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The Impact of the Ring Road Conclusion to the City of Guimarães, Portugal: Analysis of Variations of Traffic Flows and Accessibilities

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Abstract: The high traffic volume is the main source of the congestion in cities, which is a big problem on transportation systems. This congestion is the main cause of the increase in the level of noise and air pollution in urban centers what directly affects the quality of life of the population. Also, contributing to the big number of vehicle conflicts that affects the performance of the transportation systems and the quality of life of the population. These problems are the result of the high volumes of the through traffic. Therefore, to reduce the traffic volume in urban center of Guimarães, Portugal we studied a possible conclusion of the ring road, on the slope of the Penha hill for the morning peak hour. To carry out our study, the Origin – Destination Matrix for peak hour was estimated from the data of traffic counts. Concluding that there was a reduction of the traffic volume in the section of the ring road that was already built. However, in the city center there were no major variations of the traffic volume and accessibilities.

1 Introduction

In the last years, it was verified a high increase in the number of vehicular trips [1]. However, this increase is disorganized, what contributes to changes in climate condition and to the scarcity of natural resources [2]. Therefore, this disorganized increase is not acceptable, being needed a reevaluation based on the energy consumption reduction on transportation [1].

Associated to this increase of the traffic and the energy consumption, there is also the congestion phenomena in urban areas. This is related with the socioeconomic development, the fails in the traffic infrastructure construction and the urban planning that has not developed [3], being currently a big problem to the cities [4], [5]. Thus, the rapid trend of increase of the road traffic in cities, associated with the construction of a harmonious urban transportation system to ease traffic pressure is a common issue faced by many countries in urban development process [6]. The increase of road traffic volume is associated to the reduction of capacity of main roads and streets, being in the origin of the congestion phenomena. These phenomena are a problem for the cities where the solution is not immediate and they have serious consequences on many human activity domains (recreation, work, shopping, cultural activities, etc..). These phenomena also have serious consequence related with the freight transportation, contribution to delays, the lack of reliability, the bad efficiently of the freight transport companies and bad accessibilities to main points of cities. However, this problem is not of easy and quick resolution, so it is necessary to face these problems as they increase the quality of life of urban populations [7], [8].

Therefore, the road traffic congestion is directly related with the decrease of the severity in road traffic accidents because the average speed of traffic is low compared with a scenario without congestions (high speed), what results in less serious accidents, which is a good consequence, in general, of the traffic congestions, however it has another bad consequence in the life of the population [9]–[11]. Because with the increase in traffic volume, the number of conflicts near the intersections between pedestrians, bicycles and motorized transportation modes is bigger [12]–[14].

Other problems that usually are associated to congestion problems and affect the health and life quality of populations in the cities are the increase of noise and air pollution [15]–[18]. The levels of noise from the road traffic affect directly the sleep quality [19], [20], contribute to the increase of the

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stroke [21] and cardiovascular diseases [22]. As the main source of air pollution, the road traffic contributes to the increase of the respiratory and allergic diseases of drivers and residents [23]–[25], affecting the life quality of the population and the level of sustainability of the urban areas [26]. In the dense urban centers, the environmental impact is even more relevant once these places have obstacles like high buildings very close to traffic. These obstacles are associated with narrow streets and in many cases t he local meteorology condition is averse to the dispersion of pollutants from road traffic [27].

In addition, it is necessary to avoid the phenomena of urban congestion due to the existence and conflict of the through traffic in the cities [28] on high hierarchical streets, both at the road network level and, above all, in the performance of the function associated with issues of urban living in sensitive environmental urban areas [28]–[30]. This reduces congestion levels and increases the attractiveness of the suburbs, reducing the number of residents who need the private transport in urban centers [30], [31]. One of the most commonly used techniques is the diversion of through traffic from urban centers and, if possible, all heavy traffic to new high-capacity and high-speed roads, called Rind Roads, and some cities may have more than one ring and so to improve the accessibility in urban centers [32]–[35].

However, this deviation of intra-urban traffic to the ring roads increases the noise levels and emissions of pollutants in its surroundings, due to the increase of the practiced speed and increase of the volume of road traffic [31], [34], [36], [37]. But in the design of this type of road, it is important to take into account the characteristics of the infrastructure, as it plays a very important role in road safety, which is directly related to the quality of the road network protection for the benefit of all road users [38]. Since there is a direct relationship between traffic speed [39] and access points [40] and road accident rates [41]. Consequently, from the point of view of the factors, it is important that the governmental entities that manage the road network and urban transportation systems carry out the development of transportation models and traffic forecasting that allow them to analyze the phenomena of lack of traffic flow, particularly in urban centers, historical areas and other noble urban areas.

Based on all referred factor, in this paper, it is intended to develop a calculation procedure for application in the PTV Visum software and its application to a case study to the city of Guimarães to demonstrate the applicability of this type of tool in urban planning, with the creation of the Matrix Origin - Destination from data of traffic counts. Also, it is intended to analyze the creation of a possible conclusion of the ring road of the City of Guimarães to induce a possible redistribution of the traffic to reduce volume of motorize road traffic in the central urban areas. With this, it is intended to improve the accessibilities in the section of the ring road already constructed. This article is composed of 4 sections. Section 1 deals with the introduction, presenting a su mmary literature review about the subject being studied, but also the objectives and structure of the paper. In section 2 is presented the methodology used. Section 3 presents the case study and analyzes the results. Finally, in section 4 t he main conclusions are described.

2 Creation of a Transportation Model

In this section will be presented the methodology used in this work. Many points will describe the creation of the model, as the OD matrix estimation, validation and calibration process, using the transportation modelling software PTV Visum.

2.1 Physical Characteristics of the Road Network

The creation of the model is a complex process that involves several steps. Thus, during the creation of the transportation model many steps were followed to improve its reliability. Initially, the road network is drawn and characterized according to the real physical characteristics of the road, lanes and intersections. Thereby, the followed objects of de network were created:

- The **Nodes** represent the crossings between the turns defined in the network, which are all the intersections of the network (roundabouts, intersections, priority intersections, etc.);
- The **Links** represent the roads and streets, connecting the nodes to the network;
- The **Turns** represent the possible directional movements to each node of the network;
- The **Zones** represent the origin and destination points of the trips (trip generators and receiver poles).

The creation and draw of objects of the network followed the following methodologic process:

- The creation of necessary nodes in singular points (intersections, characteristic changes of lanes, etc.);
- The creation of the links of the network, being attributed the Link type (road hierarchy) as its characteristics were attributed automatically;
- The creation of the connectors from zones to road network, in a non-excessive number that does not prevent the calibration;
- Withdrawal of the turns non-allowed, node to node, to prevent the movements that do not exist.

For the modeling of the road network, it was necessary to define and characterize a road hierarchy (link types). In table 1 is presented the road used in modelling.

Table 1. Road hierarchy used for modelling [42]

Description	Base speed (Km/h)	Capacity (Veh/h/per sense)
IC – two ways	80	3500
Arterial – two ways	70	3000
Access ramp – one way	50	900
Main distributor – two ways	50	1200
Main distributor – one way	40	600
Main distributor – three-ways one way	50	1700
Main distributor – two-ways one way	40	1300
Local distributor – two ways	50	1000
Local distributor – one way one way	40	400
Local distributor – one way one way	30	500

2.2 Assignment Model

To make the assignment of traffic to road network objects, based on a mesoscopic model, is necessary to define an origin – destination (OD) matrix. This step is very important because the information inserted in the OD matrix defines the number of users who want to travel between two different zones of the area under analysis. Therefore, to define the analyzed period it is necessary to provide the following data:

- **Zoning** – definition of the zones that describe the areas with homogeneous and similar characteristics and land uses, describing the user positions in the road network. These positions correspond to origin and destination points of the trips (travel generators and receivers poles), them centers are denominated "centroid";
- **Initial Origin – Destination (OD) Matrix** – if it is not known the real initial OD matrix, it is necessary to create an initial OD matrix that

allows the convergence of creation methods and estimation of a hypothetical matrix based on traffic counts in a large set of road network elements.

There are several models to perform the OD matrix assignment to the traffic model, from dynamic models to static models. The models most used are the static models, in particular, the assignment equilibrium model. The assignment equilibrium model performs the distribution of traffic demand based on the first principle of John Wardrop. According to this model, each driver chooses a route so that his trip had the shortest possible duration/cost. This model is based initially on an incremental model of assignment of travel data, which leads the driver to select one of two routes with same impedance (duration/cost), that is, it is in a situation governed by an assignment equilibrium model when it is not possible for driver to shorten his travel time without external interventions over which he has no decision – making power. This model is manly used in congested networks with a high saturation degree because it is more efficient, and the effect of the capacity restriction tends to distribute properly to the trips by several routes, being this model more suitable for small networks with few alternatives [43].

To approximate the most possible modelled traffic values to the real values of the counts by allocation model, the PTV Visum software allows the use of the TFlowFuzzy (figure 1) algorithm that enables the utilization of traffic counts to correct and /or estimate the flows of OD matrix so that the results of allocations generate flows in the selected links, or selected turns. The TFlowFuzzy corrects the initial OD matrix comparing the traffic flows in the links and turns resulting from the allocation with the loaded traffic counts. Aiming to validate these counts by adjusting the OD matrix to approximate the most possible modelled traffic values to real traffic values. For the update, the traffic count values are compared to the modelled traffic values resulting from the pre-calculated allocation of the OD matrix that values 10 (with values of the diagonal equal to 0). The difference between the counted values and the modelled traffic values are balanced by adjustment of the OD matrix. This is an iterative process as it begins with the decrease in the error margin. The process ends when it is not possible to further minimize the traffic volumes of the links and turns. During the implementation of the algorithm must be consider the calibration of the

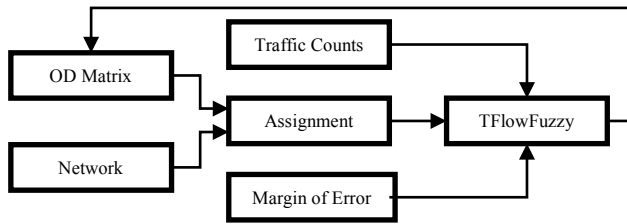network elements having traffic flows and counts [44].

Fig.1: TFlowFuzzy process (adapted from [43])

2.3 Calibration of the Transportation Model

The calibration of the transportation model involves the adjustment of the OD matrix so that the modelled traffic values coincide or approach with the traffic count values within a small and acceptable margin of error. This comparation should be made in different elements of road network (count points) such as links and turns. The parameters correctly used for the calibration of the transportation model are the GEH, RMSE and Scatter plot (R2). The GEH (Geoffrey E. Havers) compares two sets of the traffic volumes (counted and modelled) based on the chi-square test (X2), which can be calculated individually for each link (or turn) or as a global measure for the entire network and is given by equation 1 [45]:

$$GEH = \sqrt{\frac{2 \times (V_m - V_0)^2}{V_m + V_0}} \qquad (1)$$

- V_m – Modelled traffic volume per hour;
- V_0 – Observed (Counted) traffic volume per hour.

The Root Mean Squares Error (RMSE) and the R-square (R2) are correlation statistic measures between the totality of defined count data and the totality of modelled volumes. The RMSE is applied to all data set of comparison and is expressed as a unique value, equation 2 [45]:

$$RMSE = \frac{\sqrt{\frac{\sum (V_0 - V_m)^2}{C - 1}}}{\frac{\sum V_0}{C}} \times 100 \qquad (2)$$

- V_m – Modelled traffic volume per hour;
- V_0 – Observed (Counted) traffic volume per hour;
- C – Number of count points.

For a better interpretation of the results, a graph (Scatter plot) is used to represent the values of the variables observed and modeled, facilitating the visual analysis. The representation consists in the introduction of a linear regression line, with slope equal to 1. When the closer the points are to this line, that is, the higher the coefficient of R2, the better the quality of the simulation [46].

For a calibration and validation of the results, the following criteria must be respected [41]:
- 95% of the links must have a GEH ≤ 5.0;
- 85% of turns must have GEH ≤ 5.0;
- All links and turns should have a GEH ≤ 10;
- Comparison of the modelled traffic values vs. traffic count values;
- Value of R2> 0.9;
- In the scatter plot all values must be (modeled and counted);
- The RMSE value <30,0%.

3 Problem Solution

The case study is referenced to transportation modelling of distributed network of the City of Guimarães, Portugal. This network focuses on the network of main distribution roads, covering the area of the historical center and its surroundings, bounded by an Arterial Road and the Mount of Penha. The study area was divided into 27 zones (figure 2), so that the internal zones ("colored") presented are 14, which aim to represent the operation and main flows that are generated in the interior of the city based on its land uses, and the external zones ("white") presented are 13 as they characterized the points of entry and exit in the city. On the other hand, to the detriment of the non-existence of an initial OD matrix, the assignment will be made based on the estimation of the OD matrix from the traffic counts realized in several intersections presented in figure 2.

3.1 Input Data

The input data used in this study was an OD matrix and the Traffic counts. For the network of the City of Guimarães it wasn't possible to obtain an OD matrix, since the studies of traffic and transportation carried out cover a much larger study area, this is the reason to adopt an initial OD matrix of value 10 with null diagonal and dimension (27X27).
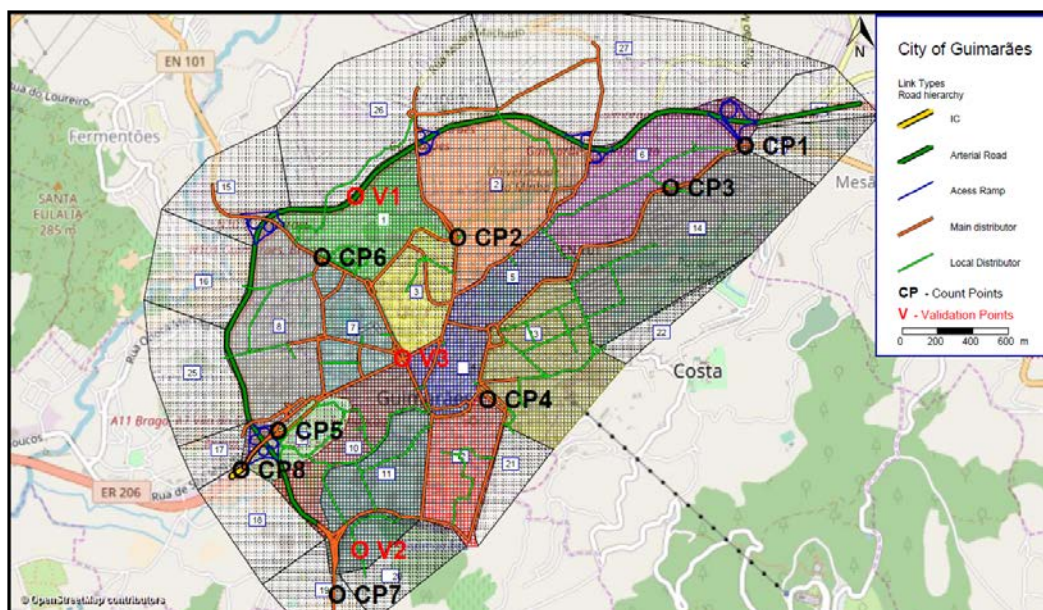
Fig.2: Map of network of city of Guimarães

The used traffic counts are referenced to the morning peak hour (8:15 a.m. – 9:15 a.m), being subdivided into 4 subclasses, motorcycles (MC), light vehicles (LV), heavy vehicles (HV) and Bus (BUS). Then these data were treated and inserted in the transportation model. It was used 8 count points (figure 2), totaling 57 di rectional movements (Turns) and 4 l inks were used. In the modelling process, the traffic was homogenized to the unit of vehicle equivalent (u.v.e.), based on the follow equivalence factors, 1 to motorcycles, 1 to light vehicles, 2 to heavy vehicle and 1,5 to bus [47].

3.2 Results of the Calibration of the Transportation Model

Applying the calibration methodology presented in section 2, it is possible to extract several sets of information, namely, the traffic volumes that are presented in the map of figure 4. Based on the comparison between the counted and modeled traffic volumes calculated in the calculation of the parameters GEH, RSME (table 2) and the analysis of the scatter plot (figure 3), it is possible to conclude that the transportation model is calibrated.

Table 2. Validation of the traffic counts values by parameters GEH and RMSE to peak hour in the morning

GEH			RMSE (%)
	Number of counts	Percentage (%)	
GEH≤5	59	97 %	7,98 % < 30%
5<GEH≤10	2	3 %	
GEH>10	0	0	

After, the transportation model was validated by carrying out traffic counts at three relevant points in the network - V1, V2 and V3 (Figure 2) and the

respective comparison with the traffic values modelled applying the validation criterion - GEH, the result of which is presented in table 3. It should be noted that, contrary to what happened with the other traffic counts, they did not enter in the calibration process of the model. They were only used to validate the model.
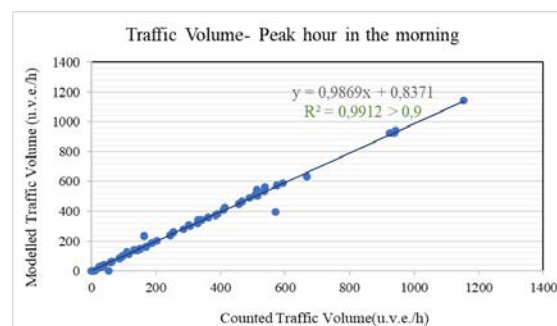

Fig.3: Scatter plot

Table 3. Validation of the model

| Validation points				
Road (validation point)	Direction	Counted traffic (u.v.e./h)	Modelled traffic (u.v.e./h)	GEH
Variant (V1)	West > East	2398	2140	5
	East > West	1397	1344	1
António Costa Guimarães street (V2)	North > South	474	369	5
	South >North	714	798	3
Dr. Alfredo Pimenta Avenue (V3)	North > South	300	317	1
	South >North	362	400	2
S. Gonçalo street (V3)	East > West	72	88	2
	West > East	282	304	1
Conde Margaride Avenue (V3)	One way	493	500	1
Gil Vicente street (V3)	One way	75	112	4
Paio Galvão (V3)	One way	491	491	0
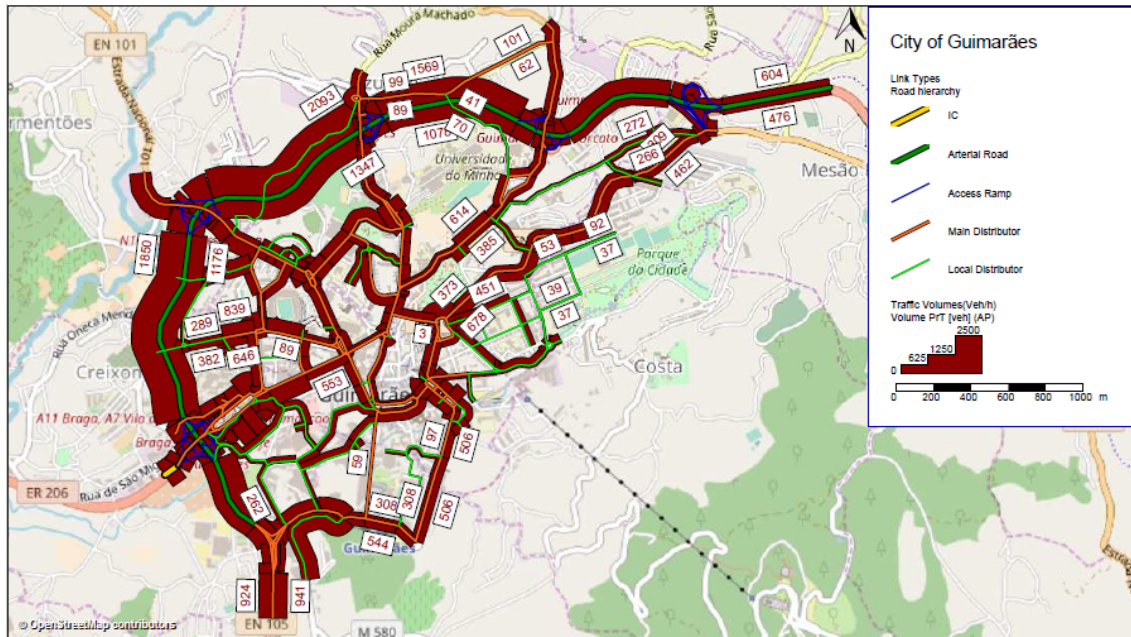
Fig.4: Traffic volumes of the model
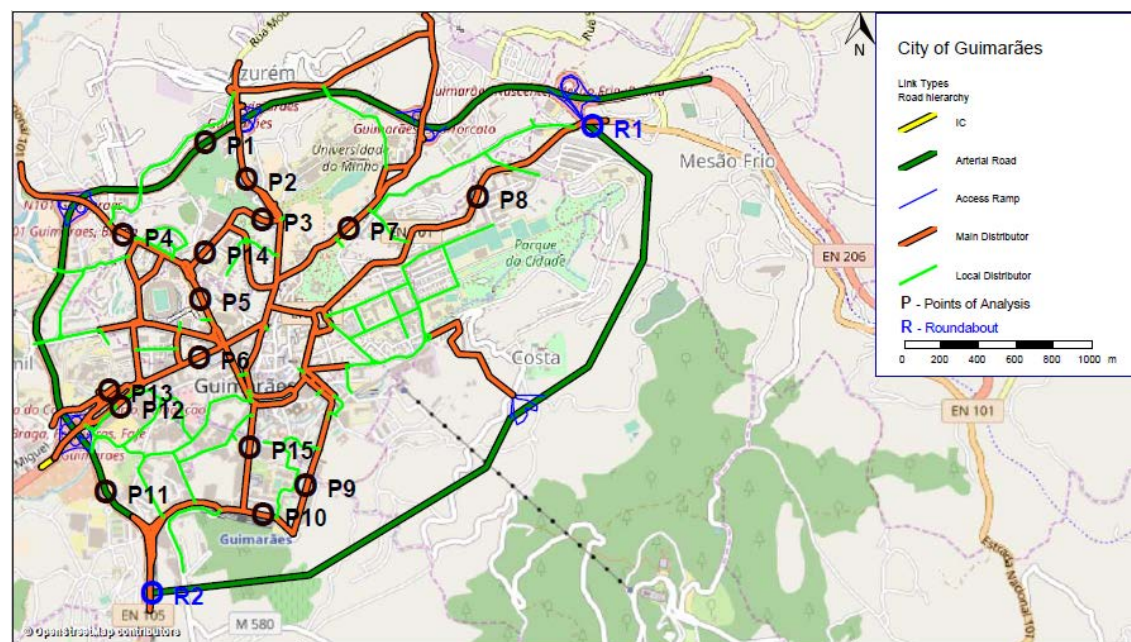
P 1 – EN 101 – Guimarães – Fafe connection	P 10 – Eduardo Manuel José de Almeida Street
P 2 – Universidade Avenue	P 11 – EN 105 – Vizela – Guimarães connection
P 3 – Cónego Dr. Manuel Faria Street	P 12 – Dr. Mariano Felgueiras Avenue (Direction A11 – Guimarães)
P 4 – EN 101 – Braga-Guimarães connection	
P 5 – Alfredo Pimenta Avenue	P 13 – Dr. Mariano Felgueiras Avenue (Direction Guimarães – A11)
P 6 – Conde de Margaride Avenue	
P 7 – São Torcato Street	P 14 – Teixeira de Pascoais Street
P 8 – Padre António Caldas Street	P 15 – D. Afonso Henriques Avenue
P 9 – D. João IV Avenue	

Fig.5: Road Network of the Alternative Scenario

3.3 Scenario Development with the Possible Introduction of the Ring Road around the City of Guimarães

In this subsection, it is presented the scenario and analysis of the conclusion of the ring road of the city of Guimarães, which surrounds half of the city, with the proposed construction of the remaining ring road on the slope of Mount Penha. Consisting the creation of a link between the southern entrance in the city, from Vizela to the northern entrance of the City, from Fafe (two cities from Portugal).

The achievement of this new connection is established using two roundabouts (R1 and R2). Thus, it was constructed a new link branch to conclude the currently ring road of the City of Guimarães (fig. 5). With this new connection it is intended that users can travel from Vizela to Fafe and vice versa more quickly, avoiding the congestion phenomena. This way, an alternative connection to the City Center and Variant EN 101 is offered, which should guarantee the necessary conditions for good circulation as a ring road. To analyze the obtained results, the traffic volumes of the road network were compared between the base scenario and the alternative scenario, and the set of 15 counting points marked in fig. 4 were selected (P). Table 4 and fig. 6 show the variations of the traffic volumes for the peak hour in the morning between the two scenarios.

With the introduction of a new high-capacity road, it was found that the volume of traffic in the peripheral roads decreases, with further decreases in traffic on the selected points (road): P2, P8, P12 and P1, considering a static demand scenario, ie, the OD matrix remains constant and thus it is possible to evaluate a hypothetical readjustment of the demand in the road network, since no significant changes are expected in the overall demand of the transportation systems of the city of Guimarães.

Table 4. Comparison of the volumes of the traffic during morning peak hour

Points	Morning Peak hour			
	Base Scenario Traffic Volume (u.v.e./h)	Alternative Scenario Traffic volume (u.v.e./h)	Traffic Volume variation (u.v.e./h)	Growth (%)
1	3484	2954	-530	-15%
2	1123	887	-236	-21%
3	864	906	42	5%
4	1451	1502	51	4%
5	513	446	-67	-13%
6	512	546	34	7%
7	899	809	-90	-10%
8	1220	697	-523	-43%
9	981	876	-105	-11%
10	1084	939	-145	-13%
11	2783	2475	-308	-11%
12	2131	1809	-322	-15%
13	963	982	19	2%
14	533	1063	530	99%
15	68	22	-46	-68%

On the other hand, it was intended to simulate the creation of an alternative connection between Fafe and Vizela, also allowing a faster connection to the center of the city by the eastern zone, and thus to relieve pressure levels in certain sections of the current variant, such as at important travel-generating poles such as the University of Minho and Hospital of Senhora da Oliveira, as can be seen in the results presented in Figure 6. Only one Point (road) suffered a significant growth rate, P14, maintaining a high ratio of volume/capacity and close to congestion of the road traffic. This way, it is possible to conclude that the change causes only a small reduction of the traffic in the area of the center of the city and in the present variant (existing ring road), thus the closure of the remaining ring of the variant, which is foreseen, is not justified.

Fig.6: Map of the ratio of Volume/Capacity

Although the analysis focuses on the optimization of routes taking account travel times, it should be noted that the partial creation of the ring road on the northeast side of the city will bring considerable benefits from the point of view of road safety and the concentration and emission of pollutants, namely PM10 and CO_2, since Point P8 has a high average slope and is congested at rush hour in the morning. Thus, future work will be carried out to cost-benefit analyze, and consider the different aspects of sustainability, namely the environmental, social and economic benefits in contrast to the direct and indirect costs associated with the creation of such infrastructure.

3.4 Accessibility Analysis of the Possible Introduction of the Ring Road around the City of Guimarães

In this section is presented the analysis of the accessibilities of main interest points and trip generator in the city of Guimarães comparing the base scenario with the alternative scenario. Also, it was selected six main points corresponding to six important places in the de city. These points are the Railway Station, the Bus Station/Guimarães Shopping, the Hospital, the Fire Station/Police Station, the Campus of the University of Minho and the Historical Center of Guimarães. With this analysis it is intended to analyze how the network behaves and allows people to move to some of these points, but more important it is intended to identify the level of readiness and help in the territory of the city of Guimarães, especially with the evaluation of the isochrones in relation to the Hospital, Fire station and Police station. As an analysis of the accessibility of the road network, it used the travel time with the traffic-loaded network. It used the PTV Visum software. Thus, figures 6, 7 and 8 show the map of accessibility of the selected points for the remaining modeled network. It is important to highlight that the phenomena of network congestion, in the peak hour in the morning, will have an important influence in the time spent in the displacements of the different areas of the city for the respective equipment under analysis.
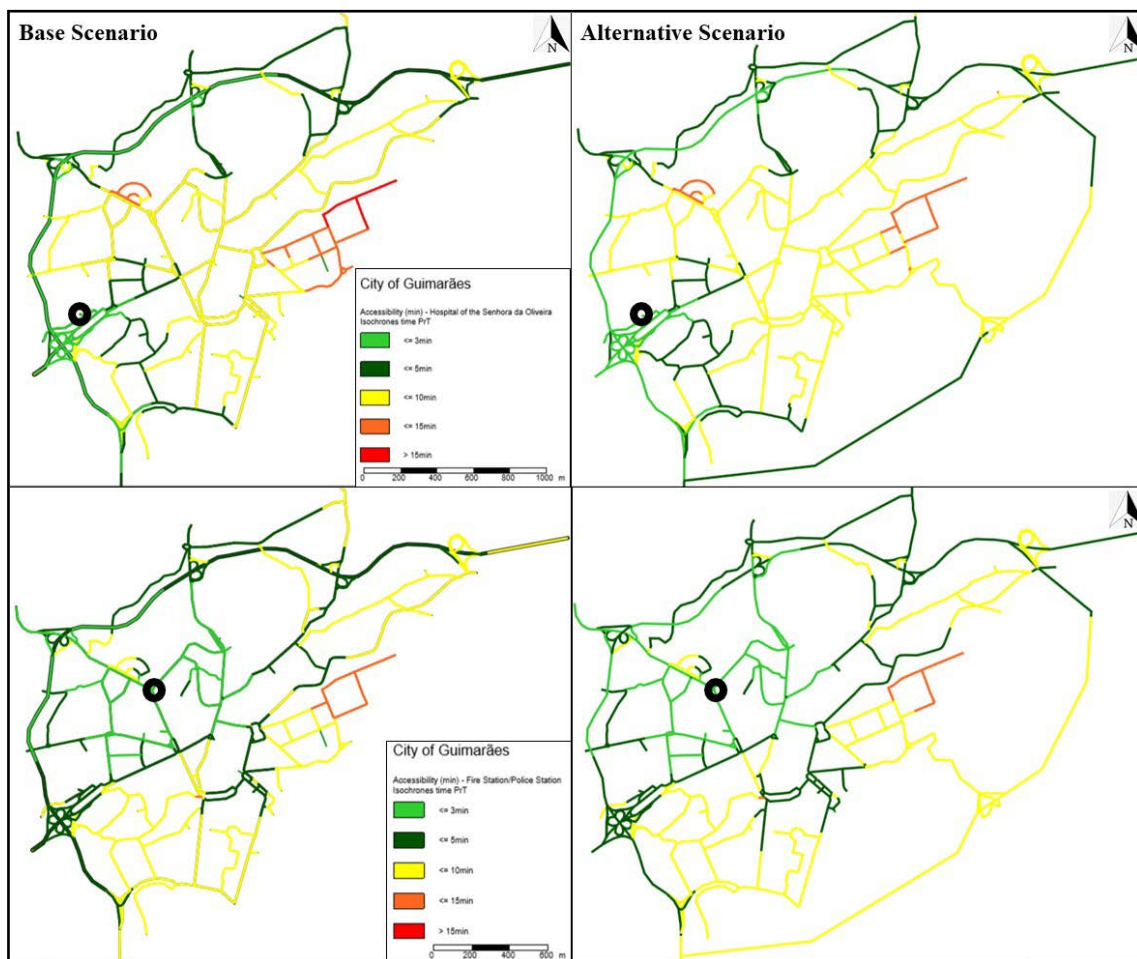

Fig.7: Points of help (hospital and Fire station/Police station)

Figure 7 shows the points of help of the city, the Hospital, the Police Station and the Fire Station. The point regarding the hospital only experienced a slight improvement with the creation of the new road (conclusion of the ring road). This improvement occurred in the east zone. On the other hand, the point concerning the Fire station and the Police Station has experienced some improvements of the accessibility in the generality of the road network. In the east zone, the improvement of the accessibility was 5 min. Other improvements were verified, but these had a lower character in the north zone of the city.

Figure 8 shows the points referring to the two main modal interfaces in the city, the bus station and the railway station. The bus station has only had a significant improvement. This improvement of the accessibility in the east zone of the city. The railway station had some improvements in its accessibility. The most notable improvements of the accessibility were near the bus station, hospital and Police Station/Fire Station.

Finally, figure 9 presents the two remaining points of interest selected, the campus of the University of Minho and the Historical Center of the city. The campus of the University of Minho had only minor improvements in east zone of Guimarães. On the other hand, the Historical Center of the city had some improvements with some impact. The main improvements were in south zone, east zone and near the Campus of the University of Minho. These improvements in accessibility are characterized by a time reduction of about 5 minutes.
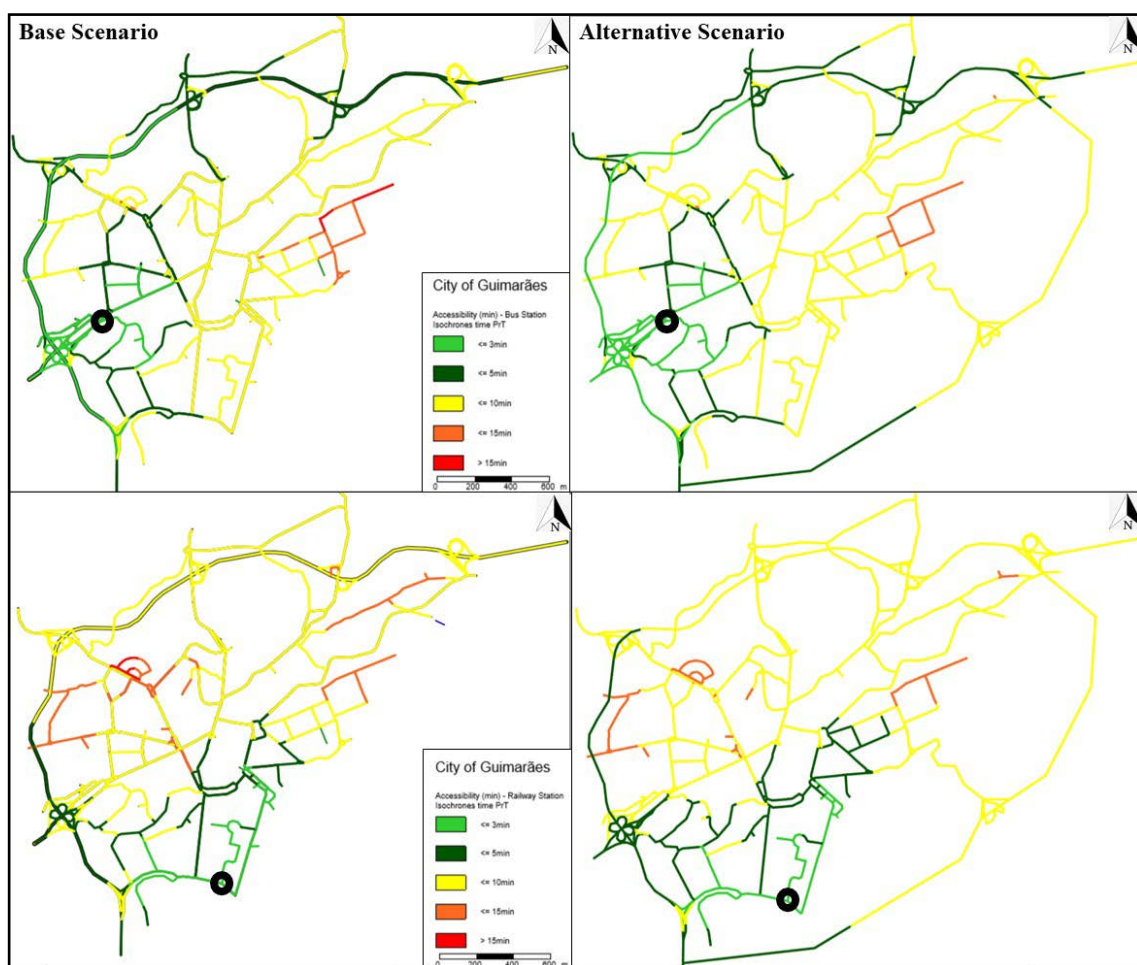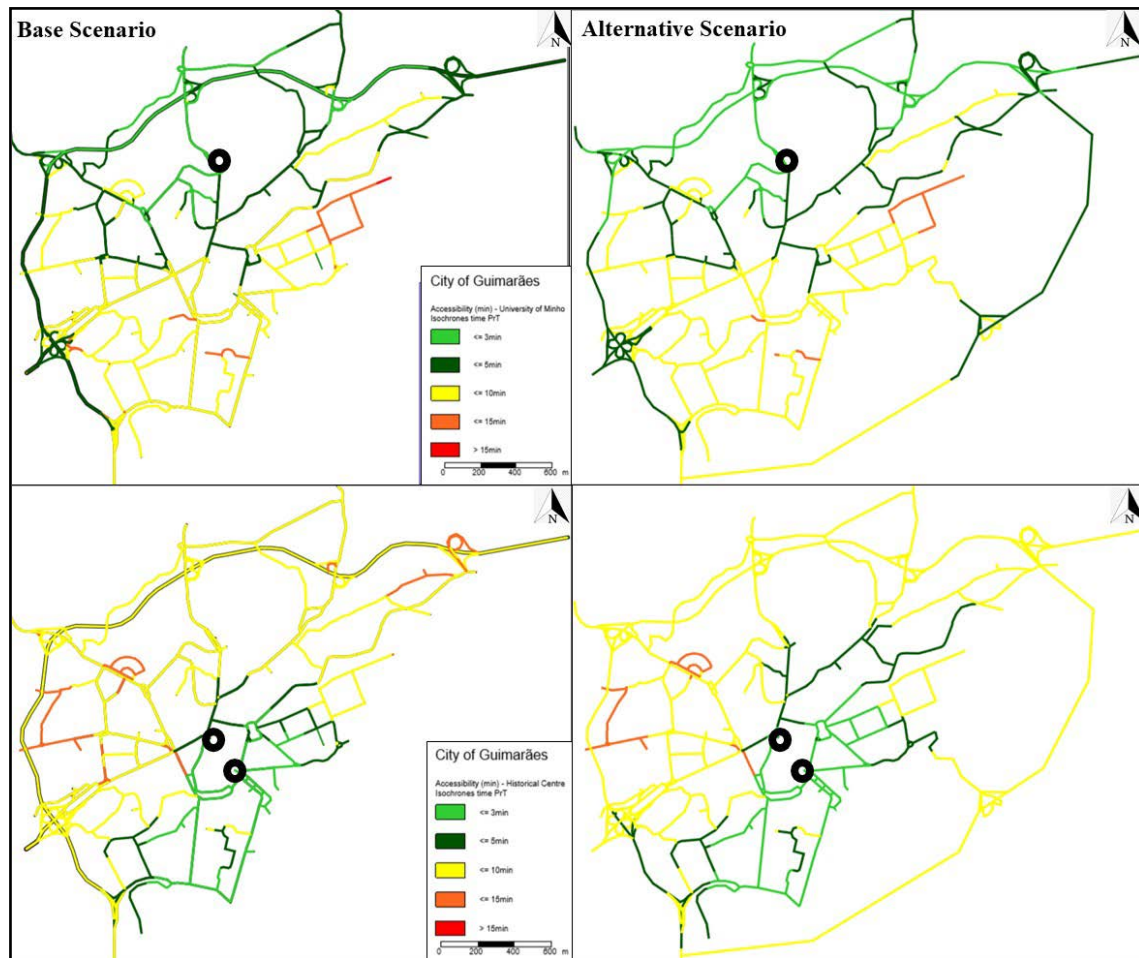

Fig.8: Modal interfaces

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Fig.9: Historical Center and Campus of the University of Minho

4 Conclusion

In this work, a modelling and estimation methodology of the OD matrix for the city of Guimarães, Portugal was applied based on traffic counts for peak hour in the morning, with its calibration and subsequent validation of the transportation model. On the other hand, it is important to highlight the possibility of validation of the OD matrix, since it was not possible to obtain an initial OD matrix. However, with a model it has been validated, being possible to run some tests and develop evolutionary scenarios about the road network of the city, such as testing the impact of some changes in the network operation that may allow to predict and identify the impact level of some proposals.

In the study of the scenario presented in this paper it was possible to verify a significant reduction of the volume of the road traffic in the section of the ring road (Arterial Road) already constructed, having been verified more decrease in other ways of direct access to the city of Guimarães (P2 and P8), reducing traffic congestion problems. Still, there is a high rise in other streets of the city (P15), not leaving this overloaded. It is concluded that the construction of the remaining ring of the ring road is not a task of great importance to contribute to the reduction of the traffic in the urban road transportation network of the city of Guimarães.

Regarding accessibility, more significant improvements were verified in relation to the railway station and historical center in generality of the road network. These improvements of the accessibility were characterized in many cases in improvements of 5 minutes, as the connection between the two modal interfaces (Railway station and Bus station) or the access to the historical center by east zone.

This type of analysis becomes valuable for the managers of territory and mobility and the governmental entities responsible for the management of the transportation systems and networks and for the management of the cities. Thus, despite the limitations that the model has, namely, the absence of an initial OD matrix, it can

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be used for future city evaluations as a complement to transportation and urban mobility planning.

References:

[1]   D. Banister, 'The trilogy of distance, speed and time', *J. Transp. Geogr.*, vol. 19, no. 4, pp. 950–959, 2011.

[2]   K. Nakamura and Y. Hayashi, 'Strategies and instruments for low-carbon urban transport: An international review on trends and effects', *Transp. Policy*, vol. 29, pp. 264–274, 2013.

[3]   A. N. R. da Silva, M. da Silva Costa, and M. H. Macedo, 'Multiple views of sustainable urban mobility: The case of Brazil', *Transp. Policy*, vol. 15, no. 6, pp. 350–360, 2008.

[4]   C. Zhang, H. Bai, S. Wang, and C. Xie, 'Review of Urban Traffic Congestion Formation and Diffusion Mechanism', *CICTP 2015*. Nov-2018.

[5]   F. Rempe, G. Huber, and K. Bogenberger, 'Spatio-Temporal Congestion Patterns in Urban Traffic Networks', *Transp. Res. Procedia*, vol. 15, pp. 513–524, 2016.

[6]   H. Zhou and H. Gao, 'The impact of urban morphology on urban transportation mode: A case study of Tokyo', *Case Stud. Transp. Policy*, 2018.

[7]   J. Zheng, 'Congestion Pricing and Sustainable Development of Urban Transportation System', in *2008 Workshop on Power Electronics and Intelligent Transportation System*, 2008, pp. 449–453.

[8]   A. Solé-Ribalta, S. Gómez, and A. Arenas, 'A model to identify urban traffic congestion hotspots in complex networks', *R. Soc. Open Sci.*, vol. 3, no. 10, p. 160098, Apr. 2019.

[9]   P. J. G. Ribeiro and L. A. Pena Jardim Gonçalves, 'Urban resilience: A conceptual framework', *Sustain. Cities Soc.*, vol. 50, p. 1-11, 2019.

[10]   M. A. Quddus, C. Wang, and S. G. Ison, 'Road Traffic Congestion and Crash Severity: Econometric Analysis Using Ordered Response Models', *J. Transp. Eng.*, vol. 136, no. 5, pp. 424–435, May 2010.

[11]   C. Wang, M. A. Quddus, and S. G. Ison, 'Impact of traffic congestion on road accidents: A spatial analysis of the M25 motorway in England', *Accid. Anal. Prev.*, vol. 41, no. 4, pp. 798–808, 2009.

[12]   P. Ribeiro, D. S. Rodrigues, and E. Taniguchi, 'Comparing standard and low-cost tools for gradient evaluation along potential cycling paths', *WSEAS Trans. Environ. Dev.*, vol. 11, pp. 29–40, 2015.

[13]   C. Lee and M. Abdel-Aty, 'Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida', *Accid. Anal. Prev.*, vol. 37, no. 4, pp. 775–786, 2005.

[14]   P. Vedagiri and B. R. Kadali, 'Evaluation of Pedestrian–Vehicle Conflict Severity at Unprotected Midblock Crosswalks in India', *Transp. Res. Rec.*, vol. 2581, no. 1, pp. 48 – 56, Jan. 2016.

[15]   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.

[16]   E. Arsenio and P. J. G. Ribeiro, 'The Economic Assessment of Health Benefits of Active Transport', in *Sustainable Urban Transport*, vol. 7, E d. Emerald Group Publishing Limited, pp. 1–22, 2015.

[17]   M. Gallo, G. De Luca, and V. De Martinis, 'The effects of urban traffic plans on noise abatement: a case study', in *WIT Transactions on Ecology and the Environment*, 2014, vol. 191, pp. 583–594.

[18]   K. Vogiatzis and P. Kopelias, 'Benefits and limitations toward a sustainable road environment during the years of economic recession', *Int. J. Sustain. Dev. Plan.*, vol. 10, no. 5, pp. 701–712, Oct. 2015.

[19]   K. Sygna, G. M. Aasvang, G. Aamodt, B. Oftedal, and N. H. Krog, 'Road traffic noise, sleep and mental health', *Environ. Res.*, vol. 131, pp. 17–24, 2014.

[20]   P. Frei, E. Mohler, and M. Röösli, 'Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality', *Int. J. Hyg. Environ. Health*, vol. 217, no. 2, pp. 188–195, 2014.

[21]   M. Sørensen *et al.*, 'Combined effects of road traffic noise and ambient air pollution in relation to risk for stroke?', *Environ. Res.*, vol. 133, pp. 49–55, 2014.

[22]   M. Basner *et al.*, 'Auditory and non-auditory effects of noise on health', *Lancet*, vol. 383, no. 9925, pp. 1325–1332, 2014.

[23]   R. J. Laumbach and H. M. Kipen, 'Respiratory health effects of air pollution: Update on b iomass smoke and traffic pollution', *J. Allergy Clin. Immunol.*, vol. 129, no. 1, pp. 3–11, Apr. 2012.

[24]   K. Zhang and S. Batterman, 'Air pollution and health risks due to vehicle traffic', *Sci. Total Environ.*, vol. 450–451, pp. 307–316,

Jorge Andres Navas Guzman,
Bruno Ramon Batista Fernandes, Mojdeh Delshad,
Kamy Sepehrnoori, Jose Francisco Zapata

2013.

[25] M. Cepeda *et al.*, 'Levels of ambient air pollution according to mode of transport: a systematic review', *Lancet Public Heal.*, vol. 2, no. 1, pp. e23–e34, 2017.

[26] C. Silva, 'Structural accessibility for mobility management', *Prog. Plann.*, vol. 81, pp. 1–49, 2013.

[27] M. Caselli, G. de Gennaro, A. Marzocca, L. Trizio, and M. Tutino, 'Assessment of the impact of the vehicular traffic on BTEX concentration in ring roads in urban areas of Bari (Italy)', *Chemosphere*, vol. 81, no. 3, pp. 306–311, 2010.

[28] T. Steenberghen, T. Dufays, I. Thomas, and B. Flahaut, 'Intra-urban location and clustering of road accidents using GIS: a Belgian example', *Int. J. Geogr. Inf. Sci.*, vol. 18, no. 2, pp. 169–181, Mar. 2004.

[29] P. Wackrill and C. Wright, 'Design of Traffic Circulation Systems to Minimise Conflict', *J. Maps*, vol. 3, no. 1, pp. 20 –34, Jan. 2007.

[30] A. Mondschein and B. D. Taylor, 'Is traffic congestion overrated? Examining the highly variable effects of congestion on travel and accessibility', *J. Transp. Geogr.*, vol. 64, pp. 65–76, 2017.

[31] L.-G. Mattsson and L. Sjoelin, 'Transport and location effects of a ring road with or without road pricing', in *ERSA 2002 - 42nd Congress of the European Regional Science Association*, 2002.

[32] P. Ribeiro and L. A. P. J. Gonçalves, 'The impact of a ring road in an urban road network. The case study of Guimarães, Portugal', *Int. J. Energy Environ.*, vol. 13, pp. 1 - 6, 2019.

[33] F. Heinzle, K.-H. Anders, and M. Sester, 'Pattern Recognition in Road Networks on the Example of Circular Road Detection BT - Geographic Information Science', 2006, pp. 153–167.

[34] B. Li and S. Tao, 'Influence of expanding ring roads on traffic noise in Beijing City', *Appl. Acoust.*, vol. 65, no. 3, pp. 2 43–249, 2004.

[35] F. He, X. Yan, Y. Liu, and L. Ma, 'A Traffic Congestion Assessment Method for Urban Road Networks Based on Speed Performance Index', *Procedia Eng.*, vol. 137, pp. 425–433, 2016.

[36] T. Samara and T. Tsitsoni, 'Road traffic noise reduction by vegetation in the ring road of a big city', in *Proceedings of the International Conference on Environmental Management, Engineering, Planning and Economics*, 2007, pp. 2591–2596.

[37] F. Perez-Prada and A. Monzon, 'Ex-post environmental and traffic assessment of a speed reduction strategy in Madrid's inner ring-road', *J. Transp. Geogr.*, vol. 58, pp. 256–268, 2017.

[38] I. Ahmed, 'Road infrastructure and road safety', *Transp. Commun. Bull. Asia Pacific*, vol. 83, pp. 19–25, 2013.

[39] C. Wang, M. Quddus, and S. Ison, 'The effects of area-wide road speed and curvature on traffic casualties in England', *J. Transp. Geogr.*, vol. 17, no. 5, pp. 385–395, 2009.

[40] C. Genre-Grandpierre, C. Sahuc, and S. Gueye, 'Speed vs locations: Accessibility level evaluations. The case of the Ring of Sciences in Lyon', *Case Stud. Transp. Policy*, 2018.

[41] M. I. Mohd Masirin, W. A. Al-Bargi, J. Prasetijo, and B. D. Daniel, 'Road Accident Analysis: A Case Study of Federal Route FT024 Yong Peng- Parit Sulong', *MATEC Web Conf.*, vol. 47, 2016.

[42] A. F. F. Ramos, 'Proposta de medidas para melhoria da mobilidade em transporte rodoviário urbano - o caso do barreiro', universidade Nova de Lisboa, Faculdade de CiÊncias e Tecnologia, 2008.

[43] J. de D. Ortúzar and L. G. Willumsen, *Modelling transport*, 4th editio. West Sussex, UK: John Wiley & Sons, Ltd, 2011.

[44] P. T. V GROUP, *PTV Visum 16 Manual*. Karlsruche, Germany: PTV AG, 2017.

[45] N. S. W. Roads and Maritime Services, *Traffic Modelling Guidelines*, 1st editon. Trasport Roads & Maritime ServiceNSW Government, 2013.

[46] C. A. T. Vilarinho, 'Calibração de modelos microscópicos de simulação de tráfego em redes urbanas', Faculdade de Engenharia da Universidade do Porto, 2008.

[47] A. P. Martins *et al.*, *Manual de estudos de tráfego*. Brasil: Ministério dos Transportes, 2006.