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# ESTIMATION OF ANNUAL TRAFFIC VOLUMES

# A MODEL FOR PORTUGAL



## 1 INTRODUCTION

The automobile characteristics regarding its large range of coverable travel distances, comfort of use and freedom to choose departure time and travel routes made it the most used transportation mode in the current transport demand framework. Due to this prevalence in the road sector, a regular and flexible quantification of car use is a major requirement of different stakeholders in our society. Such data is needed for several important activities, such as: modelling the safety and environmental impacts of road transportation; estimating performance indicators of road networks and vehicle fleets; analysing mobility and accessibility, within the framework of land use policy setting; and for the economic assessment in terms of costs and tax policies in road systems.

One of the main variables used as a measure of a road network or vehicle fleet use is the traffic volume. The annual traffic volume at the national level can be defined as the number of kilometres travelled in a country by all vehicles during a one year period; it is expressed in vehicle x kilometres (vkm) (EIA, 2005):

$$\textit{Traffic Volume (VKT)} = \textit{Number of Vehicles} \times \textit{Distance Travelled} \qquad \text{(eq. 1)}$$

The computation of the Traffic Volume, also known as Vehicles Kilometres Travelled (VKT), disaggregated by specific road classes, group of vehicles or time period is usually required to fully satisfy the needs of different stakeholders interested in the quantification of road transportation activity. In fact, the diversity of methods used in the estimation of VKT is wide due not only to the demand for different disaggregation levels of VKT estimates, but also to the variety of available data sources.

The difficulty in collecting detailed and comprehensive data from only one source of information forced countries to integrate different data sources in the modelling and calibration of their estimates. Even though international VKT estimation models tend to use multiple data sources, the UNECE (2007) proposed a model classification method based on the main data source used: traffic counts, driver surveys, fuel consumption and odometer readings. These four model classes are summarily analyzed in the next Chapter.

Currently, in Portugal there is no available data on VKT that satisfies the national and international needs in terms of: national coverage, regularity, reliability and flexibility in the disaggregation by different type of variables.

In the proposed annual traffic volumes estimation method for Portugal, odometer readings taken from vehicle technical inspections are used as a primary data source. This information is combined with the attributes of the inspected vehicles, the national vehicle fleet data, the national road traffic counts data and the attributes of the National Road Network (RRN) for disaggregation of VKT estimates by type of road and vehicle. Further improvements of the proposed method are also discussed.

# 2 CURRENT METHODS FOR VKT ESTIMATION

## 2.1 Odometer Readings

Odometer readings are the only regular records of accumulated travelled distances for the majority of vehicles, making the calculation of the exact number of kilometres driven within a given time period possible. However, odometer readings do not allow any association with geographical data regarding where these travelled distances were made. Due to this disadvantage, other sources of information are used to estimate VKT by region or road class. Another difficulty with the use of odometer readings in VKT estimation regards the evaluation of distances travelled by foreign vehicles in national territory and of journey lengths travelled abroad by national vehicles. This problem is usually mitigated using additional survey information collected at national borders.

Generically, annual traffic volumes estimates using odometer readings can be calculated using the following equation:

$$VKT_i = \left( \frac{\sum_{n=1}^{N} \frac{(R_n^{T+\Delta T} - R_n^{T})}{\Delta T}}{N} \times F \right) \times Y$$

(eq. 2)

$VKT_i$ – Annual traffic volume for the vehicle category $i$ (vkm).
$R_n^{T}$ – First odometer reading for the vehicle $n$ in the category $i$ (km).
$R_n^{T+\Delta T}$ – Second odometer reading for the vehicle $n$ in the category $i$ (km).
$\Delta T$ – Number of days between the first and the second odometer readings (days).
$N$ – Number of inspected vehicles in the category $i$.
$F$ – Total number of vehicles of the category $i$ in the national vehicle fleet.
$Y$ – Number of days in a year {365;366}.

Odometer readings are usually carried out on mandatory vehicle technical inspections. Additionally, the number of inspected vehicles in each category and its relevant characteristics must be collected. In fact, just part of the vehicle fleet is actually inspected each year, due to time intervals between inspections greater than one year and to the type of vehicles that are subjected to inspections stipulated by law.

The EU Council Directive 96/96/CE (EU, 1996) regulates the inspections of all four or more wheeled vehicles that are driven in public roads. In most EU member states, this legislation does not concern other vehicle categories such as motorcycles. In addition, specific inspection frequencies are recommended for each vehicle category in the EU Directive. For private light vehicles, for example, the first periodical inspection is scheduled for after the fourth year of age, whereas for heavy vehicles the first inspection must be carried out just after the first year. This regulations cause the absence of travelled distance data during the first four years, for private cars, if odometer readings are used as the sole data source for estimating VKT. The optimal VKT estimates of a specific year *n* will only be theoretically obtained in the year *n+5*, when the odometer readings of cars bought in the year *n* will be available. However, during this period of five years the estimates can be improved with the readings from older vehicles.

Finally, in this type of estimation methods one must take into account the possibility of reading errors, notation errors, lack of available digits in old odometers and also to illegal modification of odometer records.

## 2.2 Traffic Counts

The annual VKT estimation models based on traffic counts use the data collected on a sample of monitored road sections to estimate the VKT of the entire network. Traffic flow, usually represented by the Annual Average Daily Traffic (AADT), and length of the sampled road sections are the main variables used. One can also easily collect information regarding road infrastructure characteristics to disaggregate estimated VKT by road class:

$$VKT_j = \left(\sum_{n=1}^{N}(AADT_n \times L_n)\right) \times \frac{L_{TOTj}}{\sum_{n=1}^{N} L_n} \times Y \qquad \text{(eq. 3)}$$

$VKT_j$ – Annual traffic volume for the road class *j* (vkm).
$AADT_n$ – AADT for the section *n* of the road class *j* (vehicles/day).
$L_n$ – Lenght of the road section *n* of class *j* (km).
$LTOT_j$ – Total length of the class *j* sections in the whole road network (km).
*N* – Number of road class *j* segments with available traffic counts.
*Y* – Number of days in a year (365;366).

However, this type of models does not allow the estimation of VKT by type of driver or trip motivation. Also, as they are usually based on a spatial and temporal sample of counts, sampling errors and instrumental and other counting errors must be carefully analyzed.

### 2.3 Surveys

Surveys allow the collection of data directly from the road network user, usually by means of interviews and individual or collective questionnaires. This type of data collection has undeniable advantages in terms of the flexibility regarding the collected variables, when compared to the other types of methods previously presented. In fact, information about the vehicle, the driver and the trips made can be obtained directly from the surveys and used for VKT disaggregation. However, due to the limitations in available resources, surveys are usually based on small samples, when comparing their size with the total number of drivers or vehicles contributing to national VKT. Additionally, in order to reduce implementation costs, surveys are frequently carried out for several purposes, other than just VKT estimation.

Whatever survey collection method is used (interview by phone, postal survey…) the sampling errors, answering or form filling errors and estimation errors are issues to be duly addressed in the VKT estimation model. More detailed information about the use of surveys for the estimation of national annual VKT can be found in (UNECE, 2007).

### 2.4 Fuel Consumption

Methods for the estimation of annual VKT using fuel consumption are based on the assumption that national fuel sales records are representative of the fuel consumption in a specific year:

$$\underbrace{N \times d_{av}}_{VKT} \times cons_{av} = FC <> FS \qquad \text{(eq. 4)}$$

$N$ – Total number of vehicles in the national fleet.
$d_{av}$ – Average annual distance travelled by one vehicle of the national fleet (km/vehicle.).
$cons_{av}$ – Average consumption of the national vehicle fleet (l/km);
$FC$ – Annual estimated volume of fuel consumption for the national vehicle fleet (l);
$FS$ – Annual volume of fuel sales in the road sector (l);
$VKT$ – National annual VKT (vkm).

Even though this method is very useful when there is no record of travelled distances, it has some important limitations, such as: the need of multiple data sources, the need of several assumptions for the estimation of the average consumption and the difficulty in quantifying the fuel consumption of national vehicles outside borders and of foreign vehicles in the national road network.

# 3 MAIN AVAILABLE DATA IN PORTUGAL

## 3.1 Odometer Readings

Following the recommendations in (EU, 1996), technical inspections are mandatory by law in Portugal by the Portuguese Highway Code – *Código da Estrada* (MAI, 2005). This regulation specifies the regime of periodical inspections, and also the requirements for optional and extraordinary inspections (e.g.: alteration of the vehicle specifications). It is also regulated that an odometer reading shall be carried out in every technical inspection (DGV, 2000). However, current regulations present some coverage gaps for a complete VKT estimation:

- Absence of periodical inspections in the first four years of age for private cars.
- Absence of any type of technical inspections for two-wheeled vehicles which represent around 3% (motorcycles) of the national vehicle fleet (ACAP, 2007).
- Absence of mandatory inspections for some special vehicle categories such as vehicles manufactured before 1960, vehicles that are not usually driven in the public road network and military road vehicles.

The estimation method developed for Portugal does not consider the vehicles associated with these two last issues. To do so, further data must be collected.

For the purpose of this study, the odometer readings of Portuguese vehicles carried out between 2004 and 2006 were used as main data in the estimation of national VKT. During these three years a total of 14 334 060 inspections were made, corresponding to 5 030 034 vehicles. Moreover, the following characteristics of the inspected vehicles were provided by the DGV (General Directorate of Traffic), for the disaggregation of national VKT estimates: date of the license plate number, type of fuel, weight and engine capacity (in cubic centimetres).

## 3.2 Vehicle Fleet

In Portugal three different institutions provide information on the national vehicle fleet: DGV, ACAP and ISP. Each of these institutions has their own estimate of the national vehicle fleet, due to the different collecting methods they use: vehicle license records; vehicles sold and life expectancy estimation models; and insurance records respectively. Being the ACAP estimation the most accurate one (Lima de Azevedo, 2007), the detailed vehicle fleet records of this institution were collected for the years of 2004 to 2006. The total number of recent vehicles in each year was also compared with the license plate records.

## 3.3 Road Network

Broadly, the Portuguese road network comprises the National Road Network (RRN) and non-classified local roads (mainly municipal and private roads).

Regarding the RRN network, a database with all links was created in 2006 (Cardoso, 2007) for the detection of high accident risk sites. This database comprises a limited number of characteristics of interest to the estimation of VKT by type of road: name of the road; identification of the section’s initial and final kilometre; number and width of carriageways; percentage in the section’s length with one, two and three lanes; and an estimation of the total AADT in 2005. This database covers a total number of 1 542 sections corresponding to over 14 350 km.

This database and the AADT counts were used to estimate the VKT in the RRN by type of road for 2005. Additional information on the network characteristics and on sections updated AADT are needed for future yearly estimations.

Currently there is no database with the characteristics of Portuguese non-classified roads. In a small number of cases, these characteristics are described in municipality owned databases only, which make its use inadequate for national VKT estimation.

## 3.4 Traffic counts

Traffic count data in the RRN are published by the current major road concessionaire EP - *Estradas de Portugal S.A.* The method used in data collection data is based on both manual and automatic counts (MEPAT, 1998). For the purpose of the present study, traffic counts made between 2000 and 2003 were used in the estimation of each vehicle type contribution to the VKT by type of road in the RRN. This data was collected in a total of 560 road sections, corresponding to 51% of the RRN (7346 km).

In most cases, counts in non-classified roads are carried out by municipalities simply when an improvement of the road infrastructure is needed. Periodical and systematic counts are only carried out in big metropolitan areas such as Lisbon and Porto. These counts are not representative of current annual VKT in non-classified roads and were left aside in the proposed methodology.

# 4 THE PROPOSED METHOD

## 4.1 Model Structure

The 5 million inspections collected annually cover a total of 67% (for 2006) of the national vehicle fleet estimated by the ACAP. The correspondent odometer readings represent an important data source for systematic national VKT estimation and disaggregation by type of vehicle. However, obtaining reliable, complete and disaggregated national VKT estimates need other sources of information. Data directly related to the network use and to the real vehicle fleet in circulation (and not the inspected one) must be used.

The proposed method uses four different complementary data sources added to the technical vehicle inspections: estimates of the national vehicle fleet, the road network characteristics and national road counts (Figure 1).

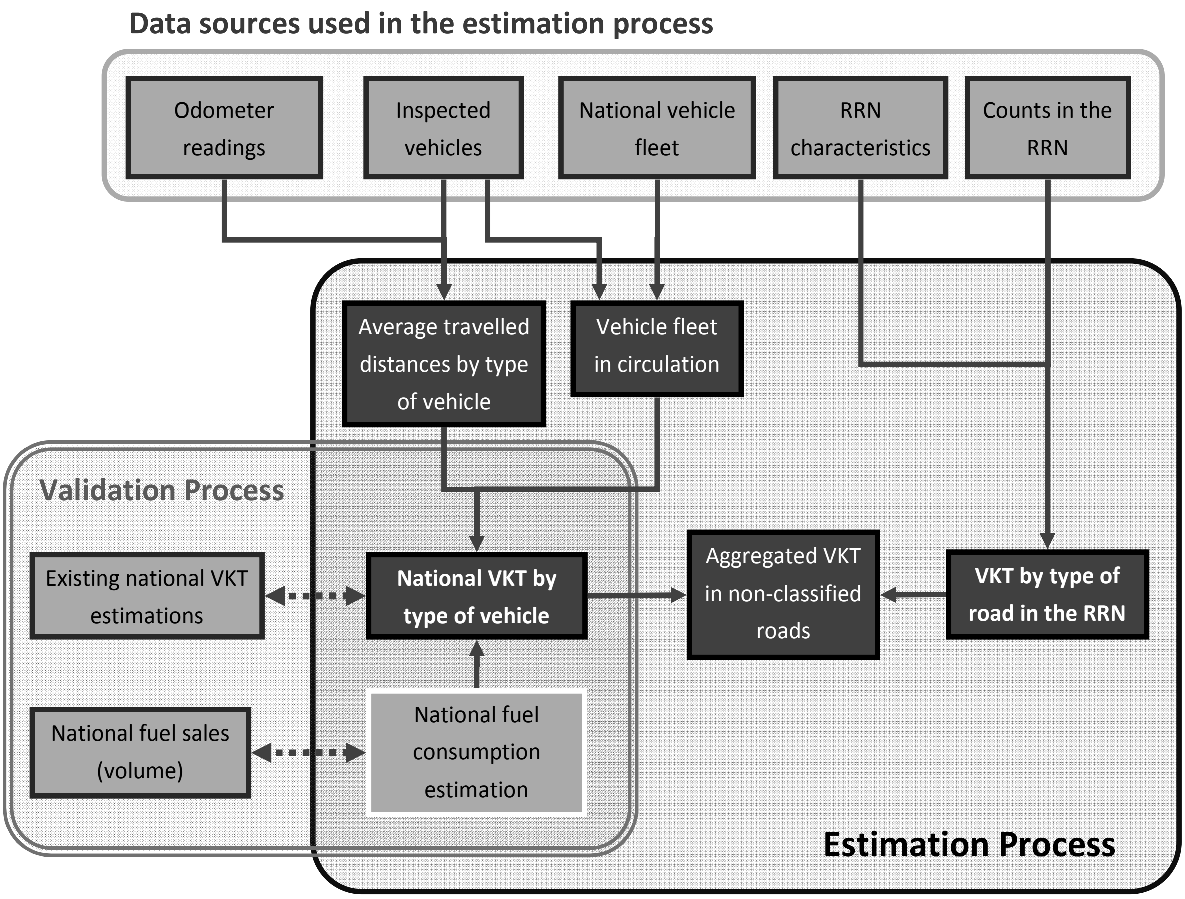


*Figure 1- Structure of the proposed method for Portuguese annual VKT estimation.*

The proposed estimation method has two types of output disaggregation components: the estimation of VKT by type of vehicle and the estimation of VKT by type of road in the RRN. The VKT outside the RRN is estimated by difference of the total VKT obtained by the odometer readings and the VKT in the RRN calculated with the national road counts.

The proposed methodology also comprises a validation process based on:

- a comparison with the existing aggregate national VKT estimates (Cardoso, 2003);
- the balance between the recorded annual fuel sales and an estimation of the fuel consumption using the COPERT III model (Ntziachristos, et al., 2000) and the calculated VKT.

## 4.2 Estimation of Annual Traffic Volumes by type of vehicle

The estimation of annual VKT by type of vehicle is based on the fundamental concept represented by equation (2). This basic concept reaches, however, some complexity when considering the different vehicle type inspection frequencies.

For each inspected vehicle, the Average Daily Travelled Distance (ADTD) is calculated for the three estimation years (2004 to 2006). The contribution of each pair of consecutive odometer readings is considered in the ADTD calculation. The general formulation of this calculation is represented by equation (5):

$$ADTD_j^i = \frac{1}{J^{TOT}} \times \sum_{k=1}^{K-1} \left( \frac{R_i^{k+1} - R_i^k}{\Delta T^{k+1;k}} \times J^{k+1;k} \right) \quad \text{(eq. 5)}$$

$ADTD_j^i$ – Annual Daily Travelled Distance of the vehicle *i* in the year *j* (km/day).
$J^{TOT}$ – Total number of days in the year *j*.
*K* – Set of odometer readings of interest for the calculation of the AATD of year *j*: {readings in the year *j*, the last reading before year *j*, and the first reading after the year *j*}.
$R_i^k$ – Odometer reading *k* of the vehicle *i* (km).
$\Delta T^{k+1;k}$ – Number of days between the two consecutive odometer readings *k* and *k+1*.
$J^{k+1;k}$ – Number of days within year *j* between the two consecutive readings *k* and *k+1*.

However, this generalization cannot be always applied. Figure 2 shows an example of the calculations made for a vehicle with biannual technical inspections. In this specific case, the data from pairs of consecutive inspections cover the travelled distances in 2003 and 2005.

However, the travelled distance in 2004 must be calculated by means of three odometer readings, weighting the ADTD in the periods of consecutive inspections. The ADTD in 2002 was calculated without considering the contribution of the first days of the year without coverage. This simplification cannot be used for 2006, due to the small number of days covered by inspections. This type of adjustment tends to be more complex for higher number of inspection plan combinations.

Also, along with these ADTD calculations, the identification and correction of erroneous odometer readings, associated with the errors specified in Chapter 2.2, are an important element of the calculation procedure. This task was undertaken by defining a range of acceptable ADTD values for each vehicle category (Goh, Fischbeck, & Gerard, 2006).

After correcting and excluding erroneous readings, the individual vehicle ADTD were aggregated by type of vehicle, considering its weight, age, type of fuel and engine. The obtained ADTD by vehicle category was multiplied by the national number of vehicles in that category. This procedure allowed the estimation of the Portuguese annual VKT of 331 categories of four and more wheeled vehicles for the years of 2004, 2005 and 2006.

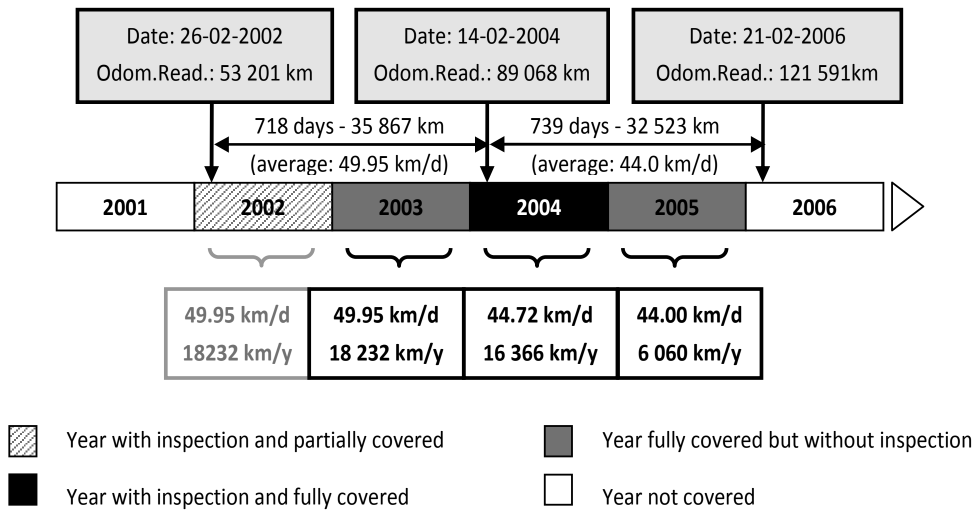


*Figure 2- Example of the calculation of the ADTD using odometer readings*

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The high number of vehicle categories makes the analysis of categorical ADTD more complex. For an easy inquiry of the estimated ADTD by type of vehicle, a simplified model was fitted, using the analysis of variance of the lognormal transformation of the ADTD (Kalinowska & Kuhfeld, 2006). The exclusive use of categorical explanatory variables in the generic model (eq. 6) produced a simplified model with multiplying coefficients (eq. 7). In fact, each category *j* of a specific variable *i* is modelled as a multiplying coefficient ($c_{ij}$). The ADTD of a vehicle type is then obtained by multiplying the corresponding factor of each categorical variable and the estimated ADTD reference vehicle category ($c_0$):

$$\ln(ADTD) = \beta_0 + \sum_i (\beta_i \times x_i) + \varepsilon \quad \text{(eq. 6)}$$

$$\mathrm{ADTD} = e^{\beta_0} \times e^{\sum_i (\beta_i \times x_i)} \times e^{\varepsilon} = \mathrm{c}_0 \times \prod_\mathrm{i} (\mathrm{c}_\mathrm{ij}) \times \mathrm{c}_\varepsilon \quad \text{(eq. 7)}$$

$x_i$ – Explanatory variable *i*: {weight; age; type of fuel; engine}.
$\beta_i$ – Coefficient associated with the explanatory variable *i*.
$\beta_0$ and $\varepsilon$ – The intercept and the error term.
*ADTD* – Average Daily Travelled Distance of a specific vehicle category (km/day);
*j* – Category index of the explanatory variable *i*.
$c_{ij}$ – Multiplying coefficient of the category index *j* of the explanatory variable *i*.

This simplified method resulted in two separated tables with the estimated reference ADTD and the multiplying factors for each category of light and heavy vehicles respectively. that can be found in (Lima de Azevedo, 2007).

### 4.3 Estimation of Annual Traffic Volumes in the National Road Network

The use of the basic concept stated in the equation (3) is straightforward when a complete data base such as the one referred in Chapter 3.3 is available. However, sine this database only has aggregated AADT, national counting panels data were used for the disaggregation of VKT by type of road and vehicle in the RRN.

AADT data collected at each one of the 560 national road counting stations were associated with a specific road section in the database, using the starting and ending kilometre post of each road section. Then, all the network sections were grouped into a total of 21 categories, according to a selected set of characteristics (type of road, number of carriageways, number of lanes and AADT). Whereas a disaggregation by geometric characteristics is straightforward, the grouping by AADT is fundamental for catching similar traffic characteristics, and to improve VKT estimates (FHWA, 2005). The sample of counting data in each road network group allowed the disaggregation of the VKT estimates for 2005 by vehicle category.

# 5 RESULTS

The proposed method was used, as a pilot application, for the estimation of the 2004, 2005 and 2006 VKT. The obtained results are presented in Table 1.

Table 1 - Estimated Annual VKT for Portugal using the proposed method (2004 - 2006)

| ($10^6$vkm) | 2006 | 2005 | 2004 |
|---|---|---|---|
| Heavy Vehicles | 6 319 | 6 772 | 7 691 |
| Light Vehicles | 81 700 | 79 920 | 80 120 |
| **TOTAL** | **86 440** | **86 690** | **89 390** |

The collected odometer readings have a better coverage of the distances travelled by the vehicle fleet for 2004 than for the other two estimation years (Lima de Azevedo, 2007). In this chapter some main results regarding the 2004 VKT estimates are presented:

- The contribution of light vehicles to the total VKT (91.4%) is considerably larger than the one from heavy vehicles (8.6%). This is due to their predominance in the total national vehicle fleet (97.4%).
- Almost the all heavy vehicles' VKT was done by diesel engines. This type of engine is also the main responsible of a high percentage of light vehicles' VKT (60.7%), in spite of the higher percentage of gasoline vehicles in the national vehicle fleet (54.5%).
- The contribution of light diesel vehicles to the total light vehicle VKT increased during the three analysed years, going from 60.7% in 2004 to 64.8% in 2006.
- Vehicles with less than one year are the main contributors to the light vehicles VKT (9.1%). These represent, however, just 5.4% of the national light vehicle fleet, indicating a high value of the average distances travelled for vehicles in this category. The dominant age category in the national heavy vehicle fleet is also the main contributor to the heavy vehicles national VKT.

Disaggregated values for VKT estimation by type of road for 2005 are presented in Table 2. The distances travelled in the RRN represent slightly more than half of the total national VKT (50.7%). The heavy vehicles travel most of their distances in the RRN (65.4%) while the light vehicles travel more outside the RRN (50.5%), including urban streets. Motorways have the higher percentage of the annual VKT amongst all RRN road classes (38.8%). The lowest road category – Regional Roads – accounts for the smallest portion of this VKT (10.5%), but the main category in the RRN with 30.0% of the total network mileage.

Table 2 - Annual VKT for Portugal by road class (2005)

| ($10^6$vkm) | All Roads | RRN | Other Roads |
|---|---|---|---|
| Heavy Vehicles | 6 772 | 4 426 | 2 346 |
| Light Vehicles | 79 920 | 39 540 | 40 380 |
| **TOTAL** | **86 690** | **43 970** | **42 720** |

The obtained estimates were found to be higher than the existing aggregated estimates (Cardoso, 2003). The existing method was calibrated for the 1998-2000 period with international data and then extrapolated for 2001 to 2006 VKT estimations. Given this, one can consider the existing estimated less reliable than those obtained by the proposed method (Lima de Azevedo, 2007).

Regarding the fuel balance validation (see Table 3), the fuel consumption volumes calculated using the estimated VKT in the COPERT III model are very close to recorded national fuel sales issued by the Geological and Energy Directorate (*Direcção Geral de Energia e Geologia*).

Table 3 - Annual balance of fuel consumption and national fuel sales (2004)

| (tons – 2004) | Fuel Sales Volume | Estimated Fuel Consumption | Difference (%) |
|---|---|---|---|
| Diesel | 4 930 826 | 4 747 417 | -3.7% |
| Gasoline | 1 927 122 | 1 789 613 | -7.1% |
| Gas | 20 134 | 17 961 | -10.8% |

The larger difference in the gasoline volumes can be justified by the exclusion of two wheeled vehicles from the proposed method. Regarding the balance of gas volumes, COPERT III does not estimate the gas consumption of heavy passenger vehicles (Ntziachristos, et al., 2000), which characterize a small portion of the Portuguese urban public transportation fleet.

## 6 CONCLUSIONS AND FURTHER RESEARCH

Estimates of annual VKT at the national level are fundamental indicators in the statistical characterization of a country's road sector activity. These statistics are needed by different focus areas such as transportation management, road safety, environmental and economical analysis and large scale urban planning.

The proposed methodology was used, as a pilot application, in the estimation of the Portuguese VKT in 2004, 2005 and 2006. The obtained results represent the first national disaggregated estimates by road class and vehicle category. However, the use of the proposed method for the calculation of flexible, systematic and harmonized estimates must rely on a periodical access to the different data sources currently available in Portugal. Additionally, the collection of supplementary data must be considered in further applications. Some key limitations were identified and cannot be mitigated without the following:

- The additional disaggregation by the vehicle type of use (e.g.: private passenger, commercial passenger, duty or mixed). This data can be collected from the IMTT (ex-DGV) database along with the inspected vehicle attributes already considered.
- Data on distances travelled by vehicles that are not subject to mandatory technical inspections, namely two-wheeled and special vehicles.
- Data on distances travelled by new vehicles to fill the existing gap on the first years of age, when no odometer readings are made due to lack of mandatory inspections at this stage.
- Data on international travelled distances, namely the distances travelled by foreign vehicles in national territory and journey lengths travelled abroad by national vehicles.

The last three supplementary data types can be estimated by collecting data from sample groups of the correspondent vehicle types using different periodical national surveys. Each of these surveys has a specific purpose and, therefore a different specification and implementation method.

Also, regarding the vehicles that are not covered by mandatory technical inspections, the modification of the current legal framework could also be considered, but falls out of the subject of this paper.

The improved statistics would allow a systematic and detailed characterization of the annual traffic volumes in the Portuguese road network, its disaggregation by different types of vehicles and road types and a comprehensive analysis of the national road mobility.

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