Estimation of Greenhouse Gas Emissions Related to Urban Driving Patterns

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ABSTRACT

Road transportation is one of the major sources of greenhouse gas pollution. In recent years there has been considerable development in vehicle technology to reduce fuel consumption and CO2 emissions of passenger cars, but at the same time number of vehicles per 1000 capita is increasing especially in developing countries. In this study, the effect of driving patterns on CO2 emissions has been investigated by testting a sample of thirty passenger cars according to three different driving cycles. Different emission reduction technologies are also investigated for the same fleet.

Key-words: Driving cycles, Greenhouse gas emissions, fuel consumption.

INTRODUCTION

Although the internal combustion engine is an old and pollutant machine for the modern world, it still holds its position in many applications against the alternatives due to some economic and technical advantages. The utilization of these machines is most likely to continue for road, marine and some aviational transportation systems in the near future.

Road vehicles are powered today by internal combustion engines of either spark ignition or compression ignition. It is not expected that full electric vehicles powered by batteries will be capable to maintain the present vehicle range with acceptable weight, dimension and cost within the next twenty years, although some restricted applications on small and medium class cars are ready to come into market. Usage of the fuel cell to produce electricity on board is expected to be possible even later then twenty years time. Within these systems the problem is the storage of hydrogen, which seems to be the only possible fuel to be used in fuel cell on board.

Electric vehicles have constrains such as high well to wheel CO_2 emissions along with the problems introduced with on board battery or hydrogen storage systems. A medium size car powered with a small (1.4 to 1.6 litre) and turbocharged Diesel engine has a fuel consumption of 6 liters/100 km on average and produces 155 g-CO_2/km. The CO_2 production could be decreased to 95 g-CO_2/km (3,6 liters/100 km) within the next ten years by reducing the vehicle mass and developments in engine efficiency and application of hybrid strategies.

CO_2 production during electricity production is on average 500-700 g-CO_2/kWh depending on the percentages of the primary energy sources (i.e. Hydrocarbon fuels, coal, natural gas, hydraulic, wind and nuclear energy) used. USA, uses 80% coal to produce electricity with an emission factor of 600 g-CO_2/kWh, while France for example has much lower average emission factor due to 75% electricity production using nuclear energy.

Approximately 25% of the total energy production of the world is consumed by the transport sector with some changes from one country to another, mostly by internal combustion engines. This corresponds to 50% of the total oil production. The share of the passenger cars within this consumptions is about 50% in the developed countries, resulting in a contribution of more than 25% to the CO_2 production as well as for other pollutant such as CO, HC, NO_x and PM.

Considering these outcomes, the research and developments activities in the automotive sector is now concentrated on the reduction of pollutant and improvement of fuel economy rather than concentrating on reliability, durability and low cost production as it was previously.

Lower CO_2 emission limits set by the authorities force the producers to build vehicles which consume less fuel on a given standard driving cycle. These test cycles, partly because of their simplicity and partly because of the requirement of standard test conditions, do not reflect the actual driving conditions on the road with respect to both for fuel consumption and for emissions (Charbonnier (1993), Cayot (1995)). To determine the emission rates more accurately complex cycles and on board measurement methods (such as mini CVS systems) were developed and used (Andre (1996), Andre (1991), Andre, Hickman, et. al. (1995), Andre, Vidon, et. al. (1995), Andre, (1995), Andre, Joumard, et. al. (1991)).

When a representative driving cycle is determined, total emission for the component *i* (including CO_2 as a measure of fuel consumption) at any point of the cycle can be calculated according to the below expression, if emission factor *(a_{ij})* is known :

$$E_i(g) = \sum_{j=1}^{n} (a_{ij}(g/km) \times \Delta l_j(km))$$

where a_{ij} is the emission factor valid for the distance interval Δl_j.

Emission factors depend on the other hand on road parameters (such as slope angel), driving behaviours (velocity, acceleration or correlation between velocity and acceleration, idle durations etc) and on driver habits (keeping constant velocity, softer or harder accelerating drive style, the using style of throttle pedal). Tests have shown that driver also has an important influence on the emissions and between the drivers variation of up to 20% is possible with regard to the emission rate, although this difference is much lower for fuel consumption (Klingenberg (1995)).

Determination of the real emission factors require considerable number of experiments. To reduce the cost and the time, global emission factors depending on the average velocity (or average power) of the representing driving cycle may be used for the estimation of greenhouse gas emissions. Realistic emission value or fuel consumption may be obtained for extra urban road or motorway traffic by using such data, but this method is not sufficient enough for the determination of real emission load in the city or on the main streets.

A more accurate but a complex way to calculate the emissions and fuel consumption on a driving cycle is by using fuel consumption and the emission map of the engine. So it is possible to obtain the emission rates point by point by calculating the power demand of the vehicle on the driving cycle and feeding back (by considering the efficiency of the power train assembly) to the engine map. This method is of course time consuming and rather expensive, because every engine must be tested on a dynamometer and emissions must be measured. Besides, the engine map does not generally reflect the dynamic behaviour of the engine (instantaneous speed and throttle valve position changes) with regard to emissions.

Another way to obtain the real emissions on a driving cycle is to use instantaneous emission factors instead of the average values. For this purposes the vehicle is tested for certain velocity, accelerations and/or acceleration-velocity intervals (or real time measurement on the road) and the three dimensional *(instantaneous)* emission map of the vehicle is obtained from the recorded data (Sturm (1996)). Even with this method there are differences up to 20 to 30% between the calculations and the experiments depending on the emission type and/or the driving cycle considered. The difference between the emission factors obtained by various methods becomes higher for lower velocities (Zachariadis (1996)). This may be due to the fact that the relatively higher accelerations correlate well with the relatively lower velocities, building operation points which cover large percentage in total emissions.

Another problem encountered at the determination of real emission rates is the effect of the road gradient on emission factors. Generally, the increase in emission values when travelling uphill can not be compensated by the reduction obtained when travelling downhill. This is the case even for fuel consumption (CO_2 emission) in the city conditions, although it can be an acceptable approximation for fuel consumption during intercity travels. Because of higher total mass to engine power ratio the impact of gradient on emission is more important for heavy duty vehicles (or for light duty vehicles) than passenger cars. But for the special road conditions this effect may gain weight for passenger cars too. For slopes higher than 2% it is assumed that the driving cycles *(driving behaviours)* are effected by the slopes. For this reason special cycles are needed to simulate the driving behaviour truly for road gradients more than 2%. Emission factors for various road gradients must also be multiplied by a gradient factor *(GF)* which depends on the slope angle and the mean speed. Its value is for CO, for example, 2 for +2 % gradient and for the cars without a catalyst, although fuel consumption increase by only 1.2 for the same condition (Hassel (1996)).

In this study the effect of driving pattern on emission and fuel consumption of passenger cars is investigated performing tests with selected vehicles on several different driving cycles including urban cycle obtained for Istanbul from collected road data.

EFFECT OF DRIVING PATTERNS ON EMISSIONS and FUEL CONSUMPTION

The driving behaviour due to traffic flow restrictions has considerable influence on fuel economy as well as exhaust gas emissions. Although standard test cycles can be used to estimate emissions and fuel consumption values per unit distance travelled for a passenger car fleet in a given region, more realistic approach requires the determination of realistic driving patterns for that region. In this study fuel consumption and emission measurements obtained using NEDC (European Driving Cycle) and FTP75 (US Federal Test Cycle) (Figure 1.) has been compared with the measurements obtained by a specific cycle developed for the city of Istanbul (Figure 2.).

The tests were done with thirty passenger cars for all three cycles under laboratory conditions on a chasis dynamometer. The distribution of age and emission technology of those vehicles were chosen to represent the passenger car fleet in Turkey.

In this study only gasoline fueled spark ignition engines were considered. The present passenger car fleet consists of four different emission technologies. The cars registered prior to model year 1994 contain no emission control system. During the following years emission standards were introduced gradually, thus vehicle categories of R15.04, EURO 1, EURO 3 and EURO 4 were considered in this study.

Tests were conducted according to the NEDC and FTP standards and the average value calculated for each emission group is given in Table 1 for both fuel consumption and CO_2 emissions. IDC (Istanbul Drive Cycle) is also applied to all vehicles tested and the measured values are also compared with the defaults given by IPCC (IPCC 1996, IPCC 2006).

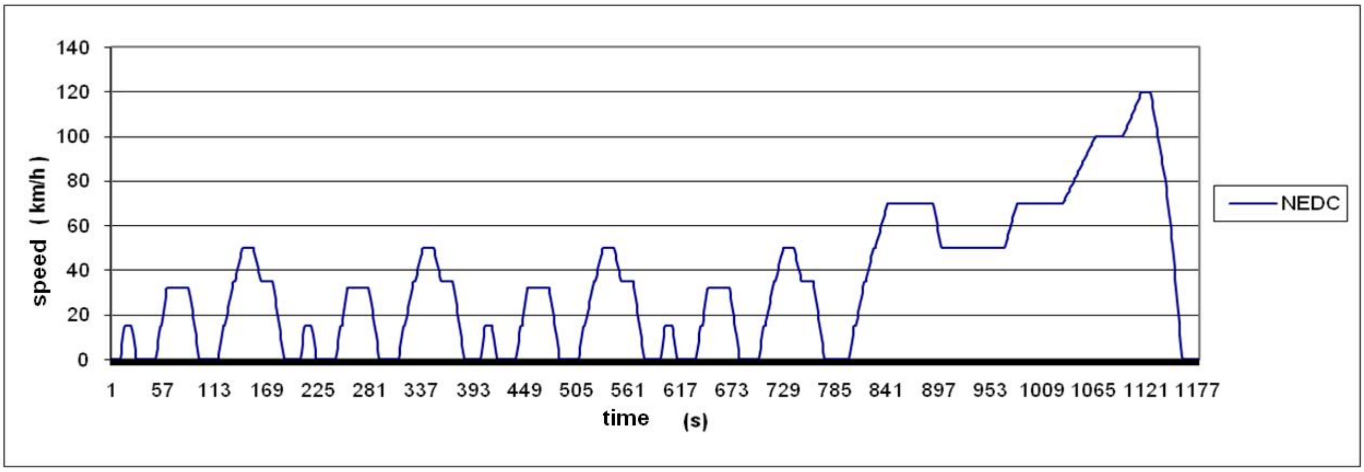
For gasoline fuelled internal combustion engines, changes in equivalence ratio during the operation of the vehicle considerably effects the emissions, especially CO and unburned HC's. Although equivalence ratio is electronically controlled for precise adjustment and set at a stoichiometric value, some instantaneous changes during operation such as cold start, acceleration, maximum power etc effects fuel economy as well as pollutant emissions. Heavy traffic condition in the city center resulting in congestion forces long idle operations, rapid acceleration-decelleration of the vehicle. These effects have clearly been observed in IDC when compared with standard cycles such as EU test cycle. Especially for vehicles which do not posses any emission control devices (uncontrolled, UC group), fuel consumption is considerable increased with tests according to IDC. In general the amount of CO_2 produced during the combustion process has a close correlation with fuel consumption. But UC group cars in general have lower combustion efficiency compared to vehicles satisfying EURO 3 and 4 standards. Therefore although fuel consumption can be high with UC group cars, CO_2 emissions do not follow the same trend while CO and unburned HC emissions are increasing.

Test according to FTP cycle on the other hand provided the lowest fuel consumption for all vehicle groups. Although acceleration and deceleration of the vehicle is effective in the FTP cycle, the maximum vehicle velocity is lower than NEDC cycle and the average velocity is higher than IDC cycle to improve fuel economy.

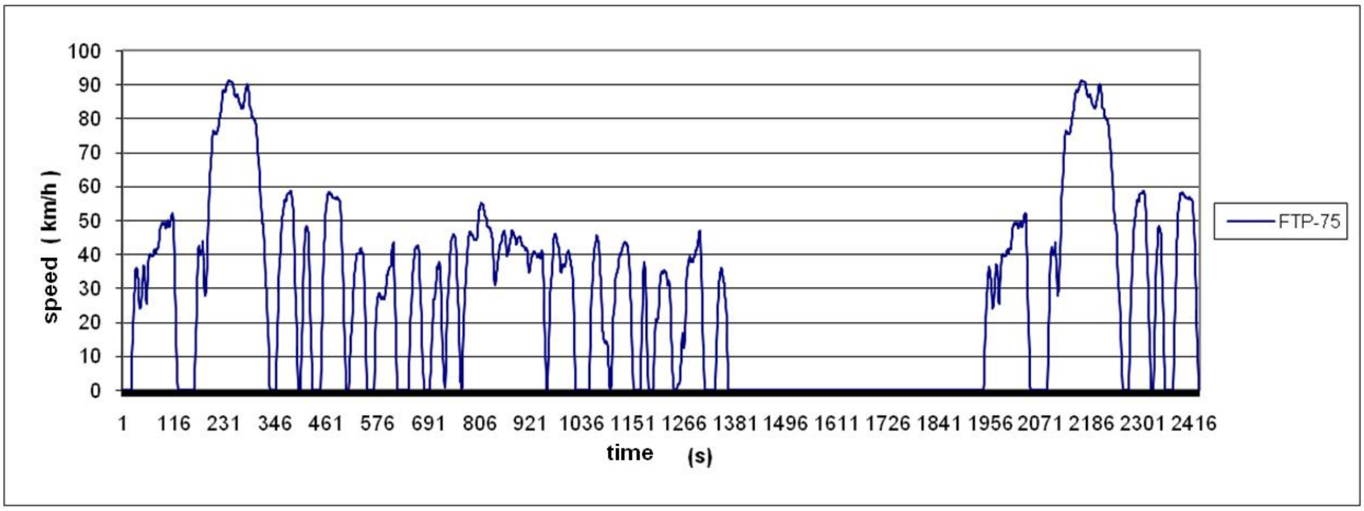
Laboratory tests were conducted with no effects due to the road gradient in standard tests as well as IDC. Some reduction in the fuel consumption measurements due to this effect can be expected.

CONCLUSION

IDC representing the real world driving conditions result in higher fuel consumption and CO_2 emission values due to the highly loaded traffic conditions in the city of Istanbul. Large idle operation durations and extremely low speed driving provided an increase in fuel consumption in comparison to the other driving cycles.



(a) New European Driving Cycle (NEDC)



(b) Federal Test Cycle , USA (FTP75)

Figure 1. *Standard Emission Test Cycles*

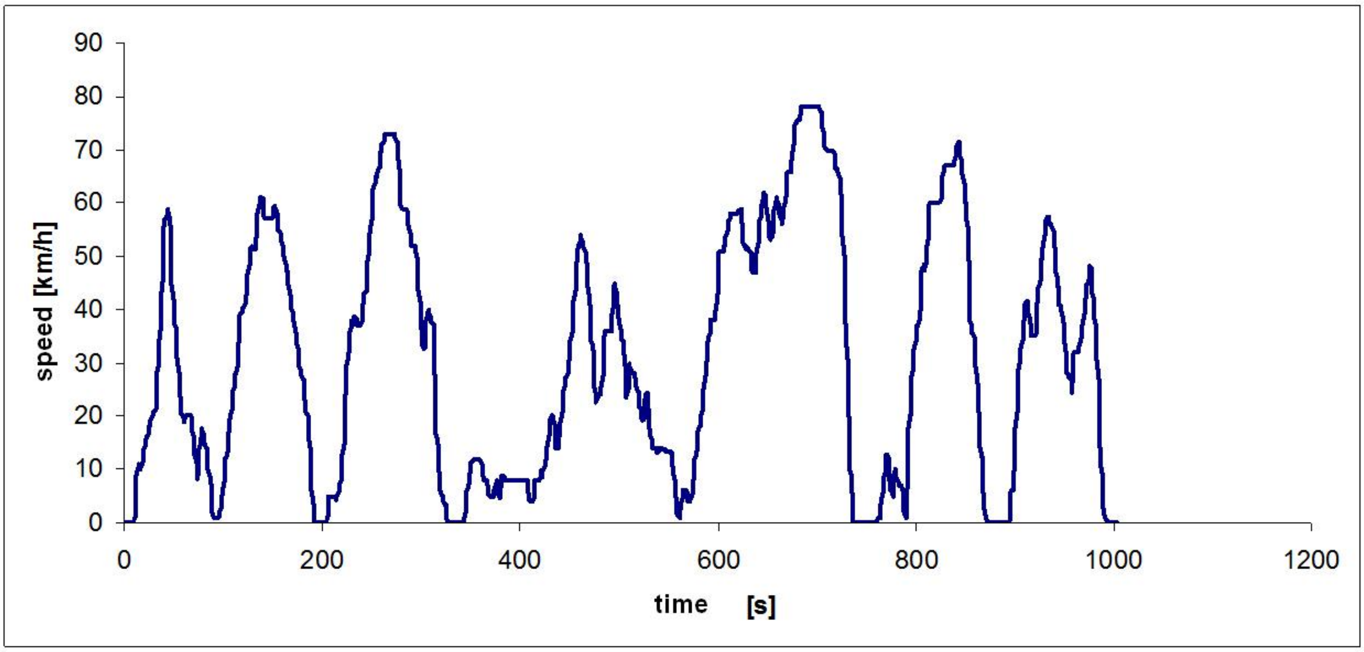


Figure 2. *Istanbul Driving Cycle (IDC)*

	FTP		NEDC		IDC		IPCC
	CO_2 [g/km]	Fuel Cons [l /100km]	CO_2 [g/km]	Fuel Cons [l /100km]	CO_2 [g/km]	Fuel Cons [l /100km]	CO_2 [g/km]
UC	149.5	7.9	169.1	8.6	157.4	9.6	270
R15.04	139.2	6.8	166.1	7.8	165.9	8.1	200
EURO1	134.8	6.0	169.5	7.5	170.8	7.8	205
EURO3	133.3	5.9	155.4	6.9	159.6	7.2	205
EURO4	144.9	6.2	153.6	6.5	164.7	7.1	205

Table 1. *Fuel consumption and CO_2 emissions obtained by using different driving cycles.*

Developments in vehicle technology considerably reduced fuels consumption values together with greenhouse gas emissions per vehicle in recent years. The shifting of average vehicle age in the car fleet to more recent model years will therefore provide an important reduction in CO_2 emissions. Some results of this issue has been observed recently in Turkey with the removal of 320,000 passenger cars from traffic by providing tax advantages to consumers.

Traffic flow has considerable influence on fuel consumption and CO_2 emissions as demonstrated with different test cycles for the same sample of cars in this study. The arrangement of the traffic flow through traffic management and planning will be effective. But, as the improvement of fuel consumption values per each car due to technological developments would not be enough in satisfying the greenhouse gas mitigation targets, utilization of alternative transport modes with lower emissions per passenger-km values is also required.

ACKNOWLEDGMENTS

The authors acknowledge the support provided by TUBITAK (The Scientific and Technological Research Council of Turkey) through the project entitled *The Reduction of Greenhouse Gas Emissions Resulting from the Transport Sector in Turkey*, No. 105G039.

REFERENCES

Charbonnier, M. A., Andres, M. (1993), **"A comparative study of gasoline and diesel passenger car emissions under similar conditions of use"**, SAE Technical Paper Series 930779, International Congress and Exposition Detroit, Michigan, March 1-5, 1993, 121-129

Cayot, J.F., (1995), **"The fight against automotive pollution. An opportunity or a threat for diesel engines ?"**, Istanbul First International Automotive Industry and Environment Conference and Exhibition, May 1995, 113-122

Andre, M., (1996), **"Vehicles uses derived driving cycles : a review of researches"**, COST 319, Estimation of pollutant emissions from transport, Proceedings of the workshop, 27-28 November 1995, Brussels, 99-109

Andre, M., (1991), **"In actual use car testing: 70.000 kilometres and 10.000 trips by 55 french cars under real conditions",** SAE Technical Paper Series 910039, International Congress and Exposition Detroit, Michigan, February 25 - March 1, 1991

Andre, M., Hickman, A.J., Hassel, D., Joumard, R., (1995), **"Driving cycles for emissions measurements under European conditions",** SAE Technical Paper Series 950926, International Congress and Exposition Detroit, Michigan, February 27 - March 2, 1995, 193-205

Andre, M., Vidon, R., Tassel, P., Olivier, D., Pruvost, C., (1995), **"A method for assesing energetic and environmental impact of traffic changes in urban areas using instrumented vehicles",** 7th WCTR. World Conference on Transport Research, Sydney Australia, July 16-21, 1995

Andre, M.,(1995), **"A review of Researches dealing with Vehicles Uses and Operating conditions, and derived Driving Patterns or Driving Cycles"**, International Workshop on Vehicle Driving Cycles: Measurement, Analysis and Synthesis, Ottawa, April 6-7, 1995

Andre, M., Joumard, R., Hickman, A.J., Hassel, D., (1991), **"Actual Car Use And Operating Conditions As Emission Parameters; Derived Urban Driving Cycles"**, INRETS, TRRL, CEDIA, TÜV Rheinland

Klingenberg, H., (1995), **“Automobil Meßtechnik, Band C: Abgasmeßtechnik”,** Springer-Verlag, Berlin

Sturm, P.J., Sudy, C., (1996), **“Instantaneous Emission Maps- Available Data Sets and Use of Data”,** COST 319, Estimation of pollutant emissions from transport, Proceedings of the workshop, 27-28 November 1995, Brussels , 19-28

Zachariadis, T., Samaras, Z., (1996), **“Comparison of Microscale and Macroscale Traffic Emission Estimation Tools: DGV, COPERT AND KEMIS”**, COST 319, Estimation of pollutant emissions from transport, Proceedings of the workshop, 27-28 November 1995, Brussels, 135-145

Hassel, D., (1996), **“Gradient Influence on Emission and Consumption Behaviour of Light and Heavy Duty Vehicles”,** COST 319, Estimation of pollutant emissions from transport, Proceedings of the workshop, 27-28 November 1995, Brussels, 39-49

IPCC, **Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories : Reffernce Manual**, Vol. 3, London, 1996.

IPCC, **2006 IPCC Guidelines for National Greenhouse Gas Inventories**, Vol. 1, Japan, 2006.