CO_2 Analyses With Model Based Regulatory Tools: VECTO Application For İstanbul Public Transportation Case

O. Özener[1], O. Gezer[2], M. Ozkan[3], N. Zacharof[4] and G. Fontaras[5]

1. Faculty of Mechanical Engineering, Yıldız Technical University, İstanbul; email: oozener@yildiz.edu.tr ,
2. Faculty of Mechanical Engineering, Yıldız Technical University, İstanbul; email: ogezer@yildiz.edu.tr ,
3. Faculty of Mechanical Engineering, Yıldız Technical University, İstanbul; email: muaozkan@yildiz.edu.tr
4. Laboratory of Applied Thermodynamics of Aristotle University of Thessaloniki, e mail: zacharof@auth.gr
5. Joint Research Centre of European Commission, Ispra, Italy, e mail: georgios.fontaras@ec.europa.eu

Abstract

The fossil fueled public transportation which circulates at inner city routes is an important focus area for CO_2 emission researches. As the number of vehicles in the fleets and the cumulative distances covered by these fleets are considerably huge, the understanding of effects such as; cruising speeds, auxiliary loads, operating planning and bus stop location choosing becomes more important on CO_2 emissions. The European Commission has already set a framework to regulate pollutant emissions and is underway to monitor and regulate CO_2 emissions with the use of Vehicle Energy Calculation Tool (VECTO). VECTO is a vehicle simulation tool developed for the certification and monitoring of fuel consumption and CO_2 emissions from heavy-duty vehicles. Trucks are already certified using VECTO since in 2019, while work is on-going for extending the tool and methodology to buses and coaches. In this context, a route in one of the biggest bus transport system- Istanbul Metrobus Rapid Bus Transport- System is modelled in VECTO environment. The model is validated with real driving fuel consumption and CO_2 emission results of the buses. The obtained results showed difference in the range of 1-5%. Further analyses indicated that VECTO could be used for assessing on-road CO_2 emissions of conventional buses and assist urban transportation planning and potentially for other regulatory purposes in Turkey as well.

Keywords: fuel consumption, CO2 emissions, certification, VECTO, city bus, heavy-duty

1 INTRODUCTION

Public transportation is used worldwide for daily commute and further development and integration of such systems could contribute in reducing pollutant road emissions. Additionally, under certain conditions and measures, it is possible that public transport can ensure shorter travel time. However, public transportation vehicles still cause significant emissions, due to their long operation time and frequency of stop-and-go operation, especially in the ones that are deployed in urban areas.

A direct comparison between public transportation would show that for example a bus has a lot higher emissions compared to a passenger car. Such a comparison could be misleading however as buses demonstrate a high occupancy rate that minimizes emissions per passenger and reduces overall road vehicle emissions. For this is reason, there is a high incentive to focus on developing a transportation system that will attract more passengers, preventing them from taking their private vehicles and to improve vehicles to reduce their emissions. The main driver for the vehicle emissions is their mass and configuration, while vehicles are highly sensitive to operational conditions, number of passengers and road grade [1].

Recently, many researchers have carried out numerous studies in public transportation field especially in metropolitan areas [2-4]. The main focus has been on integrated approaches to reduce travel time by increasing the average speed and increase carrying capacity. Bus rapid transit system (BRT) is one of them. Vehicles

within the BRT system travel completely or largely on special road lanes, which significantly reduces travel time compared to conventional public transportation strategy. BRT systems are becoming widespread rapidly, because the start-up period is much shorter than competitors. Additionally, BRT systems require very low costs compared to metro lines and light railway application.

Transient operation conditions, which are dominant in urban routes, internal combustion engines lead to higher fuel consumption and higher emissions. In addition to the frequent of stop-and-go conditions, the mass of the vehicle varies throughout the trip as passengers enter and exit the vehicles. There have been several studies that focused on fuel consumption, emissions, travel time and operating condition of conventional public transportation vehicles and BRT systems are presented below.

Zhang et al. [5] observed that average fuel consumption of vehicles operating with conventional diesel on different routes in Beijing, China, as 39.4 l/100km during non-peak hours and 44.7 l/100km during peak hours, which corresponds to a 13% increase. When compared to CO_2 emission in this study 14% emission increasing was observed as average cruise speed is inversely proportional to the intensity of the traffic conditions. Alam and Hatzopoulou [1] worked on a certain route in the city of Montreal. According to their findings, if the road grade increases, GHG emission values increase more, especially in of higher speeds. In this study, it was observed that, GHG emissions were quite volatile and didn't show certain trend at negative road grade, acceptable raising was observed at zero grade, but significantly increasing occurred at positive grade with respect to increasing of passenger. For an 7.5% road grade GHG emissions increased by 26.96% between and empty vehicle and a vehicle carrying 75 passengers. Yu and Li [6] collected real-time emission data in Nanjing, China, and evaluated the characteristics. They observed that 21% of CO_2, 22% of CO emission, 20% of NO_x and 21% of HC emission emitted during bus stop along the whole operation. In addition, an extensive literature can be found at [7, 8].

This study was carried out on the İstanbul BRT line (Metrobus line), which worlds unique intercontinental BRT system. The bus was operated with a 13,000 kg payload that was simulated with sandbags, while the relevant fuel consumption, emission and vehicle data were measured and logged during tests. Subsequently, the vehicle was modelled in VECTO simulation environment and the results were compared and analyzed. Also, further assessments were made for cleaner public transportation.

2 METHOD

2.1 Measurement System

The vehicle that was utilized for the measurements was a Euro 5 public bus which is powered by a diesel engine. The properties of the vehicle and the measurement system details are given at Table 1 and Table 2 respectively. Additionally, the relevant CAN data (actual torque, accelerator pedal position, gear, and wheel based vehicle speed) was logged. All systems were controlled by AVL system controller equipment.

Table1. Vehicle and Engine Properties

Gross Vehicle Weight	32 tonnes
Type	Articulated
Vehicle Length	18 m
Number of cylinders	6
Engine capacity	11.9 l
Power	260kW@2000 rpm
Torque	1600Nm@1100rpm
Compression Ratio	17.75:1
Min. Brake Specific Fuel Consumption *@Full Load-1400 rpm*	185 gr/kwh
Emission Certification Level	Euro 5

Table 2. Measurement System Properties

System	Device	Method	Accuracy
Fuel Consumption	AVL KMA Mobile	Rotational type flow meter	±0.1%
Emission	AVL Gas PEMS	NO - UV-RAS[i]	± 0.2%
		NO_2- NDUV[i]	± 0.2%
		O_2 - Oxygen Sensor	± 1%
		CO-NDIR[ii]	± 30ppm
		CO_2- NDIR	± 0.1%
Emission	AVL PM Pems	Soot Photoacoustics	~ 5 µg/m³

[i]NDUV : Non Dispersive Ultraviolet
[ii]NDIR : Non Dispersive Infrared

2.2 Test Route and Procedure

The test was carried on İstanbul Metrobus Line. that consists of 3 main parts:

- Söğütlüçeşme-Zincirlikuyu (SZ)→ 11 km length with 8 stations
- Zincirlikuyu-Avcılar (ZA) → 25 km length with 25 stations
- Avcılar – Beylükdüzü (AB) → 16 km length with 12 stations

The tests was carried on Söğütlüçeşme-Zincirlikuyu (SZ) direction The test route is given Figure 1. [9].



Figure 1 Söğütlüçeşme - Zincirlikuyu (SZ) Test route Google Earth image [9].

For safety issues the loading condition was simulated with sandbags, instead of passengers. One loading condition is considered with 13 tonnes of sandbag as payload. The detailed test procedure and emission analyses are described in [9] paper.

2.3 VECTO SIMULATION

Vehicle Energy Consumption calculation Tool – VECTO, is a simulation tool that has been developed by the European Commission and is used for determining CO_2 emissions and Fuel Consumption from Heavy Duty Vehicles (trucks, buses and coaches) with a Gross Vehicle Weight above 3500 kg [10].

The tools capacity for predicting CO_2 and fuel consumption accurately and the development of the simulation models are described in detail in previous works [11, 12].

The VECTO tool offers two modes for vehicle simulation; declaration and engineering modes. In declaration mode, a vehicle configuration is selected and most of the underlying parameters (e.g. axle weight distribution) are predefined according to technical specifications regulated by European legislation. On the other hand, in Engineering mode, users can set more parameters to try and experiment vehicle models [13].

Vehicle components operation are inserted by using tables (e.g. engine fuel maps transmission torque loss maps), scalar values (e.g. rolling resistance) or a combination of those. An example for the latter is air drag at zero yaw angle, providing the side winds effect in air drag at different angles that is described by a scalar value accompanied by a table. Map-type entries contain information about dynamic parameters that vary depending on engine or vehicle speed, while data considered constant during the route, such as mass and air entrainment area, are entered directly into the tool. Drop-down menus often contain categorical data such as axle configuration (e.g. 4x2, 6x2) and transmission type (e.g. Manual, AMT). [14] The job file window of VECTO is given at Figure 2.

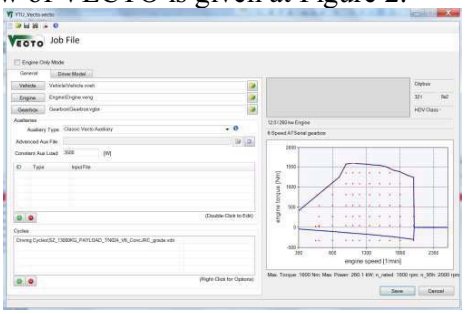


Figure 2- Job file window Vecto.

The scheme of Vecto model is also given in Figure 3.

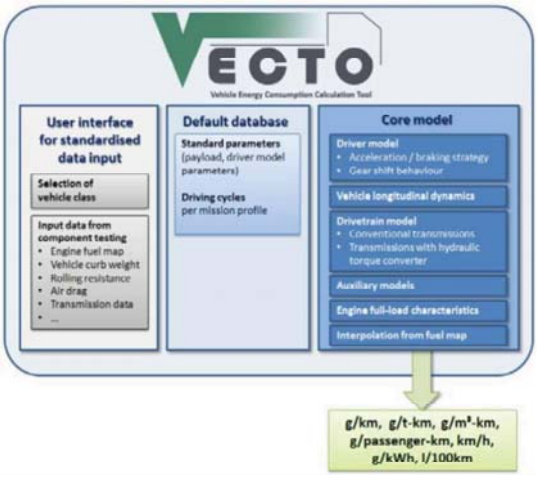


Figure 3. Scheme of VECTO model [15]

3 RESULTS AND DISCUSSION

The actual measured speed and the simulated velocity with VECTO is given at Figure 4 and both signals show a good agreement. The measured distance during the real trip was 11,410 meters and the simulated trip distance is obtained as 11,3547 meters in VECTO. The difference is noted -0.48 % lower for VECTO simulation . The regression plot for target and actual velocity regarding to distance is noted as 99% which is given at Figure 5. Also the acceleration event group histograms are compared at Figure 6 and as it is seen the acceleration values number of observations are in presents a good agreement.

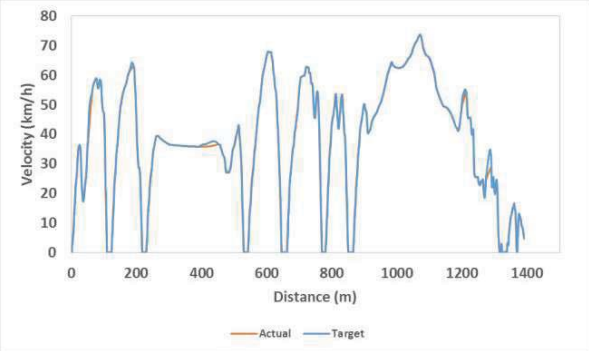


Figure 4- Actual (simulated) and target velocity comparison.

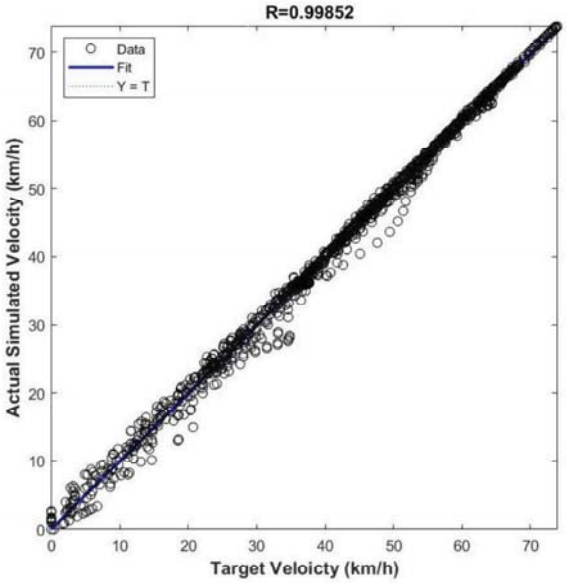


Figure 5- Actual (simulated) and target velocity comparison.

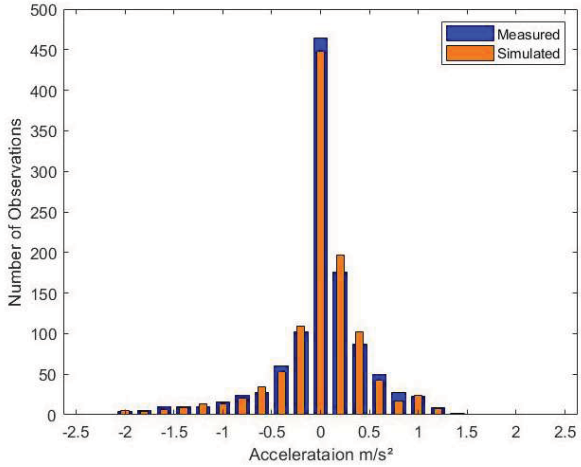


Figure 6- Acceleration values histogram

The cumulative measured and simulated fuel consumption is shown in Figure 7 and the respective values are 7727 g and 7461 g. the difference is noted as -3.5%. Also the measured average fuel consumption is calculated as 677.21 g/km and he simulated average fuel consumption is 657.15 g/km, the difference is calculated as -3%. As the differences for total and average fuel consumption are small this these differences can be decreased with a more precise altitude and detailed powertrain auxiliaries modelling.

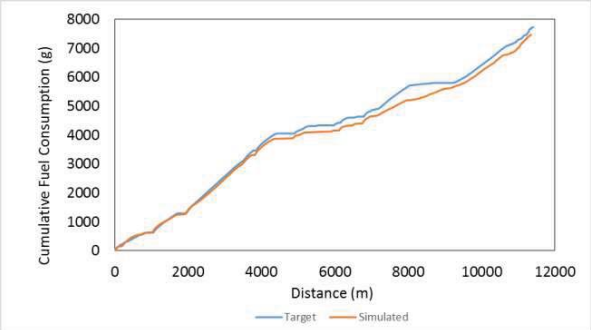


Figure 7- Cumulative measured and simulated fuel consumption comparison.

The measured and simulated CO_2 results are also compared, with the total CO_2 mass being at 24.249 g and 23.355 kg respectively with the difference of -3.7%. On the other hand, the measured average CO_2 emission was found at 2125.24 g/km, the simulated average CO_2 was calculated at 2056.90 g/km with the difference of -3.3%.

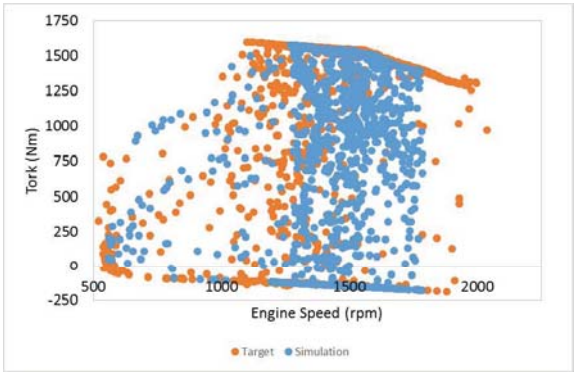


Figure 8- Logged and simulated torque speed points

The logged and simulated engine speed-torque points are given at Figure 8. As its seen the actual and simulated torque-speed points are matching with a good prediction capability and it can be said that simulation torque-speed points cover the real test (cruising) torque-speed points widely.

4 CONCLUSION

This work assessed one of the most important public transportation route of İstanbul-Metrobus Line. For this reason, a vehicle was simulated in VECTO and the results were validated with the logged data. The simulated values were found to be in acceptable range so the model can be considered as representing the real time operation in terms of Fuel Consumption and CO_2. VECTO has the capability to be used for public transportation analyses and planning as deploys several features that are needed to describe on-road conditions, such as driver models, acceleration and deceleration identifications, velocity profile applications. Additionally, there are several features that will be implemented in the future, such as predictive cruise control, hybrid vehicles etc. that will further enhance the tool's capabilities. It is recommended that a further research is should focus on modelling the behavior of additional components or energy consumers like auxiliaries etc.

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