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A Development of MARNI 12.2 Model: A Calculation Tool of Vehicular Emission for Heterogeneous Traffic Conditions

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Abstract: Recently years many efforts in transportation field have been attempted in order to overcome the global warming and climate change impact such efforts in reducing vehicle emission from the road sector. In this regard, some tools have been developed for calculating the vehicular emission quantity. However, those tools based on homogenous traffic situation in developed countries. Due to the difference of traffic behaviors on a heterogeneous traffic situation will leads to the difference on an exhaust emission from vehicles, it seems important to develop a calculation tool for such traffic situation. Regarding this, this study aimed to develop a calculation tool of vehicular emission quantity for heterogeneous traffic conditions, namely MARNI (Metropolitan Road emission Inventory) 2.2. The tool is developed based on the MARNI Model, an empirical calculation model for vehicle emission quantity based on an urban road condition in Makassar, Indonesia. The MARNI 12.2 is constructed using C# language programming on the Microsoft Windows platform. The tool is applied for the vehicle emission calculation on an arterial road in Makassar City and we compare the results using IVEM software, a calculation tool based on International Vehicle Emission (IVE) Model that developed for developing countries condition. The results provide a significant confidence in the vehicle emission calculation for the heterogeneous traffic situations. However, the MARNI 12.2 still covers passenger car types only, we expect to complete the tool involving motorcycle and heavy vehicle types in the future research activities.

Key words: MARNI 12.2, vehicular emission quantity, heterogeneous traffic, motorcycle, Indonesia

INTRODUCTION

The hazardous of vehicles have a negative impact, both on human health and environment. The hazardous include Nitrogen Oxides (NOx), Hydrocarbon (HC), Carbon Monoxide (CO) and Carbon Dioxide (CO_2). According to Hwang and Tseng (2007), globally, vehicles produce 14% of Carbon Dioxide (CO_2), 50% of Carbon monoxide (CO) and 60% of Hydrocarbons (HC) and approximately 30% of Nitrogen Oxide (NO_2).

Prediction of vehicle emissions and reduction efforts is an important topic related to solve the problem of global warming and climate change issues. To predict the emission, one of each is the International Vehicle Emissions (IVE) Model that is specifically designed to have the flexibility needed by developing countries in tackling the vehicles emissions. However, IVE Model is built based on homogeneous traffic conditions in developed countries in general (Lents *et al*., 2004). Therefore, there are differences in traffic behaviour in developing countries, especially in big cities in Indonesia, so, it is important to analyze the vehicles emissions in the heterogeneous traffic situation. Based on that, the objectives in this research is to develop a calculation tool of vehicles emission for heterogeneous traffic conditions, namely MARNI (Metropolitan Road emission Inventory) 12.2 and implement, it on arterial roads in Makassar City, Indonesia. The tools is developed based on Marni Models, an empirical calculation models for vehicle emission based on an urban road condition. The MARNI 12.2 Model is constructed using C# programming language on the Microsoft Windows platform. However, the MARNI 12.2 Model only covers the passenger car type.

Theoretical background

Heterogeneous traffic: According to Arasan and Arkatkar (2011), heterogeneous traffic consists of various type of vehicles grouped into various categories, i.e., light vehicles or passenger vehicles, heavy vehicles (buses

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and trucks), motorcycles and non-motorized vehicles. According to Gowri *et al.* (2009), heterogeneous traffic consists of various compositions of vehicles, i.e., varied of physical dimension that is light vehicles or passenger vehicles, motorcycles, trucks, non-motorized vehicles. Heterogeneous traffic is the condition where the vehicle speed is not constant (Arasan and Arkatkar, 2011), so it is almost impossible that the vehicle speed in a highway can be consistent on each lane. In this study, the heterogeneous traffic is fluctuating in vehicle speed related to the existing traffic flow condition such that the vehicle is not consistent on its lane.

Vehicle Emission Model: The estimation model of vehicle Emission (E) as shown in Eq. 1 (Lyons *et al.*, 2003; Kalandiyur, 2007), emissions estimate model of p pollutants, in the period of observation time t and for L roads segments. The estimation is done by multiplying the emission levels/Emission Factor (EF) of each road and VKT, where VKT is multiplication between the length of roads and traffic volume:

$$E_{t, l, p} = VKT_{t, l, p} \times Ef_{t, l, p} \quad (1)$$

Furthermore, emission test toward the 4 light vehicles or passenger vehicles in Vietnam has been done by Tung *et al.* (2011) and analyze by using Eq. 2, where E is Emission vehicles to the type of pollutant i which emitted by j vehicles type on L road type, N is number of vehicle and EF is the emission factor of vehicle:

$$E_{i, j} = \Sigma(N_{j, L} \times EF_{i, j} \times VKT_{j, L}) \quad (2)$$

Equation 2 elaborated as a basis of Marni 12.2 Model development.

MATERIALS AND METHODS

Before building the models and tools, the first step is measuring the vehicle emissions movement. Vehicle emission measurement results are used to model the vehicle emission factors based on heterogeneous traffic.

Vehicle Emission Measurement method: The measurements of vehicle emissions movement to 6 vehicle test has been carried out directly on the highway by using portable combustion gas analyzer (Aly *et al.*, 2011). The method of measuring the vehicle emissions is done by connecting the gas analyzer tools with a plastic hose which one of its end connected to the vehicle exhaust and the other end to the gas analyzer tools.

The portable combustion gas analyzer instrument used to measure the vehicle emissions where the type is portable combustion gas analyzer 2200. For more details the vehicle emission measurement method are illustrated in Fig. 1.

Metropolitan Road emission Inventory 12.2 (MARNI) Model: The estimation model of vehicles emissions have been developed for fueled gasoline passenger vehicle in this study which is multification between Number of vehicles (N), vehicles Emission Factors (EF), average speed fraction Distribution parameter (DC) as represented in highway driving cycle pattern and Travel Time (TT). The distribution of vehicle average speed fraction and vehicle travel time considered as representation of highway real traffic flow condition cause of the vehicles speed in each segment fluctuate related to the situation and condition parameters of acceleration, deceleration, incoming vehicles and vehicles idle. The movement of vehicle emission factors are built in accordance with the data of direct measurements on the highway approach polynomial model assumptions by adapting the emission and correction factors of passenger Vehicle Emissions IVE Model. The formulation of a mathematical model of vehicle emission factors in this study is described by Eq. 3 (Aly *et al.*, 2011), if known V is the speed of vehicle and β are parameters and vehicle emission factor β_0 is constant models:

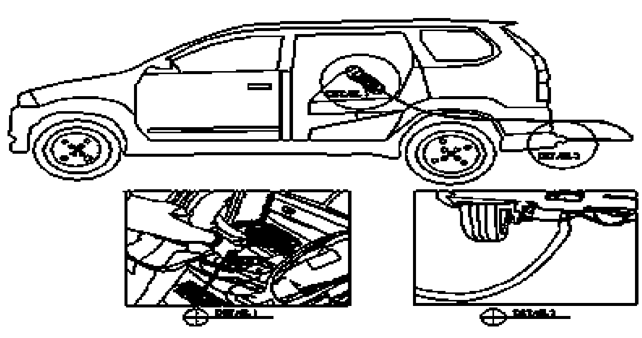

Fig. 1: Measurement of vehicle movement emission

$$FE = \beta_0 + \beta_1 V + \beta_2 V^2 + \beta_3 V^3 \quad (3)$$

The distribution of vehicle average speed fraction is Driving Cycle parameter (DC) formulated as polynomial orde-6 assumption model. The vehicle average speed fraction model is expressed by Eq. 4:

$$DC = \beta_0 + \beta_1 V^1 + \beta_2 V^2 + \beta_3 V^3 + \beta_4 V^4 + \beta_5 V^5 + \beta_6 V^6 \quad (4)$$

Where:

- V = Vehicle speed
- β = Vehicle emission factor model
- β_0 = Constant model
- 1, 2, 3......, 6 = Index of DC Model

To understand the overall stages of emission prediction model development for passenger vehicles, can be seen in Eq. 5:

$$EV_{t,p} = FE_{t,p} \times DC_{t,p} \times TT_{t,p} \quad (5)$$

Where:

- t = Index time period
- p = Pollutant type

The estimation of passenger vehicle emission for N passenger vehicle described in Eq. 6 which elaborated from Eq. 2 above, where i index = type of passenger vehicle:

$$EV_{i,t,p} = \left(\sum_{i=1}^{n} Ni \times FE_{i,p} \right)_t \times DC_t \times TT_t \quad (6)$$

Overall, the establishment of passenger vehicle emission factor model, driving cycle and vehicle travel time are develop in this model which can be used to estimate the vehicle movement of heterogeneous traffic emission quantity. A model series that have been developed in this research called the Metropolitan traffic emissions Inventory Model (Marni 12.2 Model). Marni Model is the basic model in order to estimate the movement of passenger vehicle emission quantity on the highway. Furthermore, to facilitate the use of this model, the softwere should be implemented to calculate the light vehicles emission on the road by using the C# language programming in the Microsoft Windows platform. The types of pollutants that can be calculated in MARNI Model softwere is CO_2, CO, dan NO_x.

RESULTS

MARNI 12.2 Model: The MARNI 12.2 Model activated by clicking the menu on the computer screen and the page will appear in Fig 2. Furthermore, the next screen display as shown in Fig. 3.

Figure 3 shows the data input on MARNI 12.2 Model that can be done in two ways, input the files, input the files manually. The input files is done by inputting number of vehicles, vehicles travel time, vehicles composition and driving cycles in the morning, day and afternoon peak hours. The calculation results of vehicle emissions expressed in grams, kilograms and ton by clicking the menu. Furthermore, data input in three steps, number of vehicles and travel time, vehicles composition and driving cycle. For more detail, please check in Fig. 4-6.

The calculation of vehicles emission by inputting data manually done by clicking number of vehicles and travel time, then set the roads segment in the morning, day and afternoon peak hours in accordance with road segments reviewed.

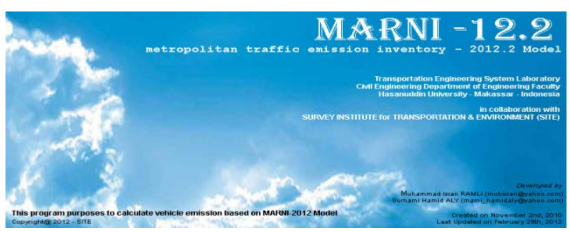

Fig. 2: Cover of MARNI 12.2 program

Fig. 3: Calculation of vehicle emission

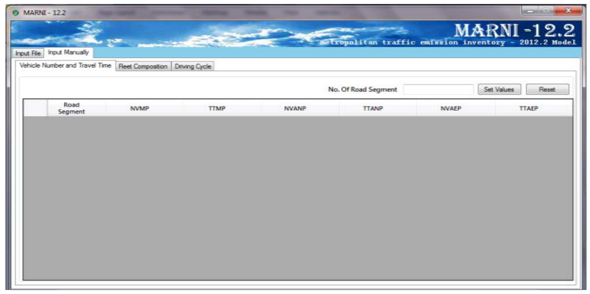

Fig. 4: Number of vehicle and travel time data (input and data manual)

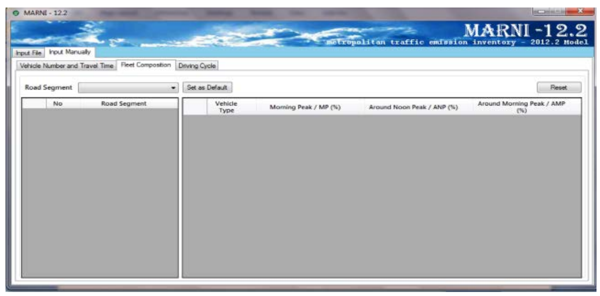

Fig. 5: Vehicle composition data

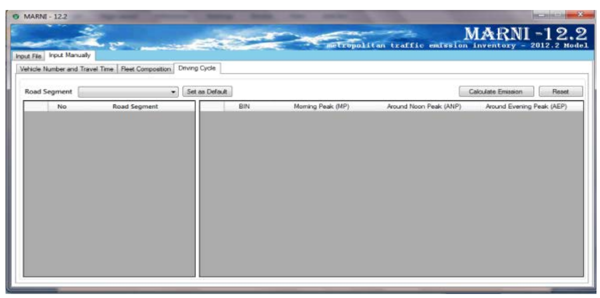

Fig. 6: Driving cycle data

MARNI 12.2 Model aplication: MARNI 12.2 Model has been applied to the arterial roads 6/2 D type (six-lane two-way split) in the city of Makassar, Indonsesia. The traffic flow circulation on these roads is shown in Fig. 7.

On the layout above shows that there are intersection and flyover infrastructure, 11 non-signalized intersection of T type, 3 T-type signalized intersections and 9 u-turn directions facilities. For u-turn is potentially changes in vehicles speed, especially for straight movement vehicles through the u-turn infrastructure. The road segments which analyzed in this study were 14 segments on the North-South and 15 segments on the South-North, observed in the morning, day and afternoon peak hours.

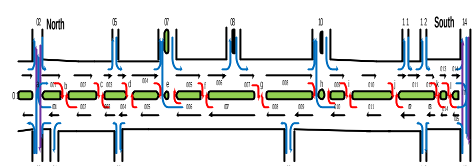

Fig. 7: Layout of vehicle traffic flow

DISCUSSION

Comparison of IVE emission base and MARNI Models: The measurement results shows that IVE emission base model of each test of vehicle type was highly fluctuated, even at the same vehicle speed condition. This phenomenon confirms that various of vehicle's driver behaviour on cars operating such as engine stress, etc. However, generally, the emission

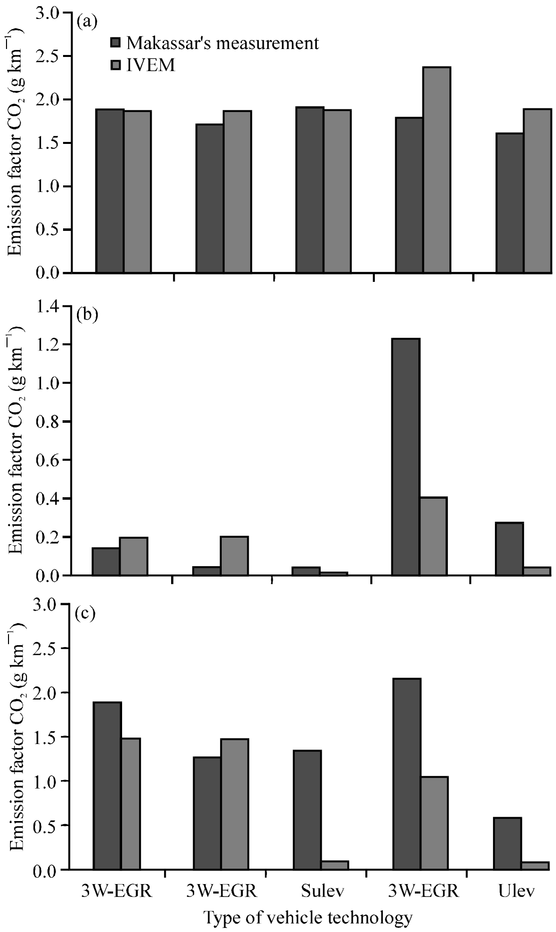

Fig. 8: Emission factor of IVEM and MARNI Models: a) CO emission; b) No_x emission; c) CO_2 emission

factors values were increasing according to the rising of vehicle speed. This is in-line with the results of previous researches such as in IVEM and mobile models (Fig. 8).

Furthermore, a verification of emission factor model was conducted to the IVEM's base emission factors. The comparing results shows that mostly CO_2 emission type of the vehicles from the model is slightly lower than the IVEM's values. In contrary, mostly CO emission type is upper than the values of IVEM. This phenomenon indicates that the passenger car in makassar exhaust CO emission in larger portion than the CO_2 emission in comparing to the international experience. It means that the cars are lower sensitive to the environmental health.

Emission quantity of vehicle movement: The prediction results of CO_2 emissions using the MARNI 12.2 Model in each segment of the road are shown in Fig. 9-11, respectively in the morning, day and afternoon peak hours. As a comparison toward the prediction of passenger vehicle emission were calculated by IVE and MARNI 12.2 Models.

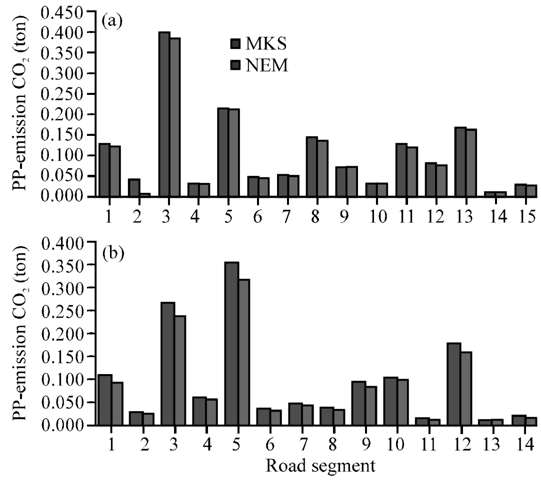

Fig. 9: Prediction of CO_2 emission at morning peak hour: a) South-North direction; b) North-South direction

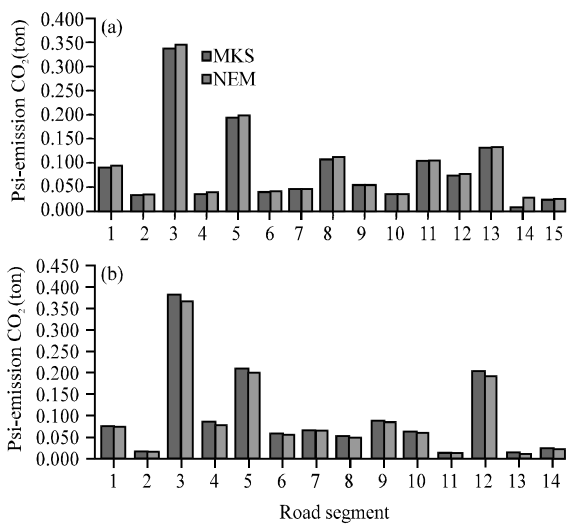

Fig. 10: Prediction of CO_2 emission at day peak hour: a) South-North direction; b) North-South direction

In Fig. 9-11 shows that the estimation of CO_2 emissions average in the the morning, day and afternoon peak hours is greater than IVE Model for both directions.

Furthermore, in Fig. 12-14 shows the estimation results of NOx emissions using MARNI 12.2 Model for peak hours in the morning, day and in every segment of the road. Similarly, in Fig. 15-17 shows that the average estimation of CO emission for both directions is higher by using the IVE Model.

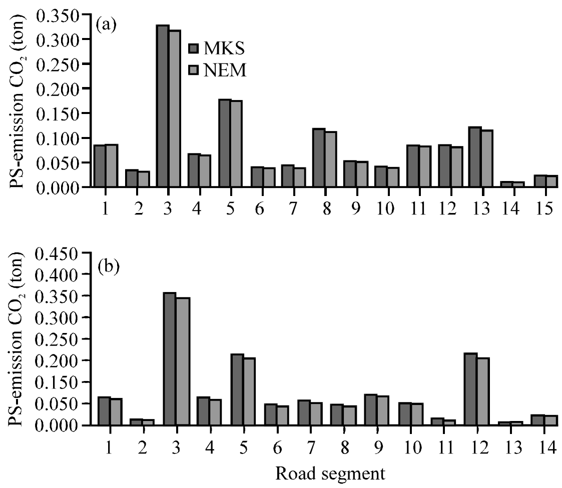

Fig. 11: Prediction of CO_2 emission at afternoon peak hour: a) South-North direction; b) North-South direction

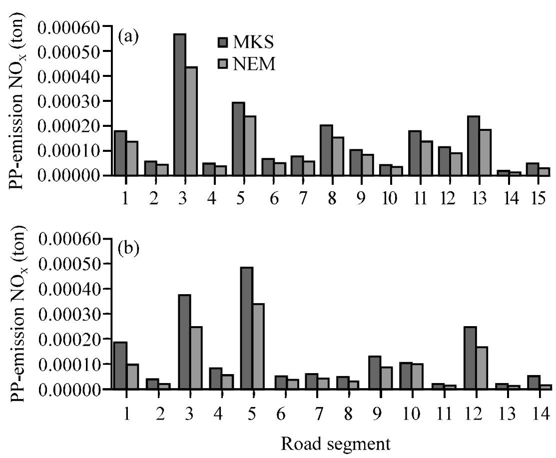

Fig. 12: Prediction of NO_x emission at morning peak hour: a) South-North direction; b) North-South direction

Overall, it appears that the highest concentration of CO_2, NOx and CO emissions happened in the morning, day and afternoon peak hours in segments 3, 5 and 13 (South-North direction) while the highest concentration of CO_2, NOx and CO emissions for North-South direction occured in segments 3, 5 and 12. This condition indicates that these segments were highest in vehicles volume and longer travel time.

The prediction of vehicles emission in each segment of AP. Pettarani road showed higher results for IVE Model. This is presumably of vehicles maintenance still poor (Ade, 2002), on the other hand, there were

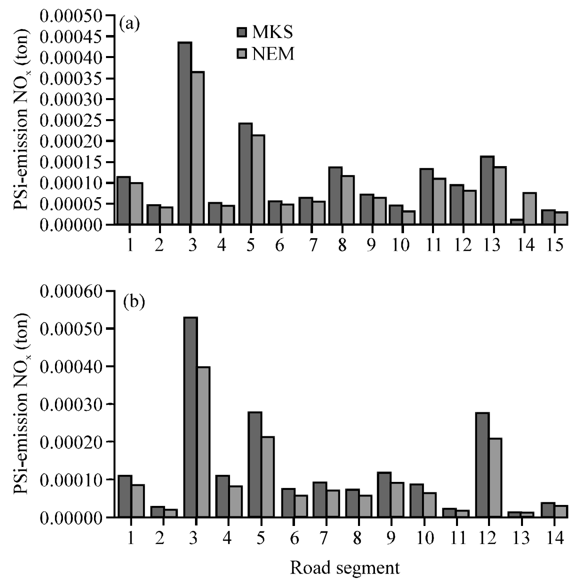

Fig. 13: Prediction of No_x emission at day peak hour: a) South-North direction; b) North-South direction

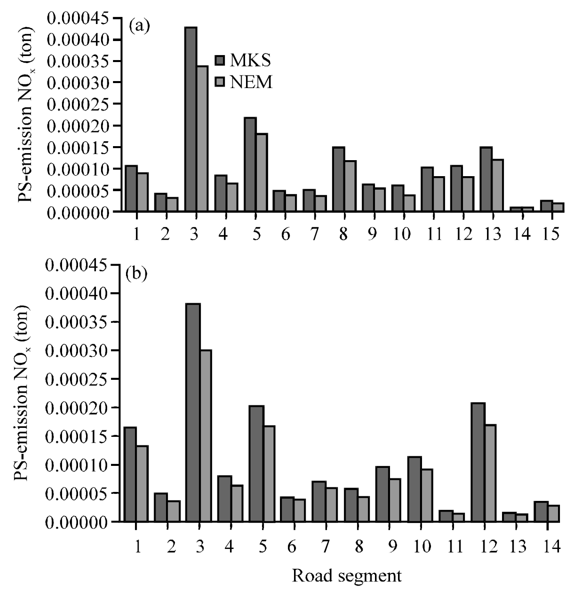

Fig. 14: Prediction of NO_x emission at afternoon peak hour: a) South-North direction; b) North-South direction

approximately 11.10% of vehicles older than 13 year but still in operation and its significantly affect the vehicles operation and such that increase in emissions as indicated at the level of stationary vehicles emission and also, the traffic flows were not stable at lower vehicle speed.

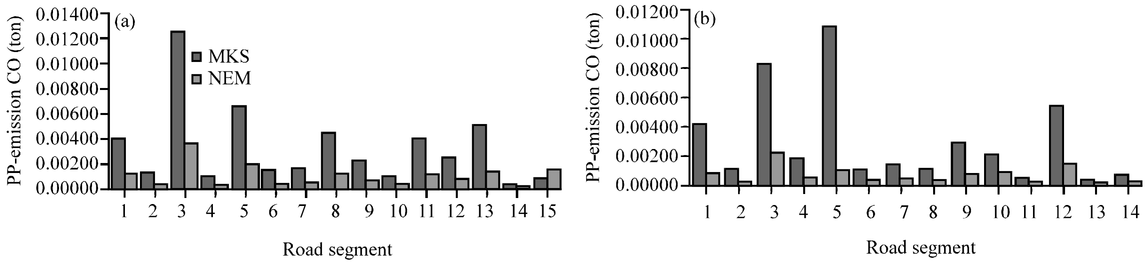

Fig. 15: Prediction of CO emission at morning peak hour: a) South-North direction; b) North-South direction

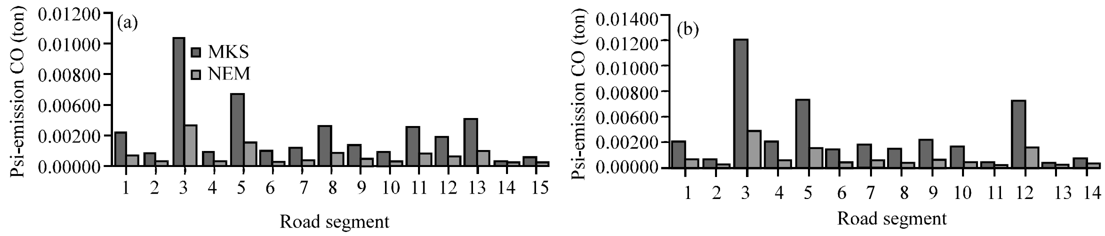

Fig. 16: Prediction of CO emission at day peak hour: a) South-North direction; b) North-South direction

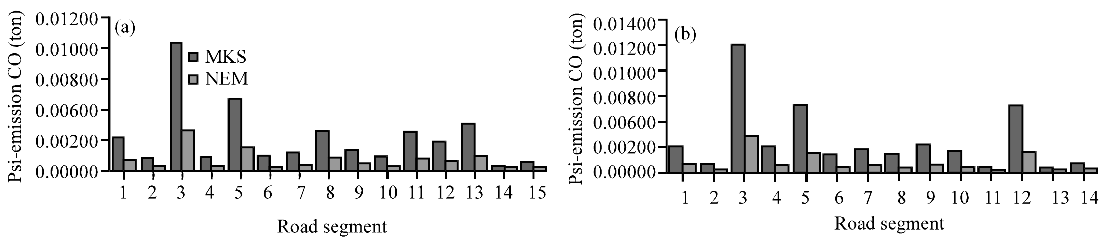

Fig. 17: Prediction of CO emission at afternoon peak hour: a) South-North direction; b) North-South direction

CONCLUSION

The MARNI 12.2 Model can be concluded as follows:

- Constructed using C# language programming on Microsoft Windows platform
- Built based on heterogeneous traffic conditions. The heterogeneous traffic that is not consistent in its lanes, fluctuated in vehicles speed such that different in homogeneous traffic conditions which underlying in IVE Model
- Used only for analyzing the emissions of NOx, CO, dan CO_2 sourced from passenger vehicles
- Can be done in two steps, files input, data input manually. The steps are input the number of vehicles and vehicles travel time, vehicles composition and the driving cycle
- NOx and CO emission factors is higher than IVE Model except for CO_2
- Has been done on arterial roads 6/2 D where the highest CO_2, NOx and CO emissions occurred in segments 3, 5, 12 and 13 (both direction) indicates that these segments consists of biggest in vehicles volume and longer travel time
- Can be completed analytical tools for motorcycle and heavy vehicle types in the future research activities

RECOMMENDATIONS

For the continuation of this study, I suggest to measure the emission of diesel-fueled vehicles, motorcycles and trucks. These vehicles type is dominantly operated in big cities in Indonesia.

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REFERENCES

Ade, S., 2002. The development of transport infrastructure to support science-based sustainable development. ITB Bandung, Indonesia.

Aly, S.H., M. Selintung, M.I. Ramli and T. Sumi, 2011. Study on emission measurement of vehicle on road based on binomial logit model. Proceedings of the 9th International Conference on Eastern Asia Society for Transportation Studies, September 30, 2011, Host Eastern Asia Society for Transportation Studies, Hasanuddin University, Makassar, Indonesia, pp: 1-12.

Arasan, V.T. and S.S. Arkatkar, 2011. Derivation of capacity standards for intercity roads carrying heterogeneous traffic using computer simulation. Proc. Soc. Behav. Sci., 16: 218-229.

Gowri, A., K. Venkatesan and R. Sivanandan, 2009. Object-oriented methodology for intersection simulation model under heterogeneous traffic conditions. Adv. Eng. Software, 40: 1000-1010.

Hwang, K.P. and P.S. Tseng, 2007. CO2 emission: Status, reduction policy and management strategy of taiwan transportation sector. Proc. East. Asia Soc. Transp. Stud., 2007: 161-161.

Lents, J.M., M. Osses, N.C. Davis, N. Nikkila and M.J. Barth, 2004. Comparison of on-road vehicle profiles collected in seven cities worldwide. Proceedings of the 13th International Scientific Symposium Transport and Air Pollution, September 13-15, 2004, NCAR, Boulder, Colorado, USA., pp: 1-24.

Lyons, T.J., J.R. Kenworthy, C. Moy and F.D. Santos, 2003. An international urban air pollution model for the transportation sector. Transp. Res. Part D Environ., 8: 159-167.

Tung, H.D., H.Y. Tong, W.T. Hung and N.T.N. Anh, 2011. Development of emission factors and emission inventories for motorcycles and light duty vehicles in the urban region in Vietnam. Sci. Total Environ., 409: 2761-2767.