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COPERT III - The effect of estimated parameters on the total emission of road transport in the Republic of Croatia

COPERT III - Utjecaj procijenjenih parametara na ukupnu emisiju cestovnog prometa u Republici Hrvatskoj

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Zagreb, December 2004

1. Introduction

The share of road transport in the total transport activity has been increasing in the recent years. The biggest rise in road traffic has been noted with passenger cars. Consequently, air pollutant emissions from transport with their harmful effects on the man and the environment have also increased. It is of vital importance (ecological, economical and political) that transport should be organised in the best possible way, i.e. in the way to satisfy the needs of people and goods with a lesser degree of undesirable side-effects, such as pollution. The price of transport organisation should be within reasonable limits, while emissions should be reduced to a minimal possible level. This can be achieved by the introduction of more stringent norms on the allowed emissions and by application of new technologies on internal combustion engines.

Computer programs for the estimation of pollutant emissions from transport have been developed in order to create a common European model for estimating the impact of transport on air pollutant emissions. These computer programs are very helpful in making decisions on the strategy for the construction and the development of road infrastructure.

This paper presents an estimation of the total minimal and maximal emissions in the Republic of Croatia and the impact of particular estimated parameters on total emissions.

The calculation of the estimated minimal and maximal emission, obtained by means of the computer program COPERT III, is based on a set of assumptions derived from the vehicle fleet statistics and estimated driving parameters. Therefore, a good knowledge of the vehicle fleet and the manner of using particular road types is very important.

2. COPERT III

COPERT III is a computer program for estimating air pollutant emissions in road transport. For the estimation, the program makes use of a method based on the transport activity, i.e. it calculates the amount of emission on the basis of the available data on fuel consumption. The results obtained by this method may be classified as emission at operating temperature, emission at cold start and emission by evaporation. The three emission types contribute to the total air pollutant emission which is defined as follows:

$$E_{\mathrm{TOTAL}} = E_{\mathrm{HOT}} + E_{\mathrm{COLD}} + E_{\mathrm{EVAP}} \qquad (1)$$

where: E_{HOT} is the emission produced during the thermal stabilised (hot) engine operation
E_{COLD} is the emission produced in warming-up phase (cold start)
E_{EVAP} is the emission of hydrocarbons from fuel evaporation (calculated only for the vehicles with an Otto engine).

Each element depends on the emission factor and on one or more parameters related to the transport activity of a vehicle. Therefore, a general expression reads as follows:

$$E_{\mathrm{x}} = e_{\mathrm{x}} \cdot a \qquad (2)$$

where: E_{x} is one of the three elements contributing to total emissions
e_{x} is the appropriate activity emission factor
a is the amount of transport activity relevant for this type of emission.

Input parameters for COPERT III are the data related to the country for which the estimation is made, and the data on the transport activity of vehicles.

The country-related data are the data on the fuel, the climate, the data related to transport activity at cold start and the data on fuel tanks.

The data on the vehicle transport activity are the data on vehicles divided into categories and types. The following data are given for each vehicle category and type: number of vehicles, average mileage per year, average speed on a particular road class, share of evaporative substances on particular road classes, road slope percentage, load effect for heavy duty vehicles, etc.

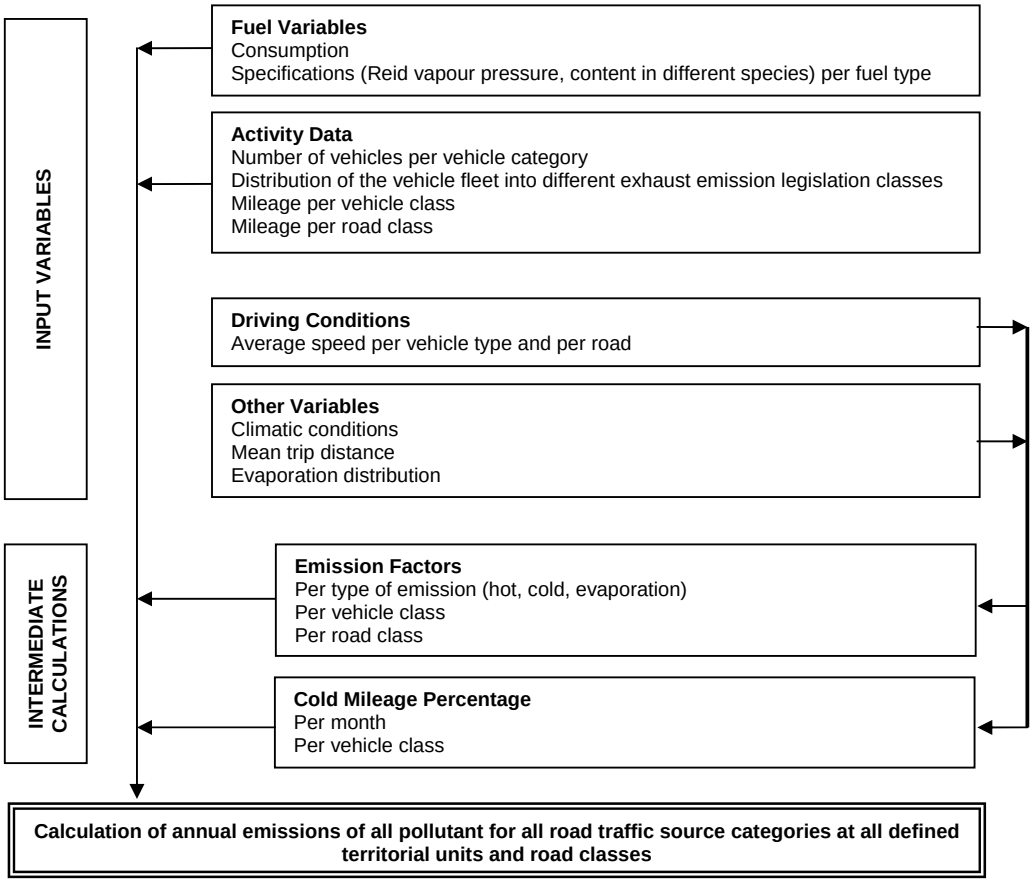


Figure 1. Flow chart of the pollutant emission estimation obtained by COPERT III [4]

COPERT III is used to calculate emission factors on the basis of input parameters, i.e. to calculate a specific emission in g/km for a vehicle of each type on every road class. The obtained results are then used to calculate emissions of a particular pollutant and the consumption of a particular fuel type.

The emission factor e_x is defined as a specific emission of a particular pollutant for a vehicle of a particular category, or a particular type, and it depends on a series of coefficients and factors, such as the vehicle speed, road class, fuel quality, etc. Emission factors can be obtained using theoretical expressions for internal combustion engines or empirical expressions resulting from tests carried out on engines in laboratories or on test vehicles driven in standardized test cycles.

$$e_x = A_1 + A_2 + A_3 + ... + A_n \qquad (3)$$

where: A_1, A_2, A_3... A_n are coefficients having an impact on a particular emission factor.

COPERT-u III divides vehicles into six categories: passenger cars, light duty vehicles, heavy duty vehicles, buses/coaches, mopeds and motorcycles. All categories are divided into different types according to the engine type (Otto and Diesel engine), the engine displacement (passenger cars) or the allowed gross vehicle weight, and to the emission control legislation (vehicles before the ECE regulations, ECE 15/00 and 15/01, ECE 15/02, ECE 15/03, ECE 15/04, Euro 1, Euro 2, Euro 3, Euro 4).

The computer program COPERT III can calculate emissions of CO, NO_x, particles (PM), CH_4, non-methane evaporable organic compounds, N_2O, NH_3, SO_2, Pb, Cu, Cd, Cr, Ni, Se, Zn, CO_2 as well as fuel consumption. Non-methane evaporative organic compounds, together with methane (CH_4), can be considered as carbohydrates - HC.

3. Calculation model

Estimated values of minimal and maximal total pollutant emission in the Republic of Croatia are obtained by the variation of parameters that have the highest impact on the total pollutant emission and by the analysis of the obtained results.

The required data on fuels have been obtained from the Croatian company INA which is the biggest fuel distributor in the Republic of Croatia. Climatic data have been obtained from the national hydro meteorological institution (Državni hidrometerološki zavod – DHMZ *in Croatian*), while the data pertaining to the number of vehicles have been provided by the Ministry of Internal Affairs (MUP RH *in Croatian*)* and the centre for vehicles of Croatia (Centar za vozila Hrvatske – CVH *in Croatian*). The values of these data have not been varied, but it should be pointed out that the number of vehicles used in the calculation has been obtained in the way that the share of a particular vehicle category has been taken from the CVH database of registered vehicles, and on the basis of that share, the number of vehicles has been calculated according to the MUP data. This approach has been adopted because the data from these two sources differ considerably. The total number of registered vehicles according to MUP is given in Table 1. Vehicles using liquefied petroleum gas as a fuel have not been taken into account due to the lack of data on their number, but their share in the total pollutant emission can be neglected.

Table 1. The number of registered vehicles in the Republic of Croatia per each category on 31st December 2003*

Vehicle category:	Mopeds	Motorcycles	Passenger cars	Buses/ Coaches	Heavy and light duty vehicles	Combined passenger/ cargo vehicles
Total number:	65 212	33 888	1 290 955	4 826	137 967	9 945

Out of eight parameters that needed to be evaluated, four parameters with the strongest influence on emissions have been entered as variables. One parameter in its minimal, mean and maximal values was taken into account in the calculation, while the other three parameters were kept constant at their mean values.

In calculation, the parameters of the road slope and vehicle load effect have a significant impact only on the emission of heavy duty vehicles, whose share in the total emissions of most pollutants is relatively small. The parameters of fuel tank efficiency and the share of emissions from evaporation on each road class can be evaluated with a relative precision from the data provided by the EU countries. In order to reduce the total number of combinations of varied parameters, these four parameters were kept constant due to their negligible impact on the calculation results, when compared with the varied parameters.

Parameters that take into consideration the change of regular maintenance service intervals and the function of the efficiency of the after-treatment system depending on mileage were kept constant as suggested in the COPERT III programme. The increase of pollutant emissions produced by vehicles with Diesel engines and vehicles with Otto engines without a catalyst depends on the regular maintenance service intervals which were standardized for the calculation purposes, so that a vehicle after service is considered in the same way as a new vehicle as far as its pollutant emission is concerned. The level of pollutant emissions produced by vehicles with Otto engines and a catalyst increases constantly in dependence on the total mileage because the efficiency of the catalyst decreases with the increase in total mileage.

Parameters with a major influence on emissions, i.e. variable parameters, are the following: average annual mileage, average vehicle speed on each road type, mileage per each vehicle type driven on each road type, the influence of cold start and the average trip length of each vehicle. After varying

* Registered road motor vehicles on 31 December 2003 – provisional data – source: Ministry of Internal Affairs, Monthly Statistics, p. 93, No 1, Zagreb 1/2004.

each of these parameters, the obtained results have been analyzed. From the result analysis the influence of each parameter on the total pollutant emission was clearly determined, and the evaluation of minimal and maximal pollutant emission could be done.

4. Analysis of the influence of particular parameters on pollutant emissions

4.1 Influence of average driving speed on different road types

Emission factor at the engine operating temperature depends on a number of different factors among which the vehicle speed plays a major role. Since it is impossible to monitor the actual driving speed of each vehicle and to thus obtain the actual emission factors, they are determined according to the average driving speed. The values of average driving speeds (for different road types and vehicle types) cannot be obtained in the Republic of Croatia, therefore, they have been evaluated on the basis of the available values of average driving speeds in some European countries with similar driving patterns and refined taking into account the national particularities of Croatia.

Table 2. Estimated values for average driving speed in km/h

	Urban	**Rural**	**Highway**
	min-mean -max	**min-mean -max**	**min-mean -max**
Passenger cars	15-25-35	50-60-70	85-100-115
Light duty vehicles	5-20-35	40-50-60	70-80-90
Heavy duty vehicles	5-20-35	40-50-60	60-70-80
Buses/Coaches	5-20-35	40-50-60	70-80-90
Mopeds	15-25-35	40-50-60	0
Motorcycles	15-25-35	50-60-70	85-100-115

Hot emissions, i.e. emissions occurring at the engine operating temperature, depending on the average driving speed can be calculated as follows:

$$E_{hot,v} = e_{hot,v} \cdot a \qquad (4)$$

where: $E_{hot,v}$ is emission at the engine operating temperature depending on the average driving speed (t/year)

$e_{hot,v}$ is emission factor at the engine operating temperature depending on the average driving speed (g/km)

a is annual mileage (km/year)

The following diagram presents exhaust emissions which vary considerably with the change of average driving speed and all other input parameters kept constant.

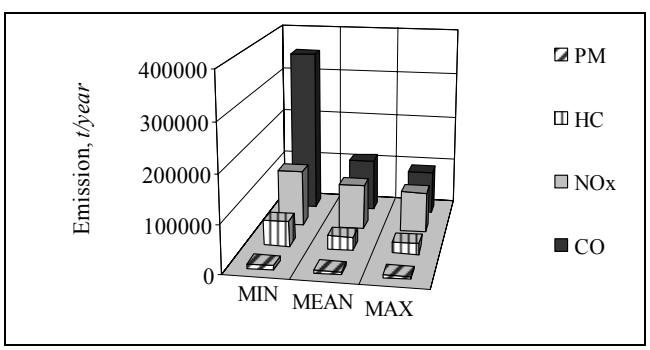


Figure 2. Influence of average speed of a vehicle on pollutant emissions

The diagram shows clearly that the change of average driving speed affects the change of emissions of CO, NO_x, HC and particulate matter (PM), which, together with the CO_2 emission, contribute to a largest extent to the total pollutant emission.

It can also be noted that the total pollutant emission decreases with the increase in the average driving speed, while the fuel consumption does not increase. In fact, fuel consumption is highest at the lowest average driving speed, while at the highest average driving speed it assumes a mean value.

Considering the vehicle type, passenger cars have the strongest impact on the change of total exhaust emission depending on the vehicle speed (approximately 75%). Depending on the engine type, passenger cars affect emissions of particular pollutants, e.g. Otto engines have a major influence on the change of CO emissions, while, on the other hand, Diesel engines have a major influence on the NO_x emission. The total number of variation combinations of the average driving speed on each road type is more than one hundred million.

4.2 Influence of cold start and average trip length of a vehicle

Cold start, in comparison with hot engine operation, causes an increased concentration of most exhaust gases in the emission of a vehicle. Although cold start emissions occur on all road types, they seem to be most likely in urban driving.

According to the methodology of COPERT III, emission factors at cold start are available, or can be estimated, only for passenger cars and light duty vehicles, assuming that these vehicles behave like passenger cars. Moreover, they are considered not to be a function of vehicle age. Cold start emissions are calculated as an extra emission over emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts. Cold emissions can be calculated by the following equation:

$$E_{\mathrm{COLD};\,i,j} = \beta_{i,j} \cdot N_j \cdot M_j \cdot e_{\mathrm{HOT};\,i,j} \cdot \left(\frac{e_{COLD}}{e_{HOT}} - 1 \right) \Big|_{i,j} \qquad (5)$$

where: $E_{\mathrm{COLD};\,i,j}$ is cold start emissions of the pollutant i (for the referent year), caused by vehicle class j

$\beta_{i,j}$ is fraction of mileage driven with cold engines or catalyst

N_j is number of vehicles of class j

M_j is total mileage per vehicle in vehicle class j

$\left(\frac{e_{COLD}}{e_{HOT}} - 1 \right) \Big|_{i,j}$ is ratio of cold over hot emission of pollutant i, relevant to vehicles of class j

The factor β depends on the average monthly temperature and the average trip length of a vehicle l_{trip}. Since the information on the average trip length is not available for the Republic of Croatia, estimated values were used. Statistical European value of the average trip length is 12.4 km. According to the statistics of some other European countries, their respective average trip length is in the range from 9 km (Denmark) to 18 km (Malta). In order to calculate the β factor using the equation below, the average monthly temperature needs to be known.

$$\beta = 0.6474 - 0.02545 \cdot l_{\mathrm{trip}} - (0.00974 - 0.000385 \cdot l_{\mathrm{trip}}) \cdot t_s \qquad (6)$$

The β factor has been calculated for the trip lengths of 9, 13.5 and 18 km, while other input parameters kept constant values. Under such conditions, the exhaust emissions change considerably depending on variable parameters. The following diagrams show these changes.

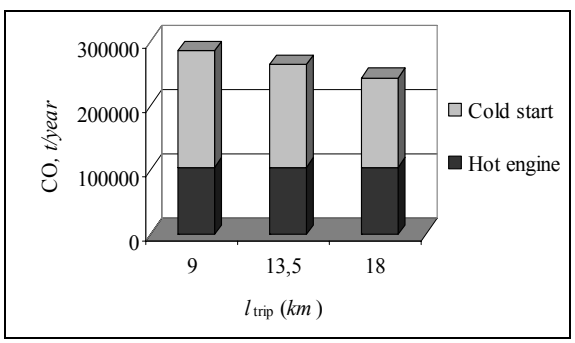


Figure 3. Influence of trip length on CO emission

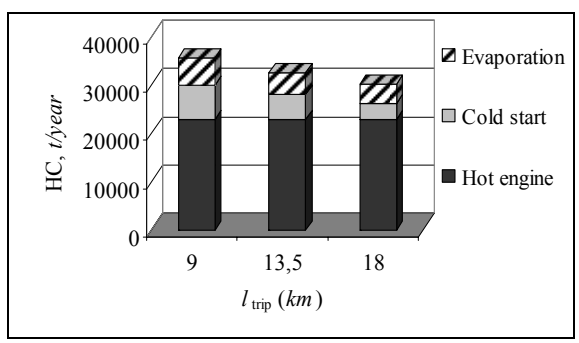


Figure 4. Influence of trip length on the HC emission

From these diagrams it can be seen that the emission increases with the decrease in l_{trip}, which is a consequence of the influence of the trip length on the emission at cold start.

4.3 Influence of driving share for each road type

It has been shown by calculations that the total pollutant emission is highest when urban driving share prevails and lowest when rural and/or highway driving share prevails. Yet, this parameter has a minor impact on the change of emission: the emission changes only slightly with the increase of vehicle operation on urban roads. Distribution of vehicle driving share for different road types in Croatia has been estimated according to the relevant distribution in the EU countries.

4.4 Influence of annual mileage

The increase in the annual mileage results with an increase in both the pollutant emission and fuel consumption.

Variable values used in the calculation are presented in Table 3.

Table 3. Mileage in kilometres per year

Vehicle category	Minimal value	Mean value	Maximal value
Passenger cars	10000	15000	20000
Light duty vehicles	10000	20000	30000
Heavy duty vehicles	50000	125000	200000
Buses/Coaches	50000	100000	150000
Mopeds and motorcycles	2000	4000	6000

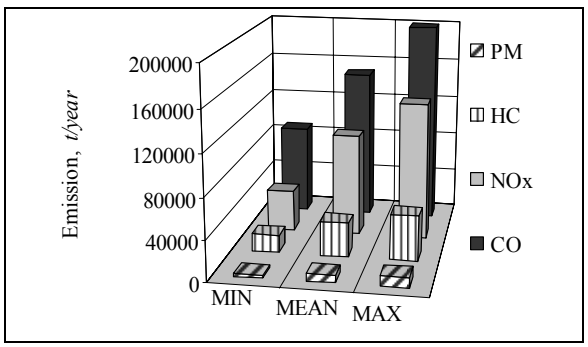


Figure 5. Influence of total mileage of all vehicles on pollutant emissions

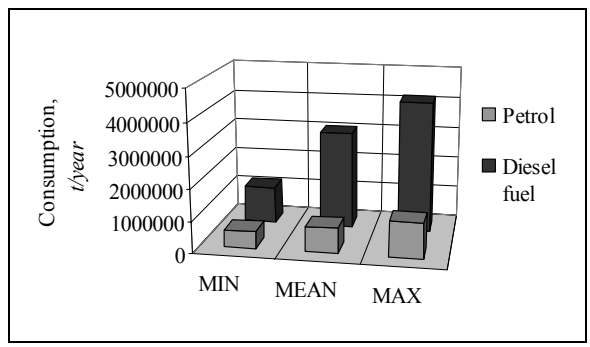


Figure 6. Influence of total mileage of all vehicles on total fuel consumption

The total mileage per year was a variable parameter which was used in its minimal, mean and maximal values for each vehicle type, while all other input parameters were constant. The total number of combinations of total annual mileage variation is two hundred and forty-three.

The calculation demonstrated that the total annual mileage is the factor which has the strongest impact on the pollutant emissions.

4.5. Minimal and maximal total pollutant emission and fuel consumption

The following diagrams give the minimal and maximal pollutant emissions estimated by a calculation model for two sets of data. The majority of data has been estimated, therefore, one set of data are for low traffic activity and more favourable conditions resulting in a lower total pollutant emission, while the other set is for an unfavourable estimation resulting in a higher maximal pollutant emission.

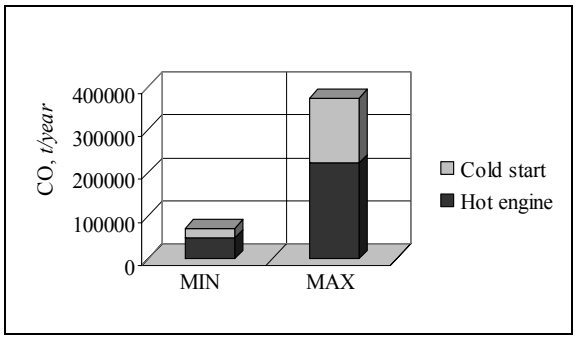


Figure 7. Minimal and maximal emission of CO

Minimal emission of CO: 71 360 t/year
Maximal emission of CO: 373 997 t/year

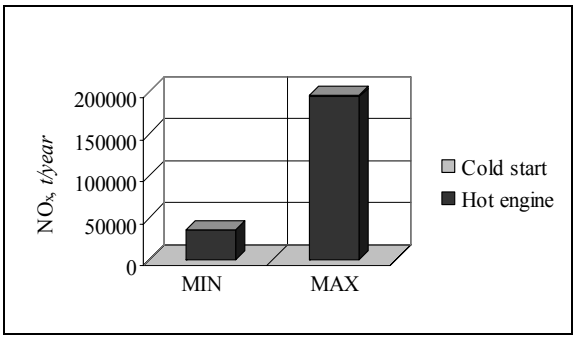


Figure 8. Minimal and maximal emission of NO_x

Minimal emission of NO_x: 35 735 t/year
Maximal emission of NO_x: 195 779 t/year

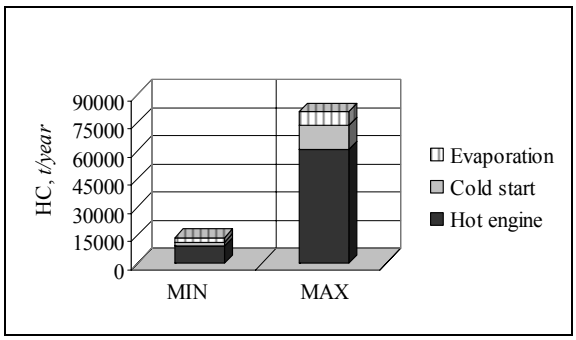


Figure 9. Minimal and maximal emission of HC

Minimal emission of HC: 13 858 t/year
Maximal emission of HC: 80 833 t/year

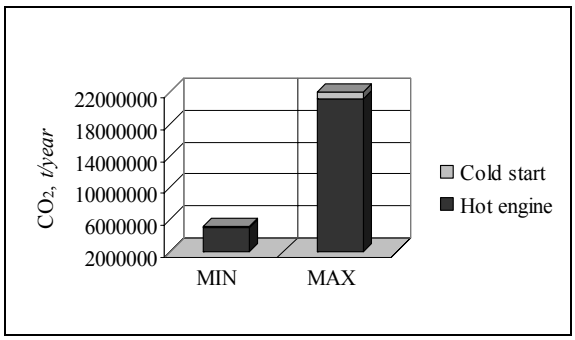


Figure 10. Minimal and maximal emission of CO_2

Minimal emission of CO_2: 5 093 131 t/year
Maximal emission of CO_2: 21 984 558 t/year

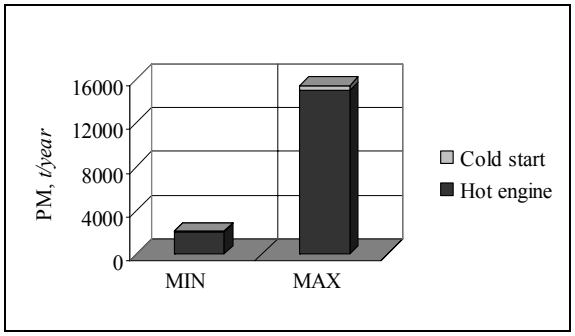


Figure 11. Minimal and maximal emission of particles (PM)

Minimal emission of PM: 2 117 t/year
Maximal emission of PM: 15 401 t/year

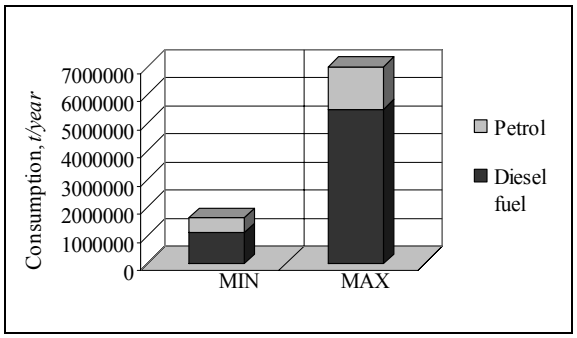
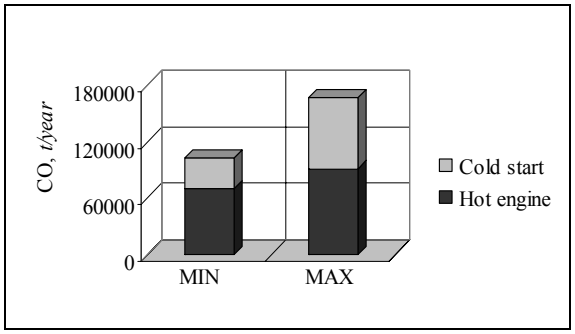


Figure 12. Minimal and maximal fuel consumption

Minimal consumption: 1 615 788 t/year
Maximal consumption: 6 984 860 t/year

The analysis of results leads to a conclusion that the range of result sets is wide. In order to obtain as accurate results as possible, it is necessary to take the fuel consumption balance as a reference value where the output value for the total fuel consumption should not exceed to a higher degree the input value for consumption, for both minimal and maximal emissions. Information on the total fuel consumption per year on national level is not available for Croatia [1], therefore, the input data on total fuel consumption was provided by INA. According to INA it is 1 889 676 t/year, and the CO_2 emission for this value of fuel consumption is 5 993 239 t/year. Results for the total minimal and maximal emissions of other pollutants for balanced fuel consumption are shown in the following diagrams.



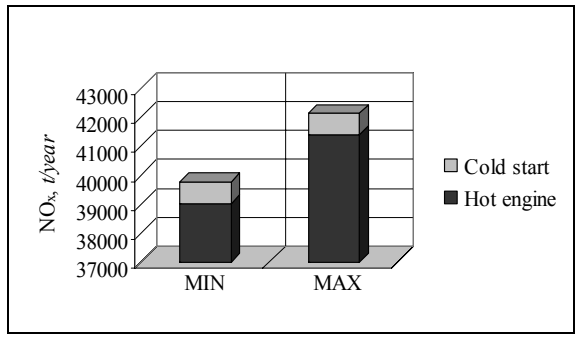
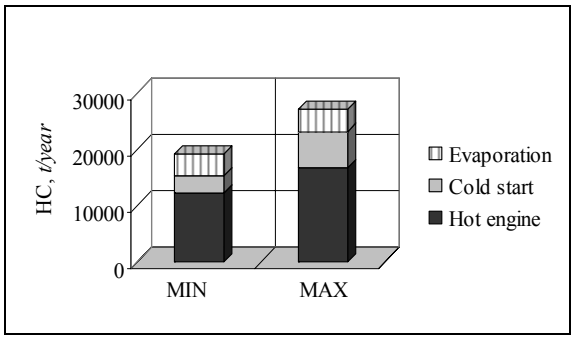


Figure 13. Minimal and maximal emission of CO

Minimal emission of CO: 102 808 t/year
Maximal emission of CO: 166 537 t/year

Figure 14. Minimal and maximal emission of NO_x

Minimal emission of NO_x: 39 748 t/year
Maximal emission of NO_x: 42 118 t/year



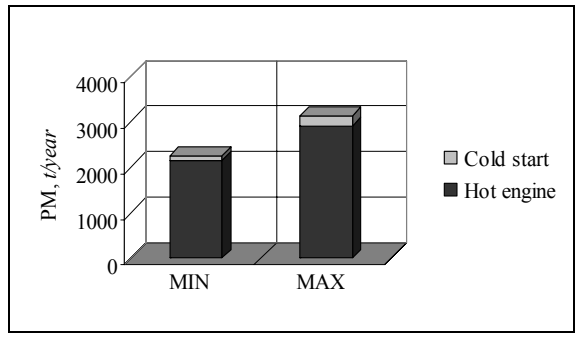


Figure 15. Minimal and maximal emission of HC

Minimal emission of HC: 19 150 t/year
Maximal emission of HC: 27 185 t/year

Figure 16. Minimal and maximal emission of PM

Minimal emission of PM: 2 245 t/year
Maximal emission of PM: 3 137 t/year

For balanced fuel consumption, a significant decrease in the range between the minimal and maximal estimated emission has been noted. For minimal emission the variable parameters were mean values of annual mileage, maximal values of vehicle speed, and the maximal value for trip length l_{trip}. On the other hand, for maximal values, the variable parameters were minimal values of annual mileage, minimal values of vehicle speed, and the minimal value of trip length l_{trip} in order to keep fuel consumption at a constant level.

5. Conclusion

Estimated results obtained by the program COPERT III indicate that four parameters, out of eight, have the biggest influence on pollutant emissions. They are: annual mileage, vehicle speed on each road type, average trip length and driving share on each road type. The highest level of pollution is in urban driving conditions, therefore, the above mentioned four parameters are taken as variables in the calculation, while the other four (road slope and vehicle load effect on each road type, fuel tank efficiency and fuel evaporation) do not influence the total pollutant emission significantly. Therefore, one of the ways of reducing pollutant emissions would be to reduce the parameters that contribute to the greatest extent to their increase. It is hardly feasible as a slight increase in pollutant emissions has been noted, new ways of reducing pollutant emissions should be found.

Pollutant emission can be reduced directly by the influence on vehicles, or indirectly by the influence of the road infrastructure and quality of fuel. The emission reduction by the influence on vehicles requires measures that would exclude old vehicles from circulation painlessly, for example with the financial support provided by the government. The introduction of new vehicles guarantees a significant reduction of pollutant emissions due to the implementation of a new technology. In addition, for optimal effect, the fuel quality needs to be improved, and the increased use of LPG by road motor vehicles needs to be encouraged.

It is also possible to reduce pollutant emissions by constructing new road infrastructure. Since the calculation results obtained by COPERT III have led to a conclusion that urban driving regime has a major impact on the pollutant emission, one of proposed solutions is the construction of city ring-roads in order to reduce the share of urban driving in the traffic activity on particular road types. An additional conclusion is that the pollutant emission is higher when length l_{trip} is shorter, i.e. short trips contribute to the increase in pollutant emissions. A possible solution to the problem would be the design of a highly efficient network of public transport (tramways separated from road traffic, underground railway, and sub-urban trains). In addition, in order to achieve the same aim of reducing the annual mileage of road vehicles, it is possible to redirect passengers and goods to railway transport, hence the need to build modern electrified railway infrastructure for high speed passenger trains and fast freight trains. More intensive afforestation can contribute to the harnessing of the CO_2 from road traffic emissions for the production of oxygen.

As four parameters which contribute significantly to pollutant emissions have been entered into calculation as variables, the result range from minimum to maximum values is wide and it is 1:5.24 for CO, 1:5.48 for NO_x, 1:5.83 for HC, 1:7.27 for PM, 1:4.32 for CO_2 and 1:4.32 for fuel consumption. In order to reduce the range of results, the total minimal and maximal pollutant emissions are presented and estimated for balanced consumption, and in this calculation, the range is much narrower, i.e. 1:1.61 for CO, 1:1.06 for NO_x, 1:1.42 for HC, and 1:1.40 for PM.

For the best possible accuracy of calculation and estimation of pollutant emissions in transport, detailed measurements have to be carried out after the model of European countries. The required data are: accurate records on mileage per year, statistical researches on driving share on each road type, driving conditions on each road type, precisely determined composition and properties of fuel, as well as the annual fuel consumption in Croatia. Depending on the chosen calculation method, the input data have to be systematized in an adequate way. If it is decided in Croatia to adopt the computer program COPERT III, which is used by most EU countries, an optimal systematization of data on vehicles and fuel would be the one presented in Table 4.

Table 4. Systematization of data on vehicles and the data required for the definition of the system and fuel consumption

Vehicle category	Engine/ fuel	Engine displacement	Year of production	Legislation standard	Number of vehicles	Annual mileage	Share of vehicles with catalyst	Share of vehicles with electronic injection	Share of vehicles with evaporation control system

	Annual fuel consumption	Lead content	Sulphur content	H:C ratio	Copper content	Cadmium content	Chromium content	Nickel content	Selenium content	Zinc content	Reid vapour pressure		
											January	...	December
Leaded petrol													
Unleaded petrol													
Diesel fuel													
LPG													

As these researches have not been completed yet, the pollutant emission has to be determined within the framework of minimal and maximal emission calculated for the most favourable and most unfavourable factors that have an impact on the emission. The number of possible combinations of these factors, i.e. the result sets, is several hundred millions. Further work should focus on narrowing the range of output results. This could be achieved by the elimination of those result combinations which give a considerable difference in the balance of total fuel consumption. It is obvious that the Republic of Croatia has a wide range of results at its disposal that can be presented to the authorized institutions in EU. A thorough analysis of these results has to be carried out in order to determine which set of results has a most favourable effect on pollutant emissions.

It is of vital importance to accurately determine the parameters required for the calculation of pollutant emissions in the last fifteen years, because, depending on the implementation of

international protocols for the restriction of pollutant emissions, one of these years could be identified as a reference year for a future reduction.

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Sažetak

Tema ovog rada je utjecaj pojedinih procijenjenih parametara u cestovnom prometu na ukupnu emisiju štetnih tvari koja potječe od istog. Opisan je računalni program COPERT III pomoću kojega je vršena analiza utjecaja pojedinog procijenjenog parametra na ukupnu emisiju štetnih tvari kao i procjena ukupne emisije štetnih tvari. Prikazano je stanje voznog parka te procijenjena prometna aktivnost Republike Hrvatske za dva krajnja slučaja od kojih jedan rezultira minimalnom, a drugi maksimalnom emisijom štetnih tvari i kod kojih je raspon setova rezultata velik. Zbog toga je prikazana i procijenjena ukupna minimalna i maksimalna emisija štetnih tvari za jedan set ulaznih podataka kod kojeg je kao referentna vrijednost promatran balans potrošnje goriva kako bi procjena bila što točnija. Nakon provedene analize rezultata dana je trenutna procjena emisije štetnih tvari koja potječe od cestovnog prometa u Republici Hrvatskoj.

Ključne riječi: zrak, onečišćenje od prometa, Hrvatska, COPERT III.

Summary

This work deals with the effect of estimated parameters in road transport on total road transport emissions. The paper also presents the computer program COPERT III used for the analysis of the effect of estimated parameters on the total emission and for the estimation of the total emission. The Croatian road fleet and the estimated fleet activity that was used in the calculation are presented for two extreme cases, one of them resulting in minimal estimated emission, and the other resulting in maximal estimated emission. In this calculation, the sets of results are large. Because of that, the estimation of total minimal and maximal emission for one set of results with the fuel balance as a reference value is also described, so that the estimation of the total emission could be more accurate. After the analysis of the results, the provisional estimation of the emission from road transport in the Republic of Croatia is presented.

Key words: air, road transport emissions, Croatia, COPERT III.

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