

Verification of IVE Model for SAIPA Co. Fleet Emission

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ABSTRACT: To determine the amount of air pollutants, produced by Iranian automakers, and compare it with old and retrofitted vehicles have become one of the important tools of urban management. The present research uses International Vehicle Emission (IVE) modeling software in order to verify SAIPA Co. fleet emissions, based on Euro 4 emission standard (SAIPA Co. recognized as a superior Iranian brand in vehicle industry). There has been attempts to determine pollutant emission from Saipa Co.-manufactured cars in the city of Tehran, in accordance with Tehran Driving Cycle along with modeling and lab results which have over 90% conformity with modeling and lab results of New European Driving Cycle. According to ISQI's 100,000-km test results, the amount of CO₂ emission modeling from X100 and Tiba2's has been about 160 gr/km, which has been within the range, whereas the modeled CO₂ emission rate has been 232 gr/km in TDC, i.e., 1.5 times more than laboratory test, due to different driving cycle usage. Significant differences between the values obtained in the emission lab and modeling at New European Driving Cycle, Tehran Driving Cycle, and Tehran Air Quality Control Company report, indicate that relying on hypothetical situation leads to inapplicable emissions value from light vehicles.

Keywords: Vehicle Industry, Tehran Driving Cycle (TDC), New European Driving Cycle (NEDC), Euro 4 Emission Standard.

INTRODUCTION

The relation between the rise of air pollutants and severity of living organisms' diseases has been known for many years, especially in case of people who suffer from heart and respiratory illnesses, related to the air pollution (Rashidi et al., 2012; Katsura, 2012; Lee et al., 2012; Sekhavatjou et al., 2011; Quesada-Rubio et al., 2011; Shafabakhsh, et al., 2018; Wang et al., 2011; Zou et al., 2011). Among the sources of pollutant emissions, the lion's share belongs to mobile sources in large cities, among which internal combustion

engines, such as gasoline engines, are an important source of airborne emissions, classified as 2B on the cancer list in the report of International Agency for Research on Cancer (IARC, 2013). Consequently, the standards for mobile source emissions were implemented in California since the 1960s, gradually becoming commonplace in other parts of the world (Pulkrabek, 1997). In 1970s, by ratifying the 70/220/EEC act, the European Commission reduced the emissions, produced by motor vehicles. Over time, due to air quality deterioration along with the need for stringent vehicular emissions

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control, the European Union formally introduced emissions laws the so-called Euro-Emission Standard in 1992 (The European Parliament and the Council of the European Union, 1992). As for Iran, the Iran's National Standard No. 7328, entitled "Road vehicles – Emissions of pollutants" was introduced in 2004 in accordance with the EU standards (The Iran's National Standard No. 7328, 2004).

There have been various software programs to estimate the amount of emissions from mobile sources, developed and promoted by U.S. Environmental Protection Agency (EPA) or the European Union. Using these software programs makes it possible to verify the results from modeling and laboratory tests, estimate the amount of pollutant emissions based on different driving cycles, and –finally– determine the emission inventories of moving resources, such as MOVES, COPERT, and IVE. EPA's Motor Vehicle Emission Simulator (MOVES) is a state-of-the-science emission modeling system that estimates emissions from mobile sources at international, national, and project levels for such criteria as air pollutants, greenhouse gases, and air toxics (Shafie-pour et al., 2013). As for COPERT, it is a software tool, used worldwide to calculate air pollutants and greenhouse gas emissions from road transport. Its development has been coordinated by the European Environment Agency within the framework of the activities of European Topic Centre for Air Pollution and Climate Change Mitigation. COPERT has been originally developed for official road transport emission inventory preparation in European Environment Agency (EEA) member countries; however, it is applicable to all relevant research, scientific, and academic applications (Shafie-pour et al., 2013; Fameli & Assimakopoulos, 2015; Kassomenos et al., 2006; Outapa, et al., 2017; Hai Van, et al., 2015; Penwadee Cheewaphongphan, et al.,

2017; Shaddick, et al., 2018). Finally, IVE software has been applied in different countries, like China (Zhang, 2013; Wang et al., 2010; Wang, et al., 2008; Guo et al., 2007), Argentina, Colombia, Chile, Brazil (Gallardo et al., 2011), Iran (Shafie-pour et al., 2013; Shahbazi et al., 2016; Ghadiri et al., 2017), and India (Mishra & Goyal, 2014; Nagpure et al., 2011). All told, the present study aims at the use of International Vehicle Emission modeling software to verify SAIPA Co. fleet emissions, based on the Euro 4 emission standard (SAIPA Co. being recognized as a superior Iranian brand in vehicle industry) as a new fleet. It attempts to determine the emission of pollutants by the Saipa Co. fleet in the city of Tehran, based on Tehran Driving Cycle. It goes without saying that the results from this study will guide the authorities to reduce the amount of air pollutants, related to old and retrofitted vehicles which do not meet Euro 4 emission standard or are not fitted with catalytic converters, as an essential step for the improvement of air quality in Tehran city.

MATERIALS AND METHODS

Tehran is the capital of Tehran province and Iran. With a population of 13,267,637 it is also the largest city of Iran (Statistical Center of Iran, 2016), stretched within an area of 613 km², with Alborz Mountains in the north and desert in the south. The annual mean daily temperature is 18.5°C, with a maximum of 43°C in July and a minimum of -15°C in January. The annual precipitation is 220 millimeters, with its maximum rate in March (39 mm) and minimum rate in September (1 mm). The weather is typically sunny, with an annual average of 2800 h of bright sunshine and a mean cloud cover of 30%. The prevailing winds blow from west and north (Amini, et al., 2016). They are several influential factors to cause major air pollution problems (Bidokhti & Shariepour, 2010) in

Tehran, which include limited public transportation alternatives, rapid population growth, and numerous personal car ownership (Naddafi et al., 2012; Shahbazi et al., 2016). The air pollution problem in Tehran gets intensified by complex terrain conditions. Being surrounded by Alborz mountain range on the north and northeast sides, leads to pollution getting dispersed by the winds on the east side of Tehran (Ashrafi, 2012; Sohrabinia & Korshiddoust, 2007; Ghadiri et al., 2017). The number of vehicles has overgrown in Tehran with the total number of registered vehicles having increased more than eight times in the last 13 years. Today, there are about 4.24 million registered vehicles in Tehran city (Shahbazi, 2015), 72% of which belong to personal light-duty vehicles, based on the emission inventory of Tehran, with the rest being composed of taxis, buses, minibuses, pickups, trucks, and motorcycles (Tehran Air Quality Control Company, AQCC, 2015).

The present study uses International Vehicle Emissions (IVE) software program in order to estimate the fleet distribution of Saipa Co. productions, recognized as one of the biggest automakers in Iran. The IVE

model is a computer program, developed by the Java programming language, which is designed to estimate mobile source emissions. The model predicts local air pollutants, greenhouse gas emissions, and toxic pollutants. The IVE model has been developed as a joint effort of the University of California at Riverside, College of Engineering – Center for Environmental Research and Technology (CE-CERT), Global Sustainable Systems Research (GSSR), and the International Sustainable Systems Research Center (ISSRC). The most important input in IVE is driver-specific factors. This software uses Vehicle Specific Power (VSP) and Engine Stress to gain the mentioned correction factors. The former is a function of instantaneous speed, elevation change, vehicle weight, drag coefficient, and air density. The emission estimation process in IVE model is to multiply the base emission rate for each technology by each of the correction factors, which are defined for each vehicle technology, and the amount of vehicle travel for each technology, to finally arrive at a total amount of emissions produced. The correction factors can be categorized into several categories (Table. 1) (Shafiepour et al., 2013).

Table 1. Effective Parameters Considered to Calculate Pollution Emissions in IVE Model

Local Variables	Fuel Quality Variables	Power & Driving Variables
Ambient Temperature	Gasoline Overall	Vehicle Specific Power
Ambient Humidity	Gasoline Sulfur	
Altitude	Gasoline Lead	Road Grade
Inspection/Maintenance Programs	Gasoline Benzene	Air Conditioning Usage
Base Emission Adjustment	Gasoline Oxygenate	Start Distribution
	Diesel Overall	
	Diesel Sulfur	

In this model, equation (1) is used for light and medium vehicles with good

accuracy:

$$VSP(kW / metric - ton)$$

$$= v \times (a \times (1 + \epsilon_i) + g \times grade + g \times C_R) + \frac{1}{2} \rho_a \frac{C_D \times A}{m} (v + v_w)^2 v + C_{if} \times g \times C_R \quad (1)$$

$$= v \times [1.1a + 9.81 \times (a \tan(\sin(grade))) + 0.132] + 0.000302 \times v^3$$

where:

$$v = \text{speed}(m/s)$$

$$a = \text{acceleration}(m/s^2)$$

$$m = \text{vehicle weight}(kg)$$

ε_i = mass factor, equivalent to the mass of the rotating parts (wheels, gears, shafts, etc.) at power train (without unit). The suffix i indicates that ε_i depends on gear, tilt, elevation, and landing length.

$$g = \text{gravity acceleration } 9.8(m/s^2)$$

$$C_R = \text{Resistance coefficient}(without\ unit)$$

$$C_D = \text{Stretch coefficient}(m^2)$$

$$\rho_a = \text{The density of the outside air is } 1.207 \frac{kg}{m^3} \text{ at } 20^\circ C$$

$$v_w = \text{Opposite wind direction}(m/s)$$

To determine the engine stress, Equation (2) is also employed:

$$\text{Engine Stress} = \text{RPM Index} + (0.08 \frac{ton}{kW}) \times \text{Preaverage Power} \quad (2)$$

$$\text{Preaverage Power} =$$

$$\text{Average}(VAP_{t=-5 \text{ sec to } -25})(kW/ton)$$

$$\text{RPM Index} =$$

$$\text{Velocity}_{t=0} / \text{SpeedDivider} (without\ unit)$$

$$\text{Minimum RPM Index} = 0.9$$

The speed drive in the above equation is based on the speed and power of the characteristics of the vehicle, all in accordance with the instructions of IVE user guide. This model considers 60 bins for specific power of the vehicle and the engine stress. By specifying these two parameters for each moment over a period of time, the temporal percentages of the vehicle, located either in each of the working phases or between them, can be determined.

The New European Driving Cycle (NEDC) test was performed, using the Regulation No. 83 (The Iran's National Standard No. 7328, 2004), and the results of the time and speed of the tested vehicles

were recorded. Using the above formulas, VSP, Speed Divider, RPM Index, Preaverage Power, and Engine Stress were obtained and the percentage of active bins was determined. The information needed to implement the IVE model is divided into two general categories: (1) fleet specifications, including information about the vehicles and the percentage of various technologies used at the fleet, not to mention the percentage of air conditioning system usage, also specified in the section. The present study considered the percentage of vehicles that used air conditioning to be 60%. Generally, the basis for car emissions, based on the information contained in the IVE database, is determined by the type and capacity of the engine and vehicle technology with the emission levels of vehicles in IVE model being measurable, thanks to the differences in existing vehicles with the default technology in IVE model database, based on emission measurement tests (Shafie-pour et al., 2013). Saipa's products, investigated in this study, were X100 family (Saipa 131 and Saipa 132) and X200 (Tiba2). The technology options used in the vehicles were selected as follows:

Technology	Petrol, MPFI
Index	Pt: Auto / Sm Tk: Lt: MPFI: EuroIV: PCV / Tank: 80-161km

The second category is (2) location details, which in turn includes the following: (a) environmental conditions such as temperature, humidity, and altitude, for which it should be noted that while gathering the information in Tehran City, the mean temperature was 28°C and the average urban slope, 2%. What is more, during the NEDC Test, the laboratory conditions were considered, and because of the vehicle positioning on chassis dynamometer, the grade was recorded zero. Another aspect, included in this category is (b) fuel characteristics that indicate the amount of contaminants and additives, summarized as following:

Table 2. Fuel Characteristics at IVE software

Overall	Sulfur(S)	Lead	Benzene	Oxygenate
moderate/premixed	low (50ppm)	none	low (0.50 %)	2.5%

Furthermore, the second category entails (c) start-up and soak time data, which due to the lack of official data on Tehran's start-up and soak time, it was gathered, based on a questionnaire, indicating the startup pattern and intervals between the two start-ups on the working and non-working days. After completing the information relevant to the Location at the Calculation tab, the concentrations of CO, VOC, VOC_{evap}, SO_x, NO_x and PM, as well as toxic pollutants and effective gaseous agents in global warming can be estimated in the daily or hourly manner, with the emission results modeled in both start-up and driving modes. Besides, due to the impossibility of transferring soak time of different parts of TDC, only the total TDC and the X100 and TIBA2 were modeled on driving mode. The last aspect of this category is (e) driving information, for which the ECE+EUDC test cycle (also known as the MVEG-A cycle) was used here for EU type approval testing of emissions and fuel consumption from light duty vehicles (EEC Directive 90/C81/01). The test was performed on a chassis dynamometer, with the entire cycle including four ECE segments, repeated without interruption, followed by one EUDC segment. Prior to the test, the vehicle was allowed to soak for at least 6 hours at a test temperature of 20-30°C. It then started and allowed to settle down for 40s. The effective year was 2000. Having eliminated the idling period, the engine started at 0s and the emission sampling began at the same time. This modified cold-start procedure is referred to as NEDC or the MVEG-B test cycle. The full test started with four repetitions of the ECE cycle, with the ECE being an urban driving cycle, also known as UDC. It was devised to represent city driving conditions, e.g. in

Paris or Rome. It was characterized by low vehicle speed, low engine load, and low exhaust gas temperature. EUDC (Extra Urban Driving Cycle) segment was added after the fourth ECE cycle to account for more intensive, high speed driving modes. The maximum speed of the EUDC cycle was 120 km/h. An alternative EUDC cycle for low-powered vehicles had also been defined with a maximum speed limit equal to 90 km/h. Emissions were sampled during the cycle, according to the Constant Volume Sampling (CVS) technique, analyzed and expressed in g/km for each of the pollutants (Iranian National Standard No. 7328, 2004). For measurement of the emission, it was necessary to carry out the standard NEDC tests in the Emission Laboratory of SAIPA Automotive Industry Research and Innovation Center (AIRIC). After settling vehicle on the chassis dynamometer, NEDC standard tests were carried out with the cooperation of the researcher, constantly supervised by technical experts of AIRIC and driver's lab. Test steps were performed with ASR and Driver's Aid software. During the standard NEDC emission test, the car moved 11.02 km in 1176 s, with an average speed of 33.73 km/h. In this paper, the driving data of Tehran city were based on the results of the study done by Fotouhi et al. (2011). Based on the results, four categories of traffic driving cycle were defined in Tehran, which included:

1. Congested driving cycle: In this traffic condition, the average vehicle speed is very low with long stops.
2. Urban driving cycle: In this traffic condition, the average vehicle speed is relatively low, sometimes with long stops.
3. Extra urban driving cycle: In this traffic condition, the average vehicle speed is mild, sometimes with few stops.

4. Highway driving cycle: In this traffic condition, the average vehicle speed is high and rarely comes with a stop.

The developed Tehran driving cycle contains 1533 s, with an average speed of 33.83 km/h, while the cars move 14.41 km. In order to validate the test results, the emission tests were carried out in Iran Standard & Quality Inspection Company (ISQI), on Tiba2 and X100 cars, and the results were recorded. In addition, Conformity of Production test (COP) was applied. COP is a means of evidencing the ability to produce a series of products that exactly match the specification, performance and marking requirements, outlined in the type approval documentation. With regard to the components that affect the emission of gaseous and particulate pollutants by the engine, emissions from the crankcase, and evaporative emissions, every vehicle that bear an approval mark under this regulation shall conform to the vehicle type approved (The Iran's National Standard No. 7328,

2004). Table 3 encompasses the differences between three kinds of driving modes.

RESULTS AND DISCUSSION

Since only the CO, NO_x, and CO₂ emissions are measured by the conformity of production test, the percentage of the agreement between measured values of the aforementioned pollutants in COP test and the modeling values (Table. 4) got calculated. As can be seen in Table. 5, the percentage of the agreement stood above 90%. Since emission modeling and measuring with Euro 4 technology have not yet been mentioned in scientific articles, other pollutants were validated based on the percentage of the achieved agreement.

According to the results as well as Figures (1), (2), and (3), CO and NO_x emissions were four times less than the On-board diagnostics (OBD) limit, which is an automotive term referring to a vehicle's self-diagnostic and reporting capability (Iranian National Standard No. 7328, 2004).

Table 3. Differences between three kinds of driving modes

Standard	Total Time (s)	Average Speed (km/h)	Total Distance (km)
NEDC	1180	33.35	10.90
AIRIC NEDC test	1176	33.73	11.02
TDC	1533	33.83	14.41

Table 4. Comparison of the results of CO, NO_x, and CO₂ modeling and COP test

gr/km	X100-ISQI	X100-Modeling	Tiba2-ISQI	Tiba2-Modeling	TDC-Modeling	OBD
CO	0.295	0.263	0.332	0.312	0.722	3.2
NO _x	0.074	0.067	0.076	0.072	0.148	0.6
gr/km	X100-ISQI	X100-Modeling	Tiba2-ISQI	Tiba2-Modeling	TDC-Modeling	100,000 km-test
CO ₂	157.76	159.867	163.25	161.89	231.626	159.806

Table 5. Percentage of result conformity of CO, NO_x, and CO₂ modeling and COP test

Percentage	X100 ISQI/ Modeling	Tiba2 ISQI/ Modeling
CO	89.19%	93.98%
NO _x	91.08%	95%
CO ₂	101.34%	99.17%

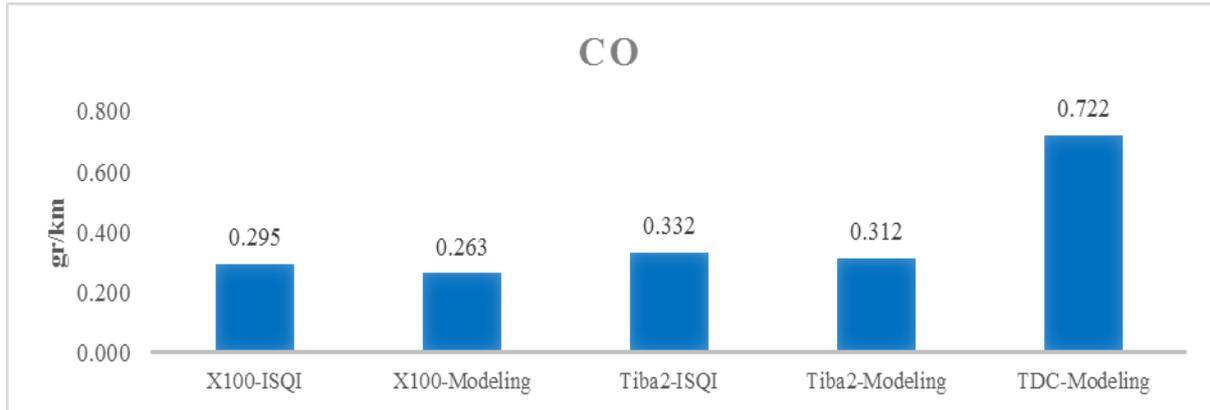


Fig. 1. Comparison of CO emission in ISQI and IVE modeling as well as TDC mode

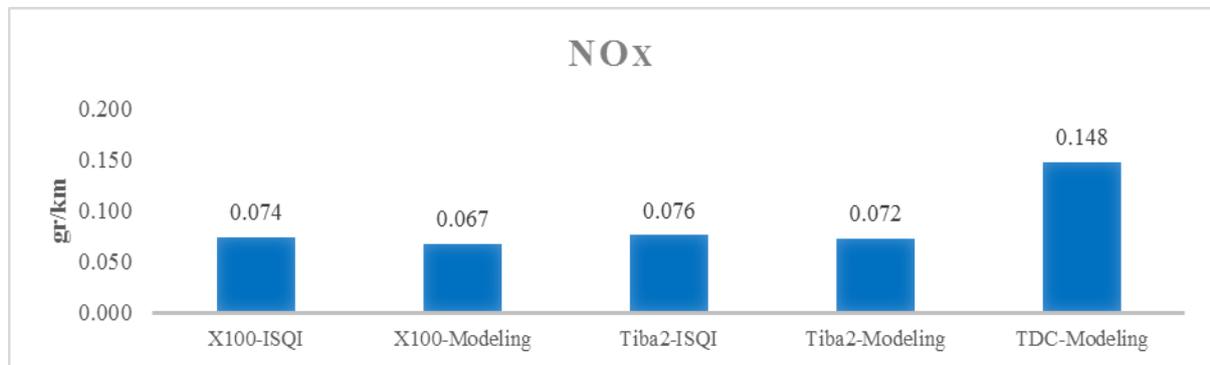


Fig. 2. Comparison of NO_x emission in ISQI and IVE modeling as well as TDC mode

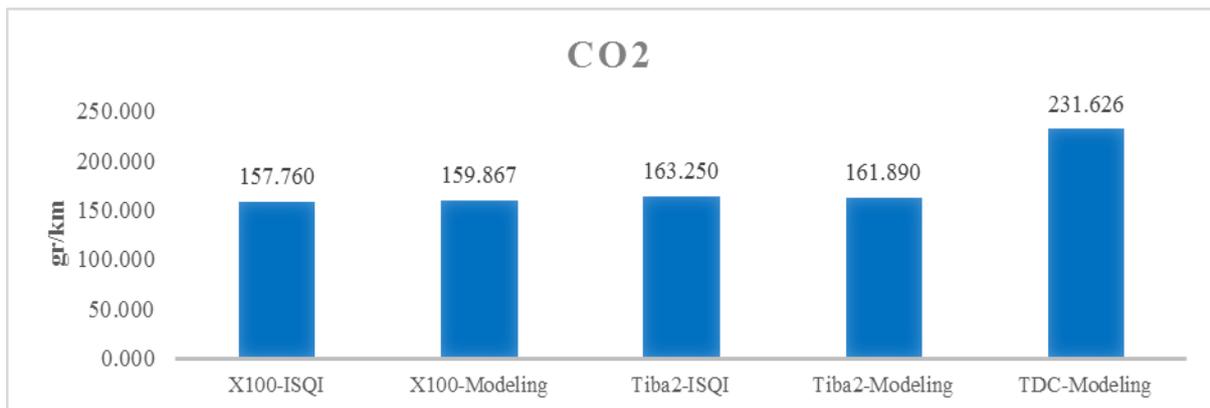


Fig. 3. Comparison of CO₂ emission in ISQI and IVE modeling as well as TDC mode

Furthermore, according to the results from ISQI's 100,000-km test, the amount of CO₂ emissions modeling from X100 and Tiba2 was about 160 gr/km that was in the range. While the modeled CO₂ emission rate was 232 gr/km in TDC, i.e., 1.5 times

more than laboratory test, because of different driving cycle usage (Li, et al., 2013; Zhang, et al., 2011; Montazeri-Gh, et al., 2007). Based on emissions modeling at TDC, Table. 6, 7, and 8 show the results.

Table 6. Emissions in gr/km, based on modeling at TDC (criteria part)

		CO	VOC	VOC _{evap.}	NO _x	SO _x	PM
start-up	TDC	13.849	1.178	1.178	0.661	0.002	0.017
	TDC	0.721	0.023	0.156	0.147	0.004	0.002
	Congested	6.495	0.559	7.563	1.558	0.094	0.038
	Urban	4.953	0.261	2.914	0.881	0.042	0.018
driving	Extra urban	1.094	0.043	0.370	0.184	0.007	0.003
	Highway	0.920	0.024	0.115	0.200	0.004	0.002
	X100	0.263	0.019	0.157	0.067	0.003	0.001
	Tiba	0.312	0.019	0.153	0.072	0.003	0.001

Table 7. Emissions in gr/km, based on modeling at TDC (toxics part)

		1,3 Butadiene	Acetaldehydes	Formaldehydes	NH ₃	Benzene
start-up	TDC	0.002	0.002	0.004	0.016	0.020
	TDC	0.000	0.000	0.000	0.085	0.000
	Congested	0.005	0.006	0.010	1.682	0.010
	Urban	0.002	0.003	0.005	0.803	0.004
driving	Extra urban	0.000	0.000	0.001	0.138	0.001
	Highway	0.000	0.000	0.000	0.097	0.000
	X100	0.000	0.000	0.000	0.050	0.000
	Tiba	0.000	0.000	0.000	0.052	0.000

Table 8. Emissions in gr/km, based on modeling at TDC (global warming part)

		CO ₂	N ₂ O	CH ₄
start-up	TDC	47.154	0.015	0.236
	TDC	231.626	0.003	0.007
	Congested	5419.665	0.068	0.160
	Urban	2419.540	0.030	0.075
driving	Extra urban	390.151	0.005	0.012
	Highway	241.330	0.003	0.007
	X100	159.866	0.002	0.005
	Tiba	161.890	0.002	0.006

Table 9. Emission rate of air pollutants in kg/year of Saipa fleet in TDC at 20,000 km survey

(kg/year)	CO	VOC	NO _x	SO _x	PM	CO ₂
TDC	144.30	4.70	29.49	0.80	0.39	46325.24
Congested	1299.03	111.71	311.56	18.74	7.68	1083933.04
Urban	990.53	52.21	176.15	8.36	3.67	483907.96
Extra urban	218.73	8.53	36.84	1.35	0.63	78030.29
Highway	184.06	4.83	40.01	0.83	0.44	48265.92
X100-LAB	52.61	3.83	13.48	0.55	0.23	31973.30
Tiba-LAB	62.40	3.88	14.43	0.56	0.24	32378.01

Table 10. Personal car emissions in AQCC report for 20,000 Km survey

CO ₂ (kg/year)	CO (kg/year)	NO _x (kg/year)	VOC (kg/year)	VOC _{evap.} (kg/year)	SO _x (kg/year)	PM (kg/year)
7800	280	16	22	5600	0.2	2

Considering the Emission Inventory of the Tehran Air Quality Control Co. (AQCC, 2015), personal car emissions were of the highest amounts for CO₂, CO, NO_x, VOC, VOC_{evap.}, SO_x, and PM pollutant agents in Tehran city (Table. 10), results show that Euro 4 Emission Standard plays an important role in reducing the air pollution.

With regard to the 20,000 km/year rate, which indicates average yearly mileage in Tehran city for passenger cars (Hashemian, 2013), Table 9 shows the emission rates of Saipa fleet in Tehran. In case of proper functioning, it meets Euro 4 standard and fits with proper catalytic converters.

Based on the results, significant differences among New European Driving Cycle, Tehran driving Cycle, and Tehran Air Quality Control Company report that expanded traffic conditions from morning traffic peak hour in working day in autumn to all traffic situations, show that relying on hypothetical situation and not taking real situations into consideration, result in inapplicable emissions from light duty vehicle. Nevertheless, due to the evolutions in technology and driving conditions, NECD has become outdated. Thanks to the shortcomings of NEDC, the automotive industry has actively contributed to the development of new global test cycle, known as the Worldwide Harmonized Light Vehicle Test Procedure (WLTP), which came into force in September 2017. The Worldwide harmonized Light vehicles Test Cycles (WLTC) are chassis dynamometer tests to determine emissions and fuel consumption from light-duty vehicles. The tests have been developed by the UN ECE GRPE (Working Party on Pollution and Energy) Group. The WLTC cycles are part of the Worldwide harmonized Light vehicles Test Procedures (WLTP), published as UNECE Global technical regulation No. 15 (GTR 15). While the acronyms WLTP and WLTC are sometimes used interchangeably, the WLTP procedures define a number of

other procedures—in addition to the WLTC test cycles—that are needed to type approve a vehicle (UNECE, European Commission, 2017).

CONCLUSION

Similar to other megacities all around the world, the increasing rate of air pollution is the major issue for urban authorities in Tehran, too. Since the mobile sources are chiefly responsible of all air pollutants emission in Tehran city, it is needed to monitor, assess, control, and reduce the amount of emissions released from mobile sources in the atmosphere. One of the outstanding urban management tools is to determine the amount of air pollutants, produced by Iranian automakers, as a new fleet, compared to others in Tehran. The present research used International Vehicle Emission modeling software to verify SAIPA Co. fleet emissions, based on the Euro 4 emission standard (SAIPA Co. recognized as superior Iranian brand at vehicle industry) as a new fleet. Based on the results, the modeling and lab results of New European Driving Cycle had over 90% conformity. According to the ISQI's 100,000-km test results, the amount of CO₂ emissions modeling from X100 and Tiba2's was about 160 gr/km, being within the range. On the contrary, the modeled CO₂ emission rate was 232 gr/km in TDC, i.e., 1.5 times more than laboratory test, as a result of different driving cycle usages.

Significant differences between the values obtained in the emission lab and modeling at New European Driving Cycle, Tehran Driving Cycle, and Tehran Air Quality Control Company report, it was revealed that relying on hypothetical situation led to inapplicable emissions values from light vehicles. More activity to eliminate end-of-life vehicles in Tehran city and use new vehicles with Euro 4 emission controller and upper, will significantly reduce the amount of pollutants, caused by light duty vehicles in Tehran.

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