Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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IOP Conf. Series: Journal of Physics: Conf. Series **1198** (2019) 082004 doi:10.1088/1742-6596/1198/8/082004

An Analysis of Air Quality through the Basis of Traffic Performance of Signaled Intersections

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Abstract. The deteriorating quality of environment can be caused by air pollution due to traffic jam in intersection. Thus, the traffic performance at intersection needs to be analyzed so that the air pollution level within that area can then be identified. This research was conducted on two connected intersections: Jelutung Intersection and Talang Banjar Intersection in Jambi City, Indonesia. This research is aimed at analyzing the performance of the intersections under the existing condition and the alternatives of traffic handling using *Vissim* program, analyzing the amount of CO_2 emission, controlling and improving air quality by using *EnViVer* Program. The alternatives for handling traffic include expanding road geometrics, resetting traffic lights, and construction of flyover. The traffic performance indicators include vehicle volumes, queue lengths, and delays. The research result shows that the alternative of construction of flyover gives both an improvement within the performance of the intersection networks and an emission reduction at its best – where the queue length of both intersections decreases to 25,69% in average and the delay decreases to 30,67%. Further, the total of CO_2 emission decreases from 391,621 gr/km to 303,9 gr/km, being a medium category while the lowest concentration of CO_2 is at interval 67.200 to 134.000 μg/m³ for the accumulation of both intersections.
Keyword. Performance, Vissim, EnViVer, Air Quality.

1. Introduction

The rate of population growth and activities in urban areas causes infrastructure capacity and environment quality to deteriorate. The environmental problem that occurs in Jambi City is a low air quality [1] [2]. Transport mode is the biggest cause of air pollution – where the main pollutant is carbon monoxide (CO) with the concentration of almost half of the entire pollutants, which include carbon monoxide (CO), nitrogen oxide (NOx), hydro carbon (HC), sulfur dioxide (SOx), other particles and other sources of pollution [3].

Based on the field survey, the vehicles that go through intersections are often times delayed due to long queues of vehicles. In Jambi City, there are 2(two) intersections that have a traffic jam problem: they are Jelutung Intersection and Talang Banjar Intersection. Not only does such problem cause a health hazard to the road users, it also deteriorates the air quality. The worst gas emission occurs not to the normal, driving vehicles, but to those that are starting (switched-on engine) but not driving.

Thus, an improvement of traffic performance is required to reduce the gas emission from vehicles. This research is aimed at analyzing the performance of intersections to obtain an effective and appropriate model in improving the perfornance of the traffic and reducing the gas emission from vehicles. Such problem can be solved by making a model of a pollutant level emission caused by a traffic emission and by using both *Vissim* Program and *EnViVer* Program.

Similar research has previously been conducted by Borge et al [4] and it presents a combination of traffic microsimulation model and emission to accurately determine the emission of a traffic activity in a particular area through the use of emission value NOx and PM_{10}, Rima D Y [5] states that there is a significant influence between a vehicle queue and an increase of pollutants at an intersection. She also states that there is a correlation between the rate of vehicle volume queueing up in traffic and a change in air quality. In addition, Linton et al [6] applied a transportation model through a microsimulation technique to obtain an emission estimate.

Mahmod and Van Arem [7] used *Vissim* Program and *EnViVer* program to simulated vehicle to infrastructure (V21) communication to reduce traffic emissions at signalized intersection. Their results showed that the total emission CO_2, NOx and PM_{10} reduces up to 15%. Giuffre and Canale [8] concluded that PTV *Vissim* and TNO *EnViVer* are selected tools to choose and evaluate the most ecologically efficient geometry which are unsignalized intersection; single-lane conventional roundabout; signalized intersection; and unconventional roundabout (turbo-roundabout).

Moreover, Kaur and Varmora [9] explained that traffic simulation tool *Vissim* has a wide range of approaches and areas. *Vissim* is a useful tool for both microscopic and macroscopic simulation models. Della et al [10] state that a U-turn flyover is the best design to improve the performance of an intersection. Similarly, Arliansyah and Bawono [11] state that the best scenario for improving the performance of an intersection is through geometric changes and traffic flow diversion.

2. Material and Method

2.1. Microsimulation through Vissim and EnViVer Program

A traffic simulation is a mathematic model through the use of computer software to help plan, design, and operate a transportation system. The model used in this research is PTV microsimulation (*Planning Transport Verkehr AG)* in *Kalsruhe, German Vissim* stands for "*Verkehr in Stadten – Simulations model*", which is software that can be used to simulate microscopic traffic and 3-D animation traffic and create a video clip record [12].

EnViVer Program that is made by TNO is a program used to model an air emission which includes CO_2, NOx and PM_{10} through the use of software. Furthermore, *EnViVer* Application that is supported by *PTV Vissim* can predict an emission value of a whole read according to average daily traffic (LHR), and study traffic environmental impacts, both in the existing situation and in modified situation [13].

2.2. Method

The methods used in this research are survey method and experiment model, where the survey was conducted to gather the primary data which consisted of geometric survey, traffic count survey, desired speed survey, and traffic lights survey.

There are 3 scenarios carried out in this research:

a. Scenario Altenative 1 – Expanding road geometrics at Jelutung Intersection and Talang Banjar Intersetion.
b. Scenario Alternative 2 – Resetting traffic lights, keeping the time cycle unchanged, changing the signal controller, and optimizing the lights cycle through *Vissim* program.
c. Scenario Alternative 3 – Construction of flyover, changing the signal controller to be 3 phases at Jelutung Intersection. On the contrary, the vehicle input, vehicle routes, and signal controller at Talang Banjar Intersection are conditioned to remain the same as the existing condition.

There are two research sites taken for this research; they are 2 (two) intersections that can be seen on the layout shown in Figure 1.

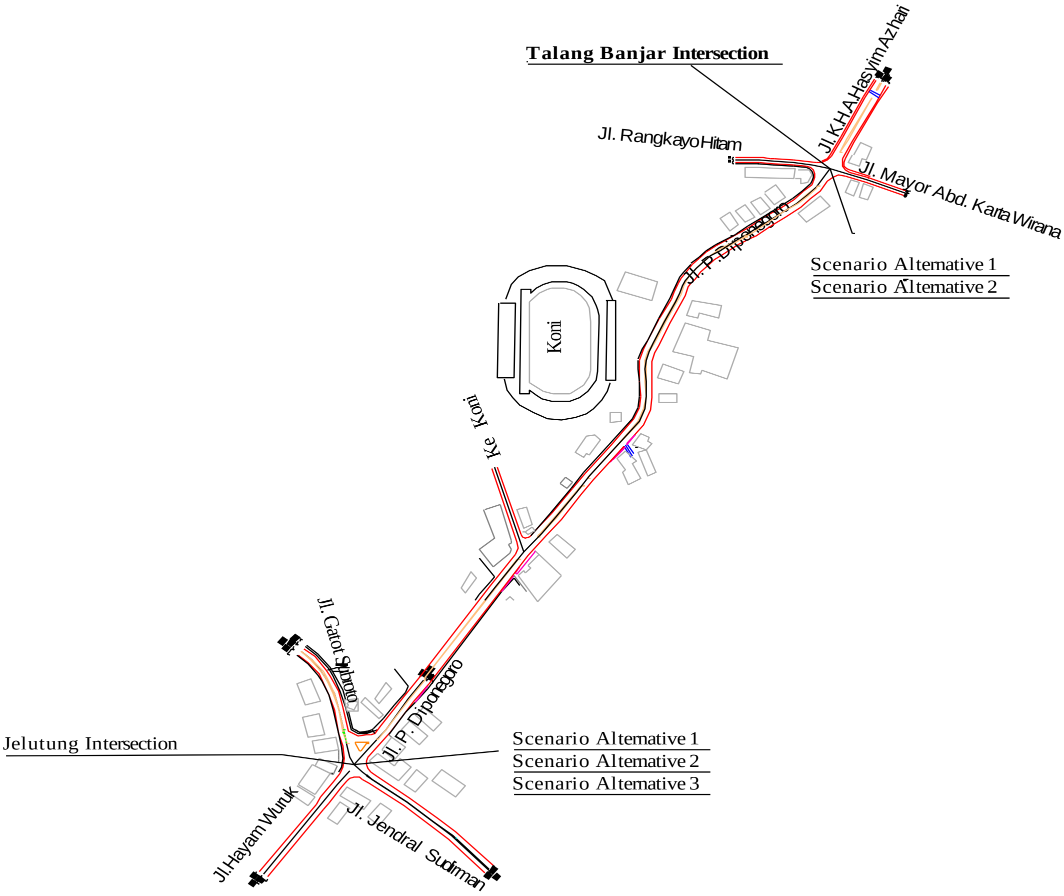

Figure 1. Jelutung Intersection and Talang Banjar Intersection

The phases of *Vissim* program and *EnViVer* program:

a. Creating road networks in *Vissim* program for the existing conditions – where the link and the connector have already been connected.

b. Inputting the data which include vehicle input, vehicle routes, vehicle composition, desired speed, and signal controller.

c. After creating the road networks and inputting data, the existing conditions is run.

d. Calibrating the existing condition model.

e. Scenario Alternative 1: Expanding road geometrics, Scenario Alternative 2: Resetting traffic lights, and Scenario Alternative 3: Construction of flyover.

f. The output obtained from the result of *running* the existing condition and the handling alternative scenario which includes the length of queue, the delay, and the volume of modelling result.

g. From the results of *running,* the output from the *Vissim* program is then saved in a zip format file (*.fzp).

h. Then, importing file (*.fzp) to the *EnViVer* program, and *running* program will generate a calculation and report emission.

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The chart flow of such model can be seen in Figure 2.

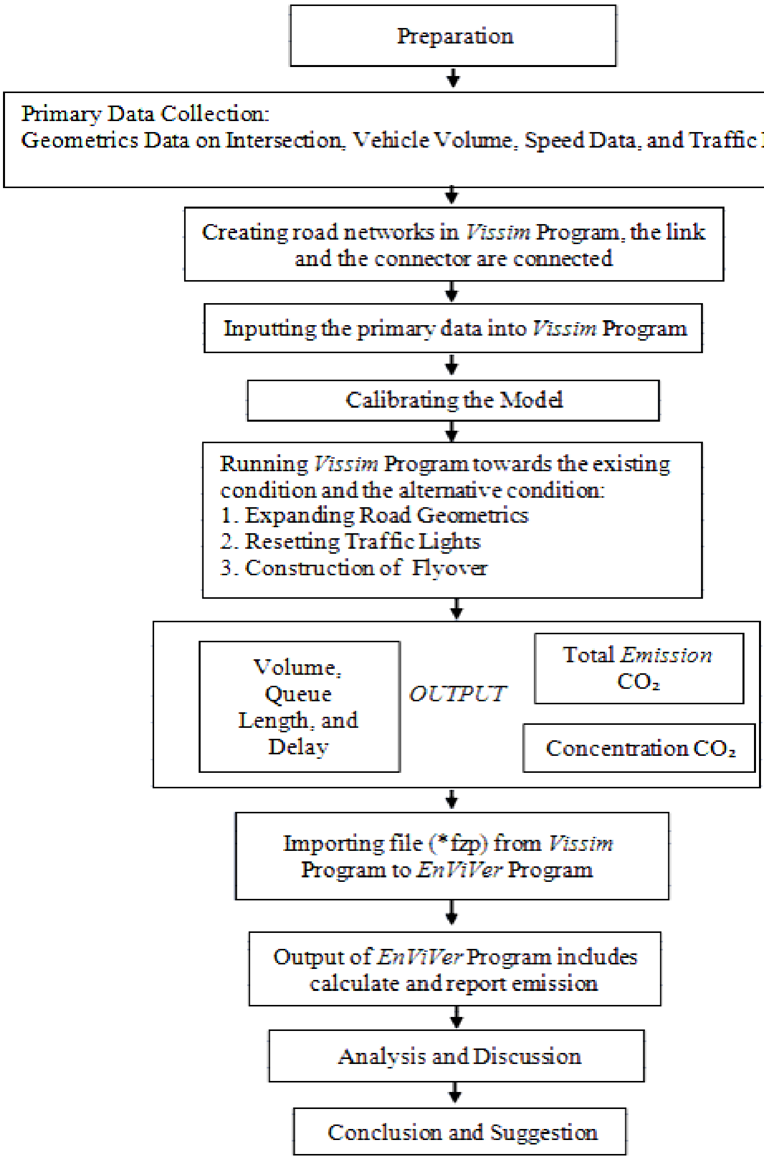


Figure 2. The Flowchart of the Model Development

Calibration is a parameter adjustment process to obtain a match between the simulated value and the observed data. Traffic data used as a comparison in the calibration process is traffic volume data at intersection [14]. The testing process of calibration – which is done by comparing the results of observation to the simulation result through the use of the absolute percentage absolute percentage formula *(MAPE)* – consists of absolute percentage, deviation percentage, a percentage difference between the actual data and the estimated data [15] such formula can be seen down below:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| x100\% \quad (1)$$

Where
n = total number/number of data
A_t = field data/observation
F_t = simulation model data

3. Result and Discussion

3.1. Analysis on the Intersection Performance within the Existing Condition and the Handling Alternative

The analysis on the intersection performance was done through the use of *Vissim* program, under the output program parameters; they are volume, queue length, and delay. Based on a *running* model reliability test, the data calibration was done between the observation result volume and the model result volume, as can be seen in Table 1.

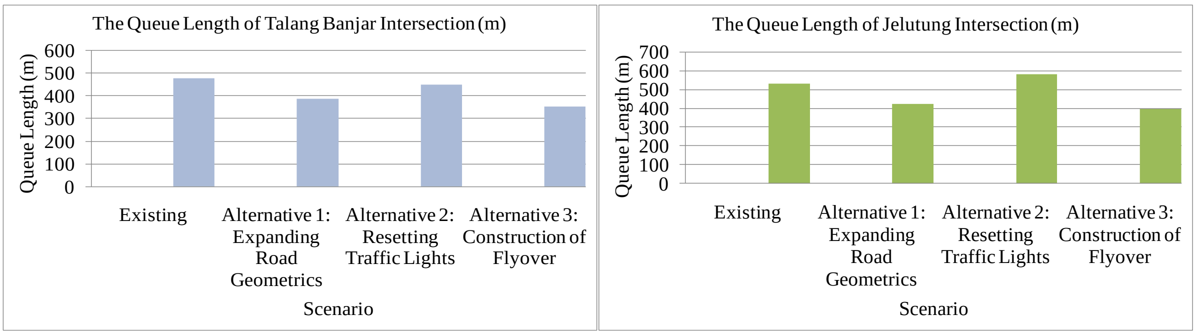
Table 1. Calibration Data of Observation Results Volume towards Modelling Results Volume

Name of Intersection	Observation *(O) vehicle/hour*	Modelling (P) vehicle/hour			
		Existing	*Alternative 1: Expanding Road Geometrics*	*Alternative 2: Resetting Traffic Lights*	*Alternative 3: Construction of flyover*
Jelutung Intersection	8974	6713	7303	6798	7742
Talang Banjar Intersection	7159	5655	5958	5556	6061
MAPE Jelutung Intersection (%)		25	19	24	14
MAPE Talang Banjar Intersection (%)		21	17	22	15

Based on Table 1, the vehicle volume of the result of modelling the scenario alternative 3 is revealed: The flyover has a bigger vehicle volume than do the other scenarios. The smallest vehicle is at the Scenario Alternative 2: Resetting traffic lights in Talang Banjar Intersection. Further, the result of modelling reliability test done to Scenario Alternative 3: the smallest percentage of the flyover falls on Jelutung Intersection, reaching 14% and Talang Banjar Intersection, reaching 15%. This indicates that the volume obtained is close to the observation result compared to the other scenarios. The smaller the percentage, the closer it is to the real data.

Similarly Putri and Irawan [15] states that the result of traffic volume calibration that they obtained-which is a difference between the inputted vehicle volume and the outputted vehicle volume and can still be tolerated with an average percentage of 41%. Based on the output running program, the existing condition of the intersections cannot accommodate traffic any more since they already have the longest queue and the highest delay.

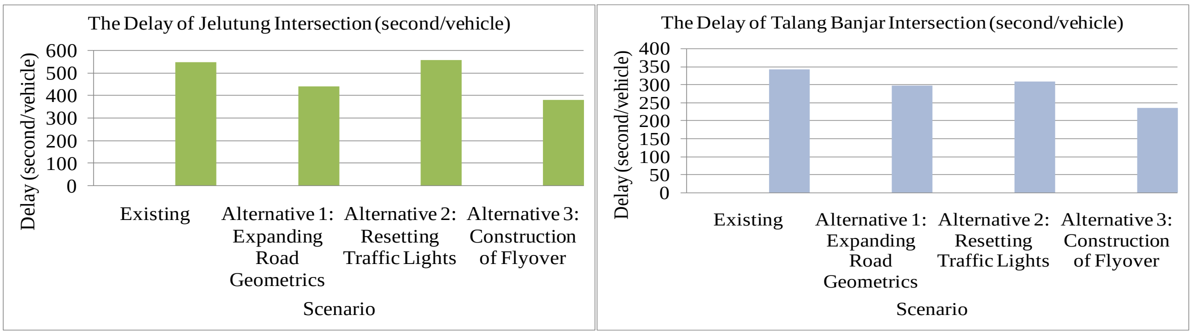
The comparison of the queue length in the existing condition and in the handling alternative can be seen in Figure 3.



(a) (b)

Figure 3. The Queue Length within the Existing Condition and the Intersection Handling Alternative Jelutung Intersection (a), Talang Banjar Intersection (b)

Based on the Figure 3, the shortest queue falls on the Scenario Alternative 3: Construction of flyover at Talang Banjar Intersection and Jelutung Intersection, whiles the longest queue falls on the Jelutung Intersection within the Scenario Alternative 2: Resetting traffic lights. The reason why it happened this way is because the behavior of the drivers was arranged to be identical to the real situation and the condition in the designed ground. A comparison in the delay within the existing condition and the handling alternative can be seen in Figure 4.



(a) (b)

Figure 4. The Delay within the Existing Condition and the Intersection Handling Alternative Jelutung Intersection (a), Talang Banjar Intersection (b)

Based on Figure 4, it can be seen that, the lowest delay falls on the model of Scenario Alternative 3: Construction of flyover has 235,27 second/vehicle at Talang Banjar Intersection, and the highest delay is 555,06 second/vehicle at Jelutung Intersection Scenario Alternative 2: Resetting traffic lights. This is due to the behavior change of the drivers who move forwards at a speed suitable with the distribution of each vehicle type and the designed scenario condition.

After several handling alternative model tests, the highest volume of vehicle falls on the Scenario Alternative 3: Construction of flyover, where the modelling result volume is close to the observation, generating the smallest volume percentage compared to the other scenarios, the shortest queue, and the shortest delay. By using the handling alternative, the queue length and delay can be minimized. Therefore, based on the analysis though the *Vissim* program, the most appropriate handling alternative falls on the Scenario Alternative 3: Construction of flyover for handling and improving the intersection performance

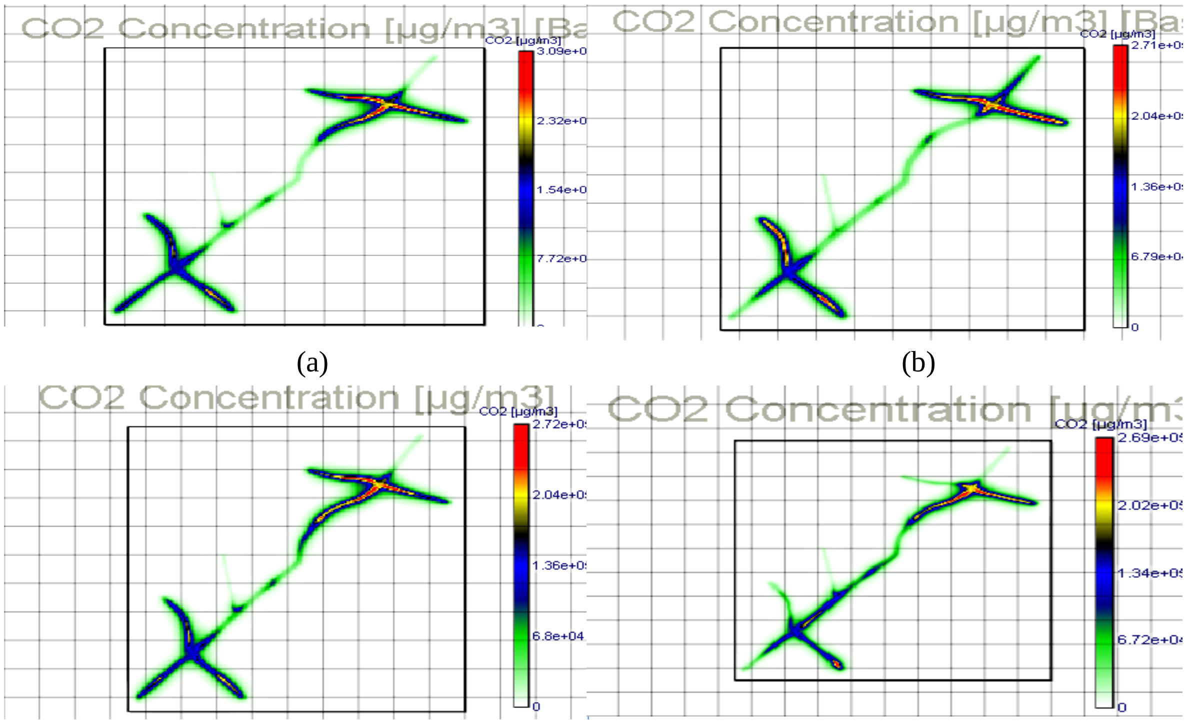
3.2. Analysis on CO_2 Emission and Air Quality Generated by EnViVer Program

The parameter of output of *EnViVer* program generated a total value of CO_2 (carbon dioxide) emission, both within the existing condition and within the intersection handling alternative, as seen in Table 2.

Table 2. Recapitulation of the Output of Emission Total Value of Intersection

Condition	Total of Emission CO_2	Concentration CO_2 (see Figure 5)
Existing	391,621 g/km	medium category is in blue 77.200 – 154.000 µg/m³
Alternative 1: Expanding Road Geometrics	324,3 g/km	medium category is in blue 67.900 – 136.000 µg/m³
Alternative 2: Resetting Traffic Lights	385,009 g/km	medium category in blue 68.000 – 136.000 µg/m³
Alternative 3: Construction of Flyover	303,9 g/km	medium category is in blue 67.200 – 134.000 µg/m³

Based on Table 2, it can be seen that the CO_2 total emission drops. Further, the total of CO_2 emission decreases from 391,621 gr/km to 303,9 gr/km, the total value of CO_2 emission within the existing condition drops after the implementation of the model of handling alternative, while within the Scenario Alternative 3: Construction of flyover obtained a smaller total emission value of CO_2 opposed to the other conditions. The alternative can improve the road performance and the air quality. This is due to the fact that the better the traffic performance, the lower the total accumulated emission of CO_2. In addition, based on an analysis through *EnViVer* program, the lowest value of the CO_2 emission falls on the Scenario Alternative 3: Construction of flyover. Thus, the most appropriate alternative scenario to be applied as one way of handling and improving the performance of signaled intersections like the ones at Jelutung Intersection and Talang Banjar Intersection is the Scenario Alternative 3: Construction of flyover. This is also in accordance with the gradation value of CO_2 concentration, as shown in Figure 5.



(a) (b)

(c) (d)

Figure 5. Gradation of CO_2 Concentration within the Existing Condition (a), Alternative 1: Expanding Road Geometrics (b), Alternative 2: Resetting Traffic Lights (c) dan Alternatif 3: Construction of Flyover (d)

Based on the picture, it is shown that the value of CO_2 concentration significantly drops within the Scenario Alternative 3: Construction of flyover, and it can be seen that the gradation of CO_2 consentration is dominated with a blue color, indicating that the value of CO_2 concentration is dominated with a blue color, indicating that the value of CO_2 concentration is at medium level – where the air quality within that level does not affect the health of human beings and animals. It, however, affects any sensitive plants and esthetic values. Decree of State Environment Minister [16] State that such model has the smallest interval compared to the others, with the green color being a good category – which is at interval 0 through 67.200 µg/m³. Meanwhile the highest gradation value is within the red color, which is at very unhealthy category – located at interval 202.000 throught 269.000 µg/m³. A model can generate a better concentration gradation, especially at road segments towards intersection.

Therefore, the most appropriate handling alternative scenario to improve the performance of intersection is created through the use of *EnViVer* program within Scenario Alternative 3: Construction of flyover. Doing so can make the lowest total value of CO_2 emission, reaching 303,9 gr/km. Such value is marked in blue and falls on medium category, while the lowest value of CO_2 concentration is at interval 67.200 through 134.000 µg/m³.

4. Conclusion

Based on the model of air quality which is conducted through the basis of signaled traffic performance through the use of *Vissim* program and *EnViVer* program, it can be concluded that:

a. The handling alternative scenario that can improve the intersections condition is through Construction of flyover – where the result shows an improvement of traffic performance and air quality.
b. Based on an analysis on Construction of flyover, the smallest volume percentage is found at Jelutung Intersection, which is 14% and at Talang Banjar Intersection at 15%. Such percentage is close to the observation volume value; the queue length at Jelutung Intersection gets shorter, from 532,64m to 396,26m. Similarly, the queue length at Talang Banjar also gets shorter, from 477,42m to 354,39m; the traffic delay at Jelutung Intersection drops from 545,20 second/vehicle to 380,10 second/vehicle. Similarly, the traffic delay also drops at Talang Banjar Intersection, from 341,21 second/vehicle to 235,27 second/vehicle.
c. By Construction of flyover, the total emission of CO_2 can be reduced, from 391,621 gr/km to 303,9 gr/km (medium category), and the lowest value of CO_2 concentration drops from interval 77.200 through 154.000 µg/m^3 to 67.200 through 134.000 µg/m^3 for the accumulation of both intersections.

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