow drivers to make certain decisions, and many are unable to stop in time in the face of a conflict, resulting sometimes in accidents. Therefore, since changes of speed are associated with the physical and behavioral conditions of drivers, it is important and justify the involvement of designers and policy makers that can use this variable in the modelling exercises in order to promote mobility and traffic safety [1].

On urban highways, users wish to run a stretch in the shortest possible time and in the safest possible way. To achieve this, it is intended that these road axes ensure, simultaneously, good levels of traffic fluidity and safety, which may not be easy, since minimal traffic disturbances can cause a significant variation in speed, creating a potential shockwave

effect, affecting all users, slowing down the average speed, that will be one of the factors that can influence travel time.

The average speed is directly associated with the travel time, since it is impossible for a vehicle to always travel at the maximum speed allowed during the particular stretch of road, and it is very difficult to use it for travel time calculations. However, it is possible for the traffic to be fluid and safe by imposing a reduction of speed limits along different sections of a road axis, increasing travel time, but with a reduction of the risk of having an accident, thus increasing road safety.

In relation to the level of detail, traffic and transport models can be classified according to the capacity to reproduce certain traffic situations with greater or lesser detail for different territorial scales [4] [5] [6], such as:

- Sub-microscopic: models with a high level of detail, where the behavior of the conductors and the operation of parts of the vehicle are described;
- Microscopic: Evaluate traffic in detail by

representing each vehicle individually;

- Mesoscopic: level of intermediate detail not distinguishing individual vehicles, but as platoons;
- Macroscopic: calculate the flow of traffic as a whole ("fluid"), not distinguishing between constituents, that is, traffic flows are treated.

Traffic simulation models offer a wide variety of solutions for a variety of problems, and can be evaluated first and foremost on the performance of the road network, which can also address environmental issues, to study and solve cases that affect and impact on footpaths, these being just a few examples of the wide diversity of micro-simulation applications.

The technological evolution allowed the appearance of various traffic simulation software, which permit the analysis of a road network, without the problems/issues inherent to the actual functioning that involve changes in the operation of road networks. These simulations are a very effective tool for determining the benefits and impacts of projects in traffic circulation involving various modes of transport, where the use of these software facilitates the analysis of flow since they require less resources and can simulate situations without any risk to users of the transport system. Yet, they are a process of high complexity.

The use of microsimulation for traffic modelling serves to simulate the individual behavior of vehicles within a traffic flow. Thus, modelling at the micro level is related with the process of creating a virtual model for transport infrastructures, in order to simulate the microscopic interactions between vehicles, treating each vehicle as an entity with the possibility of interacting with other entities in the model [5] [6] [7].

Therefore, the main objective of this paper is modelling traffic behavior and vehicle interactions in a road interchange of the freeway of the city of Guimarães, Portugal, in order to estimate the main performance impacts in traffic and safety due to possible variations of speed limits in the highway.

This work has the following structure, section 1 presented a framework on the theme, the objectives and the motivations in the development of this work. In section 2 is presented the methodology applied in this work with the descriptions of various steps. Section 3 and 4 presents the case study applied to the city of Guimarães, Portugal, and the inherent results. Finally, in section 4 are presented the main conclusions of this work.

## 2 Methodology

The process of modeling consists of several steps, from data collection to the analysis of results. Thus, this section presents the transport methodology adopted in this work (figure 1)

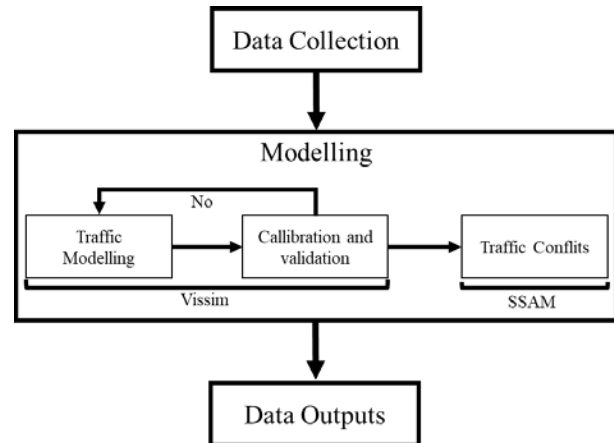


Fig.1: Overview of the proposed methodology.

Source: Own creation.

### 2.1 Modeling, Calibration and Validation

Modelling and calibration of a section of a transport network, describing and analysing the different phases: treatment of counts and introduction of the results in the model, methods of affectation of the search to the network, calibration processes of the model and origin/destination matrices and tools of support, validation of the model against reality (observed vs. modelled values).

#### 2.1.1 Data Collection

Vilarinho [2] and Serra [3] used the simulation system to analyse the performance of a road network in the cities of Porto and Guimarães, respectively, focusing on the improvement of the flow of traffic in various intersections, with the creation of scenarios. Vilarinho [2] says that although the parameters of the volumes are of easy collection, their impact on the change of variable values is reduced where the ones with the greatest sensitivity to change are travel times. The variables that presented the greatest impact on the performance of the model were speed, time of reaction and maximum acceleration.

However, the variables that are going to be collected are traffic volumes, speeds and the length of queues to be used in the Vissim software.

#### 2.1.2 Calibration

The calibration process of a model involves the modification and correction of values associated to

parameters previously defined by the software. The objective is to adapt the results of the simulation to the data collected in the field, improving the efficiency of the model in order to reproduce the behavior of the conductors and the performance of the indicators as realistically as possible, by varying the parameter values.

The model is considered calibrated when, at the end of a sequence of iterations, the parameters meet the previously defined criteria. This process is strictly necessary, since no model is expected to fit all possible traffic conditions [2].

There are several adjustment indicators, and calibration can be done through any one or all of them, such as the Mean Square Error (RMSE), the Mean Square Error (RMSP) and the "classic" GEH index, which will be briefly presented below:

- Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{\sum(V_o - V_m)^2}{C - 1}} \quad (1)$$

On what:

$V_o$ -Observed volume of vehicles per hour;  
 $V_m$ -Vehicle modeling volume per hour;  
 $C$ - Number of counted areas.

- Percent of Mean Squared Error (RMSP)

$$RMSP = \sqrt{\frac{1}{n} \sum \left(\frac{x_i - y_i}{y_i}\right)^2} \quad (2)$$

At where:

$x_i$ - Simulated traffic volume for time  $i$ ;  
 $y_i$ - Simulated traffic volume for time  $i$ ;  
 $n$ - Total number of observations.

- Mean correlation coefficient (r)

$$r = \frac{1}{n - 1} \sum_{i=1}^n \frac{(x_i - X)(y_i - Y)}{\sigma_x \sigma_y} \quad (3)$$

On what:

$X$ -Mean of simulated volumes;  
 $Y$ - Average of the volumes observed;  
 $\sigma_x$ - Standard deviation of simulated volumes;  
 $\sigma_y$ - Standard deviation of volumes;  
 $n$  Number of sections analyzed.

- GEH index:

$$GEH = \sqrt{\frac{2(M_i - O_i)^2}{M_i + O_i}} \quad (4)$$

On what:

$O_i$ - Flow observed on road section  $i$ ;  
 $M_i$ - Flow modeled on the road section  $i$ .

The criteria for the first three calibration methods are as follows [3]:

Table 1. Results of calibration of the model, parameters RMSE, RMSP an  $r$

Parameter	Result
RMSE	<30%
RMSP	<15%
$r$	>0,8

For a GEH value below 5%, it is considered that there is a good relationship between the modelled traffic volumes and traffic volumes observed. The average value for this index should be less than 4% and values ranging from 5% to 10% lead to a less detailed correction of data. When values greater than 10% are verified, it can be stated that there is a problem with the model, and this problem may be originated from poor data insertion or a poor calibration of the model [2] [3].

### 2.1.3 Validation

When the model is correctly calibrated, the validation process begins. This process intends to determine when the referred model accurately represents reality. This is an iterative process that involves the calibration of parameters and the comparison of the model with the actual behaviour. Then, to validate the model found it is necessary to use independent data for this phase. If there is no right procedure for this process, the best approach is for the modeller to find the best approach to the problem in question [2].

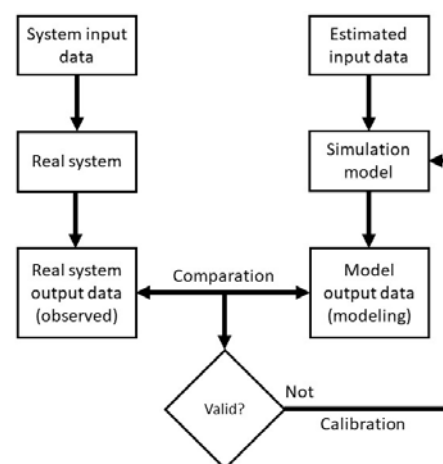


Fig.2: Logic diagram for model validation (adapted from [8])

According to the logic of the flowchart, shown in Figure 2, it is necessary to execute the simulation of the model, for each different iteration and whenever the results are not within the values of the previously defined criteria it may be necessary to repeat the calibration, adjusting some parameters. The process will be carried out as many times as necessary until reaching acceptable values.

## 2.2 Study of Traffic Modeling Software – Microsimulation

The Vissim PTV modeling software will be used because it is a very comprehensive and flexible software for planning and managing traffic. This system is one of the most widely used in the world for micro-scale transport planning, namely: [4]

- modeling of multimodal networks;
- models of microscopic behavior;
- traffic engineering (includes traffic optimization of traffic light cycles and pedestrian simulation);
- graphical analysis and through results tables, the production of reports;
- definition and analysis of multiple scenarios.

### 2.2.1 Microsimulation Modelling

Microsimulation models work by simulating a traffic system based on the individual movement of each user, calculating their speed, position, path change, acceleration, among others, individually per unit time, e.g. seconds. These models analyze the user's individual interaction with traffic signals, intersections, other users, route geometry, to obtain results with great similarity with a reality approach. Some software still uses smaller time units for more accurate results and user behavior, thus increasing the model's effectiveness. Simulation software always takes the "good" behavior of all users knowing that, unfortunately, this consideration does not always correspond to reality, since the behavior of each individual varies according to several factors, such as stress, mood, physical capacity and others, being able to affect negatively or positively the behavior of the individuals. Aggressive behaviors and/or erroneous judgments about some decisions taken during the user's circulation are factors that can cause accidents, factors that are not considered in the micro-simulation models.

#### 2.2.1.1 Microscopic Models

##### • Car-following

The car-following model corresponds to the characterization and analysis of a task of driving a vehicle on a road, based on the individual

trajectories, speeds and accelerations thereof, in relation to a vehicle in front of it. This type of chase task is simpler than any other type of chores presents in human driving. In pursuit maneuvers one can take into account passing and overtaking maneuvers. The passing maneuvers are maneuvers executed in two-way lanes, while overtaking maneuvers are performed in any roadway. For the execution of these maneuvers it is necessary to know if it is possible to carry out the same maneuvers where the vehicle is in circulation [5] [6]. The car-following model can be structured in 4 driving regimes, which vary depending on the response to the incentive received by the driver: free driving; approximation; pursuit; emergency braking [7].

##### • Lane Changing and Gap Acceptance

The processes of lane changing and gap acceptance are interdependent processes because when there is a need to change lanes or to go to a route that takes another direction, drivers also need to evaluate the existing space between vehicles to make this change, whether at an intersection or in the middle of the road. When the gap acceptance process is in progress, this indicates that the driver wants to make a change, from the road or the road in which it is to an adjacent one. The poor analysis of the traffic around them, little experience and driving weaknesses on the part of the drivers during a change of road are the factors that most influence the accidents in this process. The lane changing model has a major impact on traffic flow, with route shifting decisions depending on the driver's goals and the number of conflicts that this maneuver will create. Gap acceptance models are used for the execution of this model, because the change of track is only made if there is space between vehicles greater than the least acceptable space (critical gap) [9].

## 2.3 Traffic Conflict

The whole accident is necessarily preceded by a traffic conflict with failure or absence of evasive maneuver [11]. The conflict as an event involving the interaction of 2 or more users of the road system, where at least one user involved takes evasive action, e.g., locking and/or deflecting, to avoid a collision [10].

According to Robles [12], the most used technique for the study of accidents is the TACT, because it is where satisfactory results in terms of road safety can be obtained. Because, in order to analyze certain locations, historical series of data are often not available. Thus, without access to this

amount of information, the TACT allows setting the parameters needed to define an improvement in road safety conditions in a satisfactory way. Nevertheless, a TACT should be used as a supplementary tool to one of the other techniques as an ancillary measure to identify possible road safety improvement measures.

According to Pietrantonio [13], a conflict is composed of four phases: i) the first individual performs an action; ii) the second individual is at risk of accident; iii) the second individual reacts to the action by locking and/or bypassing; iv) the second individual follows his course in the lane.

Therefore, one of the main objectives for traffic and transport engineers is to maximize the safety of the road network, either by improving the existing network or by creating new transport models, there are several factors, such as the driver, the infrastructures, etc. which influence road safety [13,14], being necessary to work around these problems.

### 2.3.1 Security Safety Measures

Safety performance measures are defined as reflecting events with high risk relative to a projected collision point. Typically, these measurements are based on relationships between vehicle speed and space attributes. The measures are as follows [14]:

- Time to Collision (TTC) - defined as the time required for two vehicles to collide when they continue to run at the same speed and on the same path.
- Time to Accident (TTA) - time that elapses from the moment one of the road users reacts and begins an evasive maneuver until the time the user involved reaches the collision point if both road users continue to speed and the direction is unchanged.
- Post-Encroachment Time (PET) - defined as the time difference between the moment the "offensive" vehicle leaves the area of potential collision and the moment the other vehicle enters the collision area

It is possible to obtain a relation between TTC and PET in scenarios where there is persecution between vehicles.

## 2.4 Development of a Case Study

In order to test the use of micro-simulation tools (software) in the study of the operation of highways, it is necessary to develop a case study modeling a fast lane in an urban area, taking into account the available data on the demand and operation of the traffic zone to be modeled. With the results obtained with the VISSIM micro-simulation software, these results will be used in the SSAM software to

analyze existing conflicts in the course under study. Thus, it is presented a brief description about both software.

### 2.4.1 PTV VISSIM

The PTV Vissim is one of the most used worldwide software for microscopic modeling, due to its great level of microscopic detail, what allows the user to execute a realistic model quite effectively. This program can model urban and rural traffic and pedestrian flows, as well as the modeling of public road transport and private rail and transport [14].

The basic way to model a given network, or part of that network, is to connect points (intersections) with arcs and connectors (paths and path variation elements). The arcs can have one or more paths per direction, the connection between different arcs being carried out through connectors, thus building the model network. The larger the network to represent, the greater the number of arcs and connectors needed for this construction. It is in the arcs and the connectors that in these can be limited speeds and/or edit geometric parameters, such as track width, number of tracks, slope, conflict zones, etc., according to reality [14].

### 2.4.2 SSAM

This traffic conflict analysis software currently identifies, classifies and evaluates traffic conflicts based on trajectories previously defined in microscope models, e.g., PTV VISSIM software. [16]

Microsimulation is normally required to generate and collect statistical data on the severity of conflicts and/or other measures that require detailed information, such as acceleration and deceleration of vehicles, among others, that function as a substitute to in situ studies. [15]

## 2.5 Analysis of Results (Data Outputs)

After the use of both simulation software in the network in question, an analysis will be made of the results obtained, in order to perceive the reliability of the software used in traffic modeling, as well as the factors that have the strongest influence in road safety in highways, with focus on the influence of speed, intervals between vehicles and gap acceptance.

## 3 Case Study

According to Loureiro *et al.* [18] cities should also be studied and explored as working systems,

with the same needs and requirements in terms of safety and well-being that are considered for other systems, where traffic management can play an important role. Safety is a key factor to achieve urban resilience especially in transportation systems [19], and are also an important issue for other transportation systems, like public transportation [20].

The case study involves the development of a microsimulation model of a road interchange of the freeway of the city of Guimarães. A traffic model was developed in VISSIM, whose data later served to carry out a safety study through the analysis of some parameters that will allow the evaluation of the number and the severity of the conflicts in this intersection. In the following figure 3 we see the drawing of the node made in PTV VISSIM software.

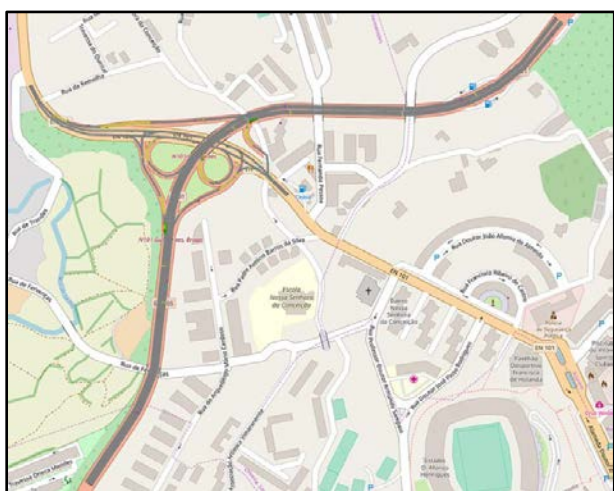


Fig.3: Interchange modelled. Source: Own creation.

Field data were collected in the network in order to ensure the reliability of the modelled interchange, and can be compared later with the results obtained in the software.

Data collection included traffic volumes, maximum and average queues and vehicle travel times.

The data collection was done at the morning peak hour (8:00 – 9:00). The traffic counts in the interchange of Fermentões included traffic counts in 8 points on the National Road – EN101, which crosses (uneveled) the freeway and the access to the freeway is made from 6 branches, and also in 4 points along the freeway (figure 4) [3].



Fig.4: Count Points in Fermentões node. Source: Google.

In order to create a traffic model for the network under study, three types of motorized vehicles were taken into account: light, heavy and buses. After this data collection, the data obtained were processed and the main results introduced in VISSIM. The insertion of the traffic volumes in the simulation software was performed with the traffic counts for periods of 5 minutes that were converted into hourly rates.

The values used in the software for the calibration and validation stages will be presented below, where some of these values have remained unchanged, that is, they were already predefined by the software as default values and others were adjusted in order to get closer to reality.

- Speed: the speeds used have been set according to the limit defined in the road code for urban expressways;
- Acceleration: the acceleration pre-defined in the software is  $3.5 \text{ m/s}^2$ , but it was changed to  $2.3 \text{ m/s}^2$  [21]
- Priority rule: The software presets a minimum interval of 3 seconds and a minimum distance of 5 meters, which have been changed to a range of 1.5 seconds and a minimum distance of 3 meters. The changes were made after observation in the road network of the users, who tended to maintain a small safety distance for entry into the road and a high reaction time;
- Distancing for an immobile object and between vehicles: for an immobile object, the distance in the software is set to 0.5 meters and has been changed to 1.0 meters;
- Overtaking: it is predefined that vehicles can pass right or left, which has been defined as a slow road, the right lane, which provides overtaking only by the left lane;

- **Positioning:** the position of the vehicles remained unchanged, that is, they are positioned in the center of the road;
- **Number of vehicles observed:** the number of vehicles the driver can observe is set to 4, i.e., he can predict the behavior of up to 4 vehicles around him;
- **Visibility:** 0.0 meters has been set for the minimum and 100.0 meters for the maximum front and rear visibility distance;
- **Lateral distance:** for a speed of 50km/h is set to 0.70 meters. When the vehicles are stationary, the lateral distance is about 0.50 meters;
- **Wait Time Before Disposal:** The time set for vehicles to wait, before being deleted from the model, is set to 30 seconds;
- **Cooperative change of track:** this function has been activated in order to improve traffic flow in the model, preventing vehicles from being immobilized while waiting for entry in another chain;
- **Advanced Convergence:** This parameter, when activated, acts as a precaution so that vehicles do not wait too long to change lanes.

Through an iterative process, the model was calibrated using the modelled traffic volumes in control points defined for calibration purposes, comparing these to the actual volumes observed in situ. The initial comparison mode was the GEH parameter and, afterwards, the remaining comparison parameters (Pearson's R, RSMP and RMSE) were used. In order to reach an optimal value, 28 iterations were performed, changing the values of some parameters previously mentioned.

For a GEH value to be acceptable, the ratio between observed and modeled traffic volume must be less than 5 (vehicles/hour) in each section that must be accomplished in at least 85% of the sections.

Table 2. Observed and modeled traffic volumes (1st iteration)

Traffic counting points	1 <sup>st</sup> iteration		
	Traffic Volumes		GEH
	Observed	Modelled	
A3	2415	1849	12.258
A6	2455	2366	1.813
Y2	1010	872	4.499
Average			3.095

After the first iteration, a series of measurements and changes of the modeling parameters were introduced in order to reduce the gap between actual

values and modelled for the calibration points. To achieve this, the percentage of vehicles choosing routes where the modeled volume was higher than that observed was gradually decreased. After 28 iterations, the calibration process of the model for the interchange was concluded, with the results presented in table 3.

Table 3. Observed and modeled traffic volumes (28th iteration)

Traffic counting points	28 <sup>th</sup> iteration		
	Traffic Volumes		GEH
	Observed	Modelled	
A3	2415	2183	4,84
A6	2455	2392	1,28
Y2	1010	898	3,63
Average			3,25

As it is possible to observe the GEH values are less than 5.0 at all points used for the calibration and the mean of GEH is also below 4.0, i.e., it is possible to consider that the model is calibrated considering the variable of the traffic volumes. After calibrating using the assessment of the GEH parameter, three more parameters were used to test and confirm the calibration of the model, such as the Mean Square Error (RMSE), Mean Square Error Percentage (RMSP) and the mean correlation coefficient ( $r$ ) – Paerson's R, that are presented in table 4.

Table 4. Criteria used in calibration

Traffic counting points	Traffic Volumes		GEH	RMSE (%)	RMSP (%)	$r$
	Real	Modelled				
A3	2415	2251	3395	8.191	7.176	0.99
A6	2455	2327	2.617			
Y2	1010	919	3.930			
Average	980	916	2.981			
Difference	823	792				

In many cases vehicular volumes were only used to carry out the calibration and validation process of the traffic models, e.g., in Serra [3]. However, for the present case study and taking into account some specific characteristics of the interchange, such as slope of roads and visibility issues related with the horizontal curve of the roads, two more variables were used to calibrate the model: the average travel time and the average number of vehicle in queues at three specific points.

For the model validation it was necessary to use different points in relation to those that were used for the calibration. The traffic volumes used for calibration were selected from several outer points

of the case study area (external volumes). In the validation, the objective is to prove that the model reproduces the reality and to show the maximum coherence in terms of traffic flows. Thus, it was selected some internal points of the study network (interchange), which are identified in the Figure 4.

Calibration is done by comparing the modeled values with the values obtained in the field by visual means, for these two parameters. Regarding travel time, there is a greater discrepancy at point A4, mainly due to the geometry of the road, which in this case presents a curve and a steep slope, speed by the drivers at about 15 or 20 km/h in relation to the limit established by law. In the following table 5 we see the results obtained for the mean of travel times.

Table 5. Difference in travel times observed and modelled

	Average Travel Times Observed (seconds)	Average Travel Times modelled (seconds)
A4	13,400	16,145
A5	14,430	13,385

The process of obtaining the values referring to the average length of the waiting queues, the maximum value and the number of queues that occur, starts with the placement of an observer at each counting point. As in the volumes, for the evaluation of this parameter, counts were made in the rush hour period (8:15 - 8:45). Only way counted 45 minutes for each point.

The counts can be averaged for the parameters under study in meters. For the calculation of the different averages, the average value of the vehicle length of about 4.5 meters was used, the average value calculated from the results obtained in the traffic simulation. Thus, with the observed values it is possible, then, to make the comparison with the models.

It can be seen that the values of the "average number of waiting queues observed" and the "average length" of these queues are close to the modeled values, but it should be noted that if there is a small difference that can be associated with the measurement method and inexperience of the observer. The largest difference of the values obtained is observed in the "average length of the waiting queues", in meters, of the points Y13 and Y17. However, it should be noted that despite the fact that the model does not present the same results, it presents acceptable similarities with reality, thus assuming the calibration of the model is complete.

Table 6. Differences obtained in queues in various parameters

	Average value of					
	number of waiting queues		maximum queue length		length of queues	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Y18		10,17	18,00	15,74	0,64	0,69
Y13	8,50	10,50	13,50	13,63	0,38	0,98
Y17	9,50	7,92	15,75	12,47	0,41	0,25

For the validation of the model it is then necessary to use different points in relation to those that were used for the calibration. For the calibration, the traffic volumes were used in several outputs of the traffic network (external volumes). In the validation phase, we want to be able to reproduce the model as close to reality as possible and to show the maximum coherence in terms of traffic flows, so that some internal points of the study network (connection node) were chosen to validate the model.

The criteria used are the same as those used for the calibration, i.e., the GEH, the RMSE, the RMSP and the correlation coefficient (r), whose results are presented in Table 7.

Table 7. Criteria used in validation

Traffic counting points	Traffic Volumes		GEH	RMSE (%)	RMSP (%)	r
	Real	Modelled				
Y7	194	217	1,604	13,193	1,065	0,970
Y8	440	436	0,191			
Y9	644	566	3,171			
Y11	342	298	1,604			
Average	270	252	1,238			

Traffic conflicts are then analyzed using SSAM software from FHWA. SSAM operates through a continuous analysis of all the photo frames of the trajectory file of the various vehicles used in a simulation. These trajectories result from the traffic model created in the Vissim.

The types of conflicts that were analysed were the rear end, lane change and crossing conflicts (Figure 5) in order to evaluate and analyze the results of the Time to Collision (TTC) and Post-Encroachment time (PET). In the present study, TTC worked between 0.0 and 1.5 seconds because, so it only evaluates moderate or serious conflicts.

Once the conflict assessment parameters are defined, all the conflicts that occur in the traffic model are obtained. Table 8 shows the total number of conflicts for the traffic model of the Fermentões interchange, which potentially occur at peak time (8:15 - 9:15) of a regular day, which will be around 1303 conflicts, divided in three categories.



Table 8. Number of conflicts

Total number of conflicts		1303
Type of conflict	Rear end	1174
	Lane change	107
	Crossings	22

According to the results presented in Table 8 it is possible to conclude that the most frequent conflicts are the rear end conflicts (1174) and that happens a little throughout the entire interchange and are more frequently in the entrances and exits of the freeway, as can be observed on the map of Figure 5. The same can be seen for the lane change conflicts, which also appear in the entrances and exits of the freeway, but much less frequently than the rear end conflicts. Yet, crossing conflicts occurred only in the National Road, in the movements from exiting the freeway towards Hospital to Azurém, for drivers who go to Braga, and at the entrance to the freeway for those who come from Guimarães.



Fig.5: Types of road safety conflicts. Source: Own creation.

The rear end conflicts are very high due to designing characteristics of the interchange, since it is a horizontal curve and with a high road gradient. Thus, situations where the pursued vehicle starts a braking will induce an evasive maneuver in the pursuing vehicle to avoid collision, and may need to brake, that is, if the pursuing vehicle is very close to the pursued, this braking action will count as a conflict. Since the period of analysis refers to the rush hour, where there are many users who drive aggressively, a very small space between vehicles has been defined in the model, and consequently there is an increase in the occurrence of rear end conflicts.

## 4 Analysis of Results

Despite the vast amount of parameters in PTV Vissim and SSAM software, it is not possible to find a set of guidelines that allow the modeler to easily identify which parameters to change for the model to be calibrated. In this specific case, the objective

of the sensitivity analysis was to try to understand how the parameters that were used to calibrate the model in PTV Vissim varied, namely:

- volumes of traffic;
- travel times;
- average length of queues;
- and the SSAM variable – number of conflicts.

When changing some modeling parameters, such as:

- speeds;
- spacing between vehicles;
- interval between successive vehicles;
- acceptance of gap intervals.

The selection of parameters was due to the information and experience of the modeler, which was collected during the work, namely in the phases of creation and calibration of the model in PTV Vissim where it was possible to verify the influence and importance of some parameters.

### 4.1 Speed Variation

In order to analyze the performance of some network operating parameters with the change of speed, three speed variation scenarios were created in relation to the limit established by law: 1° - speed increase by 10 km/h; 2nd - speed increase by 20 km/h; and, 3rd - speed decrease by 10 km/h.

As can be seen in the Figure 6, traffic volume increases, but not significantly, at points A3, A6 and Y2 progressively with increasing speed. With the decrease in speed, traffic volume decreased in relation to the volume obtained in the parameters where the increase occurred.

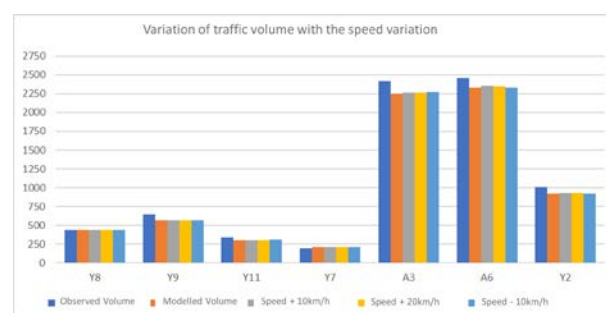


Fig.6: Variation of traffic volume with the change of speed. Source: Own creation.

Figure 7 shows the variation of travel times with the change of speeds. From the analysis of the results presented in the graph it can be concluded that increasing the speed at 10 km/h, the travel time approximates the times observed at point A4, while at point A5 it decreases and departs from that observed. With the increase of 20 km/h, there is a

significant increase in point A4. This increase indicates a shorter decision time for drivers driving on A4, so they will have less time to carry out the maneuver of change by increasing the necessary deceleration and causing further disturbances in the track, with subsequent drivers having to slow down also increasing, therefore, the average travel times. When speed is reduced, there is an increase in travel time relative to the increase in speed at both points.

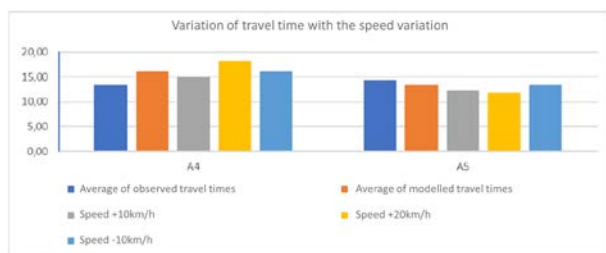


Fig.7: Variation of travel time with the change of speed. Source: Own creation.

With regard to the average length of waiting queues, it can be seen in the Figure 8 that, in relation to the final model, if the speed increases, a significant increase in queue length occurs at all points where it was evaluated, and there was a smaller variation of that queue when the speed was reduced. Nevertheless, there is generally a decrease in mean length. At point Y13 the values do not approach the observed value, being much closer to the modelling and registering almost twice the length of the queue for all the scenarios.

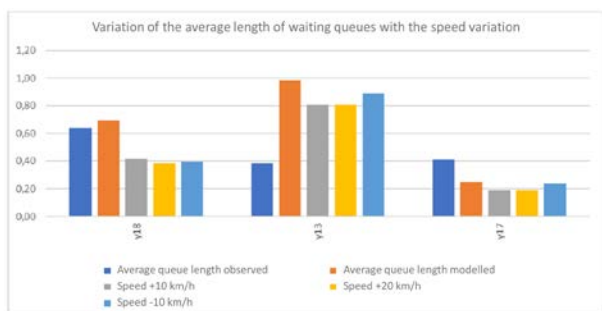


Fig.8: Variation of the average length of waiting queues with the change of speed. Source: Own creation.

In Figure 9 it can be seen that the number of approach conflicts increases when the speed is increased by both 10 km/h and 20 km/h. However, when the speed is slowed down, the number of conflicts is similar to those recorded in the final model. For change of track and crossing conflicts, there is a slight increase with the variation (positive and negative) of the speed, in relation to the final

model. But the increase in these types of conflicts is not significant in any case.

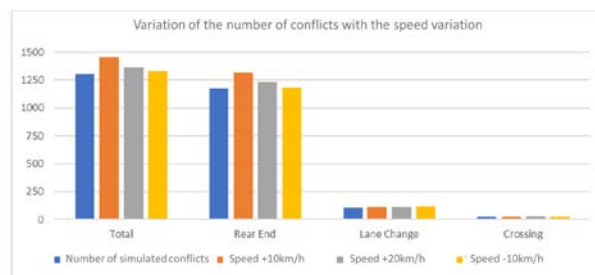


Fig.9: Variation of the number of conflicts with the change of speed. Source: Own creation.

### 4.2 Variation of Vehicle Spacing

To evaluate the impact of the vehicle spacing variation, two scenarios were defined: 1st - increased to 1.5 meters, and 2nd - increased to 2.0 meters. It should be remembered that the value of 1.0 meter for the final model in this parameter was used.

In terms of traffic volume, it can be seen from the figure that there are no significant changes in the volume value as a function of vehicle spacing at the counting points for both scenarios in relation to the final model.

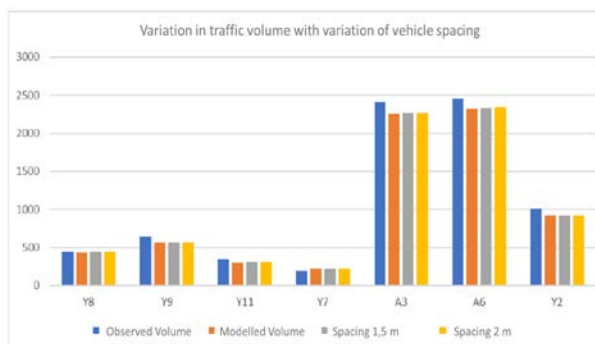


Fig.10: Variation in traffic volume with variation of vehicle spacing. Source: Own creation.

In Figure 11 it can be seen that there is a great increase in travel times at point A4 for the first scenario and an approximation of this value to the travel time observed for the second scenario. For the second scenario it is noticed that with the increase of the spacing between vehicles there is a greater fluidity of traffic, decreasing the travel time and also the number of approach conflicts. For point A6 there are no variations in average travel time as a function of vehicle spacing for both scenarios.

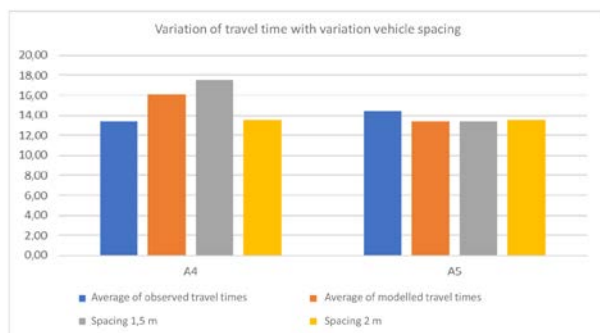


Fig.11: Variation of travel time with variation of vehicle spacing. Source: Own creation.

The average length of the waiting queues shows a decrease for both scenarios at point Y18 and no changes at the remaining two counting points, as shown in Figure 12.

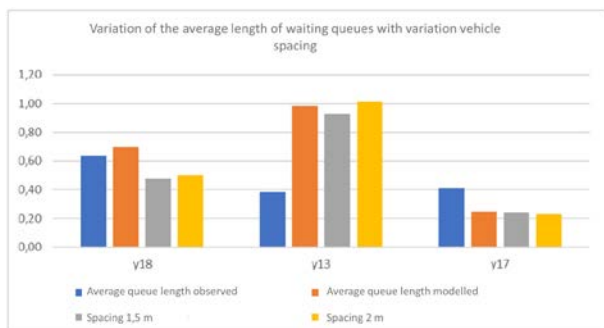


Fig.12: Variation of the average length of waiting queues with variation of vehicle spacing. Source: Own creation.

Increased vehicle spacing indicates safer driving in terms of pursuit and turnaround behaviour. In Figure 13, this effect can be proven to increase security, what is a great decrease in the number of conflicts, especially those involving approximations, where this number is reduced by about 200 conflicts. For track-change conflicts, the difference is not so noticeable, since for the first scenario the numbers of conflicts remain practically unchanged, and there is a larger decrease for the second scenario. For cross-conflict conflicts there is an increase in the value of 20 conflicts for both scenarios.

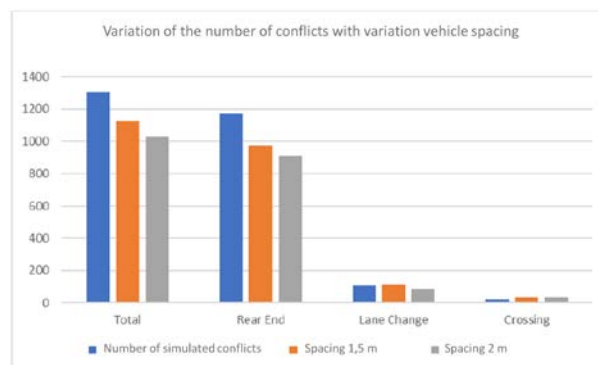


Fig.13: Variation of the number of conflicts with variation of vehicle spacing. Source: Own creation.

### 4.3 Variation of Time Interval between Successive Vehicles

For this parameter only one scenario was created, in which the interval between successive vehicles (i.e., the vehicle's time for the front vehicle) was changed from 0.5 seconds to 0.9 seconds, values standardized in the PTV VISSIM software.

The change of this parameter presents results very similar to the alteration of the spacing between vehicles. In Figure 14 it is possible to confirm that there are no significant changes in traffic volumes.

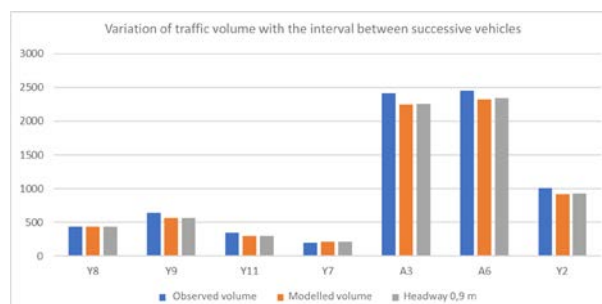


Fig.14: Variation of traffic volume with the interval between successive vehicles. Source: Own creation.

In Figure 15, we see that there is a small increase in travel times, compared to modelling, at point A4.

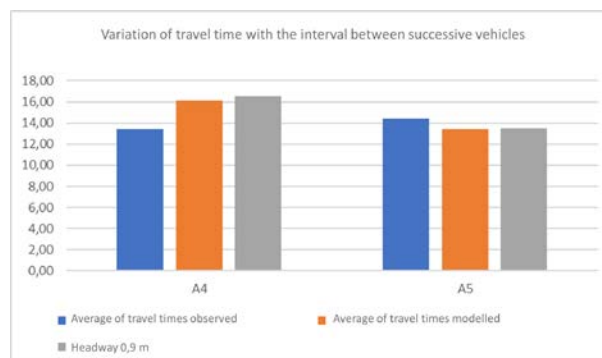


Fig.15: Variation of travel time with the interval between successive vehicles. Source: Own creation.

In Figure 16 it is possible to observe that the average waiting queue length decreased significantly at all counting points in relation to the final model: in addition, as already observed, the difference between observed and modelled values was significant in points Y13 and Y17.

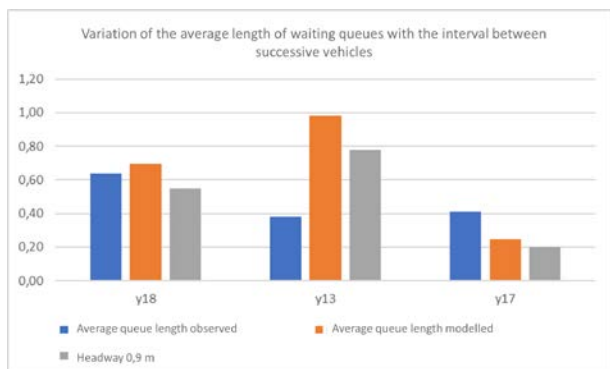


Fig.16: Variation of the average length of waiting queues with the interval between successive vehicles. Source: Own creation.

On the other hand, it is also possible to observe a sharp decrease in the number of approach conflicts. The change in this parameter also indicates an increase in traffic flow and an increase in the time for drivers to take decisions, thus driving less aggressively.

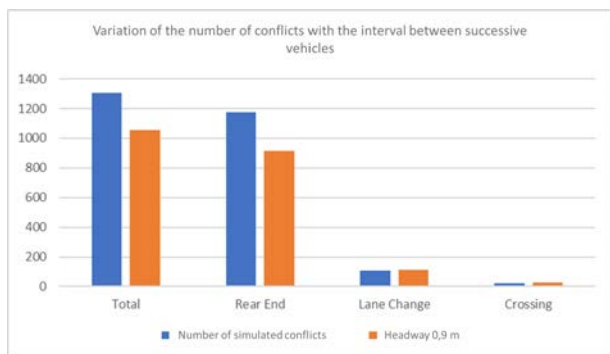


Fig.16: Variation of the number of conflicts with the interval between successive vehicles. Source: Own creation.

#### 4.4 Variation with Change in gap acceptance

The last parameter to be analyzed was the gap acceptance where, in this case, two different scenarios were created. In the first scenario the gap acceptance value was changed to 2.5 seconds and in the second scenario to 3.5 seconds.

As shown in Figure 18, traffic volume remained broadly similar to the volume of traffic modeled, with the exception of the second scenario at points

Y11 and A3, where a large number of vehicles were lost at that point.

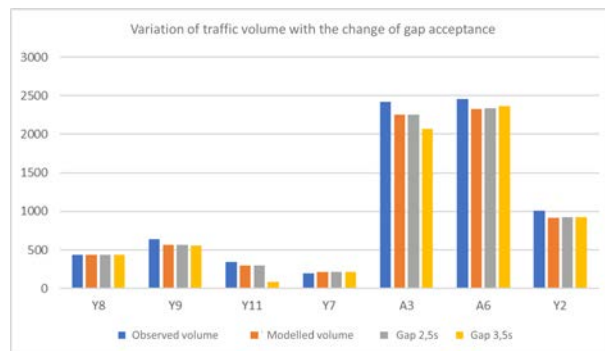


Fig.17: Variation of traffic volume with the change of gap acceptance. Source: Own creation.

Travel time also remained practically similar at point A5, reducing only slightly in the second scenario. Already in the A4 point it is possible to verify that there is a greater alternation of the values, where for the first scenario the travel time approaches the observed one and for the second there is already an increase that surpasses the value of the final model, as can be seen in Figure 19.

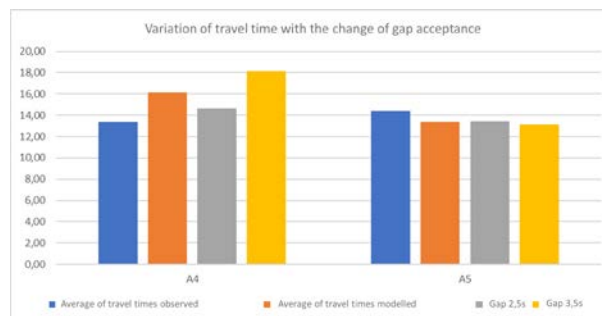


Fig.18: Variation of travel time with the change of gap acceptance. Source: Own creation.

With the values obtained for the average length of the waiting queues (Figure 20) it is possible to observe that there is a continuous decrease in the points Y18 and Y13, in relation to the final model and a similarity in all scenarios at point Y17. At point Y18 we see that with the descent, the values exceed the values observed and at point Y13 we see that the values tend to approximate the observed.

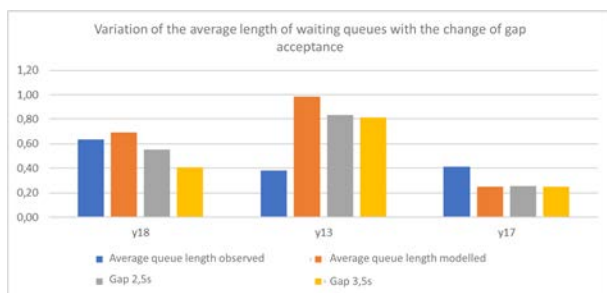


Fig.19: Variation of the average length of waiting queues with the change of gap acceptance. Source: Own creation.

As far as conflicts are concerned, we see that there is a very large increase in the total number, especially in conflicts of approach. These values are due to the fact that the increased gap acceptance value indicates that drivers will accept longer intervals than were defined in the final model. This will increase the congestion of the track, while the drivers wait for larger intervals that appear less frequently than the smaller intervals. These values for gap acceptance indicate safer driving, but even so we see that the number of conflicts increases, since there is a constant acceleration and deceleration by the drivers, causing a constant collision route between the two vehicles, which is activated when the TTC and PET limit values are exceeded. A collision route can be activated countless times during traffic congestion, resulting in an increase in the number of conflicts.

However, according to the results presented in Figure 21, it is possible to conclude that the greater the gap acceptance value, the greater the number of conflicts in the road.

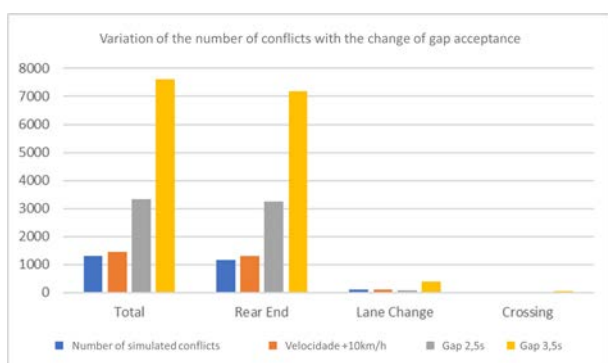


Fig.20: Variation of the number of conflicts with the change of gap acceptance. Source: Own creation.

## 5 Conclusion

Through the work carried out it was possible to perceive the importance of simulation models, more precisely the microscopic models, for the

management, planning and future projects of requalification or construction of urban roads. These models help in testing and analyzing future road design, without the need to address the real changes in the road or network experiences, thus not pestering users.

Thus, with the use of the Vissim PTV software to carry out these microscopic models, it was possible to develop a road network and study all vehicular interaction processes during morning rush hour, pre-defined time interval, perceiving, through simplifications along of the calibration, which are the most important parameters that influence the behavior of the vehicles of the traffic chains along an urban road, or particular sections such as the intersections. Also, with Vissim it was possible to analyze individually the influence that each parameter has on the modeling of nodes connecting an urban road network, realizing the consequences, that the variation of a parameter for several values have in the traffic flow.

The conflicts were also classified into three types: approach, change of route and crossing, and it was verified that, in the connection node under study, the number of conflicts due to approximations is largely superior to the other types. In addition, the SSAM also allows to evaluate the TTC and PET values of all the vehicles used in the simulation, and it is also possible to analyze the conflicts regarding the level of severity (collision, very serious, severe and average).

The location of the conflicts was obtained through ESRI's ArcGIS Geographic Information Systems software, which allowed the creation and geographic information processing through the creation of maps. SSAM itself allows you to visualize the conflict map, but with much less graphical quality and possibility of interaction. Thus, when obtaining the results of the conflicts, it was possible to verify that the SSAM does not distinguish dimensions of the trajectories of the vehicles under analysis, which were pre-defined in VISSIM, resulting in a high set of "cross-over" conflicts since it placed the roads that had different dimensions with the same value of zero. After perceiving this malfunction, these non-existent conflicts were manually withdrawn.

After obtaining the results for the final model of the road network, a sensitivity analysis was carried out, where it was attempted to explore the influence of the variation of some parameters in traffic volumes, travel times, waiting queue lengths and conflicts. The parameters that most influenced the traffic volumes were the gap acceptance variation for 3.5 seconds and the increase of the speed in 10

km/h. The most influential in travel times was the speed increase at 20 km/h and the change of the gap acceptance to 3.5 seconds, while the two speed variation scenarios were the ones that most influenced the average length of queues. The two scenarios of variation gap were, most notably, the one that most influenced the results of the total number of conflicts.

Although an in-depth study was needed to understand the operation of both the software used in this dissertation and the high volume of work associated with data collection on the ground. It is possible to conclude that the work was completed successfully, and it was possible to develop a properly calibrated and validated traffic model that can be used to evaluate the future performance of the Fermentões node and the other nodes that precede it (Hospital) and succeed (Azurém). However, it should be noted that the objective of this work was not to assess the performance of the node in terms of fluidity, but rather to evaluate the safety conditions using the results of microscopic traffic models. Therefore, a vehicle conflict analysis tool/software (SSAM) was used to identify the number and location of the conflicts and thus to evaluate and analyze the safety levels of the ferment node.

#### References:

- [1] J. L. Cardoso, 'Recomendações para Definição e Sinalização de Limites de Velocidade Máxima'. *Prevenção Rodoviária Portuguesa*, 2010.
- [2] C. A. Vilarinho, 'Calibração de modelos microscópicos de simulação de tráfego em redes urbanas'. *MSc Dissertation – FEUP*, 2008.
- [3] J. P. Serra, 'Modelação de tráfego ao nível das interseções. Uma aplicação em Guimarães', *MSc dissertation - Universidade do Minho*, 2017.
- [4] J. de Dios Ortuzar, *Modelling transport: John Wiley & Sons*, 2011.
- [5] R. W., Rothery, 'Car following Models.', *University of Texas*, 1972.
- [6] H. Botma, 'Traffic-flow models.', *Voorburg: Department of Pre-cash research SWOV*, 1981.
- [7] R. Wiedemann, 'Simulation of road traffic flow.', *University of Karlsruhe: Technical report, Reports of the Institute for Transport and Communication*, 1974.
- [8] J. C. Barceló, (2004). 'Methodological notes on the calibration and validation of Microscopic.', *Transportation Research Board 2004 Annual Meeting*, Washington D.C., 2004.
- [9] T. V. Mathew, 'Lane Changing Models.', in *Transportation Systems Engineering*. IIT Bombay, 2014.
- [10] D. Robles and A. Raia Jr., 'Estudo da correlação entre conflitos e acidentes usando a técnica sueca de análise de conflitos de tráfego.', *Universidade Federal de São Carlos-UFSCar, Departamento de Engenharia Civil*, 2010.
- [11] C. Hydén, 'The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique.' *Lund Institute of Technology*, 1987.
- [12] H. Pietrantonio, 'Manual de procedimento de pesquisa para análise de conflitos de tráfego em interseções.', *Publicação Interna, Instituto de Pesquisas Tecnológicas do Estado de São Paulo*, 1991.
- [13] A. Ferraz, A. Raia Jr., and B. Bezerra, *Segurança no Trânsito*. 2008.
- [14] F. C. Cunto, 'Assessing Safety Performance of Transportation Systems using Microscopic Simulation.' Waterloo: University of Waterloo, 2008.
- [15] PTV Group, 'User Manual PTV Vissim 9.' 2017.
- [16] FHWA, 'Surrogate Safety Measures From Traffic Simulation Models., Virginia, USA: U.S. Department of Transportation, 2003.
- [17] K. Vogel, 'A comparison of headway and time to collision as safety indicators.', *Accident Analysis & Prevention* 35 (3), 427-433. 2003.
- [18] I. Loureiro, E. Pereira, N. Costa, P. Ribeiro, and P. Arezes, 'Global City: Index for Industry Sustainable Development', *Advances in Intelligent Systems and Computing*, pp. 294 - 302, 2018.
- [19] P.J.G. Ribeiro and L. A. Pena Jardim Gonçalves, 'Urban resilience: A conceptual framework', *Sustain. Cities Soc.*, vol. 50, p. 1-11, 2019.
- [20] P.J.G. Ribeiro, F. Fonseca, and P. Santos. 'Sustainability assessment of a bus system in a mid-sized municipality'. *Journal of Environmental Planning and Management*, p. 1-21, 2019.
- [21] C. M. C. Araújo, P.J.G. Ribeiro, and F. Cunto, 'Analysis of Road Safety Conflicts. The Case Study of a Road Interchange in Guimarães, PT', *Int. J. Energy Environ.*, vol. 13, pp. 1 - 6, 2019.