



Impact Analysis of Infrastructure Changes from Signalized Intersection to Underpass on Vehicle Exhaust Emissions

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Abstract

The Medan City Government plans to make infrastructure changes by building underpass at the existing signalized intersection between Road Ir. H. Juanda and Road Brigjend. Katamso to reduce traffic congestion. In recent years, vehicle emissions have become a global concern due to their significant impact on public health and environmental quality. As road traffic and vehicle numbers continue to grow, transportation has become a key contributor to air pollution from vehicle exhaust emissions. Consequently, it is essential to assess whether the infrastructure changes from signalized intersection to underpass have an impact on vehicle exhaust emissions. The impact analysis of infrastructure changes on vehicle exhaust emissions is evaluated through traffic simulation using PTV Vissim software with two scenarios, namely the do nothing scenario (existing signalized intersection) and the do something scenario (underpass), focusing on CO, NO_x, and VOC emissions. The comparative results indicate substantial changes: CO emissions declined by 42.5% (from 40,991 grams to 23,567 grams), VOC by 37.1% (from 9,500 grams to 5,975 grams), while NO_x emissions increased by 23.3% (from 7,075 grams to 8,725 grams). These findings suggest that the infrastructure changes from signalized intersection to underpass can positively influence air quality by reducing specific pollutants. However, further studies are necessary to examine its broader impact on other types of vehicle exhaust emissions using diverse emission categories, multiple calculation approaches, and various analytical methods for comprehensive comparison.

Introduction

One of the intersections in Medan city with high congestion is the intersection between two big roads: Ir H. Juanda (West – East) and Brigjend. Katamso (North – South) in Figure 1. Located in a strategic area, the large number of vehicles passing the intersection often experience traffic congestion, especially during peak hours. Under existing conditions, this intersection is equipped with a signal-based traffic management system, but it cannot accommodate the increasing traffic capacity that causes congestion. As a solution to solve the congestion problem at the intersection, the Medan City Government plans to make infrastructure changes by building underpass at the existing signalized intersection (Aldi, 2023; Marini et al., 2025; Sohaib et al., 2024).

The underpass is an intersection where two or more road segments meet each other not in one plane but one of the segments is under the other road segment (NJDOT, 2025; Jaya et al., 2022; Eppstein & Gupta, 2017). In this infrastructure changes plans, underpass design show that Road Ir. H. Juanda segment is under the Road Brigjend. Katamso segment (Figure 2). This

infrastructure changes from signalized intersection to underpass is expected to reduce congestion by facilitating traffic flow, thereby reducing travel time and vehicle exhaust emissions.



Figure 1. Study Location: Intersection of Road Ir. H. Juanda – Road Brigjend. Katamso



Figure 2. Layout Detail Engineering Design Underpass Brigjend. Katamso – Ir. H. Juanda (Pemerintah Kota Medan, 2023)

Exhaust emissions from motor vehicles have increasingly drawn global attention in recent times. The rising traffic volume has intensified this issue, positioning road transport as a leading source of environmental pollution (Vidhi & Shrivastava, 2018; Wang et al., 2018). Vehicle emissions have significant negative impacts on human health and the environment. Vehicle emissions such as CO, NO_x, and PM, mostly from automobiles, are a major source of air pollution in urban areas, with various pollutants having damaging effects on human health and the environment (Goel et al., 2018; Iram et al., 2025; Öncü et al., 2025). In addition, vehicle emissions also contribute to environmental problems such as acid rain and water pollution (Ojolo et al., 2007; Afridi, 2025; Pandit & Sharma, 2025).

Several studies have shown that infrastructure changes can reduce emissions. A multi-lane roundabout in the urban area of Larissa, Greece, was converted from a roundabout to a turbo roundabout and emissions were reduced by up to 44% across the roundabout area and up to

23% in the roundabout area (Anagnostopoulos et al., 2025; Riccardi et al., 2022; Ali & Majid, 2023). The conversion of a signalized intersection to a roundabout in El Paso, Texas, shows a reduction in emissions of more than 50 tons per day (Sharifi et al., 2021; Frisbie et al., 2025; Acedo Aguilar & Wang, 2025). Other research in the form of optimization of existing infrastructure, in the form of optimization of left turns at four intersections in Shanghai, China which showed 30% reduction in emissions (Fan et al., 2023; Zhang et al., 2024; Fan et al., 2023). Another study in Doha, Qatar converted four three-lane roundabouts to signalized intersections along a highly congested urban corridor, resulting in emissions reductions of 37% to 43% (Shaaban et al., 2019; Hasan & Fadli, 2025; Alhadidi et al., 2025).

Therefore, as emission become an important issue for global community and road transportation is the major contributor, a study is needed to analyze whether infrastructure changes from signalized intersections to underpasses have an impact on vehicle exhaust emissions.

Methods

In conducting a study, a methodology is needed to be used so that the study can run in accordance with existing references and guidelines. The stages carried out are preparation, data collection, data processing, analysis, and finally conclusions and suggestions. The research flow chart can be seen in Figure 3.

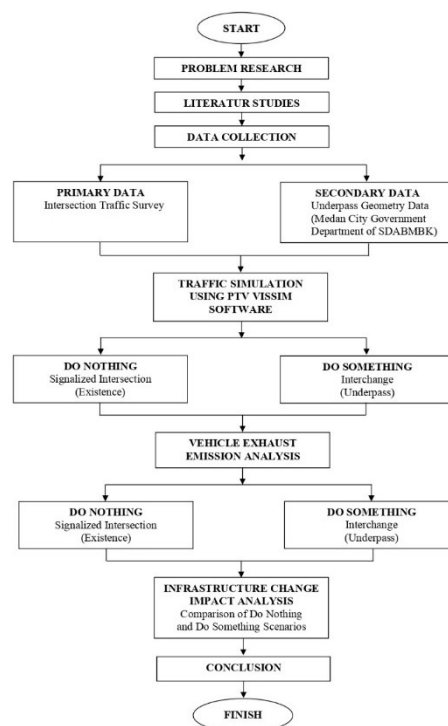


Figure 3. Flowchart

Flowchart in Figure 3 show there are three analyses: traffic simulation, vehicle exhaust emission analysis, and impact analysis of infrastructure change. Traffic simulations will be conducted using PTV Vissim for two scenarios: (1) Do Nothing: PTV Vissim will simulate traffic flow based on existing conditions (signalized intersection); and (2) Do Something: PTV Vissim will simulate the conditions after the infrastructure change to an underpass.

The data used to make traffic simulations for both scenario comes from traffic survey at study location with a survey reference from Pedoman Kapasitas Jalan Indonesia 2023 (PKJI 2023)

as standard traffic guidelines in Indonesia (Dirjen Bina Marga, 2023). The traffic survey in this study used the development of 2 time factors as observation days, namely one day for weekday travel destinations represented by Monday, and one day for weekend travel destinations represented by Saturday (United States Department of Transportation, 2018). Each observation day was conducted in 3 time periods (morning, afternoon, and evening) for 3 hours per time period. Data processing will also use PKJI 2023 as standard to obtain one peak hour traffic flows at the intersection.

Traffic data at the underpass will also use traffic survey data from the existing signalized intersection at study location during the one peak hour period, by assuming changes in movement due to the loss of right turn access at the underpass (Figure 4). Some assumptions of movements changes are: (1) The right turn movement from the North approach is redirected as a straight movement, facilitated by a U-turn at the South approach; (2) The right turn movement from the West approach is redirected as a left turn movement; and (3) The right turn movement from the East approach is redirected as a left turn movement.

The peak hour data of existing signalized intersection will be used on do nothing scenario simulation with existing signalized intersection geometry (Figure 4a), while the peak hour data with assuming changes in movement due to the loss of right turn access and underpass geometry design (Figure 4b) will be used on do something scenario.

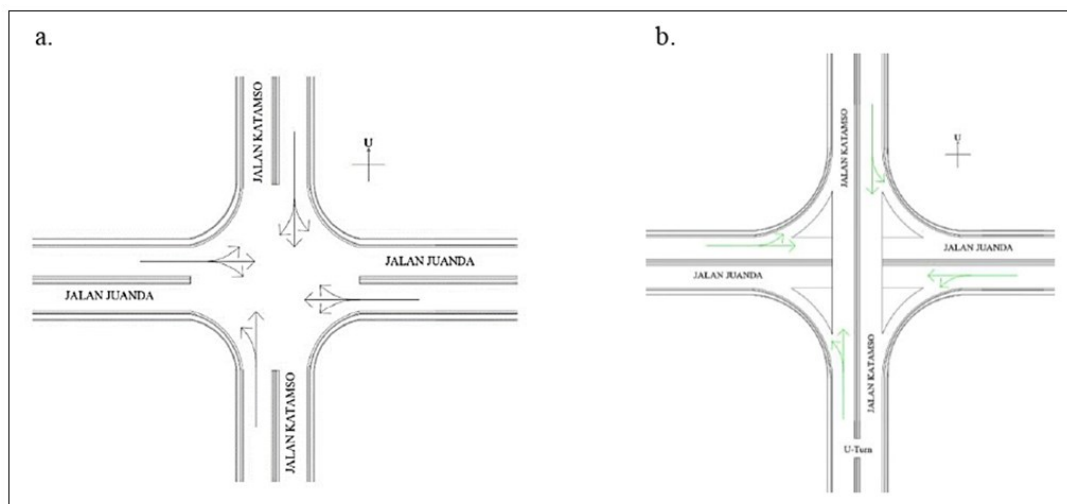


Figure 4. (a) Signalized Intersection (Do Nothing) ; (b) Underpass (Do Something)

After the traffic simulation is carried out, the vehicle exhaust emissions will be also analyzed using the PTV Vissim software with the do nothing and do something scenarios. By using PTV Vissim software as tools for emissions analysis, the vehicle exhaust emissions that can be analyzed are CO, NOX, and VOC. To analyze the impact of infrastructure changes from signalized intersection to underpass on vehicle exhaust emissions, a comparison of emissions analysis results using PTV Vissim between the do nothing scenario and the do something scenario per each type of emission (CO, NOX, and VOC) is carried out. From the differences comparison of the two scenarios, it will be known whether there is an impact of infrastructure changes on vehicle exhaust emissions, such as if there are increase or decrease in total exhaust emissions between the two scenarios.

Results and Discussion

Table 1 shows the peak hour traffic distribution at the existing signalized intersection based on the results of the traffic survey (do nothing scenario) with the peak hour at the observation of

weekday afternoon (17.15 - 18.15) with a total vehicle volume of 12346 vehicles/hour or 5695.8 pce/hour.

Table 1. Traffic Distribution of Intersections (Do Nothing Scenario)

Approach	Movement	LV		HV		MC		Total	
		veh/h	pce/h	veh/h	pce/h	veh/h	pce/h	veh/h	pce/h
North	Left Turn	158	158	4	5.2	309	46.4	471	209.6
	Straight	516	516	24	31.2	1335	200.3	1875	747.5
	Right Turn	103	103	12	15.6	124	18.6	239	137.2
	Total	777	777	40	52.0	1768	265.2	2585	1094.2
South	Left Turn	591	591	66	85.8	1207	181.1	1864	857.9
	Straight	505	505	35	45.5	1064	159.6	1604	710.1
	Total	1096	1096	101	131.3	2271	340.7	3468	1568.0
East	Left Turn	68	68	9	11.7	126	18.9	203	98.6
	Straight	581	581	32	41.6	796	119.4	1409	742.0
	Right Turn	91	91	31	40.3	86	12.9	208	144.2
	Total	740	740	72	93.6	1008	151.2	1820	984.8
West	Left Turn	197	197	11	14.3	267	40.1	475	251.4
	Straight	819	819	54	70.2	1589	238.4	2462	1127.6
	Right Turn	486	486	23	29.9	1027	154.1	1536	670.0
	Total	1502	1502	88	114.4	2883	432.5	4473	2048.9

Table 2 shows the peak hour traffic distribution at the underpass (do something) assuming a change in traffic flow in the form of loss of right turn access as shown in Figure 3.

Table 2. Traffic Distribution of Intersections (Do Nothing Scenario)

Approach	Movement	LV		HV		MC		Total	
		veh/h	pce/h	veh/h	pce/h	veh/h	pce/h	veh/h	pce/h
North	Left Turn	261	261	16	20.8	433	65.0	710	346.8
	Straight	516	516	24	31.2	1335	200.3	1875	747.5
	Total	777	777	40	52.0	1768	265.2	2585	1094.2
South	Left Turn	591	591	66	85.8	1207	181.1	1864	857.9
	Straight	505	505	35	45.5	1064	159.6	1604	710.1
	Total	1096	1096	101	131.3	2271	340.7	3468	1568.0
East	Left Turn	159	159	40	52.0	212	31.8	411	242.8
	Straight	581	581	32	41.6	796	119.4	1409	742.0
	Total	740	740	72	93.6	1008	151.2	1820	984.8
West	Left Turn	683	683	34	44.2	1294	194.1	2011	921.3
	Straight	819	819	54	70.2	1589	238.4	2462	1127.6
	Total	1502	1502	88	114.4	2883	432.5	4473	2048.9

From both traffic data in Table 1 and Table 2, existing geometry and underpass design, traffic simulations are made with PTV Vissim software for both do nothing and do something scenario. After simulation completed, vehicle exhaust emissions can be analyzed. Table 3 shows the results of vehicles exhaust emissions after simulation using PTV Vissim software in the do nothing scenario (existing conditions). From Table 3, with the total vehicles volume at

12346 veh/hour and average speeds at 24.49 km/hour, the total vehicles exhaust emissions in the signalized intersection are: 40991 grams (CO), 7075 grams (NOX) and 9500 grams (VOC).

Table 3. Vehicle Exhaust Emissions with Do Nothing Scenario

No	Approach	Movement	Vehicles Volume		Average Speeds	Vehicles Exhaust Emissions (Gram)		
			veh/h	pce/h		km/h	CO	NO _x
1	North	Left Turn	471	210	28.03	1508	260	350
		Straight	1875	747		5379	928	1247
		Right Turn	239	137		987	170	229
2	South	Left Turn	1864	858	22.84	6174	1066	1431
		Straight	1604	710		5110	882	1184
3	East	Left Turn	203	99	26.51	710	122	164
		Straight	1409	742		5340	922	1238
		Right Turn	208	144		1038	179	241
4	West	Left Turn	475	251	20.59	1809	312	419
		Straight	2462	1128		8115	1401	1881
		Right Turn	1536	670		4821	832	1117
Total			12346	5696	24.49	40991	7075	9500

Table 4 shows the results of vehicles exhaust emissions after simulation using PTV Vissim software in the do something scenario (underpass). From Table 4, with the total vehicles volume at 12346 veh/hour and average speeds at 50.18 km/hour, the total vehicles exhaust emissions in the underpass are: 23567 grams (CO), 8725 grams (NOX) and 5975 grams (VOC).

Table 4. Vehicle Exhaust Emissions with Do Nothing Scenario

No	Approach	Movement	Vehicles Volume		Average Speeds	Vehicles Exhaust Emissions (Gram)		
			veh/h	pce/h		km/h	CO	NO _x
1	North	Left Turn	710	347	53.03	1435	531	364
		Straight	1875	747		3093	1145	784
2	South	Left Turn	1864	858	47.74	3549	1314	900
		Straight	1604	710		2938	1088	745
3	East	Left Turn	411	243	51.51	1005	372	255
		Straight	1409	742		3070	1137	778
4	West	Left Turn	2011	921	48.45	3812	1411	966
		Straight	2462	1128		4665	1727	1183
Total			12346	5696	50.18	23567	8725	5975

Impact analysis of infrastructure changes from signalized intersection to underpass is carried out by comparing the results of exhaust emissions in the two traffic simulation scenarios that have been carried out. The results of this comparison will show the impact of changing the signalized intersection to an underpass on vehicle exhaust emissions. Table 5 shows a comparison of total CO, NO_x and VOC emissions under the do nothing and do something scenarios. This comparison shows that there is indeed an impact on vehicle exhaust emissions due to the change of signalized intersection to underpass, such as: a decrease in CO emissions

by 42.5%, an increase in NO_x emissions by 23.3%, and a decrease in total VOC emissions by 37.1%. This result show that infrastructure changes indeed make impact changes for emissions just like previous studies (Anagnostopoulos et al., 2025; Fan et al., 2023; Shaaban et al., 2019; Sharifi et al., 2021).

Table 5. Comparison of Total Vehicle Exhaust Emissions

No	Emissions	Emissions Total (gram)		Deviation	Percentage
		Do Nothing	Do Something		
1	CO	40991	23567	- 17424	- 42.5%
2	NO _x	7075	8725	1650	23.3%
3	VOC	9500	5975	- 3525	- 37.1%

After conducting traffic simulation and exhaust emission analysis using PTV Vissim software, it was found that there is a relationship between changes in speed and total vehicles exhaust emissions. Table 6 shows a summary of the analysis results in the form of vehicle volume, average speed, and total vehicle exhaust emissions under the do nothing and do something scenarios.

Table 3.6 Relationship between Speed and Total Vehicle Exhaust Emissions

No	Approach	Vehicles Volume		Average Speeds (km/hour)		Vehicle Exhaust Emissions (Gram)					
						CO		NO _x		VOC	
		veh/h	pce/h	DN	DS	DN	DS	DN	DS	DN	DS
1	North	2585	1094	28.03	53.03	7875	4527	1359	1676	1825	1148
2	South	3468	1568	22.84	47.74	11284	6488	1948	2402	2615	1645
3	East	1820	985	26.51	51.51	7087	4075	1223	1509	1643	1033
4	West	4473	2049	20.59	48.45	14745	8477	2545	3138	3417	2149
Total		12346	5696	24.49	50.18	40991	23567	7075	8725	9500	5975

DN = Do Nothing; DS = Do Something

It can be seen in Table 6 that on all approaches to the intersection (North, South, East, and West) there is an increase in average speed. Figure 5 shows the relationship of average speed in both scenarios to total emissions, where the blue line in the graph shows the do nothing scenario with an average speed of 24.49 km/h and the orange line in the graph shows the do something scenario with an average speed of 50.18 km/h. Based on the graph in the figure, it is known that CO emissions decreased from 40991 grams to 23567 grams, NO_x emissions increased from 7075 grams to 8725 grams, and VOC emissions decreased from 9500 grams to 5975 grams.

From the graph in Figure 5, it can be seen that there is a significant decrease in CO emissions due to an increase in the total average speed at the intersection. This is in line with the previous study where there is a 44% reduction in emissions due to changes in the shape of infrastructure at roundabouts. It also show that the significant reduction in total emissions is also supported by motor vehicles which produce high amounts of CO, especially when the engine is idling (Anagnostopoulos et al., 2025; Alam et al., 2025; Sigurjonsdottir et al., 2022).

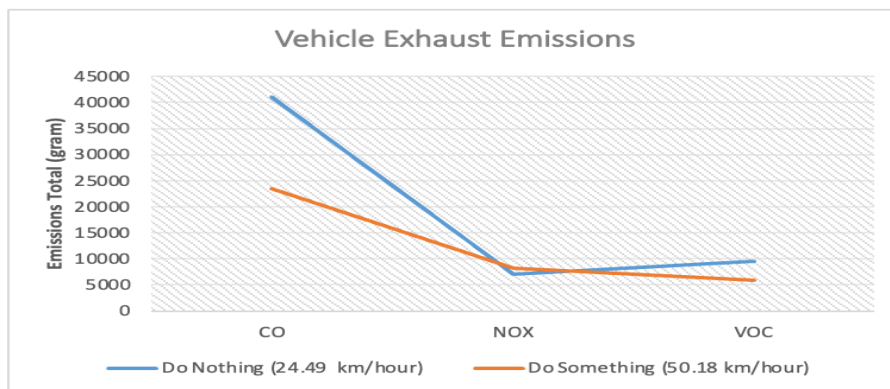


Figure 5. Relationship of Average Speed in Do Nothing and Do Something Scenarios with Total Emissions

The change in infrastructure from signalized intersection to underpass at the study location increased the average total speed from 24.49 km/h to 50.18 km/h with the removal of traffic signals at the intersection that cause control delay, which generally causes the engine to idle for a long time. The elimination of the idling condition, which is the cause of the high total CO emissions produced by motor vehicles, and the increase in average total speed to medium speed (40-60 km/h), which causes the engine to work optimally (Figure 6), caused a significant decrease in total CO emissions at the study location.

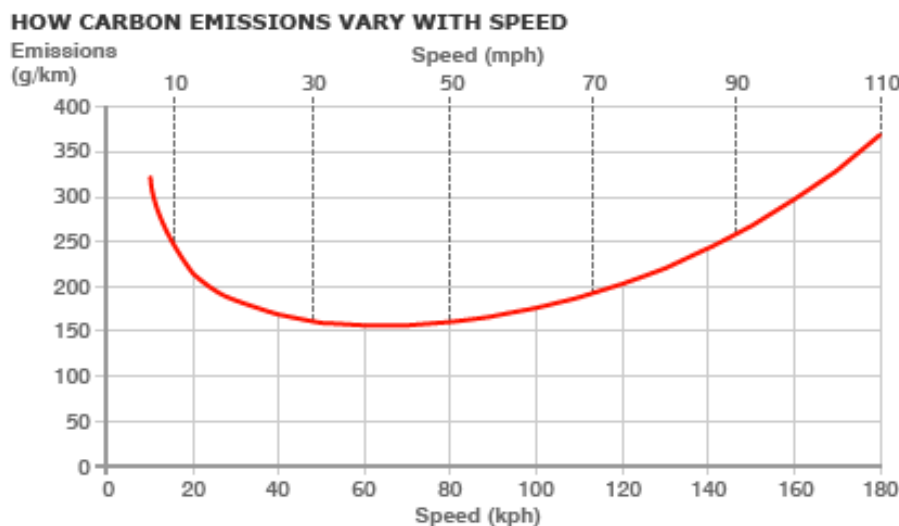


Figure 6. Relationship between Emissions and Speed (BBC News, 2007)

In addition to the significant decrease in CO emissions, Figure 5 also shows that there is an increase in NOX emissions. This increase in NOX emissions is in line with previous study where infrastructure changes from signalized intersections to roundabouts reduced CO emissions but increased NOX emissions. It also show that the increase in NOX emissions is also supported by NOX emissions that tend to increase with increasing vehicle speed (Meneguzzer et al., 2018). It can be seen by the black graph in Figure 3.3.

The increase in total NOX emissions along with vehicle speed is caused by several factors including: (1) Engine Temperature: As the vehicle speed increases, the engine temperature also increases. Higher temperatures cause the fuel combustion reaction to be more intense, which produces more NOx; (2) Air Pressure: At high speeds, the air pressure around the engine

increases, which can increase the combustion reaction rate and produce more NO_x; and (3) Air-Fuel Ratio: Under high-speed conditions, the air-fuel ratio may be unbalanced, which may cause incomplete combustion and increase NO_x emissions.

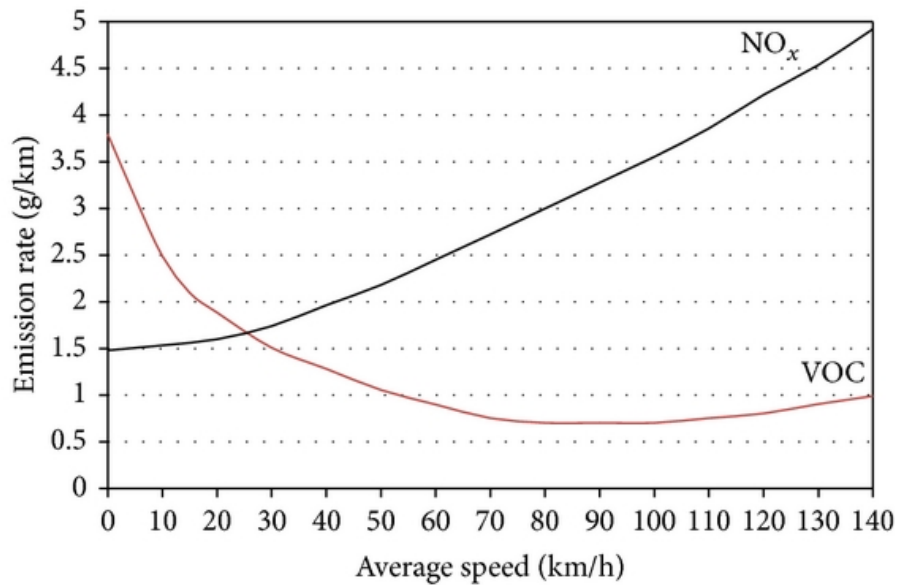


Figure 7. Relationship of NO_x and VOC Emissions to Speed (Nasir et al., 2014)

In addition to CO emissions, Figure 5 also shows that there was a decrease in total emissions in VOC emissions. The difference between the two types of emissions is that CO emissions decreased significantly, while VOC did not. However, the relationship between VOC emissions and vehicle speed is generally not linear and often forms a U-shape, similar to the relationship with CO emissions. It can be seen by the red graph in Figure 7. This is because VOC are organic compounds that are volatile at low temperatures. In the context of motor vehicles, VOC originate from incomplete fuel combustion and fuel evaporation from fuel tanks & systems. Thus, the more optimum the engine runs at medium speed, the lower the emissions.

From the increase of average speed and analysis result of vehicles exhaust emissions, it can summarize that with the same number of vehicles but with different speeds, there will be changes in the amount of exhaust emissions produced by vehicles depending on the type of emissions analyzed. The increase in average speed after the construction of the underpass causes a significant decrease in total emissions in CO type emissions, an increase in total emissions in NO_x type emissions and a decrease in total emissions in VOC type emissions. Of these three types of emissions, the type of emission that is most affected by changes in speed is CO emissions, which experienced a significant decrease in emissions.

Conclusion

Based on the analyses that have been carried out in impact analysis of changing the signalized intersection to underpass on vehicle exhaust emissions at the intersection of Road Ir. H. Juanda - Road Brigjend Katamso, there is indeed an impact on vehicles exhaust emissions because of infrastructure changes from signalized intersection to underpass in study location, such as: a decrease in CO emissions by 42.5% from 40991 grams to 23567 grams, an increase in NO_x emissions by 23.3% from 7075 grams to 8725 grams; and a decrease in VOC emissions by 37.1% from 9500 grams to 5975 grams. These analysis results show that infrastructure changes from signalized intersection to underpass make a better level of vehicle exhaust emissions for CO and VOC, so the Medan City Government's plan to make infrastructure changes by

building underpass at the existing signalized intersection between Road Ir. H. Juanda and Road Brigjend. Katamso has a good impact on air pollution levels by decreasing vehicle exhaust emissions for CO and VOC emissions. Although the infrastructure changes show promising outcomes in reducing CO and VOC emissions, further research is still required to assess its impact on other types of vehicle exhaust emissions using diverse emission categories, multiple calculation approaches, and various analytical methods for comprehensive comparison. Beyond the scope of vehicle exhaust emissions, further research are also necessary to examine the impact of changing signalized intersection to underpass in other relevant fields. This is essential to support informed decision-making regarding whether such infrastructure changes yield beneficial outcomes.

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