

Analysis of carbon monoxide (CO) with Delhi Finite Line Source (DFLS) in MT Haryono Street, Medan City

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Abstract. One source to decrease urban air ambient quality is transportation sector. Important pollutants are released by gas emissions from vehicles are carbon monoxide (CO), hydrocarbons (HC), nitrogen dioxide (NO₂), particulate matter and others. The presence of CO pollutants in the ambient air can be predicted by modeling air quality. This study aims to estimate CO concentration resulting from transportation activities using Delhi Finite Line Source (DFLS) model, comparing CO prediction using a DFLS model with CO observation in the field, and determine the suitability of the DFLS model application on the MT Haryono street in Medan City. Research was conducted for 3 days at two sample points with frequency twice daily. Based on research results, the range of CO concentration from observation between 22.903 $\mu\text{g}/\text{m}^3$ – 27.484 $\mu\text{g}/\text{m}^3$. CO observation is still below the ambient air quality standard. According to the DFLS calculations, the range of CO concentration between 1.499 $\mu\text{g}/\text{m}^3$ – 2.051 $\mu\text{g}/\text{m}^3$. The calculation index of agreement (IOA) validation test obtained value of $d = 0.22$. The DFLS model is not suitable to be applied on MT Haryono street because many factors affected such as wind direction and wind velocity, ambient air temperature and humidity

1. Introduction

One of the sectors in declining air quality is the road transportation sector (motor vehicles). Mortality rates increased by 5% and 12% in China and India respectively because air pollution from transportation sector [1;2]. The transport sector contributes the highest pollutant, which is about 80.22% - 90% of CO [3;4]. Several cities in China each year experience increased concentrations of pollutants from three cities (Haikou, Lhasa, and Zhousan) in 2013 to eight cities (Haikou, Lhasa, Zhousan, Shenzhen, Zhuhai, Fuzhou, Huizhou, dan Kunming) in 2014 [4].

Roadside air quality in Medan City is monitored on three streets only with CO concentrations ranging from 3,041 $\mu\text{g}/\text{m}^3$ – 9.276 $\mu\text{g}/\text{Nm}^3$ [5]. Based on the results of air quality index mapping for CO parameters in Medan City, there are some districts that are categorized as very unhealthy and unhealthy condition: Belawan, Medan Helvetia, Medan Barat and Medan Amplas [6]. In addition, MT. Haryono Street has heterogeneous traffic and a V / C ratio of 1.08 [7], which mean heavy traffic. To predict the concentration of pollutants in the ambient air can be used various models of FLLS, GFLS, and DFLS. According to [8], using the DFLS (Delhi Finite Line Source) model in New Delhi is suitable for predicting CO concentrations. According to [9;10], the use of the DFLS model in Surabaya is not suitable for predicting CO concentrations because of many factor influence the air pollutant dispersion.



Because of the condition of atmospheric stability in India, especially the city of New Delhi is unstable (B), with an average wind speed of 3-5 m/s and the intensity of the sun is 1.367 W/m² [11;12]. The condition of the stability of the Medan City atmosphere is also unstable (B) with negative atmospheric stability index [13]. In addition, the appropriate DFLS model is applied to heterogeneous traffic conditions [14], so in this research DFLS model is selected.

The purpose of this research is to estimate CO concentration in MT Haryono Street generated from transport activities using the DFLS Model, comparing CO concentration data using DFLS model with concentration of CO sampling data (CO observation), and knowing the suitability of DFLS model implementation in MT Haryono Street, Medan City.

2. Methodology

This study used a quantitative approach by observing vehicles (traffic counting), which calculates the type and number of vehicles to obtain the rate of emission [15]. Furthermore, the emission rate is incorporated into the DFLS model equation to obtain the calculated CO concentration. Then at the same time with traffic counting, will be done sampling of CO concentration in field (CO observation) and taking meteorological field data such as temperature, solar intensity, direction and wind speed. The concentration of CO DFLS model and CO observation will be compared with the validation test of Index of Agreement (IOA).

2.1. Data Collection

The data collected in this study consists of primary and secondary data. Primary data consists of traffic counting data, i.e. number and type of vehicle (motorcycle, passenger car, bus, and truck); sampling CO concentration data in field (CO observation) using portable CO Monitor (NDIR Analyzer analysis method) and meteorological data (temperature, speed, and wind direction).

Primary data were collected simultaneously at 2 (two) points along MT Haryono Street. Point 1 is located at Cirebon Intersection and Point 2 is located at Thamrin Intersection. Measurements are made in the morning and afternoon for 1 hour each.

The secondary data obtained from BPS Medan (such as population, area, and number of motor vehicles), BMKG Region I Medan (such as data direction and wind speed of 2011-2015), BMKG Sampali (such as solar intensity data), and DISHUB Medan City (such as data ratio V/C road segment in Medan City). This secondary data is required for determination of the sampling location and the determination of the atmospheric stability class.

2.2. Delhi Finite Line Source (DFLS) Modelling

The first step in this research is to calculate the emission rate obtained from traffic counting of each type of vehicle during sampling. The emission rate of each vehicle is calculated using the following formula [16;17]:

$$Q_L = n \times FE \quad (1)$$

Q_L = emission rate per unit length (g/m. s); N = number of vehicles per hour (vehicle/hour) and FE = emission factor (g/km.vehicle)

Next, the pollutant concentration on the highway is calculated using DFLS modeling. The DFLS equation is expressed as follows [17]:

$$C = \frac{Q_L}{2\sqrt{2}\pi\sigma_z\bar{u}_e} \left[\exp\left\{-\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2\right\} \right] \quad (2)$$

C = concentration of pollutant in ambient air (g/m³); Q_L = emission rate per unit length (g/ m. s); σ_z = vertical dispersion coefficient (m); u_e = effective wind speed (m / sec); z = receiver height or surface monitoring device (m) and h_0 = high effective source (m)

The assumptions used in this model are as follows [17]: line source (path) for the source of the pollutant is straight; meteorological data is valid; CO pollutants only come from motor vehicles along

the line source and the chemical physics transformation of CO pollutants is ignored or not included in the modeling. The rate of change of shape and its removal is not included in the modelling. Movement of pollutant is depended on the direction of wind.

The third step is to test data validation. In this validation, the results of measured CO concentration (observation data/O) is compared to calculated CO concentration (predicted data/P). Then both data (O and P) are validated using the IOA (Index of Agreement) equation. The formula used is as follows [8]:

$$d = 1 - \frac{\sum_{i=1}^N (P - O)^2}{\sum_{i=1}^N (|P - O_{mean}| + |O - O_{mean}|)^2} \quad (3)$$

P = calculated CO concentration / CO DFLS model; O = measured CO concentration / CO observation, O_{mean} = average of CO concentration from sampling result (average of CO observation)

If the validation test value of IOA (d) obtained with a range of values of 0.8-1, then the DFLS model can be used to predict CO concentrations in MT Haryono Street. If the validation test value of IOA (d) obtained with a value < 0.8, then the DFLS model cannot be used to predict CO concentrations in MT Haryono Street.

3. Result and Discussions

3.1. Number of Vehicles, Type of Vehicles, and CO Emission Rate at MT Haryono Street

The number and types of motor vehicles as well as the rate of CO emissions obtained on MT Haryono Street are presented in Figure 1.

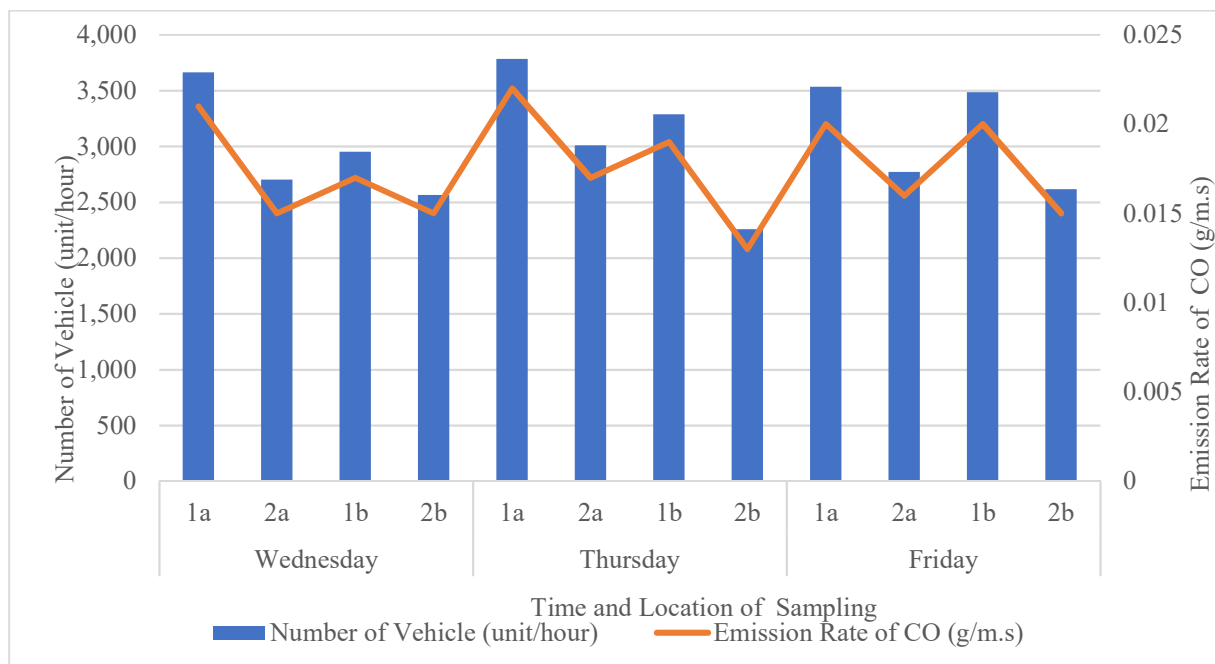


Figure 1. Number of Vehicle and CO Emission Rate at MT Haryono Street

Average of CO emission rate in the morning is 0.018 g/m.s and at noon is 0.017 g/m. s. The total emission rate is the total average of all emissions sourced from vehicles passing through MT Haryono Street. The types of vehicles that contribute most of CO emissions are passenger cars ranging from 57% - 62%.

Vehicle emissions are influenced by the number of vehicles and the value of emission factors. Based on [18], the value of CO emission factor of passenger cars is greater than motorcycles, buses and trucks, so that the emission rate of passenger cars is greater than motorcycles although the number of

motorcycles is higher than passenger cars. According to [19], emission factors are influenced by vehicle type, fuel type, driving activity, and others. Vehicle emissions are also highly dependent on congestion and driving patterns.

3.2. Measured CO Concentration on MT Haryono Street

Measurements of CO concentration at MT Haryono Street were performed using portable CO Monitor placed on the road shoulder ± 1 m from the roadside and at an altitude of approximately 1.5 m above the road surface. The monitoring result of measured CO concentration in $\mu\text{g}/\text{m}^3$ can be seen on Figure 2.

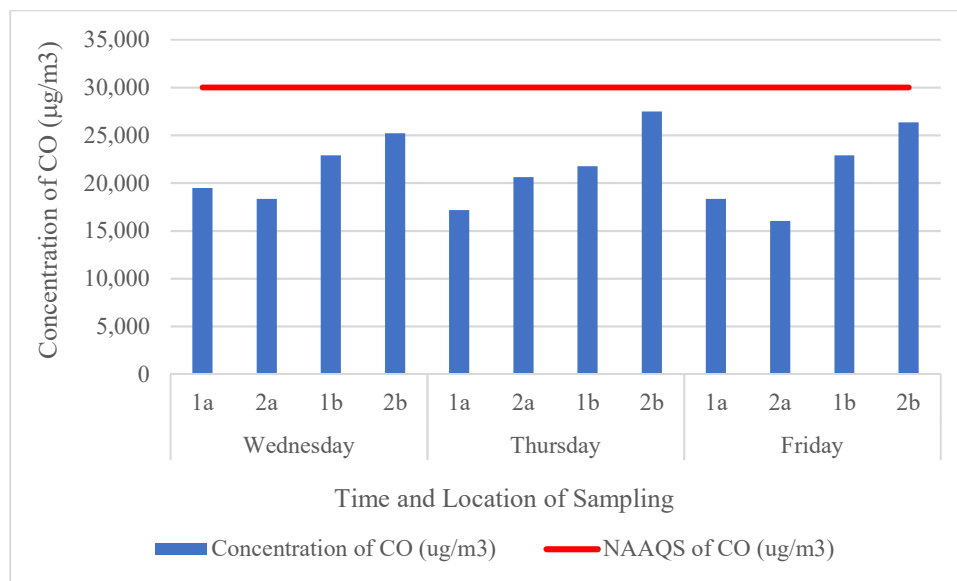


Figure 2. Concentration of CO Observation at MT Haryono Street

The highest CO concentration for monitoring is in the morning $20.613 \mu\text{g}/\text{m}^3$ and in the afternoon $27.484 \mu\text{g}/\text{m}^3$ located in point 2 on Thursday. No monitoring results have passed the standard [20] of $30,000 \mu\text{g}/\text{m}^3$, but on Thursday afternoon at point 2 the value is almost close to the standard. This needs to be aware as if exposed to CO for ≥ 8 hours, it will affect the function of body organs such as brain, liver, and central nervous [21;22]. CO is a silent killer because it has properties that are not smelly and visible. CO gas can bind hemoglobin more rapidly than O_2 , thereby reducing the oxygen capacity in the blood that can cause shortness of breath, fainting until death [23;24;25].

3.3. CO Concentration with Delhi Finite Line Source (DFLS)

The inputs in the modeling using emission rate data and meteorological factors that have been obtained from the field are included in equation (2). The result of calculated CO concentration can be seen in Figure 3.

Based on Figure 3, the range of CO concentration using DFLS Model is $400 \mu\text{g}/\text{m}^3 - 2.051 \mu\text{g}/\text{m}^3$. The highest CO concentration using DFLS Model is located at point 1 (Cirebon Intersection), on morning monitoring. The high concentration at this point because it is influenced by the source of emission in the form of the number of vehicles, meteorological factors such as wind direction and speed, solar radiation intensity, ambient air temperature and humidity.

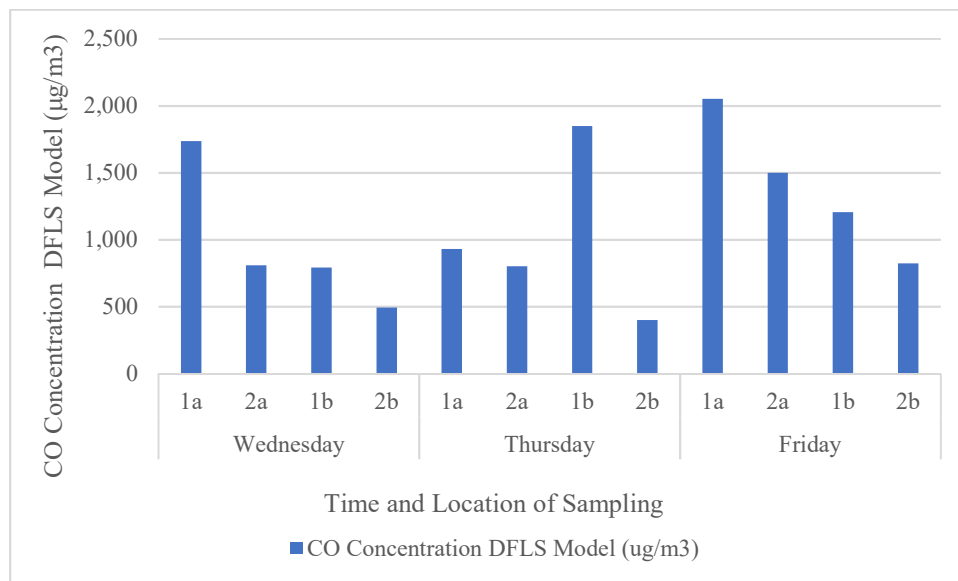


Figure 3. CO Concentration with DFLS at MT Haryono Street

3.4. Comparison of CO Observation with CO DFLS Model

Comparison of CO observation with CO DFLS Model can be seen in Figure 4.

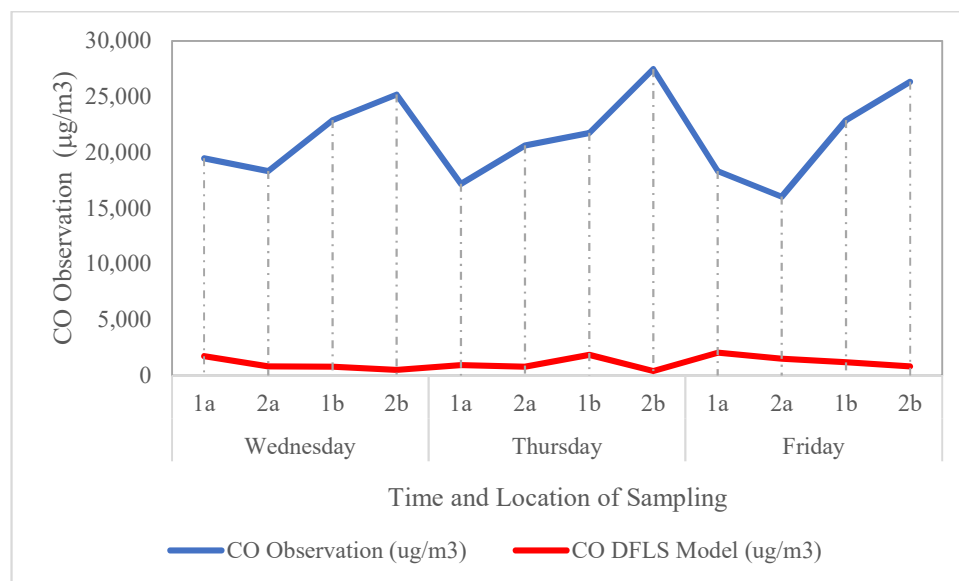


Figure 4. CO Observation vs CO DFLS Model at MT Haryono Street

The concentrations of CO at points 1 and 2 in morning measurements have similar trend but when daytime measurements have the opposite trend. The calculated CO concentration during daytime measurements at point 1 is higher than point 2, due to the number of vehicles passing in point 1 more than the point 2. Conversely, the CO concentration is measured when the daytime measurement at point 1 is lower than the point 2 due to congestion conditions in Point 2. Based on the results of the study [4], traffic congestion conditions greatly affect the increase of CO concentration in ambient air.

The highest measured CO concentration is $27.484 \mu\text{g}/\text{m}^3$. Value of this concentration can be included in high category although not yet reached the standard quality of $30.000 \mu\text{g}/\text{m}^3$. If human beings exposed every day, it can endanger human health. Precautions need to be taken to reduce the concentration. The

way of control can be done with the application of Bus Rapid Transit (BRT) and if possible increase the green area around the location.

According to [26], the application of BRT can reduce CO pollutants in areas on the BRT line by 19.4%, the area at 2.5-10 km from the BRT line by 17.2%, and the area at a distance of 10 - 30 km by 16.6%. In addition, according to [27], the use of BRT can reduce CO emissions in Medan City by 25.02% - 29.28% (CNG) and 25.17% - 29.44% (diesel). The results also show that the type and number of vehicles are strongly correlated with CO emissions.

3.5. Test Validity with Index of Agreement (IOA)

The data used for this validation calculation is the measured CO concentration data and the calculated CO concentration. The formula used in the validation test with IOA can be seen in (3). Modeling can be used if the validation values obtained in the range of values 0.8 - 1. Based on the above calculation, we can see the value $d = 0.223$, far from the range of values 0.8 - 1. This means that DFLS model cannot be used to predict CO concentrations in MT Haryono Street.

The ratio of calculated CO concentration tends to be smaller than the measured CO concentration. This can be caused by several factors, namely: road conditions at point 2 (two) have congestion, thus affecting the measured CO concentration. According to [4], traffic congestion conditions result in increased CO concentrations.

Based on the modeling assumption, that CO pollutants only come from motor vehicles and ignore the effects of other emission sources. While on field research, CO pollutant measurements are strongly influenced by other emission sources such as rail transport activities.

The spread of pollutants around the site is affected by the local topographic condition of MT Haryono Street is surrounded by a building with an altitude of $\pm 12-20$ m. According to [28], the effect of the height of the building affects the spread of pollutants that ultimately the pollutants are not spread evenly while in the model ignores the influence of maximum mixing height (MMH).

4. Conclusion

The result of calculated CO concentration with DFLS model is smaller than result of CO observation. Based on the sampling result, the maximum measured CO concentration was $27.484 \mu\text{g}/\text{m}^3$ on Thursday afternoon at point 2, while the minimum measured CO concentration was $16.032 \mu\text{g}/\text{m}^3$ on Friday morning at point 2.

Maximum CO concentration obtained using Delhi Finite Line Source (DFLS) modeling is $2.051 \mu\text{g}/\text{m}^3$ on Friday morning at point 1 whereas the minimum calculated CO concentration is $400 \mu\text{g}/\text{m}^3$ on Thursday afternoon at point 2.

The result of data validation test with Index of Agreement (IOA) is $d = 0.223$ which means DFLS model is not suitable applied in MT Haryono Street.

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