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Simulation and Validation of Carbon Monoxide Dispersion Model In the Vicinity of Baranangsiang Toll Gates in Bogor

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ABSTRACT

Over the past decade, carbon monoxide (CO) emission has risen due to the increase of vehicles. Bogor, a tourist destination city on weekends, has a heavy burden in terms of vehicle volume. The object in this study is Baranangsiang Bogor toll gates where queue of motor vehicles often occurs and allegedly produces many pollutants including CO. The goal of this paper were to simulate and validate the CO concentration in ambient air in the vicinity of Baranangsiang toll gates by the method of Finite Length Line Source (FLLS).Measurement of CO concentration was carried out using impinger. It was followed by CO concentration analysis referring to National Standard, namely SNI No. 19-4848-1996 on Pentoxide Method. Based on the results of direct field measurements and simulations that were conducted on four sampling points within 20 m and 190 m away from the pollution sources on August 26th to September 1st 2013, CO concentration, i.e. 634 - 9189 µg/Nm^3 was still within the range of pertinent standards in accordance with Government Regulation No. 41/ 1999. CO pollutant was dominantly dispersed to the East with measured wind speed of 0.3-4 m/s and atmospheric stability class B. Consequently, a settlement area called Kampung Sawahlocated in the Eastern side of the toll gate was exposed to higher CO.
KEYWORDS: Carbonmonoxide, Dispersion, Finite Length Line Sources, Motor vehicles, Baranangsiangtoll gates

INTRODUCTION

Background

Carbon monoxide being emitted by various vehicles to the air is one of the causes of air pollution. The formation process of CO depends on atmospheric ambient, meteorological conditions, emission parameters such as the action of atmospheric stratification, initial emission momentum, temperature, wind direction and speed as turbulent behaviors [22].Environmental experts were interested in the dilution process involving air pollutants CO because the dispersion of pollutants in the air affects the regional air quality that adversely impact the public health[1,4]. The dispersion of pollutants modeling from mobile sources was the tool of control and management of pollutants, notably CO. The U.S. Environmental Protection Agency (U.S. EPA) and other research institutions in the world were developing various kinds of modeling, either deterministically or statistically, in the depiction of the distribution of CO on the highway [17].Currently, in most countries, air pollution caused by the vehicular exhaust emission has increased due to the increasing amount of vehicle per year as a result of the increasing transportation needs of consumer [14,17,20].

Bogor, a tourist destination city on weekends, has quite heavy burden in terms of vehicle volume. Some places with high CO concentrations in Bogor are the toll gates, intersections, and main roads [18].The object in this study is Baranangsiang Bogor toll gates. At the gates, heavy traffic often occurs and allegedly produces a lot of CO gas. CO gas increasing occurs when motor vehicle running at low speed due to braking frequency [1,16]. Based on [5] finding at Surabaya entrance toll, it has been stated that the highest concentration of CO was 7845 µg/Nm^3 on weekdays while on holidays was 8708 µg/Nm^3. For concentrations higher than 11 700 µg/Nm^3 during 10 hours of exposure, CO may cause negative impacts on human health such as chest pain, chronic lung disease, flu-like symptoms, and headache[3].Based on the problems mentioned above, a more in-depth formulation regarding CO pollutant dispersion in the vicinity of Baranangsiang Bogor toll gates is needed. Thus, simulation and validation of CO pollutant dispersion is required. In this study, Finite Length Line Source (FLLS) mathematical model was used. It is a derivative of Line Source Gaussian model with Visual Basic programming for calculating CO concentration. Statistical validation was conducted to compare the simulated and field measured CO concentrations.

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MATERIALS AND METHODS

Time and Location of CO Pollutant Measurements

Data collection and measurement of CO sample was carried out in four points in the vicinity of Baranangsiang Bogor toll gates (managed by PT. Jasa Marga) for a week from August 26th to September 1st 2013. Two points within ±20 m apart perpendicular to highway axis point, located at either side of the roadside. Next two points within ±190 m perpendicular to highway, were located in KPP IPB Baranangsiang 4 and Kampung Sawah settlement RT 02 RW 07. CO sampling was conducted on weekdays and weekends, four (4) times a day for a week. The duration of each measurement was one hour.

The criteria for determining the location of ambient air quality samples refer to National Standard, namely SNI No. 19-7119.6-2005 on The Determination of Test Sample Location for Controlling of Ambient Atmosphere Quality. Figure 1 shows the location of pollutant CO measurement. CO sample analysis wascarried out in Laboratory of Aquaculture IPB in September-October 2013.

Materials

Materials used in this research consist of primary and secondary data.

a. Primary data, such as:
   1. CO pollutant concentration based on direct field measurement.
   2. Meteorological data at the measurement time such as temperature, wind direction and speed, relative humidity.
   3. Coordinate of measurement points and toll axis point.

b. Secondary data, such as:
   1. Numbers of vehicle passing through toll gates for three years (2010-2012), obtained from PT JasaMarga, Jagorawi Branch.
   2. Meteorological data from Meteorology Station Class I Dramaga and Meteorology Station Class III Citeko, i.e. Temperature, relative humidity, wind direction and speed, and radiation intensity from 2008 to 2012.

Figure 1 Location of Pollutant CO Measurement

Tools

Tools used in this study consist of data processing devices, in-field measurement devices, and laboratory equipment for analysis. The devices are listed below:

a. Data processing devices, such as Windows-based CPU. Software used in this process are:
   1. Visual Basic 6.0 for simulation.

2. Global Mapper 11.0 for sampling points plotting.
3. Surfer 8.0 for visualizing of CO dispersion.

b. Measurement devices in field covered impinger, thermometer, anemometer, spectrophotometer, tripod, manual counter, GPS, and portable CO meter.
c. Analysis equipment in laboratory including flasks, beakers, pipettes, and test tubes. Chemical solution KI was needed to absorb CO and Iodine Standard as primary solution.

METHODOLOGY

This study consists of five (5) phases, i.e. CO concentration measurements, CO concentration analysis in laboratory, forming Line Source Gaussian dispersion modeling using Finite Length Line Source (FLLS) method, model validation and visualization of CO pollutant dispersion pattern. The laboratory analysis of CO concentration refers to SNI No. 19-4848-1996on Pentoxide Method.

The calculation of emission load refers to [15] with speed is considered varied from 0-60 km/hour and the duration of vehicles maintenance in India and Indonesia is relatively similar between 10 and 15 years. Validation carried out in the research was according to [6,19,21] which areWilmott's Index of Agreement (d), Normalized Mean Square Error (NMSE), Pearson Correlation (R), Fractional Bias (FB), and Factor of 2 (Fa_2). According to [12], an acceptable performance of air quality modeling is according to the followingcriteria:

1. NMSE in the range 0.5.
2. FB in the range -2 to 2.
3. R and d close to 1.
4. Fa_2around 50%.

FLLS method determines the concentration of gaseous pollutant including its dispersion by dividing the segments of line source into its smallest segments. Having gained the smallest segments, then the distance between receptor and lined source is calculated in order to determine the dispersion parameter of each receptor [2,7,13]. FLLS equation according to [8] is listed below:

$$c_{(x,z)} = \frac{K}{(2\pi)^{\frac{1}{2}}}(G2 - G1) \quad (1)$$

where :

$$K = \frac{Q}{\bar{u}.\sigma_z}\left\{exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\}$$

$$G2 - G1 = \int_{B1}^{B2} \frac{1}{(2\pi)^{1/2}} exp\left(-\frac{B^2}{2}\right) dB^2$$

$$B2 = \frac{y_2}{\sigma_y}; B1 = \frac{y_1}{\sigma_y}$$

Description :

Q : Pollutant source rate. At the finite point source, unit g/sec is used. At the finite line source, unit g.m/sec is used.
$\bar{u}$: Wind speed at the-x (m/sec).
σ_z : Concentration dispersion parameter atthe-z (m).
z : Position of Z in Cartesian coordinate (in this study, z=0).
H : Effective height ofemission source (in this study, H=0).
B : The rate of road length to dispersion parameter (σ_y).

The calculation was performed on model using equation (1) including emission load to obtain Q, wind speed to obtain, road length and receptor location to obtain σ_y and σ_z as well as B_1 and B_2. Data visualization phase using Surfer software in the form of coordinate data, thus pollutant dispersion patterns can be observed based on isolate from modeling.

RESULTS AND DISCUSSIONS

Traffic Density Condition In the Vicinity of Baranangsiang Bogor Toll Gates

Baranangsiang Bogor toll gates are one of the Jagorawi toll gates managed by PT. JasaMarga. There are 9 toll booths, which 4 booths are for ticketing locations (Entrance),other 4 booths are for payment points (Exit), and the

rest one is a stand-by booth which can be operated as entrance or exit booth. The total volume of vehicle entering and exiting the toll gates in Bogor reached9 to 10 million units per year [9]. The average number of vehicle passing by a toll gate was 270 units per hour. On weekends, the average numbers of vehicle passing by Baranangsiang toll gates can reach 70 000 units/day. On the other hand, on weekdays the average is about 55 000 units. Traffic density that often occurs on holidays is caused by family travel activity with Bogor as the main destination.

According to data from [9] during 2010-2012, the most dominant type of vehicle passing by the gates is private vehicles. They were mostly diesel-driven and petrol-driven cars with two axles or Class I vehicle which cover about 97% of total numbers of vehicle. The second most dominant vehicle found is Class II vehicle such as diesel-driven small trucks and buses with two axles (3.05%). And the remaining 0.17% is Class III vehicle while Class IV and V are 0.03% and 0.02%, respectively.

Comparison between FLLS Modeling and CO Measurements Results

CO emission in the vicinity of Baranangsiang Bogor toll gates dominantlycaused by Class I and II passenger vehicles.The emission produced by these vehicle types will affect CO concentration level in the atmosphere. The comparison between simulated and measured CO concentration located within 20 m and 190 m fromthe source are illustrated in Figure 2 and 3. Figure 2 illustrates simulation results in both right and left roadside which shows almost similar CO concentration values. FLLS modeling divides the distance into its smallest segment. If the distance between the source and receptor points is equal, simulated CO concentration value will also show similar results [2,6,7,13].

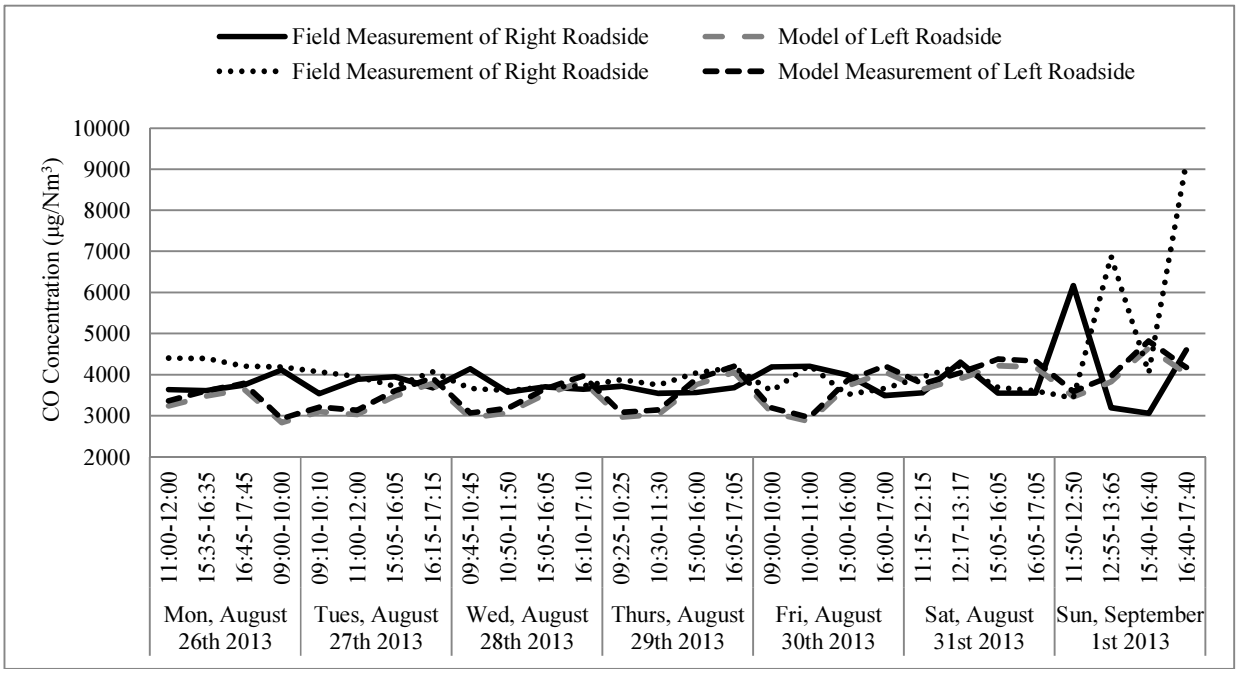

Figure 2 The comparison between simulated and measured CO concentration of two sampling points located 20 m from source on August 26th-September 1st 2013

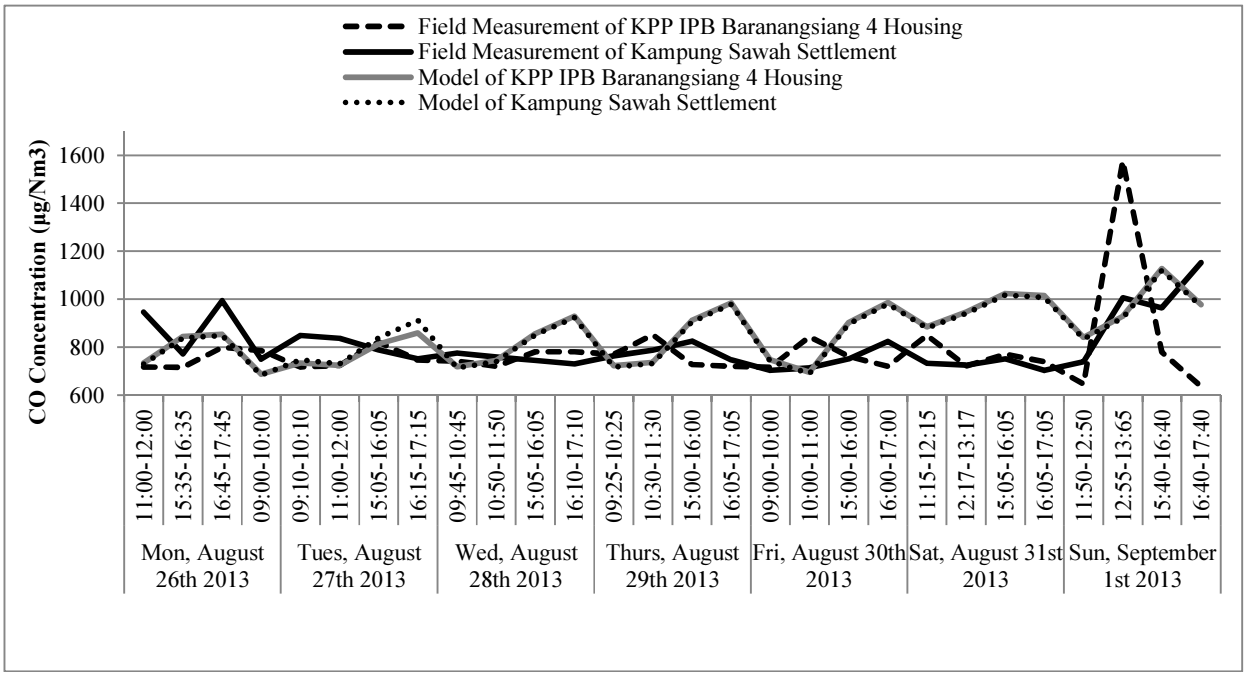

Figure 3 The comparison between simulated and measured CO concentration of two sampling points located190 m from source on August 26th-September 1st 2013

The simulated CO concentrations from FLLS modeling were in the range of 3671-5453 µg/Nm^3, taken from either side of the road (right and left roadside) which located ± 20 m from source. The highest concentration was 5453 µg/Nm^3 occurred on September 1st 2013 from left roadside at 15.40-16.40 WIB (3.40-4.40 PM). At the settlement points at either side of the road (± 190 m from source), CO concentrations were in the range of 728-1128 µg/Nm^3. The highest concentration was obtained on September 1st 2013 at 15.40-16.40 WIB (3.40-4.40 PM) valued about 1128 µg/Nm^3.

CO concentrations obtained from FLLS modeling were compared to CO quality standards for 1-hour and 24-hour measurements with each result was 30 000 µg/Nm^3 and 10 000 µg/Nm^3, respectively. All of simulated CO concentrations were still below the quality standards. Based on [11], low concentration of CO pollutant does not guarantee low concentration of other pollutants because each vehicle tends to have different emission gas compositions.

Simulation of Modeling Results

In this study, software was developed using Visual Basic 6.0 program in order to obtain accuracy and simplicity for calculating CO concentrations model. Figure 4 illustrates its preface. Simulations for CO were carried out in August 2013 using Surfer 8.0 program which is illustrated in Figure 5. Meteorological outputs and traffic conditions data used in the simulation were the average of five-year data in that specified month, with the average wind speed was 1.31 m/sec, the average wind direction is to the East at about 296°, atmospheric stability Class B, the average numbers of vehicle was 2559 units/day, the highest concentration of CO pollutant dispersion was 4000 µg/Nm^3 at 20 m at right roadside. Pollutant was dispersed to the East direction towards Kampung Sawah.

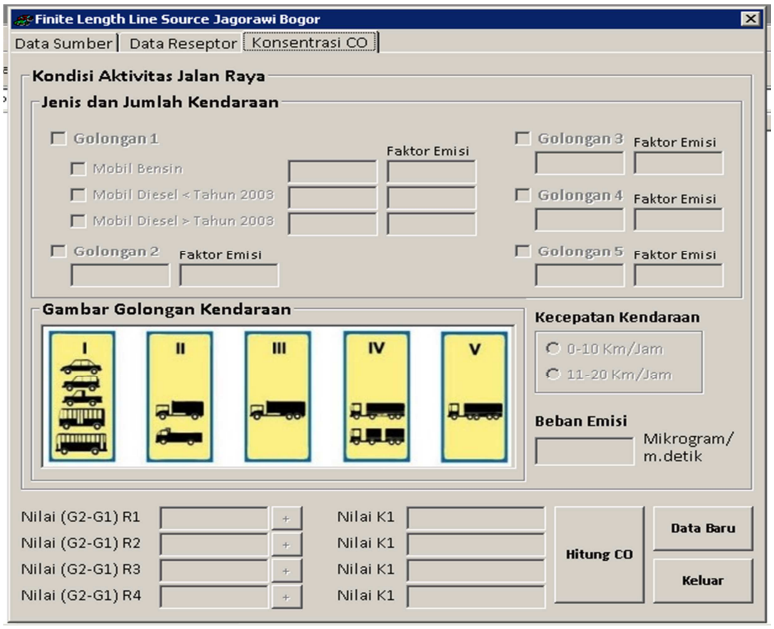

Figure 4 Preface of FLLS Software Jagorawi Bogor

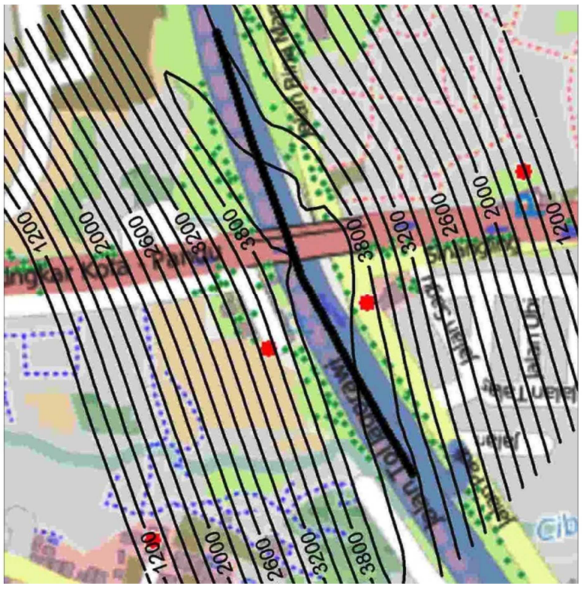

Figure 5Simulation of CO pollutant dispersion in August 2013

Validation of FLLS Modeling Results

Table 1 shows statistical calculation results to observe FLLS model performance. The CO modeling will be acceptable if its results are close to the performance criteria according to [12]. From Table 1, Willmott's index of agreement (d) of simulated and measured results indicates that the farther distance between receptor and source, the lower accuracy will be gained. With FB values gradually getting closer to zero prove that the model is appropriate to describe real conditions. The closer distance between receptor and source, the more accurate FB values will be.

Table 1 Statistical validation of CO modeling results

No	Receptor Location[a)]	The Distance from Receptor to Source (m)	The Average Concentration of Measurements (µg/Nm^3)	The Average Concentration of Model (µg/Nm^3)	d[b)]	*FB*[c)]	R[d)]	*NMSE*[e)]	Fa$_2$[f)] %
1	Left Roadside	20	3845	4017	0.3	0.06	0.06	0.05	31
2	Right Roadside	20	4201	4165	0.5	-0.04	0.21	0.03	31
3	Urban Settlements at the Left Roadside (IPB Baranangsiang 4 Settlement)	190	781	852	0.2	0.09	-0.24	0.06	28
4	Urban Settlements at the Right Roadside (KampungSawah RT 02/ RW 07)	190	806	854	0.3	0.08	0.22	0.08	30

[a] **n each point = 28 data**
[b] **Wilmott's Index of Agreement**
[c] **Fractional Bias**
[d] **Pearson Correlation Coefficient**
[e] **Normalized Mean Square Error**
[f] **Data percentage in the range of 0.5≤ Cobs/Cpred ≤2**

NMSE values are less than 0.5 at all receptor locations. The lowest NMSE value is obtained from the closest distance between receptor and source, which is 20 m. Fa$_2$percentageis decreasing proportional to the increasing of receptor distance. It is consistent with the study conducted by [6,10] that the closer distance between source and receptor, the higher COconcentration exists. Therefore, the Fa$_2$ percentage is getting lower. Pearson correlation coefficient is considerably low at all points. The numbers of sampling point is lower than the whole numbers of sampling point which consequently resulted in low R value. In the calculation of all data, R value is 0.996. The correlation coefficient indicates excellent linear relationship between real condition and its modeling results.

CONCLUSIONS

The simulation of CO pollutant dispersion was successfully developed by software FLLS Jagorawi and visualized using Surfer 8.0. Simulation for the events on August 26th-September 1st 2013 provides information about the highest CO concentration which was 5453µg/Nm^3 occurred at right roadside and the lowest was 682 µg/Nm^3 occurred in KPP IPB Baranangsiang 4. It also showed that CO pollutant was dispersed to the East direction towards Kampung Sawah.

Validation results of simulated and measured data are relatively close to the criteria. Pearson correlation coefficient was 0.966, indicates a linear relationship between model and field conditions.

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