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MONTE-CARLO SIMULATION OF ROAD TRANSPORT EMISSION

Adam Torok[1]
[1] *Budapest University of Technology and Economics, Department of Transport Technology and Economics, Hungary*

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Abstract: There are microscopic, mezoscopic and macroscopic models in road traffic analysis and forecasting. From microscopic models one can calculate the macroscopic data by aggregation. The following paper describes the disaggregation method of macroscopic state, which could lead to microscopic properties of traffic. In order to ensure the transform between macroscopic and microscopic states Monte-Carlo simulation was used. MS Excel macro environment was built to run Monte-Carlo simulation. With this method the macroscopic data can be disaggregated to macroscopic data and as a byproduct mezoscopic, regional data can be gained. These mezoscopic data can be used further on regional environmental or transport policy assessment.

Keywords: macroscopic data, Monte-Carlo simulation, microscopic data, environmental pollution, road transport.

1. Introduction

Transport represents a crucial sector of the economy. Carbon dioxide (CO_2) emissions from road transport increased by nearly 23% between 1990 and 2010, and without the economic crisis growth could have been even bigger. Transport is the only major sector in the EU where greenhouse gas emissions are still rising. Transport is responsible for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy. Road transport alone contributes about one-fifth of the EU's total emissions of CO_2 (Fig. 1).

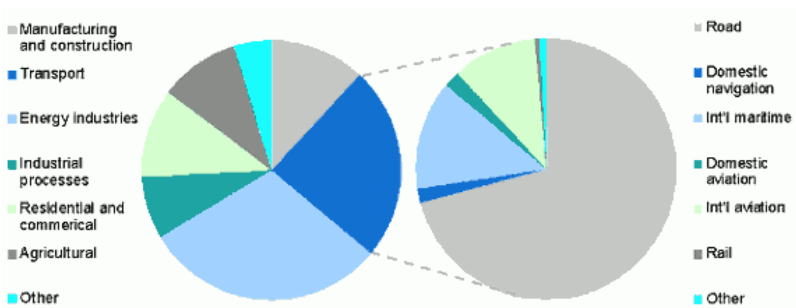

Fig. 1.
EU27 Greenhouse Gas Emissions by Sector and Mode of Transport, 2007
Source: http://ec.europa.eu/clima/policies/transport/index_en.htm

[1] Corresponding author: atorok@kgazd.bme.hu

While emissions from other sectors are generally falling, those from transport have increased 36% since 1990. Basically aggregated, national, macro level data are available on road transport fuel consumption, vehicle fleet or mileage. CO_2 emission and fuel consumption are influenced by these parameters. The existing research literatures on transport sector's CO_2 emissions mainly distinguish between model categories of methodological perspectives. The first category is the bottom-up sector analysis where the microscopic data are available (Johansson, 1995; Bellasio et al., 2007; Junevičius et al., 2011; Praveen and Arasan, 2013; Hilmola, 2013; Domanovszky, 2014; Meszaros and Torok, 2014). This method is also useable to estimate emissions based on passenger travel behaviors in cities areas (He et al., 2013). The second method is the top-down analysis. Transport sector's CO_2 emissions are generally decomposed into changes in fuel mix, modal shift, economic growth, population, changes in emission coefficients and transport energy intensity. This is a process of data disaggregation (Timilsina and Shrestha, 2009; Tian et al., 2014) where the studied factors responsible for the growth of transport sector's CO_2 emissions, and the results showed that economic growth and transport energy intensity are the principal factors. Economic growth is one main factor behind CO_2 emission increase in EU27 (Andreoni and Galmarini, 2012). The third method is system optimization. It has been widely used in forecasting energy and transport demand and CO_2 emission (Azar et al., 2003; Luckow et al., 2010; Hassan et al., 2011; Ahanchian and Biona, 2014; Motasemi et al., 2014). The fourth method is econometric models. Using time series models, (Haldenbilen, 2006; Mraihi et al., 2013) investigated the role of the fossil fuel price in the demand of the transport sector. Lu et al. (2009) and Török and Török (2014) predicted the development trends of the number of motor vehicles, vehicular energy consumption and CO_2 emission. Based on this no disaggregation method is reported yet which uses the macroscopic data and could lead to microscopic data of road vehicle's emission. In order to eliminate the gap that is found between the transformations of microscopic to macroscopic data Monte-Carlo simulation is used. The research hypothesis can be concluded as if the appropriate method can be found and used to disaggregate the macroscopic data then provided microscopic data are suitable for the assessment of regional transport and environmental policy incentives.

2. Methods

Monte-Carlo methods (or Monte-Carlo simulations) were computational algorithms that rely on repeated random sampling. Typically simulations were run many times in order to obtain the distribution of an unknown probabilistic parameter. Monte-Carlo methods are often used in three distinct problem classes: optimization, numerical integration and generation of draws from a probability distribution. In this case probability distribution was simulated by Monte-Carlo method. Let us suppose that $(\bar{x})$ average mileage has the same value as the expected value of the ζ discrete vector variable (the vector size is dependent from the vehicle fleet, the elements of the vector are the mileage of vehicles as discrete random variables), $M(\zeta_i)$. In this case the approximation of $(\bar{x})$ as average mileage based on the Monte-Carlo method can be calculated by the large numbers of Bernoulli Act (Eq. (1)):

$$P(\bar{x} = \mathrm{M}(\zeta_i))=1 \quad (1)$$

The error magnitude of the simulation is Eq. (2):

$$\delta \approx \frac{1}{\sqrt{N}} \quad (2)$$

In order to significantly decrease the magnitude of error the number of simulations is needed to be significantly increased that would lead to significant increase in computational time. The development of personal computer made feasible to build up such simulation processes in MS Excel environment and made it viable to run the simulation within a reasonable time. For instance in case of South Hungary the simulation had been running Intel® Core™ Duo CPU T2250 1.73 GHz 4 GB RAM laptop for 12 minutes. The aim of the simulation was to build up the vector variable for mileage and for fuel consumption in the investigated area to estimate the regional CO_2 emission. The aggregated data are available at the Hungarian Statistical Office. Therefore the following top-down model was used (Eq. (3)):

$$\sum_{i=1}^{n} \varepsilon_i = \sum_{i=1}^{n} (\Phi_i \cdot \frac{\rho_i}{100} \cdot \mathrm{E}_i) \quad (3)$$

where:

ε: yearly transport related CO_2 emission of investigted area [gCO_2/year]
Φ: mileage [km/year]
ρ: fuel consumption [liter/100 km]
E: Emission factor of fuel [gCO_2/liter fuel] (Török, 2009; Zöldy, 2011; Bereczky, 2012)
n: number of vehicles in the investigated area

From Eq. (3) the mileage (Φ_i) and the personal fuel consumption is not yet discovered (ρ_i), only the aggregated, national and macroscopic data is known from Hungarian Statistical Office, therefore Monte-Carlo simulation was used (Fig. 2) to determine the variables. For this reason the mileage (Φ_i) and the personal fuel consumption (ρ_i) was considered as vector variables. Monte-Carlo simulation were used to generate individual mileage and fuel consumption data for every vehicle. The mentioned two vector variables (for mileage and for fuel consumption) were used in four different cases (gasoline passenger car, diesel oil passenger car, diesel oil bus, and diesel oil heavy goods vehicle). Some simplifications were considered:

I It was assumed that the distribution of fuel consumption is a normal Gauss distribution with the expected value of 9.5 liter/100 km in case of gasoline and 7.6 liter/100 km of diesel oil (Kousoulidou et al., 2012; Samaras et al., 2012).

II The ratio of diesel vehicles (β=0,25) is considered equal to the national average (Emőd and Török, 2010).

III It was assumed that the distribution of mileage is a normal Gauss distribution with the expected value 9000 km in case of gasoline driven vehicle and 11 600 km of diesel oil driven vehicle (Paar et al., 2014).

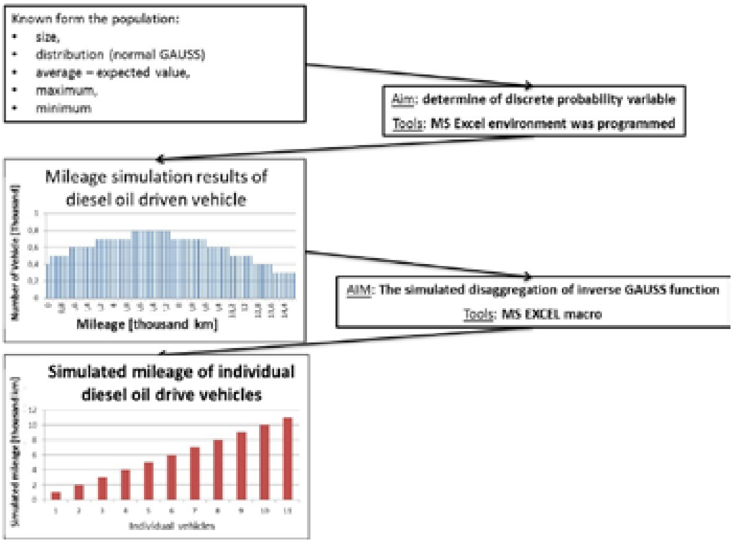

Fig. 2.
Simulation Method

3. Results

The area of investigation was the southern part of Hungary, where 24 450 inhabitants were living in 2012 of which 50.78% were female and 49.22% were male (Figs. 3a and 3b).

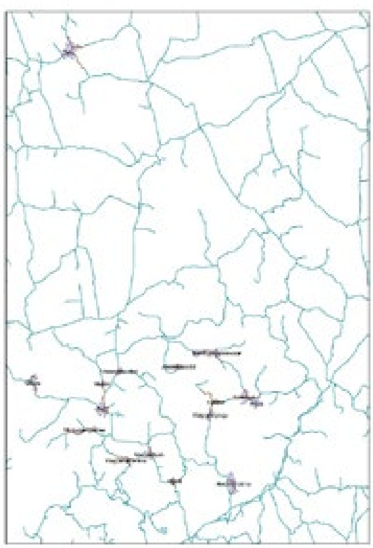

Fig. 3a.
Area of Investigation, Southern Part of Hungary

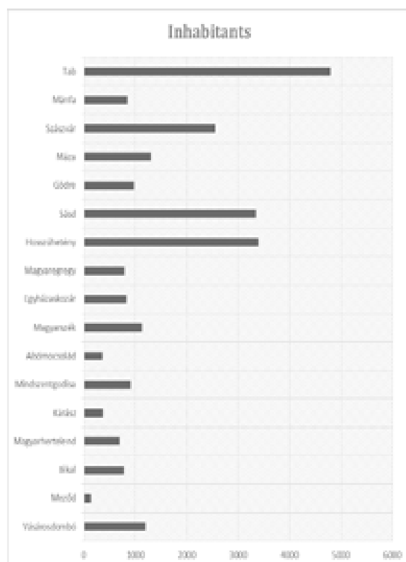

Fig. 3b.
Number of Inhabitants in the Investigated Area

The average daily traffic of the region was 2170 PCU (Passenger Car Unit). 85% of the traffic was passenger car, 10% was heavy goods vehicles, 3% was buses, 1% was motorcycle and 1% was agricultural vehicle. Based on the Monte-Carlo simulation described in methodology section, 17 124 passenger cars with gasoline engine, 5 708 passenger cars with diesel engine, 2 703 heavy goods vehicles with diesel engine and 733 buses with diesel engine were simulated. As a result of simulation 11 250 232 liter of gasoline and 43 817 722 liter of diesel oil (Fig. 4) has been consumed by the road transport sector in the investigation area.

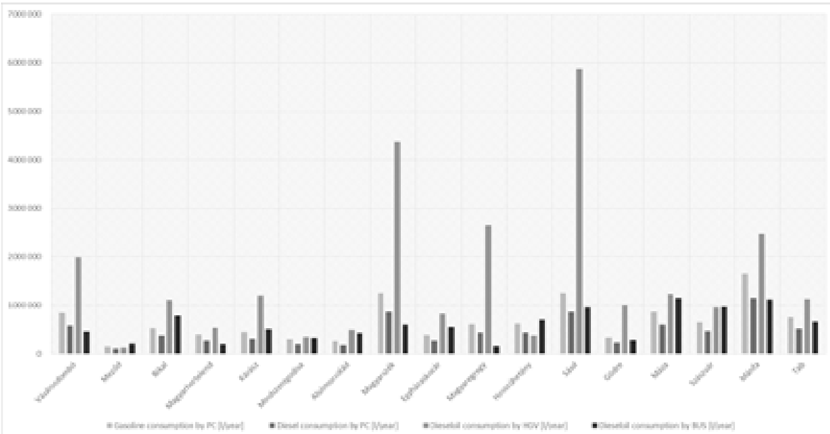

Fig. 4.
Calculated Fuel Consumption Based on the Monte-Carlo Simulation

Based on the simulation, an estimated CO_2 emission in the area (Table 1).

Table 1
Estimated CO_2 Emission by the Simulation

Mode of transport	**Estimated CO_2 emission [Gg/year]**
Passenger Cars	45.7
Heavy Goods Vehicles	57.4
Buses	21
Total	124.1

Source: own estimation based on the Monte-Carlo simulation

4. Analysis and Discussions

A Monte-Carlo simulation has been made in order to disaggregate the macroscopic data. Due to the used simulation method individual characteristics such as mileage and fuel consumption has been modeled. Whit this method the local transport and environmental policy measures can be assessed. The results of the simulation tell us that the discrete vector variable can be modeled for individual mileage and fuel consumption for different vehicle classes (passenger cars, heavy goods vehicles and buses). With the help of the simulation the CO_2 emission can be estimated. The punctuality of simulation can be increased but that would lead to significant increase in computational time. Currently only fossil fuels were considered in the simulation and in the CO_2 emission estimation as well. Further on other type of fuels can be considered such as biofuel components, biogas, electric drives and hydrogen etc. The specified results can be extended, as the Monte-Carlo simulation can not only be used in top-down model categories.

5. Conclusion

Finally, the research hypothesis can be stated as the Monte-Carlo simulation is an appropriate method that can be used to disaggregate the macroscopic data in order to provided microscopic data which are suitable for the assessment of regional transport and environmental policy incentives. This tool can have role not only in top-down models, but can have significant role in other type of estimation as well. In the future the model will be extended with role of liquid biofuel components.

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