EXTEND ABSTRACT

Analyses for planning and management support of interurban roads on the national road network

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Abstract

The knowledge of traffic in circulation is extremely important in optimizing the management of the road network and, ultimately, to ensure the mobility and accessibility of people and goods with efficiency, safety, economy and environmental sustainability. Intelligent transport systems are fundamental in collecting traffic information, through a fast and reliable network of detection systems, collection and processing of information.

The main objective was the analysis of traffic and infrastructure quality on interurban roads of the national road network. The analysis of the information collected at selected counting stations of several routes of the main network allowed the investigation of the importance of heavy vehicles by type of route, the affectation of traffic on alternative routes, the influence of traffic on pavement quality and capacity for the case of two-lane roads.

Overall, it was found that on long-distance roads there is a high complexity of traffic behaviour. Regarding the percentage of heavy vehicles, a high variation was observed for the various routes analysed (from 3,0 % to 12,5 %). In the affectation of traffic to alternative routes, it was possible to conclude that the existence of tolls and safety are factors that may have a strong influence on choices, but not always with a common pattern. It has also been possible to establish a relationship between the volume of traffic in circulation and the capacity of the roads, but this was not the case for road quality since other factors can be even more constraining.

Keywords

Road traffic, Interurban road, ITS, Vehicle detection systems, Counting, Level of Service

1 Introduction

The knowledge of the volume of vehicle traffic on a given road is extremely important in numerous analyses, such as studies of congestion, of gas emissions produced by motor vehicles, of land-use planning, or of the planning, control, safety, management and maintenance of road infrastructures, among others.

Traffic analysis is based on the characterisation of the traffic flow formed by conglomerates of vehicles within a given section and standard time period. A well-defined traffic information survey network, consisting of a traffic data collection network that operates efficiently and provides reliable data, whose analysis and processing generates results with acceptable errors, is essential to the performance of these studies.

It is essential that the road transport system is efficient by ensuring the development and proper functioning of the territory through the mobility and accessibility of people and goods in a safe, economic and effective manner.

The interaction between the elements of the road system presents a complex and unpredictable dynamic, because it's performance is dependent on the behavior of the human being. Therefore, the implementation and modernisation of elements associated with traffic control are important. The characteristics and needs associated with traffic require the constant development of new intelligent transportation system technologies, in order to improve the flow of vehicles and the safety of passengers and goods.

Intelligent Transportation Systems (ITS) consist in creating advanced applications with the aim of providing innovative services associated to the various transport modes, with the aim of making the use of the transport networks safer, more coordinated and “smarter" [1].

One of the ITS that is frequently used and is very important for the proper functioning of road infrastructure is the vehicle detection system. This type of system is essential in obtaining information on traffic flows, so it is possible to carry out proper traffic control and management and to understand the influence that vehicles have on road transport infrastructure. These sensors can be incorporated into the pavement (intrusive systems) or installed on the side of the road, on poles or structures (non-intrusive systems). They should be installed at regular intervals along the road to allow rapid detection of congestion and incidents and provide accurate real-time flow along the entire road.

Intrusive systems to the pavement are those that consist in the installation of sensors directly on the pavement. For this reason, in the process of installation or maintenance of the equipment, damage is caused to the pavement and there is a need to interrupt traffic circulation. Some examples of intrusive systems: pneumatic tube; piezoelectric sensors; magnetic sensors; inductive loop sensors; fibre optic sensors [2] [3] [4] [5] [6].

In order to respond to the security constraints associated with intrusive systems, technological developments have allowed the creation of non-intrusive systems that are installed on or next to the road. Although they are usually more expensive, they do not affect local traffic during their installation or maintenance. However, this type of system is also more susceptible to vandalism and damage due to its greater visibility. Some examples of non-intrusive systems: video images; infrared sensors; microwave sensors; ultrasonic sensors; passive acoustic sensors [3] [4] [7] [8] [9].

After contacting several companies operating in the national road network, it was found that the information on traffic flows is not being properly used. It is mainly used only for taxation purposes and compliance with contractual objectives (in the case of concessionaires). Therefore, in general, the potential of this type of information is not exploited, neglecting several traffic analyses, such as the analysis of traffic allocation on alternative routes, the influence of traffic on pavement quality or the capacity of a road, among others. These analyses could enable us to move towards optimisation of both daily operations and intervention planning.

2 Case Study

2.1 General description

Within the context of the traffic counting systems implemented in the national road network of the continent, the selection of interurban routes was carried out to analyse the characteristics of the traffic in circulation in recent years, particularly in relation to the affectation of traffic of light and heavy vehicles, and its implications on the capacity and quality of these same roads. Bearing in mind that the characteristics of the road network are very diverse and highly complex, as well as of circulating traffic, the selection process of interurban routes to be analysed in this study took into account the following main criteria:

(i) Routes with implemented counting systems and availability of information (light and heavy vehicle counting).
(ii) Routes of different categories of main, complementary and highway networks as well as national roads.
(iii) Comparable itineraries associated to common routes.

In the selection and collection process of information, the company “Infraestruturas de Portugal” and the concessionaires Ascendi and Euroscut were consulted to obtain data on vehicle counts in various routes under their jurisdiction. The three entities systematically count vehicles through inductive loop sensors installed on the pavement and located in different sections of the routes.

For the development of this study, 27 routes were considered, with special emphasis on the 6 routes presented in Table 1, taking into account light and heavy vehicle traffic during the period 2012-2017: two highways (AE_1 and AE_2), two main routes (IP_1 and IP_2), one complementary route (IC_1) and one national road (EN_1).

Table 1 - Characterization of the itineraries

Itineraries	Classification	Estimated extension (km)
AE_1	Highway	13
AE_2	Highway	127
IP_1	Main Route	58
IP_2	Main Route	18
IC_1	Complementary Route	193
EN_1	Nacional Road	105

Regarding the total volume of vehicles on these 6 routes, it was verified that EN_1 presented the highest volume of light vehicles in the time period analysed, with a maximum value of 9 672 336 vehicles in 2015. For the total volume of heavy vehicles, there is a high level of traffic in AE_1, with a maximum value of 567 597 vehicles in 2017.

It is important to note that the period of analysis coincided with a time of recovery from the economic crisis experienced in Portugal since 2009, which was reflected in a certain instability in the variation of traffic over the time studied. Regarding the routes without tolls (IP's, IC's and EN's), this instability is verified over the time period analysed. In the case of highways, the situation is different because there was a natural tendency for the increase of vehicle traffic simultaneously with the economic recovery of the country (greater willingness on the part of drivers to pay), with a special increase between 2015 and 2016.

3 Analysis of results

3.1 Analysis of heavy vehicle traffic

Heavy vehicle traffic has a major influence on road traffic, such as the design of pavements and their degradation throughout their life cycle, as well as on traffic conditions in terms of level of service. Heavy vehicles are those with a gross vehicle weight of 300 kN or more. The aim of this study was to find out, for the types of routes selected, the percentage of heavy vehicles in relation to the total volume of traffic.

Given that it was possible to obtain the volume of traffic of the counting stations belonging to the selected routes the annual average daily traffic (AADT) of light and heavy vehicles, it was intended to know the percentage of heavy vehicles by type of route. Not only the readings of all the counting stations belonging to the selected routes were considered, but also the readings of other routes with similar characteristics, in order to enlarge the database under analysis.

The percentage of heavy vehicles was set for:

(i) Toll Routes (Highways)

Four highways with similar characteristics of AADT (light, heavy and total vehicles) were considered as presented in the Figure 1. Table 2 shows the variation (maximum and minimum limit) of total, light and heavy vehicle traffic on the different highways considered for the study.

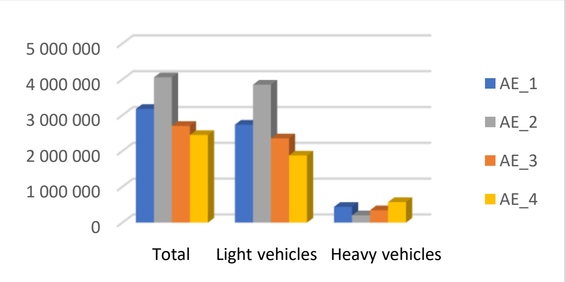

Figure 1 - AADT on the highways studied

Table 2 - Variation of the total volume of light and heavy vehicles on the toll roads analysed

Limits	Total	Light vehicles	Heavy vehicles
AE_1			
Lower	1 974 329	1 725 134	249 195
Upper	4 057 479	3 444 888	612 591
AE_2			
Lower	1 132 001	1 097 323	34 678
Upper	9 546 082	8 926 130	619 952
AE_3			
Lower	2 698 494	2 346 492	342 313
Upper	2 704 191	2 361 878	352 002
AE_4			
Lower	1 929 700	1 551 435	367 129
Upper	2 802 512	2 153 787	770 474

As it is possible to observe in Figure 1 and expected, the volume of heavy vehicles that travels in the highways is lower than the volume of light vehicles. In terms of percentage of heavy-duty vehicles, there are values of 5.0 %, 13.8 %, 12.9 % and 23.4 % for AE_1, AE_2, AE_3 and AE_4, respectively. In case of AE_4, a higher percentage was observed which is considered to be due to the fact that this highway crosses areas of high industrial occupation.

With the values of traffic an analysis of clusters was performed in order to a better understand of the factors with greater influence on the observed values: total traffic and land use. The cluster analysis method is commonly applied in the statistical analysis, since it allows to identify groups in a vast set of data in order to be able to understand the characteristics of the different elements of each subgroup. This analysis aims to divide a series of entities, individuals or objects into different groups (clusters). The focus of this analysis is on defining clusters that contain similar entities, but where each cluster is as heterogeneous as possible from the others. To simplify, the present study used the non-hierarchical method "K-means", which aims to measure the proximity between groups through the euclidean distance between the centroids of the different groups. For the development of this statistical analysis, 3 variables were taken into account: the AADT of total vehicles, the respective percentage of heavy vehicles and the location of the counting station, characterized by whether or not it is located in a commercial/industrial area. In the case of the third variable, because highways generally have low heavy vehicle traffic values compared with light vehicle traffic, the commercial/industrial zone was considered to be places with values above 12 % of heavy vehicles.

After analyzing the results for the cases of 2, 3 and 4 clusters according to the AADT and the percentage of heavy vehicles, it was possible to conclude that the best solution was obtained with the formation of 3 clusters, as observed in Figure 2.

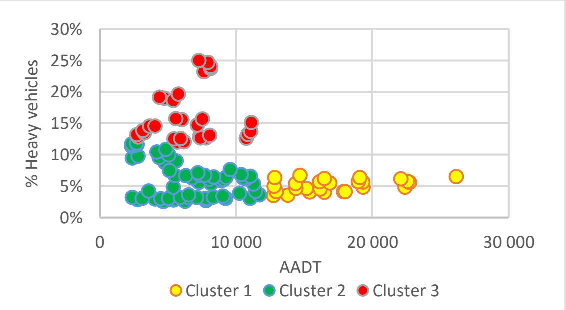

Figure 2 - Presentation of the 3 clusters

The clusters shown in Figure 2 are associated to three groups: a first group corresponding to less traffic, which is associated to a low percentage of heavy vehicles (less than 12 %); the second group is associated to sections with higher traffic (AADT over 12700 vehicles) and a low percentage of heavy vehicles; the third group corresponds to highways that are located in areas with higher commercial/ industrial density, with a percentage of heavy vehicles between 12 % and 25 %.

From this analysis and from the point of view of the percentage of heavy vehicle traffic, three final groups were considered, as seen in Figure 3: the first group formed by the association of cluster 1 and 2; the second group related to percentage values of heavy vehicles above 8%, which belong to cluster 2 and cluster 3; the third group corresponding to cases with the highest percentage of heavy vehicles, between 18 % and 25 %, and associated to a part of cluster 3. Associated to these three groups there are two trends in the percentage of heavy vehicles on highways: one in the first group corresponding to 4.75 % and the other in the second group corresponding to 12.5 %. In the case of the third group, it is considered that it is not possible to conclude a trend because of the low number of counts with a percentage of heavy vehicles above 18 %.

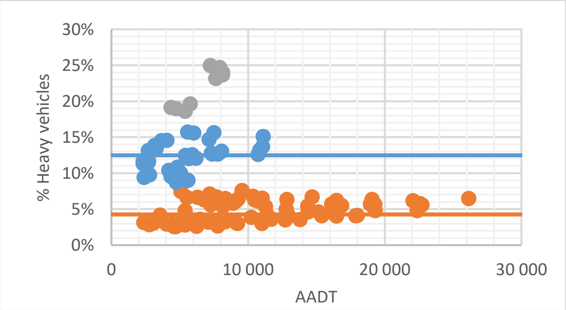

Figure 3 – Analysis of the trend in the percentage of heavy vehicles on highways

(ii) <u>Toll-free routes</u>

Moving now to the case of toll-free routes (IP's, IC's and EN's), it was not possible to obtain information on a large number of different routes. As such, a more simplified analysis was made of the average traffic values, the respective percentages of heavy vehicles and to verify some trend in the counts carried out.

For the analysis of the percentage of heavy vehicles, it was considered two main routes (IP_1 and IP_2), two complementary routes (IC_1 and IC_2) and two national roads (EN_1 and EN_2) with total annual average traffic levels presented in Figures 4 to 6. Tables 3 to 5 show the variation (maximum and minimum limit) of total, light and heavy vehicle traffic on the different routes considered for the study.

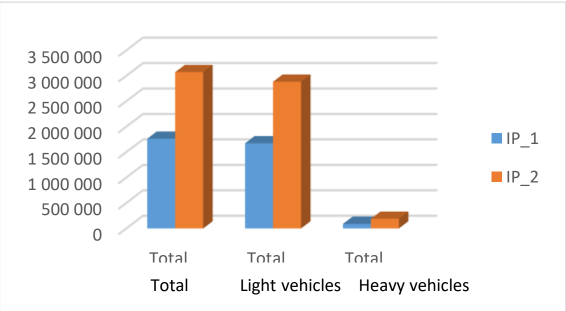

Figure 3 - AADT on the main routes

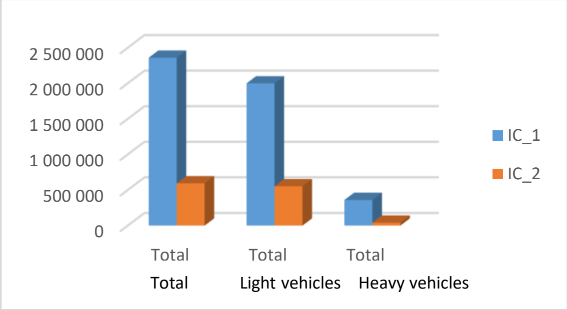

Figure 4 - AADT on complementary routes

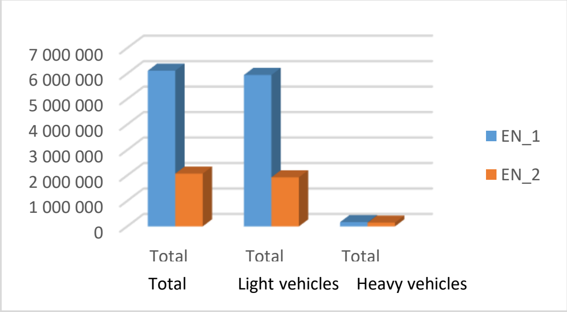

Figure 5 - AADT on national roads

Table 3 - Variation of the total, light and heavy vehicles in the IP's analysed

Limits	Total	Light vehicles	Heavy vehicles
	IP_1		
Lower	1 061 646	1 005 020	56 626
Upper	4 699 301	4 536 675	162 626
	IP_2		
Lower	748 184	701 175	47 009
Upper	4 579 563	2 496 877	401 770

Table 4 - Variation of the total, light and heavy vehicles in the IC's analysed

Limits	Total	Light vehicles	Heavy vehicles
	IC_1		
Lower	1 643 112	1 398 854	244 258
Upper	2 975 744	2 461 995	513 749
	IC_2		
Lower	271 687	256 253	15 434
Upper	1 510 993	1 398 016	112 977

Table 5 - Variation of the total, light and heavy vehicles in the EN's analysed

Limits	Total	Light vehicles	Heavy vehicles
	EN_1		
Lower	1 500 581	1 481 942	18 639
Upper	16 142 210	15 670 225	471 985
	EN_2		
Lower	1 474 077	1 398 240	59 595
Upper	2 528 760	2 411 074	336 639

Figure 3 reveals that the volume of heavy vehicle on the main routes analysed is quite low compared to the volume of light vehicles. This is justified by the fact that the average value of the percentage of heavy vehicles on each of the routes is quite similar and equal to 5.08 % and 6.18 % on IP_1 and IP_2, respectively.

Figure 4 shows that for the case of IC_2 the volume of heavy vehicles running on this complementary route is quite small in comparison with the volume of light vehicles, with an average value of 6.83 %. In the case of the IC_1, it is possible to verify a level of percentage of heavy vehicles higher than all the routes that were studied in this analysis, with an average value of 15.26 %, which is justified by the fact that this route serves several areas with high concentration of commercial/industrial infrastructures.

Through the analysis of the values measured on the two national roads, shown in Figure 5, it can be observed that EN_1 has a much higher total traffic volume than EN_2, with a difference of approximately 4 000 000 vehicles. It is interesting to highlight the fact that this difference is caused only by light vehicles traffic, since in the case of heavy vehicles traffic the average value observed is quite similar. Regarding the percentage of heavy vehicles travelling on the routes in question, it is clear that EN_1 has an average value lower than EN_2, caused by the difference in light vehicles traffic mentioned above, with values of 2.73 % and 7.12 %, respectively.

In the trend analysis, three groups were considered, one for each type of itinerary, as seen in Figure 6.

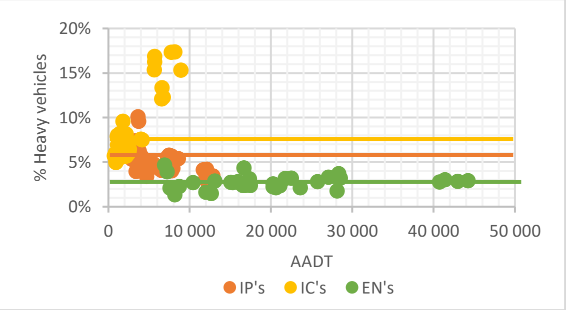

Figure 6 - Analysis of the trend in the percentage of heavy vehicles on toll-free routes

For main routes, the trend line covers all IP_1 and IP_2 route counting posts, with the exception of posts with a percentage value of heavy vehicles above 8 % and those with traffic values above 10000 vehicles, out of the large majority of coutings (outliers). By observing the trend line, it was estimated that the average value of the percentage of heavy vehicles is approximately 5.5 %.

For the analysis in the case of the complementary routes, only the group covering counting posts with a percentage of heavy vehicles below 10 % was considered. The observation of this group shows a trend towards an average value of approximately 7 % of heavy vehicles, up to the value of AADT approximately of 4000 vehicles, represented by the line in Figure 6. It is interesting to highlight that, the group formed by the counting posts with a value of more than 10 % of heavy vehicles was not able to reach any conclusions due to the lower volume of data.

Finally, in the case of the national roads, the analysis covered all counting posts for the two routes considered, despite the fact that the monthly AADT values were scattered and showed an average percentage value of heavy vehicles of approximately 3 %.

3.2 Analysis of traffic route assignment

Based on the traffic counting information, it was also intended to study the route assignment of traffic to alternative itineraries for equivalent routes. It is considered that the decision-making by drivers that underlies this affectation is very complex, but among other factors, it may be linked to safety, comfort, time and cost of travel.

For this purpose, comparative analyses were carried out between different types of itineraries that serve routes considered equivalent:

- Highway *versus* Main Route
- Highway *versus* National Road
- Main Route *versus* Complementary Route

(i) AE_1 *versus* IP_2

In this first case, the influence of the implementation of an alternative solution to a toll-free main itinerary by a toll solution was studied. The routes AE_1 and IP_2 were considered. The section of the AE_1 route under study is characterised by its development in a tunnel over an area where the IP_2 route develops in a mountainous region.

The analysis of the traffic data shows a inversion of the trend of traffic increase in IP_2 since the opening of the tunnel in AE_1, i.e., a decrease and respective transfer of light vehicle traffic from IP_2 to AE_1 (less 2741 vehicles). In the remaining period of analysis, the transfer of light vehicle traffic from IP_2 to AE_1 was consolidated, with an average value of 43.1%, with a ratio of 27.6% (2447 vehicles in June 2017) to 46.6 % (6139 vehicles in August 2017).

In the case of heavy vehicles, the opening of the tunnel had a major impact. There was a sharp decrease in heavy vehicles traffic on the IP_2, by about 25.5 %, and the consequent significant increase in the AE_1 by about 48.5 %.

This was a particular case where drivers showed a preference for using a toll route. The reason was that drivers were willing to pay for greater comfort and safety during the journey because, as mentioned above, the region of these routes develops in a rather mountainous area and is exposed to adverse weather conditions in certain seasons of the year. The alternative of tunnel circulation is more comfortable and safe, in addition to reducing travel time.

(ii) IP_1 *versus* IC_1

The IP_1 and IC_1 routes are presented as alternative solutions, both being toll-free routes. It was considered relevant to analyse two alternative routes with a different road hierarchy and with different geometry characteristics in some sections of the road and the absence of tolls on both routes.

For light vehicles traffic, there was a higher volume of vehicles in the IC_1 over the time of analysis, on average around 40 % higher than the IP_1 in the first two years, falling to around 15 % in the following two years. This decrease was probably a consequence of the slowdown in the increase of light vehicles traffic in IC_1 and of a significant increase of traffic in IP_1 during 2016.

Regarding heavy vehicles traffic, it was observed that the IC_1 presented a volume of traffic well above the IP_1, which in the months of highest traffic (July and August) was four times higher. It was also possible to observe a slight decrease in traffic volume in 2016 for both routes, but regarding the difference in traffic affectation, this remained constant throughout the analysis period with an average value of around 75 % for the IC_1. This difference can be explained by the fact that the IC_1 crosses areas with higher industrial occupancy and serves larger urban areas.

The analysis of the affectation of traffic to these routes leads to the conclusion that both itineraries are similar because they have identical infrastructures (geometry and road safety elements), which can be associated with safety and comfort of the journey. Compared to journey time, the IC_1 is less advantageous due to high traffic, especially of heavy vehicles with a tendency towards higher and more frequent congestion, which leads to longer journey times.

(iii) AE_2 *versus* EN_1

For the AE_2 and EN_1 itineraries it was intended to analyse two routes of significantly different level of importance and to study the influence of road geometry on comfort and safety and on the fact that it is a toll route and a toll-free route, respectively.

Analysing light vehicles traffic, there was always a higher traffic trend on EN_1, with an affectation above 60 % in most of the months. This difference decreased between consecutive months over the period of analysis, and in August 2016 similar traffic values were observed between the two routes and, in August 2017, there was even a inversion of the trend, with the presence of a higher volume of traffic on AE_2 compared to EN_1 (negative EN_1/AE_2 ratio of 9.29 %).

In the case of heavy vehicles traffic, a similar trend was found, i.e., higher in EN_1. It should be noted that there was a change in the preference of heavy vehicle drivers on both routes after 2016, with a decrease in the volume of traffic on EN_1 and a consequent increase in AE_2, with higher levels of traffic on AE_2 for the first time in May 2016, continuing the trend until the end of 2017. It was possible to associate this particular behaviour with the simultaneous reduction of toll tariffs on the highway and the execution of improvement works on the national road.

The results obtained in these routes show that the difference in traffic volumes between the national road and the highway may be closely associated, as expected, with the cost of the toll.

3.3 Influence of traffic on pavement quality

In the course of this analysis, it was not possible to see a clear influence of the variation of the traffic on the condition of the pavement due to the lack of information provided concerning to the pavement conditions.

For this analysis were considered two sections of three studied routes (IP_1, IC_1 and EN_1), which were evaluated regarding the quality índex (the parameters realted to IRI and rutting) and the pavement structure.

Due to the lack of information and the high complexity and quantity of factors that influence the pavement behaviour over time, it was not possible to observe such influence.

3.4 Analysis of traffic influence on capacity

Based on the traffic information associated to the IC_1, it was analysed the influence of heavy vehicle traffic on road capacity. A simplified analysis was carried out based on the methodology established in the Highway Capacital Manual (HCM) for interurban roads.

The capacity of a road is defined by the maximum hourly traffic flow rate that can be expected on a section of a road, by direction or in both directions in the case of opposite directions, over a given period of time, under the prevailing road and traffic conditions [10]. As prevailing road conditions for the definition of capacity, those that are defined by their physical characteristics (e.g. width) or those that are dependent on the nature of the traffic (e.g. percentage of heavy vehicles) are considered. The capacity indicator is therefore quite important for understanding the traffic conditions of vehicles in a given section of the road, mainly with regard to their speed and density.

The assessment of capacity is based on the level of service (LOS) of a road. The purpose of the LOS is to categorise in a qualitative way the influence of several factors on the operating conditions of a road, affected by various traffic volumes, such as speed, journey time, traffic congestion, freedom to overtake, etc. Considering the approach used in the HCM, there are 6 LOS, from A to F.

As volumes and geometric constraints increase, the ability to overtake decreases and, consequently, platoon formation occurs. Therefore, on roads with one lane per direction, normal traffic circulation in one direction influences the traffic in the opposite direction, with drivers having to reduce the speed they are travelling as the traffic volume increases and the possibility of overtaking decreases.

This type of route is used to connect the main traffic generators (cities) and tend to serve long distances, containing sections inside and outside localities. This fact is extremely relevant for the analysis carried out because, according to the HCM methodology, for two-lane roads (one per direction), it is necessary to identify the location and respective function of the section analyzed in order to define the criteria to be taken into account for determining the LOS and capacity.

For Class I sections, in order to calculate the LOS it is necessary to take into account the determination of two variables: one as a function of Average Travel Speed (ATS); and one as a function of the percent time-spent-following (PTSF). For Class II sections, it is only necessary to analyse the PTSF. In Table 6 and Table 7 are presented the intervals of the different LOS in the case of a class I and class II section, respectively.

Table 6 - LOS for class I two-lane roads

LOS	PTSF (%)	ATS (km/h)
A	< 35	> 90
B	> 35 - 50	> 80 - 90
C	> 50 - 65	> 70 - 80
D	> 65 - 80	> 60 - 70
E	> 80	< 60

Table 7 - LOS for class II two-lane roads

LOS	PTSF (%)
A	< 40
B	> 40 - 55
C	> 55 - 70
D	> 70 - 85
E	> 85

The main objective of this analysis is to study the factors that have the greatest influence on the variation in ATS, PTSF and, consequently, the LOS of a two-lane road. In order to simplify the case study, certain parameters based on the characteristics observed in IC_1 were defined as constants throughout the various iterative analyses, whose values are presented below in Table 8.

Table 8 - Constants adopted in the LOS analysis from IC_1

Peak-hour factor	0.95
Lane width	3.5 (m)
Shoulder width	2.25 (m)
Access-point density	0
Directional split	50/50

The most relevant factors for this study were the volume of traffic, the percentage of heavy vehicles, the type of terrain, the percentage of no-passing zones and the based free-flow speed (BFFS). Therefore, several hypotheses were adopted, taking into account the variation of each of these parameters, in order to, as already mentioned, verify the influence that each parameter has on the final result of the LOS (ATS and PTSF). For instance, two sections located in different areas were considered, one being class I and the other being class II, subject to 5 different traffic flows per direction of traffic (100, 200, 300, 400 and 500 vehicles per hour) depending on the different types of terrain, level and rolling, the percentages of no-passing zones, 20 % and 80 %, and the BFFS, 60 km/h and 80 km/h. In order to complement the analysis of the results, Figures 8 to 11 show the graphs of the ATS/PTSF ratio, corresponding to the cases in which the BFFS of 60 km/h and 80 km/h was taken into account, depending on the percentage of no-passing zones and the percentage of heavy vehicles, for the determination of the LOS.

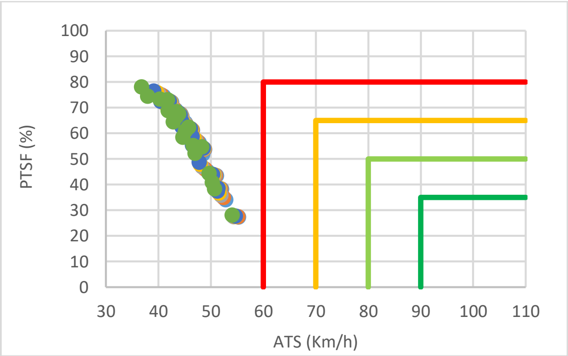

Figure 7 - ATS/PTSF ratio related to the percentage of heavy vehicles (BFFS=60 km/h)

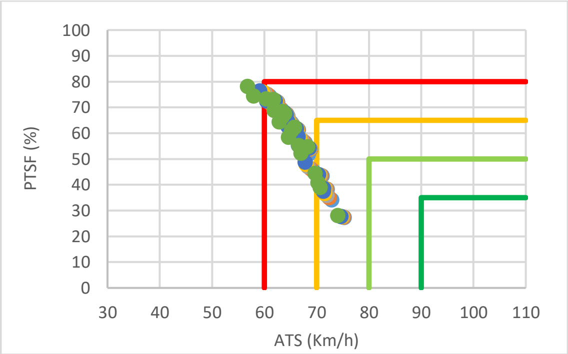

Figure 8 - ATS/PTSF ratio related to the percentage of heavy vehicles (BFFS=80 km/h)

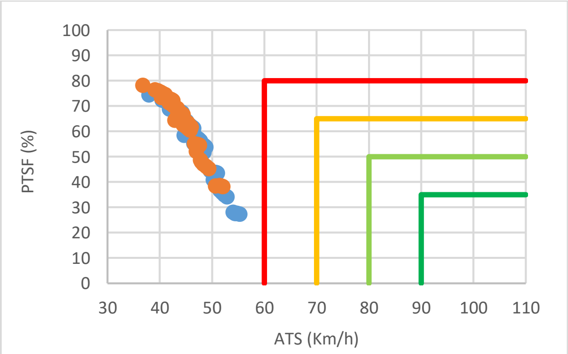

Figure 9 - ATS/PTSF ratio related to percentage of no-passing zones (BFFS=60 km/h)

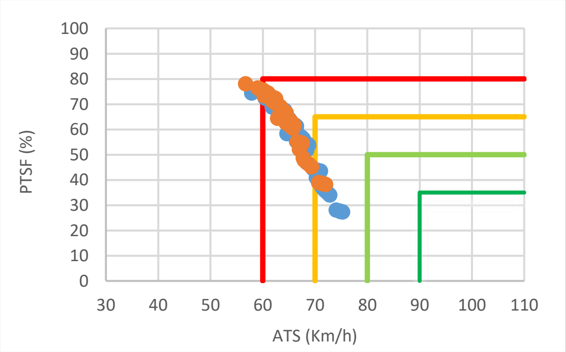

Figure 10 - ATS/PTSF ratio related to percentage of no-passing zones (BFFS=80 km/h)

Based on the results obtained, as expected, it was possible to see that traffic flow conditions deteriorated with the increase of the traffic flow, the increase of no-passing zones, the decrease of BFFS and/or with the change of the type of terrain from level to rolling, which resulted in an increase of the LOS.

After analyzing in a more detailed way, the values obtained from the ATS for the different percentages of heavy vehicles considered in this study, it was possible to conclude that the factor with the greatest influence was the BFFS. A change of 20 km/h resulted in a LOS variation of one or two levels. The impact of this variation is visible in Figures 8 to 11, where a shift to the left of the results of the graph is observed. This shift was due to the reduction of the BFFS from 80 km/h to 60 km/h, with the LOS changing from D and, in some cases, from C to E. Regarding the total average value of all ATS considered in the study, this difference of 20 km/h can be seen through the variation of the average speed from 66.2 km/h (BFFS equals 80 km/h) to 46.2 km/h (BFFS equals 60 km/h), or vice-versa. Concerning the impact verified by the variation of the no-passing zones from 20% to 80%, there is a decrease of the ATS, with an average value of approximately 2,6 km/h and 2,2 km/h for the type of level and rolling terrain, respectively, for both cases in which the BFFS was considered 60 km/h and 80 km/h. Finally, the influence that the change from level to rolling terrain has on ATS is reflected in the average reduction of 2.7 km/h and 2.3 km/h in the case of 20 % and 80 % of no-passing zones, respectively.

In the case of the values obtained from the PTSF for the different percentages of heavy vehicles considered in this study, it was found that the variation of the no-passing zones had the most relevant and harmful impact, with the average increase of the PTSF of about 8 % and 7 % for the type of level and rolling terrain, respectively. Regarding the variation from level to rolling terrain, it was observed that the value of the PTSF decreased, on average, by approximately 6.4 % and 5.3 % in case of considering 20 % and 80 % of no-passing zones, respectively. It should be noted that for the case of the PTSF analysis, the BFFS did not have any influence on its final outcome.

After the parametric study regarding the IC_1 according to the HCM method, the LOS of the two different sections (section I and section II) was analysed. Both sections are class I, with traffic volumes and percentage of heavy vehicles that were recorded in the counts carried out between 2014 and 2017, in order to study the results obtained from the variables ATS and PTSF in real traffic situations. It should be noted that the same geometric characteristics and orders of magnitude of the variables taken into account in the parametric study presented above were considered, as shown in Table 6.

The BFFS considered, for both sections analysed, was 80 km/h, since these sections do not cross localities, with the possibility of driving at higher speeds (speed limit of 90 km/h) and without major constraints. Regarding the variables no-passing zones and type of terrain, the first section represents a road with 20 % no-passing zones, while the second section presents 80 %, and the two possibilities of type of terrain (flat and undulating) were considered in both cases to cover a wider variety of possible situations over the whole length of the IC_1.

Concerning the volume of traffic considered for the analysis, the counting posts with the highest percentage values of heavy vehicles were selected in order to measure, once again, their influence on the LOS and, consequently, on the capacity of the IC_1. Four traffic counts were considered, the first for 2014, with a monthly AADT value of 7653 vehicles per day, the second and third for 2017, with monthly AADT values of 5647 and 8930 vehicles per day, respectively, and, finally, the fourth count refers to the average of all traffic values collected during 2017, presenting a monthly AADT value of 6732 vehicles per day.

Looking at the results achieved for the four traffic volumes in question, it is possible to see that, regardless the variation in the type of terrain and/or the percentage of no-passing zones, LOS D is always the same in all cases, despite variations in the ATS and the PTSF. Only in the case where the traffic volume is 5647 vehicles per day with level terrain on section I, the LOS is close to C.

Figure 12 and Figure 13 show more clearly the position of the different cases considered for the IC_1 capacity analysis in relation to the limits of the different LOS for class I sections.

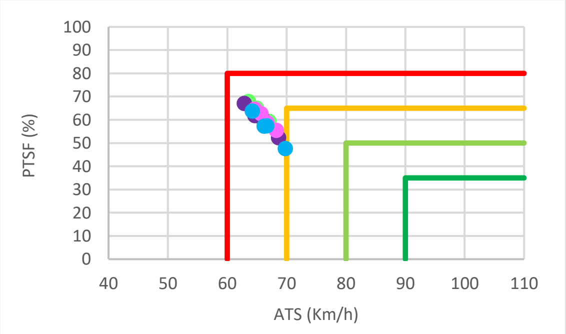

Figure 11 - ATS/PTSF ratio related to the percentage of heavy vehicles in IC_1

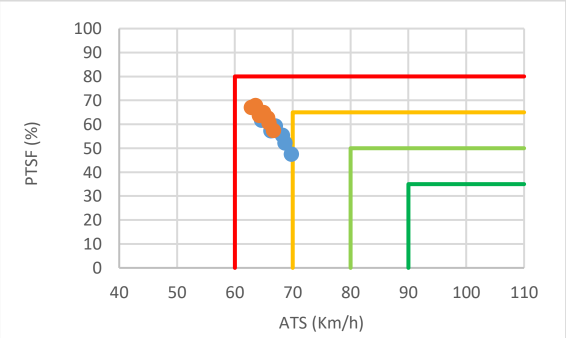

Figure 12 - ATS/PTSF ratio related to the percentage of no-passing zones in IC_1

4 Conclusions

In the present study, vehicle counting data obtained using vehicle detection systems were analysed, divided into two classes (light and heavy vehicles). This type of information is of great importance for the development of traffic studies, with the relevance of the effect of heavy vehicles traffic on road infrastructure conditions (management, control, safety, quality, capacity, among others) having been highlighted throughout this work.

Regarding the analysis of results, first of all, a study was carried out on the percentage of heavy vehicles travelling on the different types of routes. In the case of the toll roads analysed (highways), there were two distinct trends for the percentage of heavy vehicles, the first being 4.75 % (mostly residential areas) and the second 12.5 % (mostly commercial/industrial areas). In the case of toll-free routes, the trends in the percentage of heavy-duty vehicles were 5.5 %, 7 % and 3 % for the IP's, IC's and EN's, respectively. The most relevant conclusion that could be drawn is the fact that the trend in the percentage of heavy vehicles travelling on each type of itinerary depends on their location. This means that it is expected that an itinerary located next to a commercial/industrial zone will have a higher percentage of heavy vehicles travelling than an itinerary located in a residential area.

The route assignment of traffic was analysed in the case of alternative itineraries and different hierarchical levels for the same route. Throughout this study it was possible to conclude that, as expected, in terms of time, comfort and safety, highways are, generally, the best solution. However, regarding the cost variable, the highway presents itself, from the outset, as a less desirable solution because it has an associated circulation cost (toll). Analysing the most relevant aspects that were found in the three cases considered, it was possible to observe that, in exceptional situations of improving traffic conditions, drivers are willing to pay a circulation tariff to have greater comfort and safety in their journey. Another relevant aspect that was observed in the third case analyzed was the increase in traffic (especially of heavy vehicles) on a highway caused by the reduction of toll rates and the existence of several works to improve an alternative national road to this route.

Through the capacity study on a two-lane road, using two sections of the IC_1 as a case study, it can be seen that the increase in the total volume of vehicles in circulation and, consequently, the increase in the number of heavy vehicles, is one of the most conditioning factors in the degradation of the LOS of a road. It is also important to note that, regardless the conclusion presented above, it was found that for a given volume of traffic, the change in the percentage of heavy vehicles does not present a significant change in the LOS.

In summary, with the development of this study it was possible to understand the importance of information related to traffic flows in the different types of routes, with a special focus on the differentiation of the type of vehicles into light and heavy vehicles, and some of the areas that are crucial to acquire this type of information, specifically in the study of traffic route assignment and the management of a road capacity.

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