Analysis of Air Pollution due to Vehicle Exhaust Emissions on The Road Networks of Beringin Janggut Area

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Abstract. Vehicle exhaust emission in transportation activities is one of air pollution causes. The increasing number of motor vehicles, lack of space availability on roads, and road side activities can cause congestion. The purpose of this research was to analyze the road network performance and vehicle exhaust emissions on the road networks of Beringin Janggut area of Palembang through traffic simulation using Vissim software and vehicle exhaust emission calculation using EnViver software, and the results were compared with ambient air measurement results at the research location, as well as providing alternative solutions to existing traffic condition. The outputs of Vissim software on the existing condition showed a long queue on traffic flow from Kolonel Atmo 2 street to the Masjid Lama 2 street with a value of 130.51 m, and there was a long delay on traffic flow from Kolonel Atmo 1 street to Rustam TP Effendi street (Southward) total of 105.37 seconds / vehicle. The EnViver software output showed the highest concentration for carbon dioxide (CO₂) pollutant of 181,000 μg / Nm³, the highest concentration for nitrogen oxide (NOx) pollutant of 534 μg / m³, and the highest concentration for Particulate Matter (PM₁₀) pollutant of 36 μg / Nm³. From the EnViver software outputs, the results showed the highest concentration of Particulate Matter air pollutants (PM₁₀) from direct ambient air measurement at the research location had a difference of 79 μg / Nm³. The existing concentrations of air pollutants resulting from EnViver software output and ambient air measurements on the road network of Beringin Janggut area were still below the ambient air quality standard limits set in Government Regulation No. 41/1999 on Air Pollution Control. Alternative 1 with parking rearrangement was better than alternative 2 with the lanes separation between public and private vehicles in improving road network performance and reducing total emission values due to vehicle exhaust emission from existing conditions.

Keywords : Vissim software, EnViver software, vehicle exhaust emission, CO₂, NOx, PM₁₀.

1. Introduction
The area of Beringin Janggut Palembang is one of the commercial center areas that has long been operating in the city of Palembang. Roads in this area are always jammed during rush-hours, due to heavy traffic and high side barriers in the area. Besides Road bodies in the Beringin Janggut area used for parking vehicles, it is also used by some traders as a place to conduct trading activities. In the Beringin Janggut area there is also a traffic sign intersection which is a joint of the Kolonel Atmo...
Street and the T.P Rustam Effendi street, therefore, during peak hours there is always a traffic congestion at this junction.

One of the negative effects of traffic congestion is air pollution. Motorist vehicle exhaust emissions using fossil fuel oil are the main causes of air pollution. Pollutants released by motorist vehicles include carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxide (NOx) in the form of nitric oxide (NO) and nitrogen dioxide (NO₂), hydrocarbons (HC), sulfur oxides (SOx) in forms of sulfur dioxide (SO₂) and sulfur trioxide (SO₃), and particulate matter (PM₁₀). Pollutants caused by emissions of these vehicles are harmful pollutants and can have a negative impact on human health if exposed continuously and in the long term.

Several studies on air pollution due to motor vehicle emissions on road traffic activity had been conducted. A study conducted on traffic flows on six Xi'an city streets where the calculation of emission strength using the multiplication formula between emission factor and vehicle travel distance showed that the concentration of NOx, HC and CO pollutants due to vehicle emissions were 46.43%, 62.47%, and 51.64% [1].

A research conducted on the traffic of three streets in the city of Medan were Medan-Binjai KM 10 street, Medan-Tg street, Morawa KM 10, and Medan-Tembung street, with emission calculations using the emission factor formula showed that the largest percentage of carbon monoxide emissions were from motorcycles while for nitrogen oxide and sulfur dioxide pollutants were from vehicular trucks [2].

A research on the traffic activity in the traditional market area of Mranggen Semarang through a micro simulation approach with Vissim software tool showed that the CO value due to vehicle emission was 474,343 ppm / hour which exceeded the pollutant level of 20 ppm / 8 hours, and the value NOx due to motorist vehicle emissions of 92.90 ppm / hour that exceeded the pollutant level threshold of 0.05 ppm / 24 hours [3].

A research conducted at the intersection of roads in central and eastern Surabaya aimed to determine fuel need and motor vehicle exhaust emissions. Parameters of motor vehicle exhaust emission research were CO₂, HC, NO, PM, and SO₂, where NO and SO₂ exhaust emission concentrations were calculated using Meti-Lis with gaussian plume model. It was assumed that fuel consumption also produced high CO₂ emission. Calculation of air pollutant concentration from of CO₂, HC, NOx, PM, and SO₂ was conducted to find out whether the air pollutant from existing condition was still in accordance with the air pollutant standard issued by the World Health Organization (WHO). NO and SO₂ exhaust emissions generated by motor vehicles exceeded the secured level suggested by the World Health Organization (2016) [4].

In research conducted by Andres Monzon, Alvaro Garcia Castro, and Cristina Valdes which aimed to measure motor vehicles emissions applying information and communication technology. The research methodology was based on the combination of model simulation variation in micro and macro scale. The research object was a sample vehicle prepared and representative characteristics of vehicles operating in Madrid road traffic. Research location was on M30 road in Madrid. From the data obtained in the location, a micro-scale simulation with Vissim software and macro-scale simulation with Vissim software were used. The scenarios applied in this research were speed regulation, effective route arrangement, driving method, and traffic management. The result showed that there was a decrease of emission due to motor vehicle by 3% after the implementation of improvement scenario. In this study the calculation of air pollutants as the result of transport activities becoming basic comparison when scenario improvement applied [5].

Frantisek Petro and Vladimir Konecky in their research aimed to calculate emissions from transport activities and using the results to proceed to external cost calculations caused by negative impacts of emissions. It compared three computer softwares used to calculate emissions ie, Map & Guide, NTMCalc Basic 4.0, and EcoTransit. From the comparison result, the most suitable software for emission calculation continued to external cost calculation was Map & Guide because it showed emission factors on route passed [6].
In addition, a research conducted at a two-track roundabout between the warszawska, marszalkowska, rycerska, and lubelska roads in Rzeszow city through traffic simulation methods with Vissim software followed by emissions calculations from motorist vehicles with EnViver software showed the emission factors for NOx and PM10 increased at the peak time traffic. The results of microscopic emission calculations using EnViver software compared with mesoskopic model calculations using COPERT 5 software showed that there was a factor difference of NOx of 7-18% [7].

From several researches conducted above shows that the network performance of a road network will greatly determine the level of pollution occurred due to traffic activities on it. By using Vissim software, it can be simulated traffic activities that occur on a road network, from the simulation of traffic through Vissim software can be calculated the vehicle exhaust emissions due to traffic activities.

This research was conducted on the road network of Beringin Janggut to analyze road network performance of vehicle exhaust emissions through traffic simulation using Vissim software and followed by calculation of vehicle exhaust emissions using EnViver software, and the results were compared with direct ambient air measurements at the research location, and also to provide alternative solutions to the existing condition.

2. Research Methodology

2.1. Research Location

This research was conducted on the road network of Beringin Janggut area of Palembang city which consisted of Jalan Kolonel Atmo, Jalan T.P. Rustam Efendi, Jalan Masjid Lama, Jalan Segaran and Jalan Kebumen Darat, and also there were 2 intersections included, Megahria intersection and Pasar Burung intersection. Simpang Megahria is an intersection between Kolonel Atmo street and T. P Rustam Efendi street while Simpang Pasar Burung is an intersection between Kolonel Atmo street and The Masjid lama street, with a limitation of traffic network area of 1 square kilometer.
2.2. Data collection

The data used in this study were the primary data obtained directly in the research location and secondary data obtained from other parties. Primary data in this research included traffic data in form of traffic volume, vehicle speed, and parking event obtained by survey at research location, geometric data of road obtained by direct measurement at research location, and air pollutant data obtained by measurement directly in the location through coordination with Technical Implementing Unit of Environmental Laboratory of Environment and Land Agency of South Sumatera Province. Primary data collection were obtained on the same day on 8 March 2018 starting from 06.00 am until 18.00 pm.

Weather at the time of survey for data collection was in bright conditions with air temperature 32°C.

Traffic data collection included traffic volume, vehicle speed and parking data, surveyors on each road segments on the Beringin Janggut road network to record traffic volume, vehicle speed and parking events. The data of traffic volume were recorded per hour for each road segment from 06.00 am to 06:00 pm, the vehicle speed data were measured using a speed gun by taking samples of 30 vehicles for each type of vehicle on the Beringin Janggut road network, parking was collected by recording parking events following time of entry and exit of vehicles at the parking point at the Beringin Janggut area.

The pollutant data collection on ambient air was carried out by placing the air quality measuring device in form of Non-Dispersive Infrared device for measuring CO pollutant concentration, impinger tube for measurement of NO2, SO2 and O3 pollutants, High Volume Air Sampler (HVAS) device used for pollution concentration measurement of PM10. The air pollutant concentration in ambient air were placed at the Beringin Janggut intersections where its location was the congestion point and the largest emissions of motor vehicle exhaust on the Beringin Janggut road network. Data collection of pollutant concentration in ambient air was conducted from 08.10 am to 05.15 pm. The secondary data used in this research were aerial photographs taken using Google Earth software that will be used as the background for the road network in data processing by using Vissim software.

2.3. Data Analysis

Data analysis were conducted by entering data of existing traffic condition and geometric data of road network at research location to Vissim software. In this process, to produce the desired value then it required a trial and error process that will be done several times. The calibration and validation process will be carried out to achieve a simulation of traffic flow of Vissim software output that was in accordance with the existing condition in the research location. Traffic simulation data of Vissim software output according to the existing condition were processed using EnViver software to obtain emissions from vehicle exhaust emissions in form of carbon dioxide (CO2), nitrogen oxide (NOx), and particulate matter (PM10). The concentration of air pollutants in form of particulate matter (PM10) of EnViver software output will be compared with the result of direct measurement of ambient air in the research location to find out the suitability between air pollution calculation as result of activity by using software and reality in the research location. From the existing traffic conditions data, a simulation scenario for handling parking rearrangement will be made on the research location with Vissim software and will be followed by air pollution calculation with EnViver software, the total emission value of the existing will be compared with the total emission value of the parking rearrangement scenario.

3. Results and Discussion

3.1. Road Network Modeling Using Vissim Software

Traffic modeling on the Beringin Janggut road network was conducted using Vissim software. The data obtained directly from surveys and field measurements were entered into the Vissim software. Traffic modeling began with input data base in form of type, class, and vehicle category, driving behavior, followed by making the road network according to the original condition in the field, and then were input the vehicle volume and its composition. The next step was to do the calibration
process by changing average standstill distance value and additive part safety distance value on the driving behavior in the traffic model by trial and error. Validity model was conducted by comparing vehicle volume on existing traffic with vehicle volume in traffic simulation model using Vissim software, and then statistical test was conducted using Geoffrey E. Havers (GEH) formula to determine whether or not the simulation model using Vissim software was acceptable. The validity of simulation test using Vissim software can be seen in table below.

**Table 1. Validity Test of Traffic Simulation Models on Existing Conditions Using Vissim Software**

| No | Roads                             | Existing Vehicle Volume | Vehicle Volume on Vissim Model | Percent age | Statistic al Test Value (GEH) | Note  |
|----|-----------------------------------|-------------------------|-------------------------------|-------------|-----------------------------|-------|
| 1  | Jl. Kolonel Atmo                  | 1607                    | 1423                          | 88.55 %     | 4.73                        | Accepted |
| 2  | Jl. T.P. Rustam Effendi (Selatan) | 1504                    | 1337                          | 88.90 %     | 4.43                        | Accepted |
| 3  | Jl. T.P. Rustam Effendi (Utara)   | 240                     | 178                           | 74.17 %     | 4.29                        | Accepted |
| 4  | Jl. Kebumen Darat                 | 630                     | 519                           | 82.38 %     | 4.63                        | Accepted |
| 5  | Jl. Masjid Lama                   | 473                     | 376                           | 79.49 %     | 4.71                        | Accepted |
| 6  | Jl. Segaran                       | 366                     | 278                           | 75.96 %     | 4.90                        | Accepted |

The road network performances that need to be analyzed using Vissim software on the road network were the queue length (Qlen) and delay (Veh Delays). In existing traffic simulations using Vissim software, node points to analyze traffic performance were located at Megahria intersection and Pasar Burung intersection. From the results of existing data processing using Vissim software obtained results in form of vehicle volume, queue length (Qlen) and delay (Veh Delays). Recapitulation of data output from Vissim software for existing traffic conditions on the road network of Beringin Janggut area can be seen in the table below.

**Table 2. Existing Road Network Performance Outputs from Vissim Software**

| No. | Vehicle Flows                              | Vehicle Volume (Veh/hour) | Queue Length (m) | Delays (sec/veh) |
|-----|--------------------------------------------|---------------------------|-----------------|-----------------|
| 1.  | Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2   | 1423                      | 52.39           | 86.67           |
| 2.  | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (South) | 1337                      | 53.71           | 105.37          |
| 3.  | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (North) | 178                       | 52.39           | 61.09           |
| 4.  | Jl. Kolonel Atmo 2 – Jl. Kebumen Darat   | 519                       | 126.29          | 99.26           |
| 5.  | Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2   | 376                       | 130.51          | 99.51           |
| 6.  | Jl. Masjid Lama 1 – Jl. Masjid Lama 2    | 278                       | 55.39           | 46.70           |

3.2. Calculation of Air Pollution Using EnViver Software
The calculation of air pollution was conducted using EnViver software. The result of traffic running simulation of the road network of Beringin Janggut area using Vissim software was in form of a file.fzp than imported into EnViver software. The results obtained from the EnViver software were the
total value of the calculation of vehicle exhaust emissions in form of carbon dioxide (CO\textsubscript{2}), nitrogen oxide (NO\textsubscript{x}), and particulate matter (PM\textsubscript{10}) and the color gradient display for each pollutant concentration on the road networks of Beringin Janggut area.

**Figure 2.** The Total Value of Vehicle Exhaust Emissions on The Road Networks of Beringin Janggut Area

From Figure 2 above, the first line represents the total emission value of vehicle exhaust emission on Beringin Janggut road network, the second line shows the value of vehicle exhaust emissions per hour on the road network of Beringin Janggut area, and the third line shows the value of vehicle exhaust emissions motor per kilometer on the road network of Beringin Janggut Area. From figure 1 can be seen the total value of motor vehicle exhaust emissions on the road network of Beringin Janggut area for carbon dioxide (CO\textsubscript{2}) pollutant of 548.224 kg, nitrogen oxide (NO\textsubscript{x}) pollutants of 1659.392 gr, and particulate matter (PM\textsubscript{10}) pollutants of 103.159 gr. For the highest concentration of each type of pollutant from the results of EnViver software output can be seen in the table below.

**Table 3.** Highest Concentration of Pollutants Output from EnViver Software on Existing Traffic Condition

| No | Pollutants                | The Highest Concentration |
|----|--------------------------|---------------------------|
| 1  | Carbon dioxide (CO\textsubscript{2}) | 181,000 μg/Nm\textsuperscript{3} |
| 2  | Nitrogen Oxide (NO\textsubscript{x})  | 534 μg/Nm\textsuperscript{3}  |
| 3  | Particulate Matter (PM\textsubscript{10}) | 36 μg/Nm\textsuperscript{3}   |

3.3. Pollutant Concentration on Ambient Air

Data collection for the amount of pollutant concentration in ambient air was conducted on the research location at the measuring point which was considered most representative and held on 08 March 2018 from 08.10 am until 17.15 pm along with the implementation of traffic data survey, where the air sampling process and data processing were conducted under supervision of Technical Implementing Unit of Environmental Laboratory of the Environment and Land Agency of South Sumatra Province.

The data of air pollutant concentrations on ambient air due to traffic activity in the road networks of Beringin Janggut area can be seen in the table below.
Table 4. Pollutant Concentrations of Ambient Air on the Road Networks of Beringin Janggut Area

| Measurement Time | Pollutant Concentrations | Unit |
|------------------|--------------------------|------|
|                  | CO  | NO\textsubscript{2} | SO\textsubscript{2} | O\textsubscript{3} | PM\textsubscript{10} |
| 1 08.10 - 09.10  | 2,290 | 97.4 | 75.8 | - | 78.8 μg/Nm\textsuperscript{3} |
| 2 09.20 - 10.20  | 5,726 | 98.8 | 115 | - | 95.2 μg/Nm\textsuperscript{3} |
| 3 10.25 - 11.25 | 10,307 | 175 | 131 | - | 115 μg/Nm\textsuperscript{3} |
| 4 11.30 - 12.30 | 9,162 | 148 | 129 | 122 | 111 μg/Nm\textsuperscript{3} |
| 5 12.50 - 13.50 | 6,871 | 99.2 | 116 | - | 92.9 μg/Nm\textsuperscript{3} |
| 6 14.00 - 15.00 | 4,581 | 98.7 | 115 | - | 91.5 μg/Nm\textsuperscript{3} |
| 7 15.10 - 16.10 | 4,581 | 147 | 153 | - | 102 μg/Nm\textsuperscript{3} |
| 8 16.15 - 17.15 | 2,290 | 98.2 | 76.4 | - | 90.1 μg/Nm\textsuperscript{3} |

The comparison between the pollutants concentration in the ambient air on the road network of Beringin Janggut area with the threshold of air quality standard based on Government Regulation No. 41 year of 1999 on Air Pollution Control can be seen in the table 5 below.

Table 5. The Comparison of Pollutant Concentrations of Ambient Air on the Road Networks of Beringin Janggut Area toward the Threshold of Air Quality Standard

| No | Pollutants               | Concentrations | Threshold Air Quality Standard |
|----|-------------------------|----------------|-------------------------------|
| 1  | Carbon monoxide (CO)    | 10,307 μg/Nm\textsuperscript{3} | 30,000 μg/Nm\textsuperscript{3} |
| 2  | Nitrogen dioxide (NO\textsubscript{2}) | 175 μg/Nm\textsuperscript{3} | 400 μg/Nm\textsuperscript{3} |
| 3  | Sulfur dioxide (SO\textsubscript{2}) | 131 μg/Nm\textsuperscript{3} | 900 μg/Nm\textsuperscript{3} |
| 4  | Oxidants (O\textsubscript{3}) | 122 μg/Nm\textsuperscript{3} | 235 μg/Nm\textsuperscript{3} |
| 5  | Particulate Matter (PM\textsubscript{10}) | 115 μg/Nm\textsuperscript{3} | 150 μg/Nm\textsuperscript{3} |

From table 5 it can be seen that the concentration of air pollutants on the road networks of Beringin Janggut area is still below the threshold of air quality standard set under Government Regulation No. 41/1999 on Air Pollution Control, but the concern is the PM\textsubscript{10} pollutant concentration quite high, so it is necessary to take measurement of air quality improvement especially from the transportation sector as one of contributors to air pollution due to vehicle exhaust emissions.

3.4. The Comparison of Highest Air Pollutant Concentration Output of EnViver Software and Concentration of Pollutants on Ambient Air

The same parameter between EnViver software output and ambient air measurement results is particulate matter (PM\textsubscript{10}) concentration. The comparison between PM\textsubscript{10} concentration from EnViver software output and ambient air measurement on the road network of Beringin Janggut area can be seen in the table below.

Table 6. The Comparison between Highest PM\textsubscript{10} Concentration Output of EnViver Software and Ambient Air Measurements

| Particulate Matter (PM\textsubscript{10}) Concentration | EnViver Software Output | Ambient Air Measurement Results |
|-------------------------------------------------------|-------------------------|--------------------------------|
|                                                      | 36 μg/Nm\textsuperscript{3} | 115 μg/Nm\textsuperscript{3} |
From table 6 above, the concentration of particulate matter (PM$_{10}$) of ambient air measurements has a difference of 79 $\mu$g/Nm$^3$ from the EnViver software output, the PM$_{10}$ concentration measured on the ambient air above the highest PM$_{10}$ concentration value of the EnViver software output. The highest concentration of PM$_{10}$ for ambient air measurement occurred for 1 hour from 10:25 am to 11:25 am and almost simultaneously with peak traffic volumes on the road network of Beringin Janggut area that occurred at 11.00 am until 12.00 pm which was simulated with the Vissim software device on time interval of 3600 seconds, where the simulation results of Vissim software were used to measure PM$_{10}$ concentration by using EnViver software. The difference of PM$_{10}$ concentration occurred because the EnViver software calculated the concentration of air pollutants based only on emissions from transport activities while the ambient air measurement calculated the concentration of air pollutants from all sources of pollutants where in this research location sites there were grocery stores and materials warehouses. When the measurement of ambient air was conducting, the loading and unloading activities occurred in time at 11:00 am to 12:00 pm.

Another possible cause of the different air pollutant concentrations was the lack of accuracy of the Vissim software traffic model on existing traffic conditions in the field, and also occurred due to errors during ambient air measurements caused by wind and humidity pressures.

### 3.5 Alternative 1 Scenario by Rearrangement Parking Points

At the research location there are parking spots along the road network of Beringin Janggut area. On the T.P Rustam Effendi street, there are several parking spots disturbing the traffic flow, especially during peak hours and cause congestion for transportation to Kolonel Atmo street. On Beringin Janggut street has been closed completely because it is used as a trading place and will be planned to be re-arranged, so that the parking point that disrupts the traffic flow in T.P. Rustam Effendi street can be partially transferred to Beringin Janggut street. The road network performance results from Vissim software output with alternative 1 scenario parking rearrangement can be seen in the table below.

| No. | Vehicle Flow                      | Vehicle Volume (veh/hour) | Queue Length (m) | Delays (sec/veh) |
|-----|-----------------------------------|---------------------------|-----------------|-----------------|
| 1.  | Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2 | 1,438                     | 31.75           | 15.14           |
| 2.  | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (South) | 1,340                     | 31.75           | 14.48           |
| 3.  | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (North) | 184                      | 30.88           | 10.90           |
| 4.  | Jl. Kolonel Atmo 2 – Jl. Kebumen Darat | 524                      | 123.30          | 88.83           |
| 5.  | Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2 | 393                      | 123.76          | 89.79           |
| 6.  | Jl. Masjid Lama 1 – Jl. Masjid Lama 2 | 297                      | 48.87           | 38.11           |

After modeling using Vissim software, emission calculation values from vehicle exhaust emission were input into EnViver software for traffic simulation model of parking rearrangement. The results obtained from EnViver software showing there were a lot of rearrangements on the road networks of Beringin Janggut area as shown in the figure below.
Figure 3. The Total Value of Vehicle Exhaust Emissions on The Road Networks of Beringin Janggut with The Parking Rearrangement Scenario

From Figure 3 it shows the total value of motor vehicle exhaust emission on road network of Beringin Janggut area with implementation of parking rearrangement scenario for carbon dioxide (CO$_2$) pollutant of 393.715 kg, nitrogen oxide (NO$_x$) of 1069.236 gr, and Particulate Matter (PM$_{10}$) of 83.302 gr. For the highest concentration of each type of pollutants the results from EnViver software can be seen in the table below.

Table 8. The Highest Concentration of Pollutants Output from EnViver Software on Traffic Conditions with Implementation of Parking Rearrangement Scenario

| No | Pollutants                           | The Highest Concentration |
|----|-------------------------------------|---------------------------|
| 1  | Carbon dioxide (CO$_2$)             | 166,000 μg/Nm$^3$         |
| 2  | Nitrogen Oxide (NO$_x$)             | 577 μg/Nm$^3$             |
| 3  | Particulate Matter (PM$_{10}$)      | 32.1 μg/Nm$^3$            |

3.6. Alternative 2 Scenario Separating Lane between Public Vehicle and Private Vehicles

Kolonel Atmo street in the road network of Beringin Janggut area is passed by public transportation from Lemabang and KM 5 area, these public transportation often stop to wait for passengers so it affects the traffic flow on these street. In alternative 2, it will be planned to lane separation between public transportation and private vehicles, public transportation is on the left lane of Kolonel Atmo street. The road network performance from Vissim software output for alternative 2 scenario with lanes separation between public and private vehicles can be seen in the table below.

Table 9. Road Network Performance with Alternative 2 Scenario Results from Vissim Software Output

| No. | Traffic flow                     | Vehicle Volume (veh/hour) | Queue Length (m) | Delays (sec/veh) |
|-----|----------------------------------|---------------------------|------------------|------------------|
| 1   | Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2 | 1,418                     | 52.41            | 81.64            |
| 2   | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (South) | 1,328                     | 52.10            | 80.91            |
| 3   | Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (North)  | 181                       | 52.41            | 60.99            |
| 4   | Jl. Kolonel Atmo 2 – Jl. Kebumen Darat | 536                       | 73.14            | 36.11            |
| 5   | Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2 | 382                       | 73.32            | 26.13            |
| 6   | Jl. Masjid Lama 1 – Jl. Masjid Lama 2 | 304                       | 35.74            | 18.23            |
After modeling using Vissim software then vehicle exhaust emissions will be computed using EnViver software for traffic simulation models as alternatives of lane separation between public and private vehicles. Results obtained from EnViver software can be seen in the figure below.

![Figure 4. Total Vehicle Exhaust Emissions with Alternative Lane Separation between Public Vehicles and Private Vehicles](image)

From Figure 4 can be seen that the total value of vehicle exhaust emission on road network of Beringin Janggut area for carbon dioxide (CO$_2$) is 447.136 kg, nitrogen oxide (NO$_x$) is 1034.450 gr, and Particulate Matter (PM$_{10}$) is 93.568 gr. For the highest concentration of each type of pollutants, the results of EnViver software can be seen in the table below.

| No  | Pollutants                  | The Highest Concentration |
|-----|-----------------------------|---------------------------|
| 1   | Carbon dioxide (CO$_2$)     | 184,000 μg/Nm$^3$         |
| 2   | Nitrogen Oxide (NO$_x$)     | 657 μg/Nm$^3$             |
| 3   | Particulate Matter (PM$_{10}$) | 35.1 μg/Nm$^3$          |

### 3.7. Analysis of Road Network Performance Comparison

Comparison between road network performance on the road networks of Beringin Janggut area for existing condition, alternative 1 with parking rearrangement and alternative 2 with lane separation between public vehicle and private vehicle traffic simulation result using Vissim software are presented in table 11. below.

| Traffic Flow                                      | Vehicle Volume (veh/hour) | Queue Length (m) | Delays (sec/veh) |
|--------------------------------------------------|----------------------------|------------------|------------------|
| Existing Condition                                |                            |                  |                  |
| Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2          | 1,423                      | 52.39            | 86.67            |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (South) | 1,337                      | 53.71            | 105.37           |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (North) | 178                        | 52.39            | 61.09            |
| Jl. Kolonel Atmo 2 – Jl. Kebumen Darat           | 519                        | 126.29           | 99.26            |
| Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2            | 376                        | 130.51           | 99.51            |
| Jl. Masjid Lama 1 – Jl. Masjid Lama 2             | 278                        | 55.39            | 46.70            |
### Table 11. Continue

| Traffic Flow                                           | Vehicle Volume (veh/hour) | Queue Length (m) | Delays (sec/veh) |
|--------------------------------------------------------|---------------------------|------------------|------------------|
| **Alternative 1**                                       |                           |                  |                  |
| Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2                | 1,438                     | 31.75            | 15.14            |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (Selatan) | 1,340                     | 31.75            | 14.48            |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (Utara)   | 184                       | 30.88            | 10.90            |
| Jl. Kolonel Atmo 2 – Jl. Kebumen Darat                 | 524                       | 123.30           | 88.83            |
| Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2                 | 393                       | 123.76           | 89.79            |
| Jl. Masjid Lama 1 – Jl. Masjid Lama 2                  | 297                       | 48.87            | 38.11            |
| **Alternative 2**                                       |                           |                  |                  |
| Jl. Kolonel Atmo 1 – Jl. Kolonel Atmo 2                | 1,418                     | 52.41            | 81.64            |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (South)   | 1,328                     | 52.10            | 80.91            |
| Jl. Kolonel Atmo 1 – Jl. T.P. Rustam Effendi (North)   | 181                       | 52.41            | 60.99            |
| Jl. Kolonel Atmo 2 – Jl. Kebumen Darat                 | 536                       | 73.14            | 36.11            |
| Jl. Kolonel Atmo 2 – Jl. Masjid Lama 2                 | 382                       | 73.32            | 26.13            |
| Jl. Masjid Lama 1 – Jl. Masjid Lama 2                  | 304                       | 35.74            | 18.23            |

From table 11 can be seen that there was a decrease in the queue length and delays time when applied alternative 1 scenario or alternative 2 scenario. On vehicle flow from Jl. Kolonel Atmo to Jl. T.P. Rustam Effendi (south) with the highest delay time in the existing condition was 105.37 sec/veh decreased to 14.48 sec/veh when applied alternative 1 scenario, it became 80.91 sec/veh when applied alternative 2 scenario. On vehicles flows from Jl. Kolonel Atmo 2 to Jl. Masjid Lama 2, the highest queue length in the existing condition was 130.51 m decreased to 123.76 m when applied alternate 1 scenario, and it became 73.32 m when applied alternative 2 scenario.

### 3.8. Comparison Analysis of Vehicle Exhaust Emission Value

The Comparison between the total value of vehicle exhaust emissions and the highest concentration value of each pollutant in Beringin Janggut area for existing condition, alternative 1 scenario with parking rearrangement and alternative 2 scenario with separating lane between public vehicle and private vehicles, the calculation result from EnViver software can be seen in table and picture below.

### Table 12. The Comparison of Total Emission Values

| No. | Conditions                                              | CO₂       | NOₓ        | PM₁₀       |
|-----|--------------------------------------------------------|-----------|------------|------------|
| 1.  | Existing                                               | 548.224 kg| 1659.392 gr| 103.159 gr |
| 2.  | Alternative 1 Scenario Parking Rerangement            | 393.715 kg| 1069.236 gr| 82.302 gr  |
| 3.  | Alternative 2 Scenario Lanes Separation between Public Vehicles and Private Vehicles | 447.136 kg| 1304.450 gr| 93.568 gr  |

From table 12 it can be seen that there is a decrease in the total value of vehicle exhaust emission for carbon dioxide (CO₂) from the existing condition of 207.485 kg at alternatives 1 and 154.064 on
alternative 2. For nitrogen oxide (NOx) there is a decrease in total emission value from the existing condition of 562.601 gr on alternative 1 and 327.387 gr on alternative 2. For Particulate Matter (PM_{10}) there is a decrease in total emission value of 38.765 gr from the existing condition in alternative 1, whereas in alternative 2 there is a decrease in total emission value of 27.499 gr from the existing condition.

Among the three types of air pollutants mentioned above, carbon dioxide (CO_{2}) is the most dangerous pollutant for humans when exposed for long periods of time, the scenario of parking rearrangement is considered quite effective in reducing air pollution on the road networks of Beringin Janggut Area.

![Figure 5. The Comparison of The Highest Concentration of Carbon Dioxide (CO_{2}) from EnViver Software](image1)

![Figure 6. The Comparison of The Highest Concentration of Nitrogen Oxide (NOx) from EnViver Software](image2)
Figure 7. The Comparison of The Highest Concentrations of Particulate Matter (PM$_{10}$) from EnViver Software

From Figure 5, Figure 6, and Figure 7. It can be seen that alternative 1 is better than alternative 2 in reducing air pollutant concentration due to vehicle exhaust emission on the road network of Beringin Janggut area.

4. Conclusions
Based on the results of data analyses, it can be concluded as follows:

1. The highest concentration of air pollutants due to vehicle exhaust emissions in the road networks of Beringin Janggut area from EnViver software output were 181,000 μg/Nm$^3$ of CO$_2$, 534 μg/Nm$^3$ of NOX, and 36 μg/Nm$^3$ of PM$_{10}$ concentration.

2. From EnViver software output obtained a difference of 79 μg/Nm$^3$ of particulate matter (PM$_{10}$) from ambient air measurement

3. Particulate matter concentration (PM$_{10}$) of ambient air measurements from EnViver software output on the road networks of Beringin Janggut area was still below the ambient air quality standard as specified under Government Regulation No. 41 of 1999 on Air Pollution Control.

4. The alternative 1 scenario for parking rearrangement was better than the alternative 2 for the lane separation scenario between public and private vehicles as it was quite effective in reducing air pollution on the road networks of Beringin Janggut Area.

5. The results of this research are in line with the research conducted on the M30 road in Madrid City [5] where there is a decrease in the total value of vehicle exhaust emissions when applied improving scenarios to existing traffic conditions using simulation software.

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