# REAL DRIVING EMISSIONS AND FUEL CONSUMPTION CHARACTERISTICS OF ISTANBUL PUBLIC TRANSPORTATION

by

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*Public transportation, which uses intra city lines frequently, has vital importance on the cities air pollution. The fossil fuel based drive units, which emits pollutants, are the primary source of this interest. Also, the fuel consumption is another major concern because of economic aspects. For an efficient and clear transportation, the pollutants and fuel consumption has to be analyzed, considering the operating conditions. In this context, the Metrobus line of Istanbul city which crosses from European side to Asian side of the city was analyzed with portable emission measurement system and portable fuel consumption meter devices. The relevant bus operating data were also collected during the operation. The data were analyzed while considering the operating modes like acceleration, deceleration, and constant speed cruises. The emission factors were developed. The pollutant emissions generally decreased as the vehicle speed increased while the fuel consumption increased for the same acceleration level. These results show the importance of operating conditions and their non-linear effect on emissions and fuel consumption Istanbul public transportation.*

Key words: *real world emissions, fuel consumption, public transportation*

## Introduction

The International Energy Agency reported that 63.7% of world oil consumption is used for transportation and also 35.3% of $CO_2$ emissions arouse from oil usage [1]. From the perspective of European Union (EU), transportation is one of the biggest sector that is responsible for approximately 25% of the GHG. On the other hand the road transportation industry is responsible for approximately 70% of this GHG directly. So the EU and also other countries worldwide are taking actions in this context in order to reduce emissions and $CO_2$ targets from different modes of transport [2]. Public transportation which uses intra city lines raise concern about both emissions and fuel consumption challenges. The emission perspective is important for the city inhabitants considering environmental pollution that arise from it. Fuel consumption is also important because of the operating cost of public transportation and also for the $CO_2$ targets.

Istanbul City, with a population of about 15 million is one of the biggest metropolis in the world that has thousands years of history. The city's public transportation is operated by the Istanbul Public Transportation Company (IETT) [3]. The real on-board emissions and fuel consumption of these lines are directly related to operating parameters of the buses driving in the city. Also, the amount of GHG, $CO_2$, which is emitted into the atmosphere from public trans-

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portation, is directly related to the amount of fuel consumed during the operation. Therefore, predicting and optimizing the effects of different bus rides on fuel consumption over this route is important for establishing more economic and cleaner public transportation system.

In this context, lots of valuable research that analyses the real driving emissions and fuel consumption data can be found in the literature.

Yu and Li [4] investigated real driving instantaneous data for identifying and comparing emissions created near bus stops and to find out the parameters that effects the pollutants emitted. They used the measurements of an Euro III diesel bus operated with regular conditions on a specified route. The emission distribution along the bus route, the spatial and temporal characteristics of emission generated near bus stops, the length of stop influence zone, emissions and their potential influence from bus stop characteristics in different modes were studied in the research. They revealed that approximately 20% of emissions were generated near bus stops, and approximately 30% at road intersection segments while approximately 50% was at links (normal cruise). The $CO_2$, $NO_x$, and total hydrocarbons (THC), increased approximately 60%. While CO, increased approximately 20% in traffic congestion times compared to normal day cruises. The median emission values of minor arterial roads were found to be slightly higher than the principal arterials and local streets. The passenger number at the stops directly influenced the idling time at the stop as well as the emissions. They found that the road type has no significant influence on emission factors near bus stops.

Rubino *et al.* [5] compared the real driving emissions and new European driving cycle (NEDC) data of two light duty vehicle that travels around, inside Milan city. The test vehicles were at first tested also on chassis dynamometer for NEDC cycle. Then, the vehicles were equipped with portable emission measurement system (PEMS) equipment and tested under the real driving conditions. The real $CO_2$, $NO_x$, THC, and particulate matter (PM) emissions were found to be two times higher than the NEDC cycle values in [$gkm^{-1}$]. The results revealed that traditional test cycles are not sufficient to represent real driving condition emissions. Zhang *et al.* [6] tested 75 Beijing public buses fueled with diesel, compressed natural gas (CNG) and diesel hybrid for four years in Beijing. The real driving emissions and the global positioning system (GPS) data of these busses were recorded with 1 Hz during the research. Effects of operating conditions on the fuel consumption were also been studied. The results obtained revealed that, the average speed had important non-linear effect on fuel consumption and $CO_2$ emissions. Authors recommended that energy advanced management systems should be implemented for more efficient real world operation. The fuel consumption and $CO_2$ emissions were found to be inversely proportional, with the average speed lower than 30 km/h. But when the speed increased over 30 km/h the traffic conditions effect on $CO_2$ and fuel consumption became less significant. There was 5% improvement in fuel consumption possibility reported with better traffic conditions for public busses. The load effect on fuel consumption increase was found to be less significant when compared with traffic effect.

Wang *et al.* [7] measured the on-board emission data of Euro III and Euro IV busses in Beijing, fueled with conventional diesel and CNG. They revealed that emission and fuel factors all decreased with the increase of vehicle speed. On the other hand, the factors increased with the increase in acceleration values. They found strong correlation between the emissions/fuel factors and the vehicle specific power. The effect of deceleration was found to be less significant on fuel consumption and emission rates.

Wang *et al.* [8] studied the correlation between speed and on-board pollutant emissions of a light duty vehicle at different altitudes. The results they obtained show that with the increase of vehicle speed, CO and THC emissions decreased while the PM and $NO_x$ emissions increased. The CO decrease was explained by the higher in-cylinder temperature at high loads and increased oxygen concentration at higher turbocharger speed, with the increase of vehicle speed. Also they related the THC decrease to the higher cylinder temperature with the increase in the speed of the vehicle. The $NO_x$ increase was explained with the increase in peak cylinder temperature with the increase in vehicle speed. While the PM increase was explained by the strengthened pyrolysis and shortage of oxygen in some reaction zones with the increase in vehicle speed. The increase in altitude was as a result of all pollutant emissions at each vehicle speed and this was explained by the rich mixture formation; because of diluted intake charge with the increase in altitude.

Noland *et al.* [9] developed a vehicle performance and emissions monitoring system that monitors the on board pollutant emissions and driving characteristics of a vehicle in London Urban area. They found that increase in emissions was related to the acceleration events and also the emission variation is directly related to the instantaneous speed.

Durbin *et al.* [10] measured five different heavy duty vehicles with three different emission certification level. They revealed that the emissions from these vehicles were related to the operating conditions and also to the emission component, the age certification levels. They found out that the $NO_x$ emission decreased with the newer model vehicles with the increasing certification level. The PM level is lower for new busses at intra city cruises but higher for highway driving conditions. The THC emissions are found to be altering with the cruising modes. The CO emissions were observed to be relatively low under steady-state conditions low limits.

Guo *et al.* [11] measured the real world condition emissions of 13 selective catalytic reduction equipped buses fueled with diesel and CNG with different emission certification levels. The CNG buses were found to be advantageous for $NO_x$ and PM emissions and disadvantageous for CO and THC. Also the diesel fueled buses were found to be better in terms of lower CO and THC emissions. Similar to buses, Vujanović *et al.* [12] introduced an energy efficient fleet management process for road freight transport companies. The impact of vehicle load factor on fuel consumption has been quantified in their researches. The results have confirmed that specific fuel consumption increases with the cargo weight, relative to the load factor increase, although this relation is not proportional.

In this research, real driving emission and fuel consumption data of a public bus, operated on a dedicated transit bus line of Istanbul (Metrobus), were evaluated and analyzed. Also, alternative cruise scenarios for cleaner and cost efficient public transportation were discussed.

**Table 1. Vehicle and engine properties**

| | |
|---|---|
| Gross vehicle weight | 32 tones |
| Type | Articulated |
| Vehicle length | 18 m |
| Number of cylinders | 6 |
| Engine capacity | 11.9 l |
| Power | 260 kW at 2000 rpm |
| Torque | 1600 Nm at 1100 rpm |
| Compression ratio | 17.75:1 |
| Minimal brake specific fuel consumption at full load – 1400 rpm | 185 g/kWh |
| Emission certification level | Euro V |

## Experimental method

### *Measurements*

A diesel fueled public bus was used for measurements. The vehicle properties are given in tab. 1. The AVL KMA Mobile was used for fuel consumption measurements. AVL MOVE system consisting of AVL gas PEMS 493 for CO, $CO_2$, $NO_x$, oxygen measurements, and AVL PM PEMS equipped with micro soot sensor was used for soot monitoring. The gravimetric PM collection unit of the PM PEMS was not used during the road measurements. The soot was continuously measured. The position of the vehicle in terms of latitude, longitude, and altitude was monitored at Hz GPS equipment. The temperature, humidity and atmospheric pressure were also monitored at 10 Hz resolution during the measurements. The installed emission and fuel consumption measurement system details are given in tab. 2. Also the relevant controller area network (CAN) data (actual torque, accelerator pedal position, gear, and wheel based vehicle speed) of the vehicle needed for further analyses were collected with Goblin System CAN diagnostic tool [13] during the measurements with 1 Hz resolution. All systems were controlled by AVL system controller equipment. The measurement system configuration is presented in fig. 1.

**Table 2. Measurement system properties**

| System | Device | Method | | Accuracy |
|---|---|---|---|---|
| Fuel consumption | AVL KMA mobile | Rotational type flow meter | | |
| Emission | AVL gas PEMS | NO | → NDUV[1] | ±0.2% |
| | | $NO_2$ | → NDUV | ±0.2% |
| | | $O_2$ | → Oxygen sensor | ±1% |
| | | CO | → NDIR[2] | ±30 ppm |
| | | $CO_2$ | → NDIR | ±0.1% |
| Emission | AVL PM PEMS | Particulates | → Gravimetric | – |
| | | Soot | → Photoacoustics | ~5 μg/m³ |

[1] NDUV: non dispersive ultraviolet
[2] NDIR: non dispersive infrared

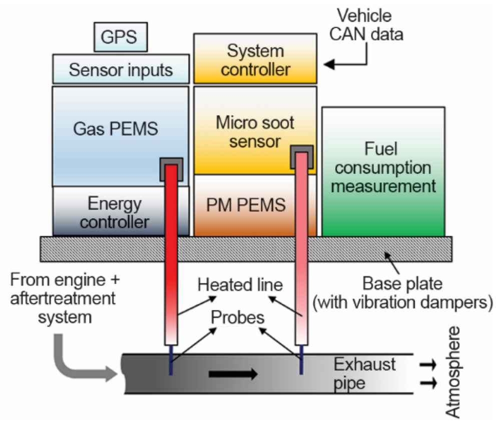


**Figure 1. Test system configuration**

The vehicle was loaded with sandbags for the simulation of passenger weights. The measurements of real trip with real passengers were not considered in this because of safety issues. Two measurements event were considered (1) half load condition (HL) with 6500 kg of sandbag, and (2) full load condition (FL) with 13.000 kg of sand bag. The HL condition was assumed to represent the normal day time usage, and FL condition was assumed to represent the heavily loaded conditions as early in the morning and afternoon peak periods. For stabilizing the vehicle, the sandbags were distributed equally for the main vehicle and the articulation of the vehicle. The trips were executed with the method of front bus following within approximately 20 meters. Ten full line measurements with set-up were made at each direction. Also the GPS speed-time data of 10 real trip with real passengers (TWP) and without test set-up were logged during normal day operations for comparing the test bus speed data on both directions. The exhaust mass flow, which is needed for gravimetric emission analyze, was calculated through ISO 16183 [14, 15] carbon balance method.

### *Test route*

The tests were carried on Metrobus line of Istanbul. Metrobus line, which crosses the city axle, consist of 52 km dedicated route. The route is divided into three parts. These parts and their properties are given at tab. 3. The test route consist of only the first part of (Zincirlikuyu – Z → Sogutlucesme – S) the Metrobus line. It is 11 km long and has 8 stations in both directions (Z → S and S → Z) of the routes. The routes' map derived from Google map with stations is given in fig. 2. This part of the line was chosen for this research because it is the only part that crosses from Europa Continent side to Asia Continent side of the Istanbul City. Also, the test route is the only part in which the Metrobus uses 1.25 km public traffic, because of the 15 Temmuz Sehitler Bridge (old 1st Bosphorus Bridge) pass in which the traffic density is relatively high in daily usage [16, 17]. The average speed of vehicle when the bus is cruising in the dedicated part of this line does not alter in wide band. But the traffic density on the bridge as regards the daily hours affects the cruising characteristics.

**Table 3. Metrobus Line Properties**

| Part no. | Directions | Length [km] | Number of stations |
|---|---|---|---|
| 1 | Sogutlucesme – Zincirlikuyu | 11 | 8 |
| 2 | Zincirlikuyu – Avcilar | 25 | 25 |
| 3 | Avcilar – Beylikduzu | 16 | 5 |


**Figure 2. Metrobus line Zincirlikuyu – Sogutlucesme part with stations**

## Results

The speed, road gradient, and altitude profiles of the test vehicle for both ZS and SZ directions, measured at the rush hours of the city according to the Yandex Traffic Reports [16, 17] between 18:00 and 20:00 hours at FL tests is presented in fig. 3. The maximum speed limit of buses (70 km/h) which was adjusted by IETT *via* using vehicle on board diagnoses system and the bus stops are evident from the trajectory. The bus can exceed this limit due to road grade, *etc.* only for few km per hour. Also, evaluating acceleration, vehicle speed, *v*, performance zone map, and the histogram data of these cruises are given in figs. 4 and 5.

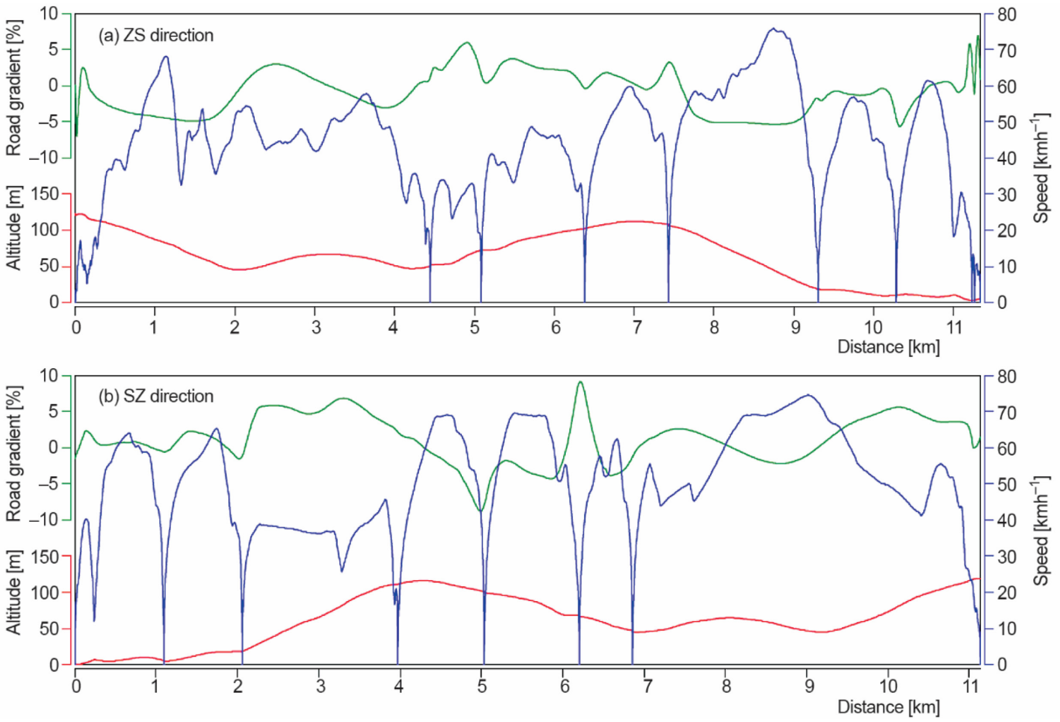


**Figure 3. The speed trajectories: (a) ZS direction, (b) SZ direction**

The trips were divided in four speed modes additional to the analyses. Speed mode 1 (SM1) – 0-5 km/h which included the vehicle stopping at bus stop and bus stop approaching and departing cruises, speed mode 2 (SM2) – 5-40 km/h and normal cruising (the most frequent speeds used in the daily cruise), speed mode 3 (SM3) – 40-70 km/h fast cruising, and speed mode 4 (SM4) – $v > 70$ km/h; over speed cruising. The average speed, acceleration, and relevant trip summary data of 10 tests that were collected during this research on both directions and the data with real passengers from 10 trip are given in tabs. 4 and 5, respectively.

**Table 4. Vehicle speed mode percentages**

| | | ZS | SZ |
|---|---|---|---|
| SM1 | % | 11.90 | 10.75 |
| SM2 | % | 63.74 | 67.91 |
| SM3 | % | 23.94 | 21.32 |
| SM4 | % | 0.40 | 0.00 |

As it is seen from tab. 4, the public bus stops at the stations and cruises at the creep speed approximately 10% in time basis range for both directions. Also, the SM2 level speed was the total dominating speed range approximately

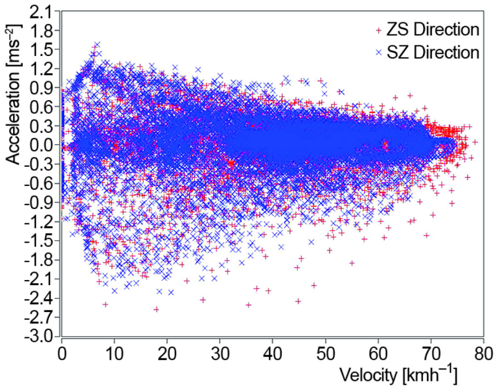


**Figure 4. Operating performance zone map of Metrobus in ZS and SZ directions**

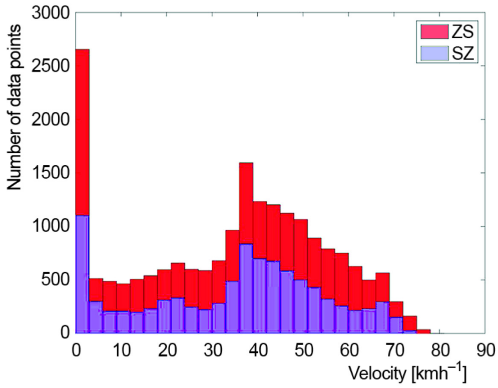


**Figure 5. Operating speed histogram for ZS and SZ routes**

60-70% for both directions and the SM3 range consist of approximately 20-25% range for both directions which are the second dominating speed range. The SM4 mode, which is available because of downhill elevation change, was the smallest part of the cruise with less than 0.5%.

**Table 5. Characteristic average values for the trips**

| Direction | Unit | ZS | | SZ | | ZS (TWP) | SZ (TWP) |
|---|---|---|---|---|---|---|---|
| | | FL | HL | FL | HL | | |
| Speed | kmh$^{-1}$ | 33.74 | 35.36 | 35.08 | 33.80 | 34.17 | 33.16 |
| Acceleration | ms$^{-2}$ | 0.28 | 0.29 | 0.26 | 0.24 | 0.28 | 0.24 |
| Deceleration | ms$^{-2}$ | –0.37 | –0.40 | –0.31 | –0.35 | –0.36 | –0.33 |
| Acceleration duration | % | 49 | 49 | 47 | 51 | 50 | 51 |
| Deceleration duration | % | 37 | 35 | 39 | 37 | 38 | 37 |
| Cruising + stop duration | % | 14 | 16 | 14 | 12 | 12 | 12 |
| Trip duration | seconds | 1212 | 1161 | 1173 | 1190 | 1170 | 1180 |
| Maximum gradient | % | 6.89 | | 9.12 | | – | |

As it seen in tab. 5, the average speeds for ZS and SZ lines changed between 33-35 km/h for both directions. The acceleration for ZS direction is higher than SZ direction which is related to the gradient profile of SZ line. The altitude profile of SZ line is presented as a long upward hill cruising with a maximum gradient, while the ZS direction is presented as a classical downhill cruising from beginning to end. Also the average acceleration and deceleration durations of the trips were compared for both directions and TWP. The average rate for acceleration is approximately 50% and the deceleration is approximately 35%. In summary, the acceleration and deceleration consisted of approximately 80-85% of the cruises. The average trip durations are also compared in tab. 5. It was found that the ZS direction trip duration is a little bit higher than SZ which can be attributed to the traffic flow behavior of Istanbul on the intercontinental bridge.

*Emission factors and fuel consumption results*

The emission factors [$gkm^{-1}$] (which was calculated by the gravimetric emission values to the total cruising length) in both direction are given in fig. 6. It can be observed that while the factors are varying in a wider range because of the non-linear behavior of the trip line, the averages values are similar. The average fuel consumption for both directions measured during the tests in l/100 km is given in fig. 7. As it is seen from both figs. 6 and 7, the average values are higher for SZ directions (except $NO_x$ and soot for ZS direction FL condition) which can be described with the altitude change of the route. Also, the widened high end and low end results indicate dependency of these parameters on vehicle operating conditions.

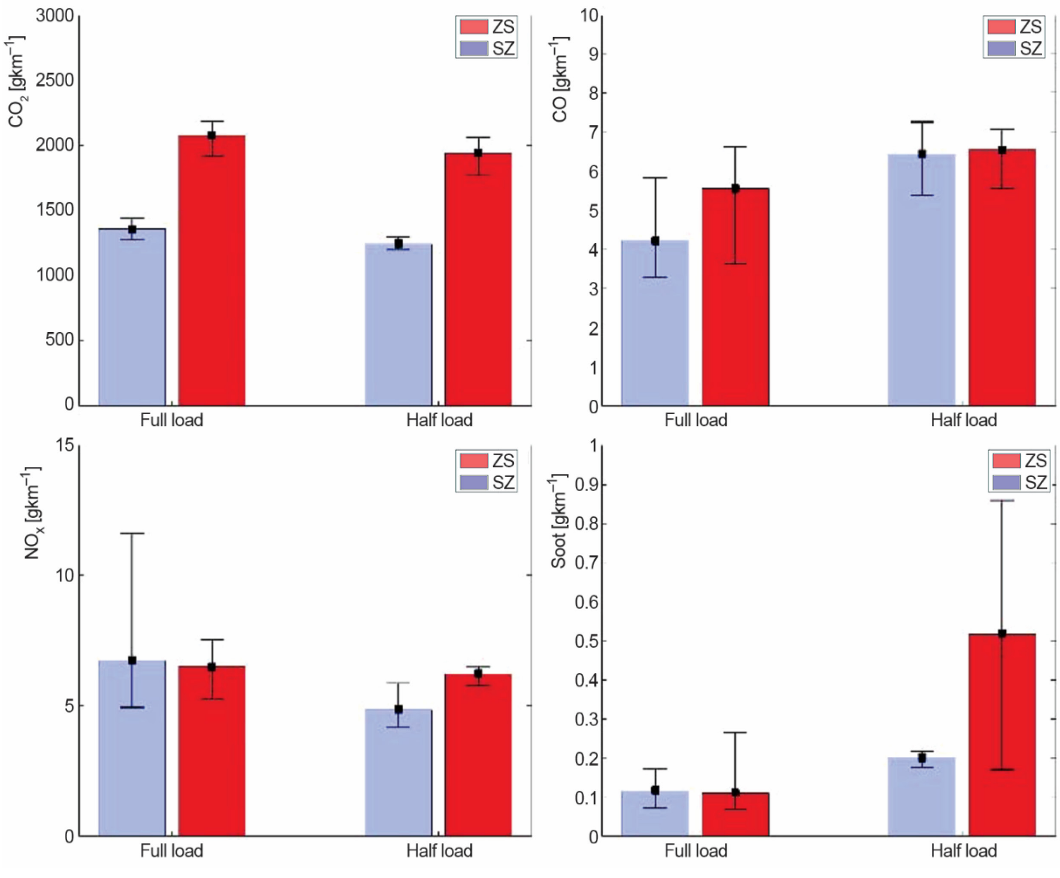


**Figure 6. The $CO_2$, CO, $NO_x$, and soot emission factors of FL and HL cruises on ZS and SZ direction**

As it is seen from fig. 3, the altitude difference for SZ direction is higher than the ZS direction. For the same route comparisons at FL and HL load conditions, emission factors characteristics are altering. For soot emissions, HL average values were found to be higher than FL values. This phenomenon can be explained by the more aggressive accelerator pedal usage of a lightweight bus, which leads to a higher soot formation because of the increase in acceleration demand.

As it is seen from fig. 7, the average fuel consumption is more for SZ direction for the same loads compared to ZS direction which is primarily due to road gradient given in fig. 3. For both directions, the halving the load resulted in a decrease in the fuel consumption.

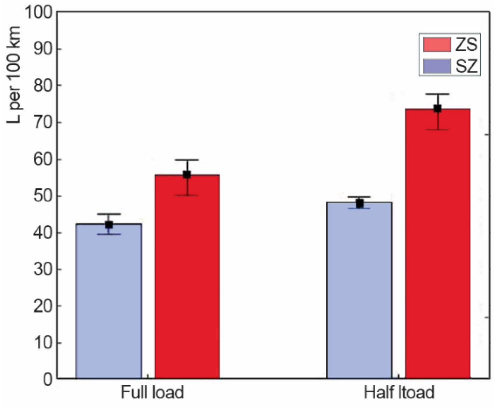


Figure 7. Average fuel consumptions for ZS and SZ directions in l/100 km

### *Emission & fuel rate contour maps*

The time based fuel rate and emission factors [$gs^{-1}$], contour maps with the changing of vehicle speed and acceleration are presented in figs. 8 and 9. The trip whose data is presented in fig. 8 started at 19.00 p. m. from Z direction and following to this event. The bus returned from S direction and its data are presented in fig. 9. These two trips were chosen because of the traffic conditions in the intercontinental bridge. As it seen from the figures, the maximum positive acceleration reaches up to approximately 1.5 $m/s^2$ and the negative acceleration reaches up to approximately –2.2-2.4 $m/s^2$. Also, it can be seen from figs. 8 and 9 that ZS and SZ directions of the acceleration is a major factor that effects the fuel consumption and emissions. The values for negative acceleration zones are higher for SZ direction which should be attributed to the elevation profile of SZ direction (upward cruising). For ZS direction, it can be understood that the engine control system cuts the fuel injection for most of the negative acceleration zones which makes emission factor and fuel consumption lower for ZS direction. This is because of the elevation profile (downhill cruising). But the deceleration is found to be

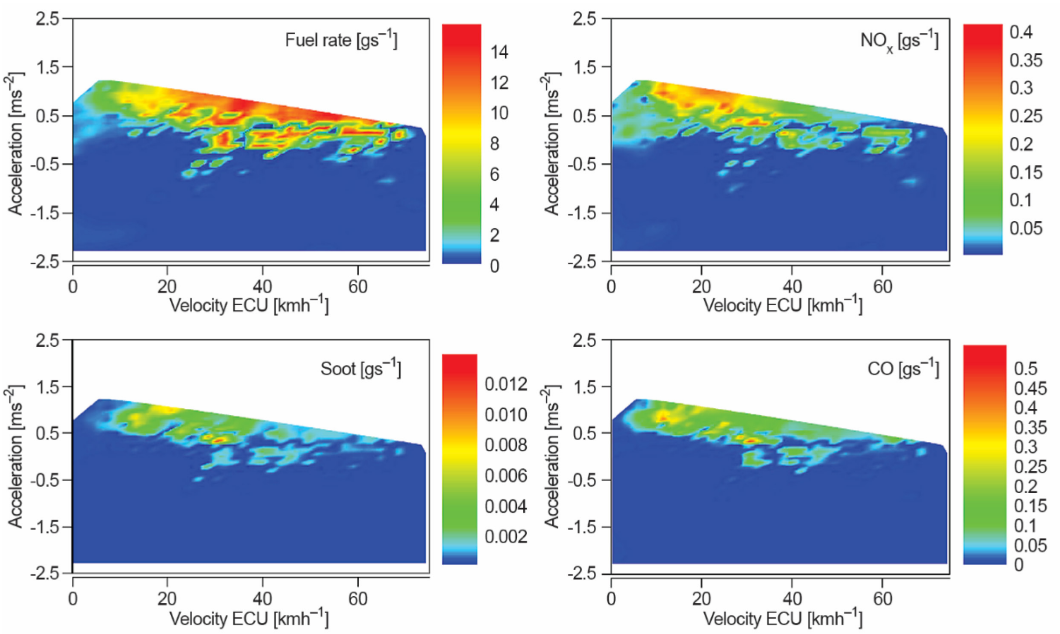


**Figure 8. Fuel rate [$gs^{-1}$] and emission factor [$gs^{-1}$] changes *via* vehicle speed and acceleration for ZS direction with FL** (*for color image see journal web site*)

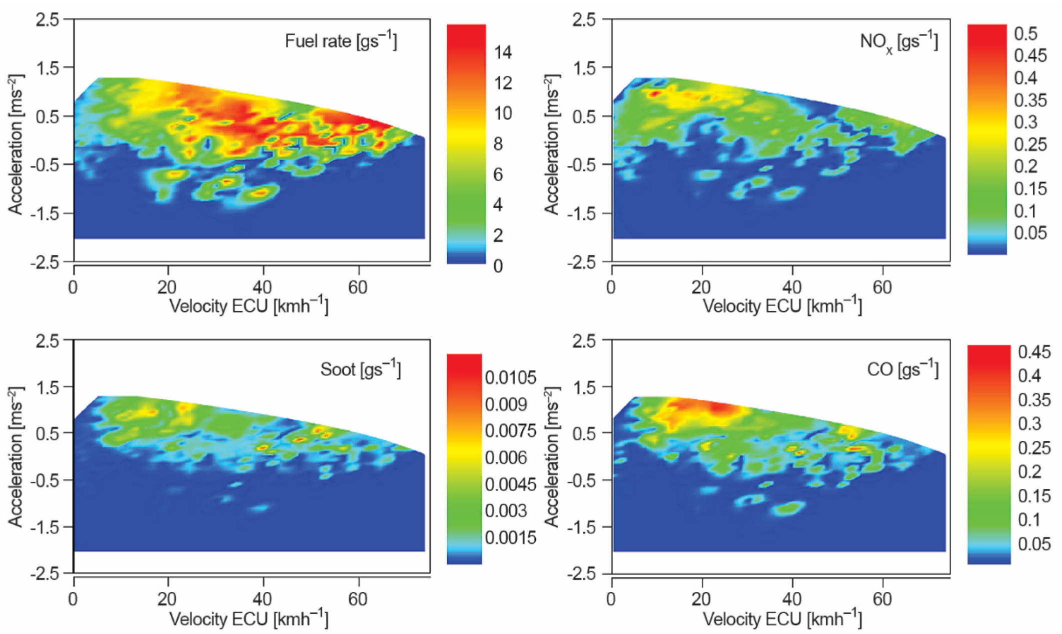


**Figure 9. Fuel rate [gs$^{-1}$] and emission factor [gs$^{-1}$] changes *via* vehicle speed and acceleration for SZ direction with FL** (*for color image see journal web site*)

less significant for both fuel consumption and emissions compared to acceleration. Both emission factors are decreased with the increase of vehicle speed for the same acceleration level. These results are harmonious with [7, 9]. For the time based fuel factor, it is found out that increase of vehicle speed resulted in increase in fuel factor for the same acceleration level.

### *Emission factors and fuel rate contour maps with acceleration*

The percentage of fuel consumption as regards the acceleration modes are given in fig. 10(a). The constant speed cruising and stopping modes which forms the smallest percent of the total cruise both in time basis was also evaluated together. Considering the fuel consumption with regards to the acceleration modes, the positive acceleration modes dominated the cruises with approximately 50-60%. The deceleration fuel consumption changed by approximately 30-40% and the stop cruise modes were lower than approximately 10% for both directions. The fuel consumption as regards the speed modes are given in fig. 10(b). Considering the speed modes, the dominating speed range for fuel consumption was SM3 (40-70 km/h), the second was SM2 (5-40 km/h), and the third was SM1 (< 5 km/h and stop). As can be seen from fig. 10(b), the SM4 fuel consumption can be neglected in the total. It is obvious that, contrary to the time basis share of modes (SM2 is dominating the cruises within approximately 65% in tab. 4) the total SM3 fuel rate was higher for both directions because of the higher power demand at higher speeds. So it is obvious that the buses should be travelling within the speeds closer to SM2 for more economic public transportation which optimizes the cruise and trip duration efficiency. On the other hand, it is seen that the deceleration events formed 30-40% of total fuel consumption which can be interpreted as high for a modern

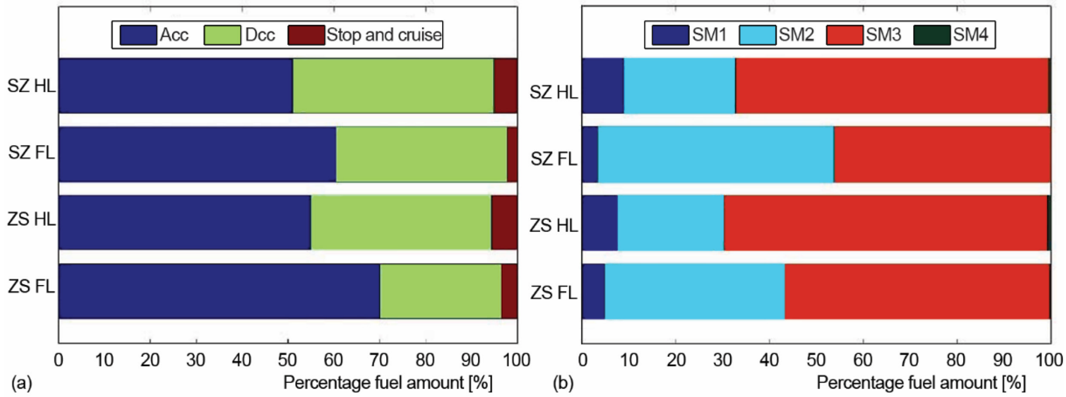


**Figure 10. Average fuel consumption percentages in mass basis for different acceleration (a), and speed (b) modes for SZ direction with FL** (*for color image see journal web site*)

public transportation operation. So it is obvious that, for reducing the fuel consumption, the fleet buses should be equipped with predictive cruise control which will help to manage the cruising modes.

### *Emission percentages regarding acceleration and speed modes*

The percentage of pollutant emissions, soot, $CO_2$, CO, $NO_2$, NO, and $NO_x$ for the different acceleration modes are given in fig. 11(a). The constant speed cruising and stopping modes were evaluated together again. Considering all emissions with regard to the acceleration modes, the positive acceleration modes massively dominated the total emissions with 60-70%. The deceleration share was 20-30% and stop cruise mode share was smaller than 10%. Considering the speed modes, the emission share for SM2 and SM3 dominated the share within 30-40% rate. The SM1 mode was smaller than 10%. The SM4 mode with less than 1% share can be neglected in terms of emissions. As it is indicated from the previous section for fuel consumption, the deceleration event share for emissions are not negligible, a more advanced vehicle speed control system need is obvious for this type of operation. Contrary to the time basis

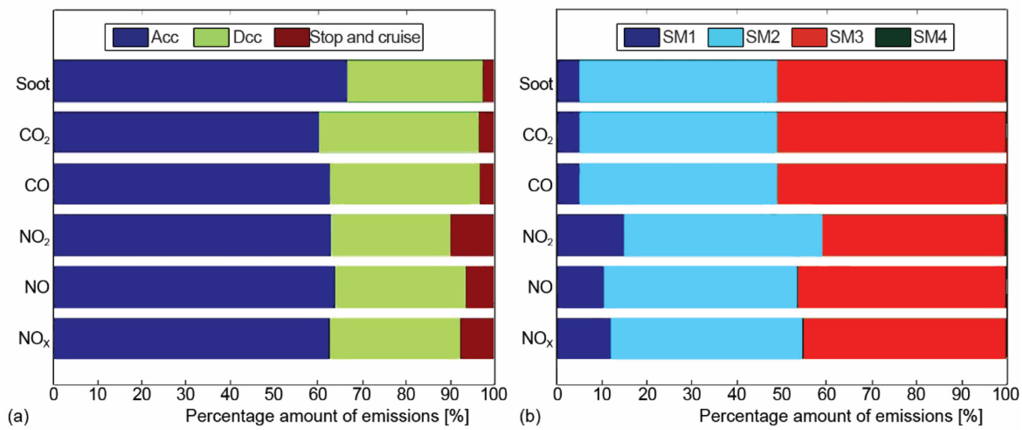


**Figure 11. Average emission percentages in mass basis *via* acceleration and speed modes for SZ direction with FL** (*for color image see journal web site*)

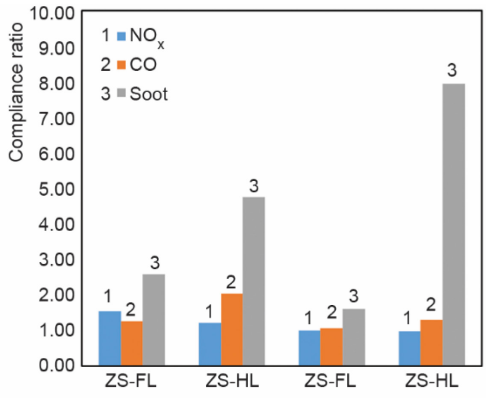


**Figure 12. Emission approval level compliance ratios**

share of SM, the total SM3 emission rates were higher for both directions because of the higher power demand at higher speeds.

*Compliance with approval emission levels*

As the test engine emission approval level was Euro V, the test average brake specific emissions were compared with the regulation limits [18]. The compliance ratios are presented in fig. 12. The THC emission was not measured, so the compliance ratio for THC is not given. Also for the PM values the measured soot values were used. The ZS and SZ refer to route while FL and HL refer to load condition of trips. As can be seen from fig. 12, the soot emitted during the trips was far beyond the approval level. The $NO_x$ and CO emissions present better compliance ratios compared to soot within the limits of 1-2.

## Conclusion

The findings of this research present the following conclusion. The average speed and acceleration have a major non-linear effect on both fuel consumption and emissions of the tested vehicle. Considering the operation within very frequent intervals on a dedicated line (with known gradient and road profile), this transportation line needs a more advanced energy management system which should include control systems both in the vehicle side and fleet management side. The emissions factors were decreased with the increase of vehicle speed for the same acceleration level while the time based fuel factors tends to increase with the increase of vehicle speed for the same acceleration level. The predictive cruise control system, which used the load data and traffic situation information on the selected route, should be implemented for the vehicle side for the management of more environmentally friendly and cost effective operation. In addition to this, a predictive passenger analysis system for stations and bus stops should be implemented with this system for application of predictive algorithms. As it is indicated from the previous section for fuel consumption, the deceleration event share for emissions were not negligible, the need for a more advanced vehicle speed control system is obvious for this type of operation. Contrary to the time basis share of SM, the total SM3 emission rates are higher for both directions because of higher power demand at higher speeds.

This phenomenon indicates that an optimized dynamic cruise control algorithm is needed for environmentally friendly public transportation.

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## References

[1] ***, International Energy Agency – Key World Energy Statistics, Paris, 2014
[2] ***, European Union, EU Reducing Emissions from Transport, http://ec.europa.eu/clima/policies/transport/index_en.htm, 2015

[3] ***, IETT, Istanbul Public Transportation Company, 2015
[4] Yu, Q., Li, T., Evaluation of Bus Emissions Generated near Bus Stops, *Atmospheric Environment, 85* (2014), March, pp. 195-203
[5] Rubino, L., *et al.*, PEMS Light Duty Vehicles Application: Experiences in Downtown Milan, SAE Techical paper 2007-24-0113, 2007
[6] Zhang, S., *et al.*, Real-World Fuel Consumption and $CO_2$ Emissions of Urban Public Buses in Beijing, *J. Applied Energy, 113* (2014), Jan., pp. 1645-1655
[7] Wang, A., *et al.*, On-Road Pollutant Emission and Fuel Consumption Characteristics of Buses in Beijing, *Journal of Environmental Sciences, 23* (2011), 3, pp. 419-426
[8] Wang, X., *et al.*, On-Vehicle Emission Measurement of a Light-Duty Diesel Van at Various Speeds at High Altitude, *Atmospheric Environment, 81* (2013), Dec., pp. 263-269
[9] Noland, R. B., *et al.*, The Vehicle Emissions and Performance Monitoring System: Analysis of Tailpipe Emissions and Vehicle Performance, *Transportation Planning and Technology, 27* (2004), 6, pp. 431-447
[10] Durbin, T. D., *et al.*, Emissions from Heavy-Duty Vehicles under Actual On-Road Driving Conditions, *Atmospheric Environment, 42* (2008), 20, pp. 4812-4821
[11] Guo, J., *et al.*, On-Road Measurement of Regulated Pollutants from Diesel and CNG Buses with Urea Selective Catalytic Reduction Systems, *Atmospheric Environment, 99* (2014), Dec., pp. 1-9
[12] Vujanović, D., *et al.*, Energy Efficiency as a Criterion in the Vehicle Fleet Management Process, *Thermal Science, 14* (2010), 4, pp. 865-878
[13] ***, Goblin System Can Analyse Tool, www.goblinsystem.com, 2016
[14] ***, AVL GMBH, ISO16183, Measurement of Gaseous Emissions from Raw Exhaust Gas and of Particulate Emissions Using Partial Flow Dilution Systems under Transient Test Conditions, AVL Concerto Post Processing Manuel, 2016
[15] ***, International Standarts OrISO, I. S. O. Heavy Duty Engines – Measurement of Gaseous Emissions from Raw Exhaust Gas and of Particulate Emissions Using Partial Flow Dilution Systems under Transient Test Conditions 2002
[16] ***, Yandex, Istanbul Annual Traffic Report, https://yandex.com.tr/company/press_center/ infographics/ traffic2012, 2012
[17] ***, Yandex, Istanbul Annual Traffic Report, 2013
[18] ***, European Union, EU – Euro 5 Emission Standarts-2005/55/EC, http://ec.europa.eu/ environment air/transport/ road.htm

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