Optimization of Fuel Consumption of a Bus used in City Line with Regulation of Driving Characteristics

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Abstract—The fuel cost of the motor vehicle operating on its common route is an important part of the operating cost. Therefore, the importance of the fuel saving is increasing day by day. One of the parameters which improve fuel saving is the regulation of driving characteristics. The number and duration of stop is increased by the heavy traffic load. It is possible to improve the fuel saving with regulation of traffic flow and driving characteristics. The researches show that the regulation of the traffic flow decreases fuel consumption, but it is not enough to improve fuel saving without the regulation of driving characteristics. This study analyses the fuel consumption of two trips of city bus operating on its common route and determines the effect of traffic density and driving characteristics on fuel consumption. Finally it offers some suggestions about regulation of driving characteristics to improve the fuel saving. Fuel saving is determined according to the results obtained from simulation program. When experimental and simulation results are compared, it has been found that the fuel saving was reached up the to 40 percent ratios.

Keywords—Fuel Consumption, Fuel Economy, Driving Characteristics, Optimization

I. INTRODUCTION

For a vehicle powered with an internal combustion engine, the amount of fuel consumed per unit road and per unit vehicle weight and the emission emitted are two important criteria in terms of fuel economy and environment. Decrease of fuel amount consumed per unit road and unit mass will indirectly decrease the amount of emission resulting from combustion. [1]

Specific fuel consumption, brake power and operation time of the engine will determine the amount of fuel consumed. Instantaneous braking power depends on the physical properties of the vehicle, topographic characteristics of the line, environmental conditions, performance characteristics of the engine and on the driving characteristics [2]-[3]. The term ‘driving characteristic’ covers acceleration, deceleration, and variation of speed, maximum driving speed and gear step preferences of the driver.

The fuel consumption of a vehicle in urban and suburban traffic is determined by the complex interaction of many factors. These include the detailed control inputs the individual driver makes to his vehicle, how his vehicle interacts neighboring vehicles and with a complex traffic control system. As a consequence of these factors, vehicles operating in urban traffic undergo frequent changes in speed. Fuel consumption is affected by the manner in which individual and collective human behavior interacts with a large complex system, as well as by the physical characteristics of the vehicle. Driving characteristics are crucial for fuel consumption especially while driving in the city [4]. In this study, it is aimed to decrease the fuel consumption of a bus operating through the city line by the regulation of driving characteristic.

Fuel cost has a significant share within the operating expenses of establishments that perform public transportation. The bus used in the study has been selected among a bus fleet belonging to Istanbul Metropolitan Municipality, Directorate General of I.E.T.T. Directorate General of I.E.T.T, which provides public transportation services in Istanbul controls a fleet composed of nearly 2609 buses. There are 2676 (bus) stops in 525 lines. Number of daily trips is approximately 28,500. Daily number of passengers is approximately 3,200,000. Daily fuel consumption is approximately 266,500 liters. The line where measures between Eminönü and Uçşehitler is conducted has a length of 6.300 meters and there are 10 bus stops. The distances between stops are respectively 1090, 810, 570, 790, 656, 588, 330, 356, 170, 550 meters [5,6]. In the measurements, Corryss-Datron measurement devices were used, which belong to Mercedes-Benz Türk A.Ş. bus factory R&D department.

The study is composed of three parts. In the first part, cumulative fuel consumption, road, speed, acceleration, deceleration values and gear steps of a bus working on intracity line were recorded with 1-second intervals. The passengers on the bus are counted in each stop and recorded accordingly.

All Measurements are performed at warmed-up engine condition. The bus was drove by different drivers at reel traffic conditions. In the second part, the measured data are analyzed and the impact of driving characteristic on the fuel consumption has been determined. In the third part, software, which calculates fuel consumption, was written. Measurement results and software outputs are compared and the validation of the model was made. Later on, studies were conducted on the decrease of fuel consumption by the regulation of driving characteristic via utilizing the software.
II. CALCULATION OF FUEL CONSUMPTION

To keep a vehicle moving, the engine has to develop sufficient power to overcome the opposing road resistance power, and to pull away from a standstill or to accelerate a reserve of power in addition to that absorbed by the road resistance must be available when required.

The road resistance opposing the motion of the vehicle is made up of four components as follows:

- Rolling resistance, $R_R$
- Aerodynamic drag, $R_{Aero}$
- Climbing resistance, $R_C$
- Acceleration resistance, $R_{Acc}$ [7]

$$B_e = \frac{b_r P_e \int dv}{v^2 dt}$$

$$P_e = R \cdot v$$

$$R_\Sigma = R + R_{Aero} + R_C + R_{Acc}$$

$$R = f \cdot m \cdot g \cdot \cos \alpha$$

$$R_{Aero} = \frac{1}{2} \cdot \rho \cdot A \cdot C_D \cdot A \cdot v^2$$

$$R_C = m \cdot g \cdot \sin \alpha$$

$$R_{Acc} = \varphi \cdot m \cdot \frac{dv}{dt}$$

[8,9]

According to the Equations, fuel consumption increases by the first power of acceleration and third power of driving speed. For the fuel consumption to be decreased, acceleration and maximum driving speed should be as low as possible.

During the accelerating movement, acceleration resistance emerges on top of the resistances formed during constant speed driving.

Rolling resistance coefficient ($f$), mass of the vehicle ($m$), angle of ascent ($\alpha$), specific mass of the air ($\rho$), and frontal area ($A$) are the variables that are out of control and command of the driver while driving. Vehicle speed ($v$), acceleration ($dv/dt$) and deceleration ($-dv/dt$) are controlled by drivers. The preference of gear level has a notable impact on the fuel consumption. The selection of gear level depends on the driving characteristics. Because, the gear level used affects engine speed and therefore specific fuel consumption. According to the above-specified equalization, with the acceleration and increase of the speed which are under the control of the driver, fuel consumption increases [10]-[11].

III. CHARACTERISTICS SECTIONS OF THE VEHICLE MOVEMENT

It is possible to travel over a specific distances with different speed-time trajectories. Acceleration, deceleration and constant speed values selected will determine the fuel consumption. Speed-time trajectory composed of acceleration, constant speed and deceleration sections are named regular trajectory (RT). In the Fig. 1, the travelling over the same distance with different speed-time trajectories has been exemplified.

![Fig. 1 Two different example for Regular Time – Speed and Time-Distance trajectory](image)

Driving style can have a significant bearing on fuel consumption, but it is often unclear how one should controlled the vehicle to get the best possible fuel economy [12]. Likewise, theoretically, limitless number of Regular Time-Speed trajectory (RT) may be acquired with different acceleration, constant speed and deceleration values. The variation of speed-time trajectory will cause different amounts of fuel consumption in the same distance. The determination of the option providing the least fuel consumption among the limitless option will require optimization. In reality, this operation covers certain acceptances. Though the options are endless, it is only possible to realize some of them. Motor and power train characteristics include the most significant restrictions. For that reason, engine performance and driveline system characteristics should also be taken into consideration in the optimization [13].
In case the distance being travelled over is ceaselessly long, then the impact of acceleration and deceleration on the fuel consumption will be less. However, in intracity trips when the vehicle stops frequently, acceleration and deceleration has a significant impact on the fuel consumption. The increase of acceleration will increase acceleration resistance and therefore fuel consumption will increase. As to deceleration, it increases the fuel consumption with turning kinetic energy of the vehicle into thermal energy without using it for travelling over.

A good driver, in terms of obtaining the best possible fuel economy, is sensible, steady and drives at modest speed [2].

IV. Measurement Results and Analyses

A. Measurement Results

In order to better understand the general characteristics of trips, as an example, time-speed and distance-speed trajectories belonging to 19:25 trip was given in Fig. 2 and 3. Time-speed and distance-speed trajectories of other 11 trips are similar to the trajectories of 19:25 trip. From the graphics, we see and understand that the bus does not travel with a stable speed between the stops and that the bus firstly accelerates and then decelerates between the stops. The movement of the bus between stops may be separated into two parts as acceleration and deceleration. After acceleration period, there is a deceleration process within a similar period. Speed-time trajectory of the bus between stops is quite different from the regular trajectory created by deceleration, constant speed and deceleration sections.

In order to facilitate the interpretation of results in terms of driving characteristics, a calculation has been made in terms of fuel amount consumed per unit road and unit mass. Fuel consumption and time measurement results have been given in Fig. 4 and Fig. 5 respectively according to Departure time. Fuel consumption which measured has been named MFC.

![Fig. 2 Time - Speed trajectory of 19:25 trip](image1.png)

![Fig. 3 Time - Distance trajectory of 19:25 trip](image2.png)

![Fig. 4 Fuel consumption variation according to departure time](image3.png)

![Fig. 5 Time variation according to departure time](image4.png)

In most of the times, fuel consumption is associated with traffic density in direct proportion. The decrease of trip duration indicates that average speed has increased and therefore the traffic density has decreased. Yet, the decrease of traffic density does not always indicate that the fuel consumption has decreased. As in trips, the departure times of which are 20:25 and 21:25. As to 19:25 trips, while the trip duration has increased due to the traffic density, fuel consumption has realized under 20:25 and 21:25 trips.

B. Analysis of Measurement Results

In order to analyze the results, characteristic sections must be determined.

Characteristic sections having an impact on the fuel consumption have been provided below.

- Stops (In the stops and due to the traffic)
- Acceleration
- Constant speed
- Deceleration [1]

In acceleration, constant speed and deceleration sections, different road resistance groups have an impact on the bus. Rolling resistance, aerodynamic resistance, climbing resistance and acceleration resistance, acceleration period are
resistances that the engine has to overcome. In travelling at the 
constant speed, the resistances that the engine has to overcome 
are rolling resistance, aerodynamic resistance and climbing 
resistances. And in deceleration period, while rolling 
resistance, aerodynamic resistance and climbing resistance try 
to stop the vehicle, negative acceleration resulting from 
deceleration creates a push impact driving the vehicle to move 
in the reverse direction to other resistances. In the deceleration 
period, incase total resistances are positive, the engine must 
overcome the resistances.

1. Analysis of fuel consumption

Measurement results indicate that approximately 73-89% of 
the fuel consumed in trips with different traffic conditions and 
passenger numbers is consumed at the acceleration part (Fig. 
6). The amount of fuel consumed depends on the maximum 
speed and the time elapsing to reach that speed.

Dense traffic conditions will limit maximum speed. On the 
contrary, open traffic conditions will allow drivers to drive the 
vehicles with a full speed and generally drivers use this 
possibility. Measurement results indicate that there is a 
deceleration process similar to the deceleration time after the 
trip with a high speed. In general, in this process when 
braking system is put into service, kinetic energy of the 
vehicle is turned into thermal energy with braking system or 
engine brake. As the kinetic energy, which is obtained with 
the conversion of chemical energy of the fuel and which 
enables the movement of the vehicle, is turned into thermal 
energy via the braking operation, this will cause the increase 
of fuel consumption. Measurement results have indicated that 
the fuel consumed in deceleration processed in trips with high 
speeds is more than the fuel consumed in constant speed 
processes.

2. Analysis of Fuel Consumption

Although trips are made with different traffic density and 
passenger number, the periods of acceleration and deceleration 
have similar values (Fig. 7). 83-94% of the total distance is 
travelled over in acceleration and deceleration periods. From 
the Fig. we understand and see that traffic and load conditions 
have an important impact on the acceleration and deceleration 
characteristic.
The differences between measured and calculated fuel consumptions result from the assumption that weights of all passengers are equal to one another and instantaneous resistance variations that are not anticipated. Relative error is ±2.2 (Fig. 8).

VI. RESULTS OF MATHEMATICAL MODEL

In this part, the amount of fuel to be consumed in case the bus travels over the distance between the bus stops in conformity with regular trajectory resulting from acceleration, constant speed and deceleration processes has been calculated by the employment of a software. In the calculations, measurement values have been used for the number of passengers and stop times. Acceleration and deceleration trajectories have been created with average data obtained from measurement results for each gear step/level. Gear transitions are made by considering real usage conditions. Two different modes have been used for constant speed values. In the first mode (MODE 1), a constant speed value has been selected in a way that the trip times calculated and real trip times will be the same. In the second mode (MODE 2), constant speed value has been sought, by which optimum fuel consumption is enabled. In MODE 2, different from the MODE 1, it has been changed in a specific interval and constant speed value providing the least fuel consumption has been sought. Fig. 9 indicates real and regular trajectory variation for MODE 1. Although speed-distance trajectories are different, travelling time and average speed are the same for both of the trajectories.

In the calculations, a similar arrangement has been made by taking total trip time as the basis. The purpose of MODE 1 is to enable regulated trajectories to be in conformity with real trip times. In the calculations made in both of the modes, real values of the number of passengers and distances between bus stops have been taken. Because, in order to decrease fuel consumption, variation of passenger number and the distance travelled over is in contradiction to the service purpose of the bus.

The results demonstrate that it is possible to decrease fuel consumption by regulating speed-time trajectory (Fig. 10).

The results calculated indicate that the rate of fuel consumed in the motion at constant speed in accordance with MODE 1 and MODE 2 speed-time trajectory (Fig. 12 and 13). This is a result of avoiding acceleration and deceleration course which causes the increase of fuel consumption. Along with that, we see that fuel economy is better in MODE 2, where movement is less at the constant speed.

Traveling the distance between the bus stops in accordance with speed-time trajectory arising from acceleration, constant speed and deceleration processed will improve fuel economy up to 30% for MODE 1 and up to 41% for MODE 2 (Fig. 11). For MODE 1, we have observed that fuel economy...
The results obtained in the study demonstrate that a fuel economy by average 11% may be achieved in Mode 1 and by 31% in Mode 2, which aim to complete the trips within the same period. Aside from fuel cost, there will be a significant decrease in CO₂ and other emissions and PM released by busses.

CO₂, CO, HC, NOₓ, SO₂, and PM constitute an important part of Diesel motor exhaust emissions. As combustion in diesel engines realizes in the condition of high access air coefficient, HC, CO emission resulting from the emission is at an insignificant level. In consequence of advancements in the diesel fuel technology, sulphur amount within the fuel has been decreased down to 10 ppm level and SO₂ amount given off from the exhaust has significantly decreased. For diesel engines, NOₓ, CO₂, and PM are emissions that are primarily taken into consideration. [14]-[15]

Although environmental effects of NOₓ emission via post-combustion emission decreasing systems, this increases the operating costs of the systems. For CO₂, the case is quite different. It is because the only known method to decrease CO₂ emission is consuming less fuel. As a result of combustion of one kg carbon, approximately 3.67 kg CO₂ is released into the atmosphere. Approximately 86% of diesel fuel is composed of carbon [16]-[17].

In Istanbul, where the study was conducted, approximately 266,500 liters of diesel fuel is consumed on a daily basis with the intracity public transportations by bus. According to results obtained from the calculations, with the regulation of driving characteristic, there is a potential to improve fuel economy by 10-41%. With the effects to arise in the implementation of simulation results to real conditions, even in the improvement of fuel consumption by 10%, significant economic and environmental benefits will be achieved. The improvement of fuel economy by 10% will decrease the amount of fuel consumed in a day by 26,650 liters and decrease CO₂ amount released into the atmosphere by 60 tons. Annual decrease amount in CO₂ emission will be approximately 21,900 tons.

VII. Conclusion

The results indicate that the impact of driving characteristics is more obvious in traffic conditions with less density. However, it is not a realistic approach to expect drivers to conform to driving conditions to improve fuel economy. For that reason, it will be useful to equip the vehicles with auxiliary equipments that establish speed and acceleration control in terms of improving fuel economy. Nowadays, the information such as gradient and cornering data could be transferred into the vehicle management system (VMS) via GPS and also the ongoing traffic condition data could be transferred in to the VMS via GPRS. It is possible to establish a system that informs the driver about driving conditions for a fuel efficient drive or that bans the driving conditions except the fuel efficient drive via processing previously mentioned data with the engine specifications. The use of proper speed-time trajectory to be chosen depending on simultaneous traffic information will significantly decrease the fuel consumption.

REFERENCES


APPENDIX

Technical specifications of the city bus used in study

Vehicle mass : 10300 ±%5 (kg)
Pasenger : 97+1 (person)
Engine : RABA-MAN D 2156 HM6UT
Engine brake power : 162 (kW) / 2100 (rpm)
Engine brake torquce : 819 (Nm) / 1600 (rpm)
Gear box : C sepel ZF S6-90U-049
Wheels/ Tire size : 8.00-20” / 11.00R-20 STC

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He was born at Istanbul - 29.06.1980. He took his bachelor degree from Mechanical Engineering Department- Automotive Subdivision at 2004 from Yildiz Technical University(YTU)-Istanbul and he took his master degree from Mechanical Engineering Department Automotive Subdivision from YTU at 2007. During his master research he worked on determining the flame speed of alternative internal combustion engines fuels. His PhD is ongoing at YTU Automotive Subdivision by the year 2011 and he is working on optimizing the multiphase injection strategies at common rail equipped injection diesel engines. Now he is working at Yildiz Technical University Mechanical Engineering Department Automotive Subdivision at Istanbul as a Research Assistant since 2005. He made publications and researches about the fuelling the compression ignition(CI) engine with biodiesel, its effects on engine performance and lubrication characteristics. He also made researches about gasoline fumigation at diesel engines and application of artificial neural networks for identifying the engine performance values at CI engines. Some publications are : i- “Comparison of Fuel Consumption and Emissions Of An Urban Bus Fuelled with Diesel and Biodiesel.” pg.49-67. Özkan Muammer, Özener Orkun ,Özoğuz Berk, Yüksel Levent . 3rd International Symposium on Environment, Athens, 22-25 May 2008. ii- “Modeling the Effects on Fuel Costs When Farmers Produce Their own biodiesel Fuel.” pg.67-77 Özkan Muammer, Özoğuz Berk, Özener Orkun. 3rd International Symposium on Environment,Athens,22-25 May 2008. ii- “The Effect and Comparison of Biodiesel-Diesel Fuel on Crank Case Oil „Diesel Engine Performance and Emissions.” Pg.173-179 . Levent Yüksel, Hakan Kaleli, Orkun Özener, Berk Özogu. Serbia trib’09 International Conference, 2009 Belgrade/Serbia. His research areas; combustion, internal combustion engines, pollutant emissions, bio fuels , artificial neural networks, multiple injection in diesel engines. Irfan Yavaslı got his BS degree on mechanical engineering from Yıldız Technical University in 1970 and MS degree from Yıldız Technical University in 1972. He participated Research activities at Cranfield Institute of Technology in 1976 and Institute for Internal Combustion Engines of Vienna Technical University in 1981. He was the Dean of Mechanical Engineering Faculty between 1992 and 1997. He worked as a project supervisor on various projects with TÖPAŞ which produces Fiat Auto products in Turkey. Currently he is the Professor of Yıldız Technical University and the Head of Automotive Studies Subdivision and LC Engines Laboratory