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A Study of Roundabout Sustainability using Traffic Simulation - A Case Study at Ayer Hitam Signalised Intersection

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Abstract: Through urban planning and municipal administration, a sustainable city seeks to solve issues of social, environmental, and economic effect. By integrating environmentally friendly options into local infrastructure, many sustainable efforts are made possible. Vehicle emissions from the road traffic have always been considered one of the most significant sources of global issues due to their harmful effects on the environment and human beings. Additionally, it is currently a concern for sustainability, especially in urban areas. This matter has inspired the researchers to simulate various systems to identify factors and provide solutions for the issue of emission. In this study, VISSIM software was utilised to develop a traffic simulation to estimate emissions level at Ayer Hitam's signalised intersection in reference to the intersection type as an independent factor. The signalised intersection and a roundabout were chosen to represent controlled and uncontrolled intersections. It aimed to compare the difference in emissions level between the signalised intersection and roundabout. The results of this study show that roundabouts are more effective in enhancing traffic flow than signalised intersections in terms of travel time, delay, queue and have 48.59% lower for (CO), (NOx) and (VOC) emission. An improvement in vehicle emissions results from this study indicates that roundabouts have the potential to contribute to a more sustainable transportation system and sustainable city.

Keywords: Traffic simulation, intersection, roundabout, vehicle emissions

1. Introduction

The increasing of global urbanization is leading to rapidly growing cities all over the world and it created numerous challenges to maintain sustainable cities and society. Sustainable development implies a balance between social, economic, and environmental development objectives [1] and transportation is one of the important elements in balancing it. Transportation can connect one place to another and allow people to interact with others. Transportation should move passengers and goods efficiently, with least negative impacts on society and environment but it is not easy

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to implement [2]. Compared to others, land transportation is more popular and used in people daily routine. Driving single occupancy vehicle fueled by gasoline and diesel is the norm. This situation contributes to automobile centered at urban and suburban area and it lead to traffic congestion and increases air pollution [3]. It is impossible to ban personal vehicles off the road in the long run since there is still too much reliance on them and their numbers are growing every year. To maintain the sustainability of the city's environment, it is crucial to adapt the infrastructure, especially the road design, to the sustainable concept that can produce fewer vehicle emissions.

Road transportation significantly contributes to air pollution in the urban and rural areas. In recent years, various studies have confirmed that air pollution is one of the most critical problems in the transportation sector. In reference to global warming, an approximate amount of greenhouse gases including 77Gg of carbon dioxide (CO_2) was released from automobile exhaust in 2010[4]. It was then estimated to increase rates of 1.7% in the upcoming twenty years [5]. This is also proved to be affected by vehicle emissions which leads to the impact of photochemical reactions that adversely affect human beings and ecosystems [6]. It's crucial to reduce vehicle emissions in order to lower air pollution exposure for people and ecosystems. Other harm airborne emissions from vehicles include volatile organic compounds (VOC), nitrogen oxide (NOx), and carbon monoxide (CO).

Concentration of air pollution is predominantly expected at congested intersections in urban areas. Numerous factors affect traffic flow disruption and these include geometric configuration, type of control, control delay, traffic volume and drivers' behaviours and at the same time increase the emission rates of vehicles at such locations.

The emission of greenhouse gases by vehicles at congested traffic flow has been claimed to be higher in percentage between the figures of 10% to 200% in comparison to free-flow traffic [7]. Researchers such as Liu et. al. have also reported that emission concentrations are soaring during peak hours over off-peak hours [8], for example Etim [9] once claimed that carbon monoxide (CO) levels during peak hours happen to be 36.3 ppm, meanwhile it is 27.5 ppm during off-peak hours. Additionally, Kumar [10] found the concentration of NOx levels to be 3.6 times greater during peak hours compared with off-peak hours. Numerous studies also indicate that the intersection has the worst air pollution. This is because intersections are places where several roads converge, creating a dense concentration of moving traffic. At intersections, traffic is frequently backed up, causing idling cars and slow-moving traffic. For the road network to be used more sustainably, traffic-related issues at signalised intersections must be resolved.

Vehicle emissions may vary in subject to the traffic, geometric design, vehicle characteristics, atmospheric conditions, and driving behaviour. The configuration of lanes for example has affected the nature of traffic flow and emission rates at intersections through the existence of exclusive lane sets despite being widened or not [11]. In addition to the road configuration, vehicles have a slower speed and longer travel time at congested intersections, causing them to form a queue [12]. At a red light, idling vehicles waste energy and produce more emissions because they are still using fuel but are not moving. This is especially problematic when traffic is heavy because cars may idle for long periods of time at intersections.

Other road geometric design, such as roadside configuration, has a significant impact on driver discomfort and has the potential to influence operating speeds, according to Stamatiadis et al. [13]. Mecheri et al. [14] stated that narrower lanes typically result in slower operating speeds. This might be as a result of the fact that drivers feel more uncomfortable driving at higher speeds in narrower lanes or think that narrower lanes are better suited for lower speeds. In general, lower operating speeds lead to lower emissions because slower moving vehicles use less fuel and produce fewer pollutants. Slower speeds, however, might also result in more congestion, which might have a detrimental impact on emissions of its own.

In China, Bing et al. have explored geometric design and traffic at intersections and these result in the findings of their impact on emissions. They have considered several geometric factors such as lane width, number of lanes and intersection lane configuration as a means to conduct simulation analysis. Further, the free-flow speed of one-traffic related factor has also been taken into account as a means to conduct the similar analysis. In this situation, the intersection lane configuration parameter consists of specific turns, such as a right turn, a left turn, and a u-turn. The researchers have discovered several impacts on emissions which have been highlighted below:

i. Widened lane width has brought on the rise of CO emissions.

ii. Increased numbers of vehicle lanes have resulted in the decrease of all three emissions (what, what, what).

iii. Intersection lane configuration has role in traffic emissions, and

iv. 23-24 mph average speed is associated with the lowest traffic emissions.

Furthermore, the researchers have contended that the change in driving behaviour and operating conditions can be difficult. On the one hand, some geometry and traffic-related factors in regards to highway design and traffic management are believed to be practicable and feasible for emissions reduction.

It is observed that interruptions in traffic flow and vehicle emissions are affected by the cycle of traffic signals at intersections. According to Li et al.,[15], the cycle time of traffic signals has an important role to a preferred distribution of traffic flow. Incompetent cycle time and high traffic capacity often lead to traffic congestion at intersection areas. Vehicles might wait longer at red lights. Drivers may become more impatient as a result, and they may also drive more aggressively or dangerously to make up for lost time. As the cycle time of traffic signals is designed to minimise the total vehicle delay and vehicle stop at intersections without ignoring the effect on the environment, thus it is presumed that optimal cycle time will somehow reduce the duration of vehicle queues and delay time at intersections [16]. Roundabouts have been proposed as a replacement for stop-controlled junctions around the world in order to improve traffic operational and performances [17]. In many countries, this alternative is used to solve traffic problems at various intersections as roundabouts can minimise vehicle delays despite the high frequency of traffic movements [18]. Hence, vehicle emissions can be reduced and accumulated in one area.

The purpose of roundabouts is similar to traffic signals and stop signs as they are believed to control vehicle movements on the road. This facility is perceived as a circular intersection with special design and traffic control features. The features include traffic control for each incoming vehicle, channelled approaches, and designated geometric curves to ensure that travel speeds on a roadway are equivalent to or less than 50 km/h [19]. Interestingly, roundabouts have some advantages in comparison to the other types of intersections. Firstly, it increases traffic capability by reducing conflict points and enhancing the safety of travel. Secondly, a roundabout has high efficiency without signalised control since vehicles shall pass the intersection at a normal pace, eliminating the delay of vehicles caused by a typical signalised intersection. Since vehicles are unexpected to stop at the approach of a roundabout, stop and start movements are decreased and this is somehow opposed to the conventional intersections.

According to Kumar, running a vehicle engine while it is stationary on the road, produce emissions, which are more prominent at signalised intersections [20]. On the contrary, roundabouts are proven to improve the quality of air and noise on the road. Specific geometric parameters are designed to reduce vehicles' speeds and calm the traffic as roundabouts are perceived to be one of the traffic calming methods that are safe and efficient in controlling intersections. The roundabout forces drivers to decelerate as they approach it, veer around its central island and accelerate as they exit the circling traffic [21]. By facilitating roads with roundabouts, this method may reduce exhaust emissions from vehicles compared to other intersection control methods. While roundabouts are typically thought of as an efficient tool for controlling traffic and lowering emissions, they occasionally have adverse effects on congestion and emissions. Poorly designed or located roundabouts can exacerbate congestion and emissions. For example, a roundabout located near a major highway exit or on a busy commuter route can lead to longer queue lengths and delays. In addition, the way drivers behave at roundabouts can affect the amount of traffic and the amount of emissions. Delays, accidents, and higher emissions can result from aggressive or reckless driving, failing to yield to other vehicles, and other dangerous behaviours. Studying the effects of roundabouts on emissions and traffic can help determine whether they can be used as a strategic means of reducing environmental issues at intersections.

Physical experiments to test the effects of changing current signalised intersections to roundabouts are challenging, especially if the study includes testing various traffic scenarios. This is because it is so expensive. The best method for solving the issue will therefore be to use a computer simulation. In this study, the outcomes of the simulation that was run at the Ayer Hitam intersection are discussed. The location of this intersection is in Batu Pahat, Johor, Malaysia.

This study aimed to determine whether converting a signalised intersection to a modern roundabout in Ayer Hitam, Johor Malaysia would result in a reduction in pollution from the traffic. The same parameters were utilised for both simulation environments and compared CO, NOx, and VOC as the effectiveness measures, comparing signalised intersections to modern roundabouts using micro simulations of VISSIM. Interestingly, the hypothesis proved that the converted (modern roundabout) and the existing condition (signalised intersection) were improved in term of vehicle emission gasses.

Reducing vehicle emission gasses will improve air quality. Good air quality will help the environment and provide comfort to city dwellers. When city dwellers feel comfortable doing their daily activities, the economic and social sectors become balanced without neglecting the sustainability of the environment. Choosing the suitable road geometric design is important to preserve environment and help to achieve sustainable transportation system, city and society objectives.

2. Methodology

2.1 Study Site and Data Collection

Ayer Hitam intersection is a 4-leg intersection located in Batu Pahat District of Johor, Malaysia. In the north-south direction, there is an arterial road connecting Kluang to Batu Pahat (Jalan Batu Pahat - Jalan Kluang) and East-West (Jalan Ayer Hitam – Jalan Besar) connecting Kulai to Yong Peng. As the surrounding areas are popular tourist destinations, these have caused more traffic during weekends and public holidays. As a result, conflicts and delays happen every day especially during rush hour. This issue has provided a solid reason to choose this intersection as a case study.

A three-hour sample period was collected from 6.30 am to 9.30am on two different days as a means to record the highest traffic volume for this study. An appropriate angle was selected to set up the video recorder for taking footage of the traffic situation. Next, a camera was installed at the high point of the intersection area to ensure that the video could catch a complete view of traffic flow at that time. Once the intersection was videotaped, the clips were processed to collect volumetric traffic data for VISSIM simulation. Table 1 below shows the data gathered from the videos.

Location of the camera for data collection is shown in Figure 1 meanwhile, a satellite view from Google Earth indicates the study location is in Figure 2.

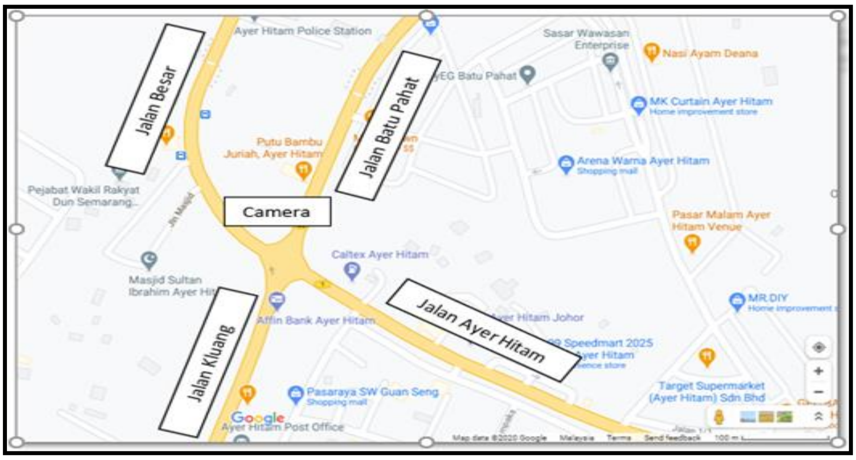

Fig. 1 - Location of camera at Ayer Hitam signalised intersection (Map from Google Earth)

Fig. 2 - Ayer Hitam signalised intersection (map from google earth)

2.2 Research Data

Table 1 and Figure 3 present the basic data and geometrical layout of the intersection. Right turn and left turn lanes were provided on each intersection and based on the measurements, the lane width scaled between 3.5m and 3.8m.

The intersection was governed by 4-phase signal control with 185 seconds per cycle time. Data for signal control at this intersection are shown in Table 2, while other data such as traffic composition, type of vehicle and vehicle movements are shown in Table 3.

Table 1 - Data collected from study sites

Types of data	Data collected
Geometry	Type of intersection Number of lanes Lane width
Traffic	Traffic composition Type of vehicle Vehicle movements
Signal Control	Signal timing group for every phase Signal timing cycle length

Fig. 3 - Geometry at Ayer Hitam signalised intersection

Table 2 shows the signal control phases at Ayer Hitam signalised intersection. Based on the table, all phases shared the similar time period for all red light and amber light. Phase 1 represented signal control from Jalan Batu Pahat direction while Phase 2 signified signal control from Jalan Kluang direction but both arms had the same time period for red light and green light that exhibited 134 seconds for red light and 45 seconds for green light. Signal cycle time for the whole intersection was 183 seconds. Figure 4 shows the signal phases at Ayer Hitam intersection by intersection approach.

Table 2 - Signal control phase at Ayer Hitam signalised intersection

Phase	All Red	Amber	Red	Green
Phase 1	3	3	134	45
Phase 2	3	3	134	45
Phase 3	3	3	149	30
Phase 4	3	3	144	35

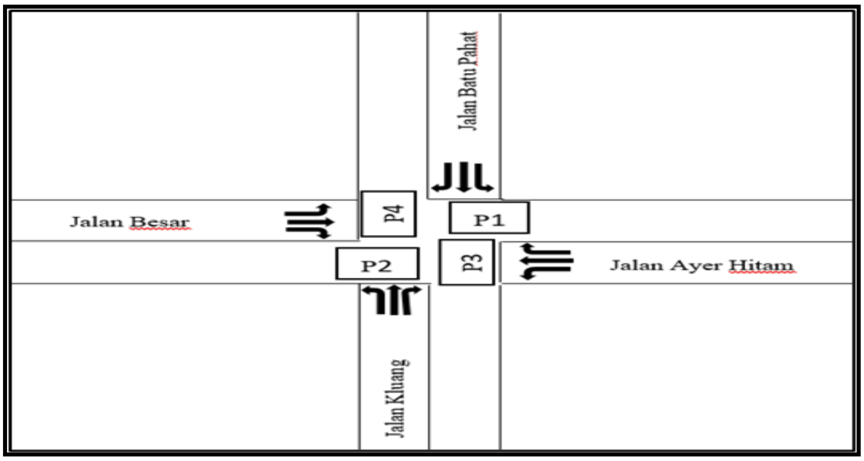

Fig. 4 - Signal phase at Ayer Hitam intersection

Data on turning movement was collected during the peak periods in the morning on a weekday. This indicated the actual traffic distribution across the intersection in the simulation. Data collected by the research team for the one-hour surveys are shown in Table 3.

Table 3 - Traffic composition at ayer hitam signalised intersection

Vehicle movement	**From Batu Pahat**			**From Kluang**			**From Jalan Besar**			**From Jalan Ayer Hitam**		
Movement Direction / Type of Vehicle	Turn Right	Throu gh	Turn Left	Turn Right	Throu gh	Turn Left	Turn Right	Throu gh	Turn Left	Turn Right	Throu gh	Turn Left
Car	238	505	103	135	300	76	129	129	173	75	104	175
Motorcycle	57	114	61	16	41	45	26	96	124	20	43	75
Van/Small Lorries	28	23	6	4	13	3	3	6	4	12	9	14
HGV/Bus	47	54	5	13	38	7	10	28	27	15	16	23
Total	**370**	**696**	**175**	**168**	**392**	**131**	**168**	**259**	**328**	**122**	**172**	**287**
Volume Percent	29.82	56.08	14.10	24.31	56.73	18.96	22.25	34.31	43.44	21.00	29.60	49.40
Total Volume	**1241**			**691**			**755**			**581**		
% Car	64.32	72.56	58.85	80.36	76.53	58.02	76.78	49.81	52.74	61.48	60.47	60.98
% Motorcycle	15.41	16.38	34.86	9.52	10.46	34.35	15.48	37.06	37.80	16.39	25.00	26.13
% Van/Small Lorries	7.57	3.30	3.43	2.38	3.32	2.29	1.79	2.32	1.23	9.84	5.23	4.88
% HGV/Bus	12.70	7.76	2.86	7.74	9.69	5.34	5.95	10.81	8.23	12.29	9.30	8.01

2.3 Traffic Simulation Development

Due to a stochastic microscopic simulation model that can simulate traffic operations in urban areas, VISSIM software was used in this study [22]. VISSIM can transform field data into numbers and mathematical values and simulate complex traffic flow [23]First, a traffic simulation model was created using the Vissim software platform for the network of signalised intersections in Ayer Hitam ,Johor Malaysia. The data collection process generated the necessary data for simulation data input, including the road geometry, relative flow of traffic volume, vehicle volume, routing, and traffic signal cycle at intersection. One of the data inputs for VISSIM simulation was the relative flow of traffic volume for each lane. For each approach, the number of vehicles and the vehicle routing decision were counted and entered into the simulation. Road geometry was observed and measured on the site while the time for each signal phase of the traffic signal cycle was recorded and set in the software. The traffic simulation model involves the following steps:

i. Network Development,
ii. Model Parameters,
iii. Network Calibration and
iv. Model Validation.

2.3.1 Network Development

The creation of a network that precisely replicated the physical characteristics of a test site was a necessary step in this process. This is the most crucial component of the simulation model. Links and connectors are the fundamental elements used in VISSIM to build traffic networks. To symbolise the study site at Ayer Hitam, a signalised intersection with four legs was made. Then, using the Ayer Hitam signalised intersection location as a test model, a network of roundabouts was created.

2.3.2 Model Parameters

Every type of vehicle that is used on the simulation model is dealt with by the vehicle model. The simulation model takes into account the width and length at the study location. In addition, the maximum and minimum desired speeds for each type of vehicle were gathered from the study location and input as parameters. The vehicle composition and vehicle flow based on on-site data collection are used as inputs to simulation models for traffic composition. The Wiedermann 74 Car-following model, which is based on psycho-physical driver behavior, has also been used to simulate vehicle following behaviour in the simulation model in addition to the model development for this study. Summary of input parameters for model development is shown in table 4.

Table 4 - Input parameters for model development

	Types of data	**Data type**
Basic input data	Geometry	Type of intersection
		Number of lanes
		Lane width
		Link length
		Number of lanes in each link
Basic input data	Traffic	Traffic composition
		Type of vehicle
		Vehicle movements
Basic input data	Signal control	Signal timing group for every phase
		Signal timing cycle length
Basic input data	Speed data	Vehicle desired speed
Secondary data	Calibration data	Driver behaviour
		Conflict area
		Traffic volumes
		Delay
		Queue

2.3.3 Network Calibration

Calibration is the process of adjusting the model to replicate observed data and observed site conditions to meet the model objectives of this study. This process involves adjusting the model parameters such as average standstill distance, safety distance and vehicle lane changing. A vehicle stopping gap was employed as a means to calibrate the simulation model. Once a survey and camera observation were conducted, a stopping gap of 2.5m was set as a model of onsite behaviour before the simulation was calibrated. Simulation was performed by using the provided parameter as the input to the simulation model in order to estimate the output. As the output of the current simulation model were traffic volumes, the simulations were then run for a total time of 3600 seconds.

2.3.4 Model Validation

Model validation is the process of comparing the calibrated model's results between simulated values and field measurements for parameters, which can be seen in traffic volumes. The traffic volume and vehicle composition were recorded as inputs to the simulation model. Then, the simulation was performed with three random seed values for 3600 seconds. The average traffic volume simulated by the model was compared to the real data that had been recorded from the study location as a means to check the validity of the model.

After developing and running the simulation models, traffic flow in the models were confirmed by comparing the models with the traffic flow that had been recorded at study location. Traffic simulation models should depict the traffic flow at study location. If traffic flow in the simulation differs from traffic flow at study location, the error from the model needs to be amended before the simulation can be re-run.

On the other hand, a roundabout simulation model was developed using the same volume data. The model was executed to obtain results for roundabout performance in order to evaluate the emissions of both models. These processes needed to be done as a means to determine which intersection would produce the lowest emissions.

3. Results and discussion

3.1 Simulation model from VISSIM

The simulation model will be performed once the parameters input mentioned in the previous section are inserted. Simulations produced by VISSIM can be used to compare the vehicle emissions level between signalised intersection and roundabout. In this study, the same vehicle composition and vehicle speed were employed for both simulations. Simulation models in this software can be seen in 2D and 3D as shown in figure 5,6,7 and 8. The figures show the models that had been developed for both sites. Traffic flow in simulation was compared to traffic flow at study location before the results for vehicle emissions were extracted.

Fig. 5 - Simulation model for Ayer Hitam intersection in 2D

Fig. 6 - Simulation model for Ayer Hitam intersection in 3D

Fig. 7 - Simulation model for roundabout in 2D

Fig. 8 - Simulation model for roundabout in 3D

3.2 Intersection Performance Results

This section explains the situations of vehicle queue lengths, vehicle delays, vehicle travel time and road level of service for the signalised intersection as well as the evaluation of the roundabout after its implementation. All the results for intersection performances related to four approaches at Ayer Hitam signalised intersection can be seen in Table 5, 6, 7 and 8. Moreover, Figure 16, 17 and 18 show the results of comparison between signalised intersection and roundabout.

As vehicle queues took place during red traffic lights, the Batu Pahat - Kluang leg had the longest vehicle queue among all legs. Batu Pahat approach had the highest traffic volume and vehicle queue which made it impossible to completely discharge during green lights. This situation similarly happened at Batu Pahat - Jalan Ayer Hitam route. The other vehicle continued to queue before the previous vehicle managed to clear the traffic. Somehow, this contributed to the long vehicle queues at both routes. However, a different condition happened at Batu Pahat to Jalan Besar and Kluang to Jalan Ayer Hitam routes. They had zero queue due to no traffic signals and vehicle interruption passing through the routes. Only a short queue occured for all routes as vehicles from all sides still had to wait for the roundabout to be clear before they could pass through the circle. As the vehicle queue length affects vehicle delay time, this shows that the longer vehicle queue length on the road, the longer the time spent on their journey. Figure 9 shows the comparison of vehicle queues between the signalised intersection and roundabout.

Table 5 - Vehicle queue results

Movement	signalised intersection (metre)	Roundabout (metre)
From Batu Pahat to Jalan Besar	0	6.17
From Batu Pahat to Kluang	210.80	6.17
From Batu Pahat to Jalan Ayer Hitam	172.35	6.17
From Kluang to Jalan Besar	18.89	1.53
From Kluang to Batu Pahat	24.61	1.53
From Kluang to Jalan Ayer Hitam	0	1.54
From Jalan Besar to Batu Pahat	15.31	7.76
From Jalan Besar to Kluang	0.01	7.76
From Jalan Besar to Jalan Ayer Hitam	17.49	7.76
from Jalan Ayer Hitam to Jalan Besar	9.59	1.55
from Jalan Ayer Hitam to Batu Pahat	0.68	1.55
from Jalan Ayer Hitam to Kluang to Batu Pahat	12.56	1.55

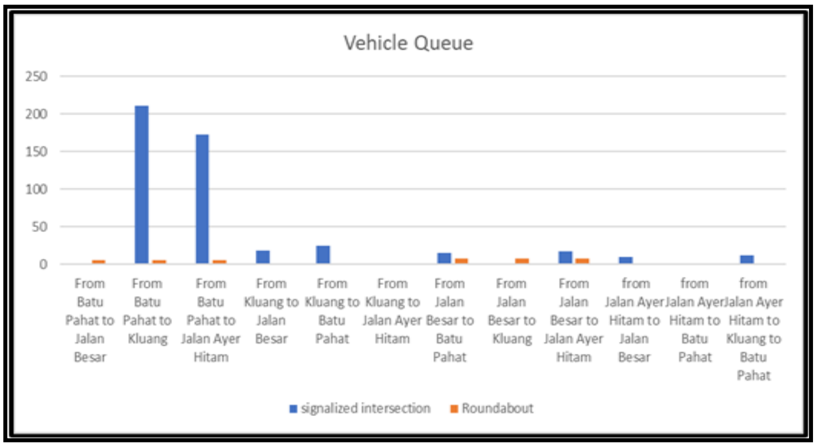

Fig. 9 - Vehicle queue results comparison

Table 6 - Vehicle delay results

Movement	**Signalized intersection (Second)**	**Roundabout (Second)**
From Batu Pahat to Jalan Besar	126.77	0.95
From Batu Pahat to Kluang	152.83	1.07
From Batu Pahat to Jalan Ayer Hitam	155.66	0.91
From Kluang to Jalan Besar	52.78	0.94
From Kluang to Batu Pahat	54.26	0.85
From Kluang to Jalan Ayer Hitam	7.34	0.69
From Jalan Besar to Batu Pahat	55.27	4.07
From Jalan Besar to Kluang	2.37	4.70
From Jalan Besar to Jalan Ayer Hitam	57.69	4.81
from Jalan Ayer Hitam to Jalan Besar	52.02	0.82
from Jalan Ayer Hitam to Batu Pahat	2.63	1.14
from Jalan Ayer Hitam to Kluang to Batu Pahat	56.89	0.37

Vehicle delay in simulation is defined as average total delay per vehicle in seconds. In simulation, the total vehicle delay is recorded for every vehicle after each vehicle completes the travel time section. Table 6 shows the results from delay output in simulation for signalized intersection and roundabout. Figure 10 shows vehicle delay time decreased at roundabout for all routes except Jalan Besar to Kluang. This situation happened because vehicles from Jalan Besar needed to wait for vehicles from Batu Pahat to pass through Batu Pahat-Kluang route before they could enter the route due to high traffic volume from Batu Pahat approach. Additionally, the Batu Pahat approach also had a high delay time as shown in Figure 10. As total vehicle travel time is related to vehicle delay time, this shows that the longer vehicle time spent on the road, the higher the time travel to their destinations. The simulation results below indicate that the vehicle travel time at the roundabout was minor compared to the situation at the signalized intersection.

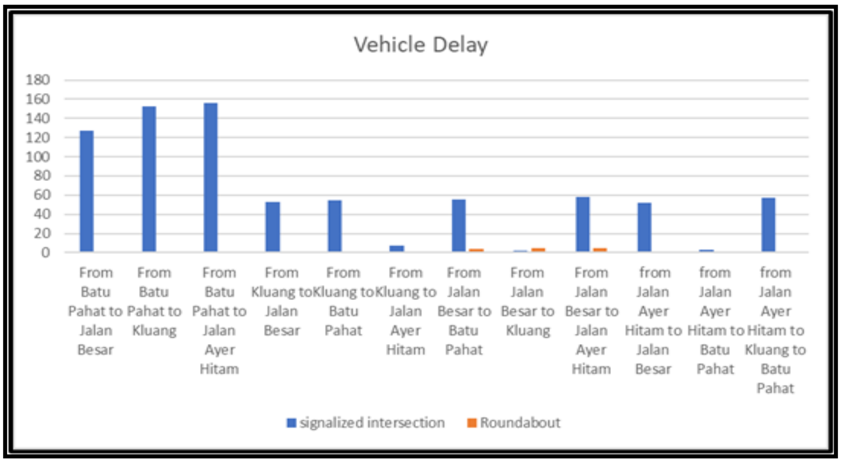

Fig. 10 - Vehicle delay results comparison

Table 7 - Vehicle travel time results

Movement	**Signalized intersection (Second)**	**Roundabout (Second)**
From Batu Pahat to Jalan Besar	175.06	42.83
From Batu Pahat to Kluang	207.28	47.09
From Batu Pahat to Jalan Ayer Hitam	212.87	53.68
From Kluang to Jalan Besar	98.59	45.42
From Kluang to Batu Pahat	103.75	40.63
From Kluang to Jalan Ayer Hitam	48.51	36.75
From Jalan Besar to Batu Pahat	103.09	51.81
From Jalan Besar to Kluang	39.86	42.19
From Jalan Besar to Jalan Ayer Hitam	108.07	49.79
from Jalan Ayer Hitam to Jalan Besar	103.89	43.52
from Jalan Ayer Hitam to Batu Pahat	47.59	38.89
from Jalan Ayer Hitam to Kluang to Batu Pahat	108.33	46.52

Theoretically, travel time can be defined as the duration for a vehicle to reach its destination when there is no obstacle on the road. This obstacle can be implicated by accidents and traffic jams. However, when vehicles reduce speed during passing, they will also reduce the speed in the area. Figure 11 illustrates that the travel time for the roundabout was shorter than the signalised intersection for all routes. Unfortunately, this did not happen at Jalan Besar to Kluang route due to the high traffic volume at Batu Pahat approach. High traffic volume made Batu Pahat traffic to all routes the longest vehicle travel time. The amount of time spent for a vehicle in travelling is one of the important parameters to measure the traffic level of service (LOS).

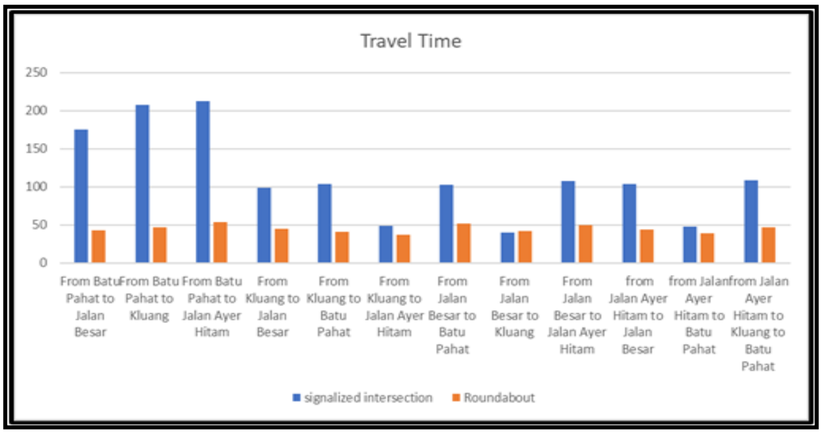

Fig. 11 - Vehicle travel time results comparison

Meanwhile, level of service can be described as the operation of the intersection based on vehicle delay measurement. Highway Capacity Manual provides a procedure to measure level of service on the road. The manual divides traffic quality into six levels of service which range from A to F. Level A represented a good quality of traffic while level F stood for the worst traffic quality. A good traffic quality can be perceived when a driver has the freedom to drive their vehicle at free flow speed. Table 8 shows the difference in level of service between signalised intersection and roundabout for twelve routes at Ayer Hitam. The roundabout showed a better level of service than the signalised intersection except for Jalan Besar to Kluang due to high vehicle delay time.

Table 8 - Intersection level of service (LOS) results

Movement	Signalized intersection	Roundabout
From Batu Pahat to Jalan Besar	LOS F	LOS A
From Batu Pahat to Kluang	LOS F	LOS B
From Batu Pahat to Jalan Ayer Hitam	LOS F	LOS B
From Kluang to Jalan Besar	LOS E	LOS A
From Kluang to Batu Pahat	LOS E	LOS A
From Kluang to Jalan Ayer Hitam	LOS B	LOS A
From Jalan Besar to Batu Pahat	LOS E	LOS B
From Jalan Besar to Kluang	LOS A	LOS B
From Jalan Besar to Jalan Ayer Hitam	LOS E	LOS_C
from Jalan Ayer Hitam to Jalan Besar	LOS E	LOS_A
from Jalan Ayer Hitam to Batu Pahat	LOS B	LOS_A
from Jalan Ayer Hitam to Kluang to Batu Pahat	LOS E	LOS A

3.3 Vehicle Emission Results

In this study, the vehicle emissions found were CO, NOx and VOC. The emissions units were reported based on vehicle grams per vehicle miles travelled (grams/VMT). The results are presented in table 9 and Figure 12.

Table 9 - Vehicle emission results from vissim

Emission type	signalised intersection	Roundabout	% of Difference
CO (grams/VMT)	16951.26	8713.33	48.59
Nox (grams/VMT)	3298.10	1695.30	48.59
VOC (grams/VMT)	3928.62	2019.40	48.59

Table 9 shows that carbon dioxide (CO), nitrogen oxides (NOx) and volatile organic compound (VOC) emission at the intersection was 48.59 % higher than at roundabout. This situation proved that congested traffic flow had increased vehicle emission. Compared to the situation at the roundabout, traffic flow at the signalised intersection was slow. Vehicles took time to clear the area due to traffic signals. Meanwhile, vehicles were not required to stop and wait for a long time at the roundabout to continue their journey, so the route was cleared from vehicles thus reducing emissions. However, based on the previous research, not all roundabouts are reliable in reducing vehicle emission better than signalised intersections. It was claimed that the situation would depend on the traffic flow and location intersections. Results from previous research shown in table 10.

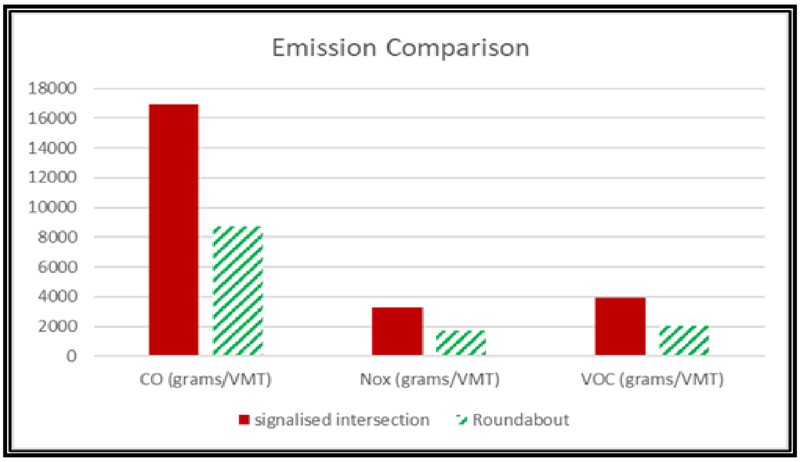

Fig. 12 - Vehicle emission results comparison

Table 10 - Results emission at signalised intersection vs roundabout from previous research

Researcher	Emission	Signalised intersection (grams)	Roundabout (grams)	%Difference
(Meneguzzer et al., 2017)[24]	CO	0.13203	0.09827	+25.57
	NOx	0.06081	0.09079	-49.30
(Meneguzzer, et al., 2018)[25]	CO	0.15310	0.10189	+33.45
	NOx	0.6342	0.8967	-41.39
(Shaaban et al., 2018)[26]	CO	67450	107770	-59.78
	NOx	5500	9400	-70.91
(Hatice G. Demir and Yusuf K. Demir,2020)[27]	CO	821	780	+49.93
	NOx	223	216	+31.39
(Kutlimuratov et al., 2021)[28]	CO	7791.01	9458.50	-21.40
	NOx	1515.85	1840.19	-21.40
	VOC	1805.64	2191.99	-21.40
Current study	CO	16951.26	8713.33	+48.59
	NOx	3298.10	1695.30	+48.59
	VOC	3928.62	2019.40	+48.59

Figure 13,14,15 and Table 10 show the emission rates are different between this study and the other five study locations from other researches in regard to intersection types, geometry, and traffic flow, respectively. Emission rates are believed to increase together with high traffic delay, but this hypothesis differs for every location. When the traffic demand increases, this leads to the delay of traffic flow and as result, the average emission rates increase for both roundabouts and signalised intersections. Furthermore, the number of lanes on the road and poor traffic signals phases will also lead to the higher emission rates at signalised intersections. It happens when a part of vehicles arrive before the queue has cleared and are required to stop at the next signalised intersection due to poor phases of traffic lights. These stop-and-go cycles for deceleration and acceleration action result in higher emission rates at signalised intersections instead of roundabouts.

Roundabout emission rates are expected to decrease at an approximately rate for the same traffic flow and volume. However, some locations portrayed otherwise as it was assumed that the signalised intersections at that location might have good traffic signal phases and traffic performance. In this case, the roundabout had higher emission than the signalised intersection.

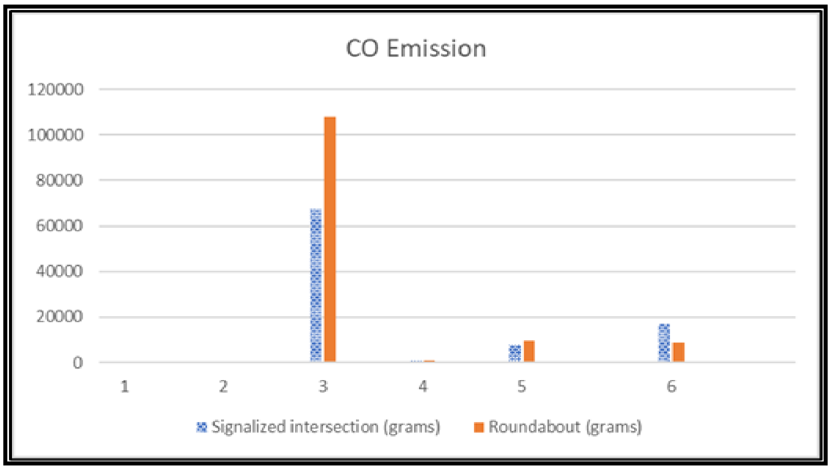

Fig. 13 - Vehicle emission results comparison (CO)

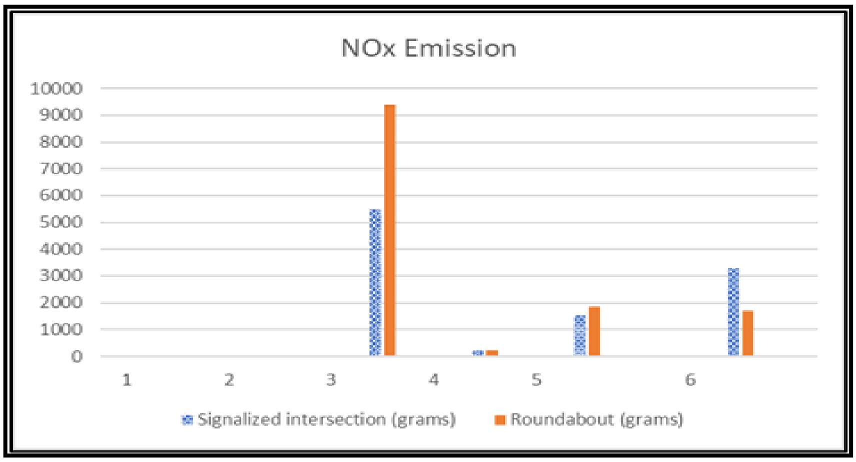

Fig. 14 - Vehicle emission results comparison (NOx)

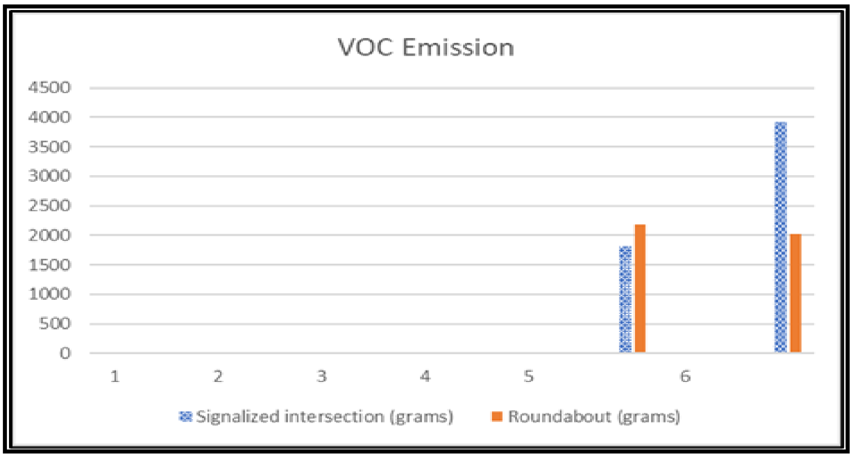

Fig. 15 - Vehicle emission results comparison (VOC)

Table 11, 12 and 13 indicate the emission results for each route at Ayer Hitam intersection. Figures 16, 17 and 18 specify the comparison between CO, NOx and VOC emission at signalised intersection and roundabout at the location. The convenience of a roundabout based on the findings of this study was the smoothness of traffic flow. This could be done due to the minimisation of traffic delay on the road. With similar traffic volume, the roundabout had better performance than signalised intersection.The results in Table 11, 12 and 13 show the effect of intersection types and traffic operations on emission rates that seemed to be significant for CO, NOx and VOC. In regards to the traffic flow and vehicles passing by the intersections; a continuous movement at the roundabout was dependent on drivers' behaviour and judgement. Meanwhile, drivers at the signalised intersection were controlled by traffic signal phases.

Another factor that influenced the emission rates was the number of lanes at the intersection. In this situation, the number of lanes for both scenarios are the same, which was two lanes. Based on the simulation that had been demonstrated, it was proven that more advantages could be seen at the roundabout by looking at the traffic performances and emission reduction compared to the signalised intersection even though both of them happened to implicate the same traffic volume

Table 11 - Vehicle emission results from vissim (CO) by approach

Movement	Signalized intersection	Roundabout
From Batu Pahat to Jalan Besar	526.85	206.55
From Batu Pahat to Kluang	2906.78	826.52
From Batu Pahat to Jalan Ayer Hitam	1506.85	613.53
From Kluang to Jalan Besar	352.80	183.87
From Kluang to Batu Pahat	820.87	390.47
From Kluang to Jalan Ayer Hitam	175.22	182.52
From Jalan Besar to Batu Pahat	315.13	231.38
From Jalan Besar to Kluang	343.36	425.92
From Jalan Besar to Jalan Ayer Hitam	621.03	491.72
from Jalan Ayer Hitam to Jalan Besar	417.41	240.67
from Jalan Ayer Hitam to Batu Pahat	376.19	396.91
from Jalan Ayer Hitam to Kluang to Batu Pahat	289.19	167.56

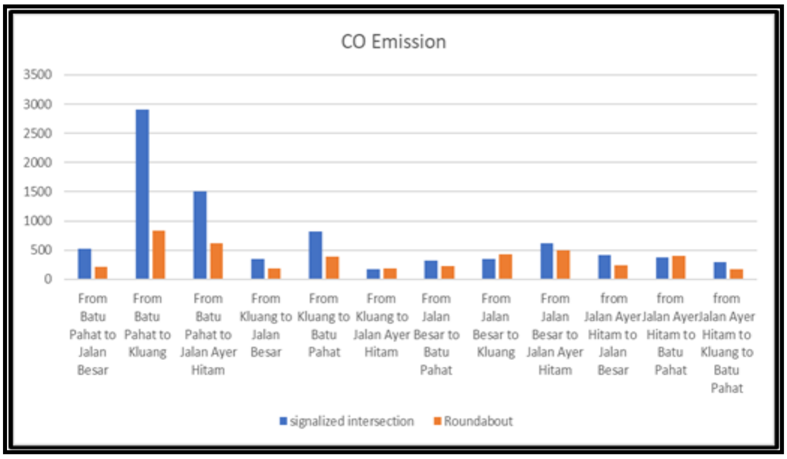

Fig. 16 - CO emission results comparison

Table 12 - Vehicle emission results from vissim (NOx) by approach

Movement	Signalized intersection	Roundabout
From Batu Pahat to Jalan Besar	102.51	40.19
From Batu Pahat to Kluang	565.55	160.81

From Batu Pahat to Jalan Ayer Hitam	293.18	119.37
From Kluang to Jalan Besar	68.64	35.78
From Kluang to Batu Pahat	159.71	75.97
From Kluang to Jalan Ayer Hitam	34.09	35.51
From Jalan Besar to Batu Pahat	61.31	45.02
From Jalan Besar to Kluang	66.80	82.87
From Jalan Besar to Jalan Ayer Hitam	120.83	95.67
from Jalan Ayer Hitam to Jalan Besar	81.21	46.83
from Jalan Ayer Hitam to Batu Pahat	73.19	77.22
from Jalan Ayer Hitam to Kluang to Batu Pahat	56.27	32.60

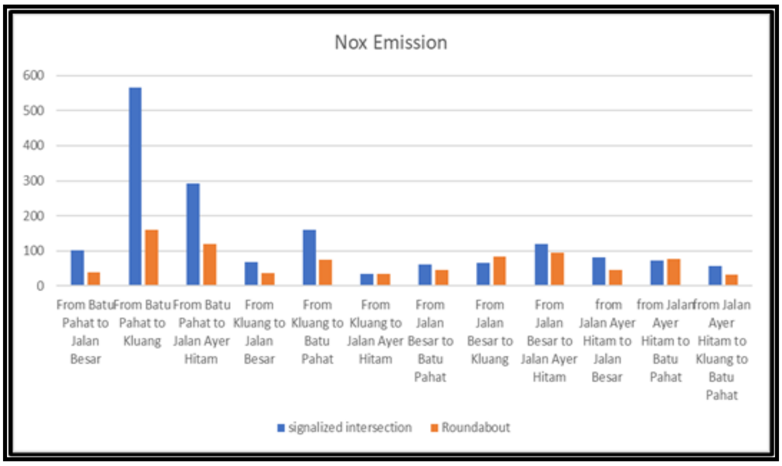

Fig. 17 - NOx emission results comparison

Table 13 - Vehicle emission results from vissim (VOC) by approach

Movement	Signalized intersection	Roundabout
From Batu Pahat to Jalan Besar	122.10	47.87
From Batu Pahat to Kluang	673.67	191.55
From Batu Pahat to Jalan Ayer Hitam	349.23	142.19
From Kluang to Jalan Besar	81.77	42.61
From Kluang to Batu Pahat	190.24	90.49
From Kluang to Jalan Ayer Hitam	40.61	42.30
From Jalan Besar to Batu Pahat	73.03	53.63
From Jalan Besar to Kluang	79.58	98.71
From Jalan Besar to Jalan Ayer Hitam	143.93	113.96
from Jalan Ayer Hitam to Jalan Besar	96.74	55.78
from Jalan Ayer Hitam to Batu Pahat	87.19	91.99
from Jalan Ayer Hitam to Kluang to Batu Pahat	67.02	38.83

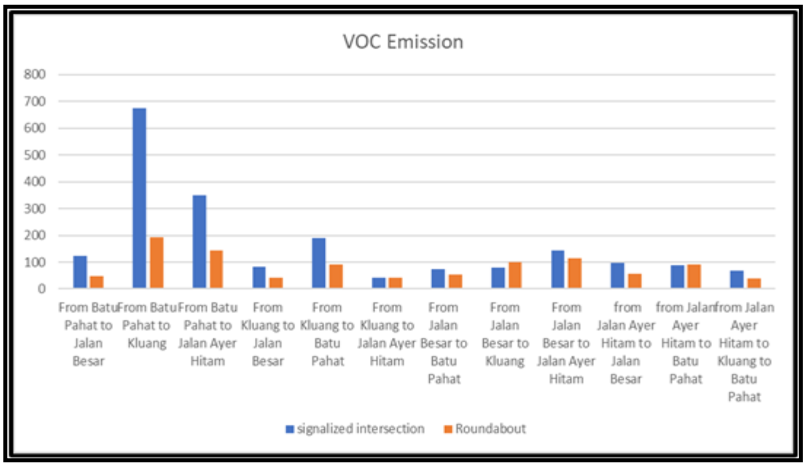

Fig. 18 - VOC emission results comparison

4. Conclusion

Although the signalised intersections are expected to improve the road users' safety and reduce traffic accidents, they could not avoid the occurrences of traffic congestion. This happens as traffic signals lead to the increase of vehicle queue, delay and travel time. Not only that, when the level of service has worsened, this leads to a higher level of vehicle emission.

It's important to note that many of roundabout negative effects are preventable with appropriate design, instruction, and enforcement. The negative effects on congestion and emissions can be reduced by designing roundabouts that are appropriately sized and situated, promoting safe pedestrian and cycling access, and encouraging safe and responsible driving behaviour. In general, roundabouts are still a useful tool for controlling traffic flow and lowering emissions in many situations, despite the fact that they can have adverse effects on congestion and emissions in some circumstances.

This paper has evaluated the connection between vehicle emission level and intersection network performances at roundabout and signalised intersection. In order to carry out this experiment, a simulation model was employed in order to visualise the real intersections. Vehicle emissions of NOx, CO and VOC were recorded throughout the analysis. Results shows that vehicle emission from roundabout intersection is 48.59% lower than signalised intersection. This study has supported the notion that installing roundabouts can increase intersection network efficiency and lower car emissions. Implementing the roundabout could thereby improve transportation system and the city's sustainability.

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