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Effect of Intersection Control Type on Vehicle Emissions: A Case Study in Egypt

Ibrahim M. I. Ramadan[a], Osama H. Ahmed[a] and Mohamed S. Abdel-monem[a¶]
[a]Civil Engineering Department, Faculty of Engineering, Benha University

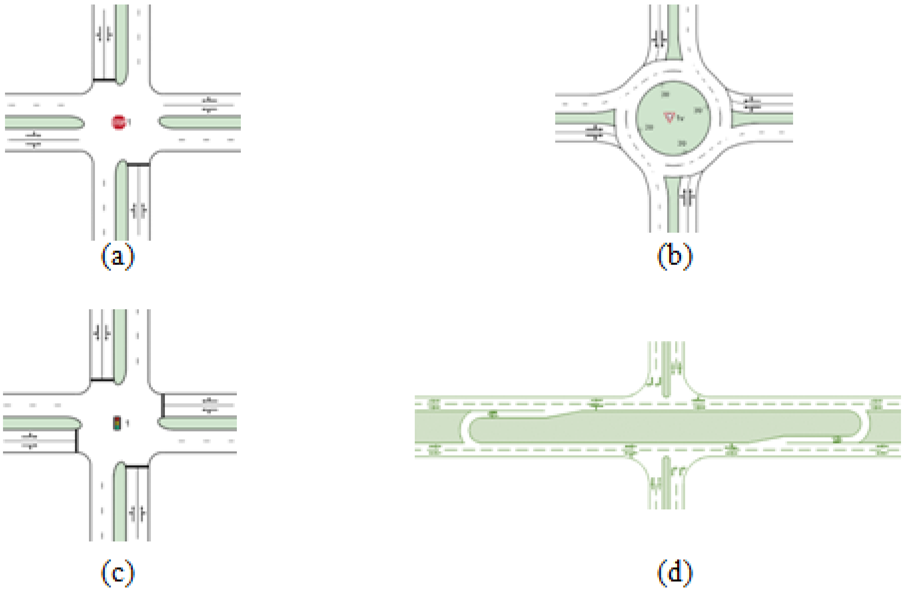
Abstract The climate change due to transport projects has received a great attention in the recent decade. Any new transport project should be planned not only for its physical aspects as right-of-way, cost and safety, but also for its impact on the environment. The environmental quality degradation substantially increases the cost of this project. In Egypt, the choice of intersection control type in a new project depends only on the performance and the cost. This study focuses on the environmental aspect as a comparisonscreen for the intersection evaluation. The study investigatedfour intersection types including; two-way stop control, midblock U-turn, roundabout and traffic signal intersections in terms of the environmental influences. On-board measurements from test vehicles including; speed, time, position, fuel consumption and emissions of CO_2, HC, NO_X and CO have been collected. By using statistical methods, the differences in fuel consumption and emission contribution have been estimated and compared for each type of intersection. The study found that two-way stop control intersections and midblock U-turnsexert low fuel and low emissions in lighttraffic. In medium traffic volume, the roundabout would be the suitable alternative. As the traffic volume increases, the roundabout experiences a significant increase in delays and emissions compared to the traffic signal intersection. In this case, traffic signal would be the best choice.

KEYWORDS**:** Intersection, Control Type, Vehicle Emission, Fuel Consumption

1. INTRODUCTION

Intersection type selection means that we need to evaluate several intersections against several criteria to determine the most suitable alternative. This alternative should path through screening process to evaluate the performance of each alternative. For example, intersection projects should consider right-of-way, environmental, cost, and safety aspects. These are the targets that will be used to compare alternatives. Although environmental damages increase the cost of any project, most proposed transport project is planned only for its physical aspects as operational performance, cost and safety. It is neglecting the impact of fuel consumption and the air pollution. In last years, air quality and saving in fuel consumption received an increasing attention and researches practice. Intersection is considered a critical element in the street networks that impact the air quality. Intersection control type significantly influence emissions rates and fuel consumption [1]. At intersections, especially in congestion areas as the case of Greater Cairo Region, vehicles experience a significant increase in delay, slow down, numerous stops, and thus exert interrupting driving patterns. Several studies have recommended that roundabouts are safe and efficient and can improve traffic flow compared to other types of intersection control [2]. In Egypt, there is a rapid development in urban areas what means a lot of new intersections and a large amount of air pollutants. Emissions such as carbon dioxide (CO_2) has aggravated Green House Gases effect on the universal. In the previous studies of emission models, most of them used only the historical data to develop the required emission models. The use of real-world emission data is still rare in developing these models.

The main purpose of this study is to compare the different intersection types in terms of fuel consumption and emission rates. But first, there is a need to develop fuel consumption and emission models. These models will be necessary to quantify the impact of each intersection on air quality. To accomplish this purpose, a large amount of real-world emission measurements was collected by using test cars and GPS data. These tools were used to extract the instantaneous emission rates and fuel consumption data. The on-board measurements were gathered by the Egyptian Environmental Affairs Agency. Second-by-second data for position, fuel consumption and the emissions of nitrogen oxides, hydrocarbons, carbon monoxide and carbon dioxide were measured. These data were fed to SPSS software to develop emission and fuel consumption regression models. The models were used to evaluate the impact of the different intersection types on air quality. The study investigated four intersections including; two-way stop control, midblock U-turn, roundabout and traffic signal intersections as shown in Fig. 1.



(a) Two-way stop (b) Roundabout
(c) Traffic signal (d) Median U-Turn

FIG 1. Intersection configurations.

2.LITERATURE REVIEW

There are a lot of variables that influence vehicle energy and emission rates near intersections. Many literatures were reviewed to well identify factors that impact fuel consumption and emission rates near intersections. Ahn et al. [3] conducted experiments to collect data from site and dynamometer for modeling emission rates and fuel consumption as a function of the acceleration and the speed. The models gave good prediction for fuel consumption and emission rates. Rakha et al. [4] demonstrated that the microscopic emission models can be applied for both field and simulated records for speed and acceleration. The study demonstrated that emissions are sensitive to the combined effect of acceleration and speed. The study proved that models based only on the average speed failed to compute the impact of drive modes on the measure of effectiveness. Ding et al. [5] noted that speed and acceleration are two essential variables to estimate emission rates and fuel consumption. These two variables account for62.0 % to90.0 % of the squared error (R^2) for all MOEs. The study concluded that number of stops, speed, acceleration, and kinetic energy are important variables to estimate emission and fuel consumption. The models computed fuel consumption and emissions of CO, HC, and NO_x to about 0.96 of emission estimates.

Bokare and Maurya [6] demonstrated that emissions as HC, CO and NO_x are sensitive to speed at the same acceleration level. The study proved that, at the same acceleration level, emissions initially decrease with increase in speed and then increase with further increase in speed. Also, emissions are found to increase with the increase in acceleration . Sharma et al. [7] manipulated data to develop emission rate models in the form of second-degree polynomial function by using speed as anindependent variable. They employed three test cars, namely; car, suv and truck. The emission rates for these three types of carsfor emission of CO_2, CO, HC and NO_xwere developed. The speed levels and the emission rates showed very strong correlation. The correlation for the emissions were found satisfactory by considering experimental errors (R^2) between 0.32 for CO to 0.95 for CO_2.

Boubaker et al. [8] selected the roundabout and signalized intersections in their study. They developed fuel consumption and emission models with a traffic simulator. The model for the roundabout took into account the traffic volumes. The result of the model underscores the effect of intersection type in fuel consumption and emissions. They noted that the roundabout reduces emissions and can improve environment quality. Ahn et al. [9] compared the stop control, traffic signal and roundabout intersections. They demonstrated that, roundabout on high-speed approaches does not necessarily save fuel consumption and reduce emissions compared to other intersection types. They found that roundabout intersections produced significant increases in fuel consumption and emission rates relative to two-way stop control intersections. Emissions for HC, CO, NO_x, and CO_2 increased with values 344.0%, 456.0%, 95.0%, and 10.0% respectively. In additions, the roundabout fuel consumption increases 18% with compared to the two-way stop-controlled intersection. The study demonstrated that signalized intersections were the best alternative when traffic volume increased. The roundabouts produced higher fuel consumption and emission rates when compared to the signalized intersections.

Meneguzzer et al. [10] assessed the effects of replacing the signal intersection with the roundabout intersection on pollution rates. They used experimental vehicles equipped with a portable emission measurement system that study the CO_2, CO and NO_x. They found that emission of CO and CO_2 are generally lower for the roundabout than for the signal intersection, while NO_x emission arises opposite results. They demonstrated that driver behavior and trip direction have a great impact on the pollutants. Hallmark et al. [11] measured emission with two drivers inside two roundabouts, two four-way stop controlled and two signal intersections. They compared the air quality impacts for signal, four-way stop, and roundabout intersections. The study concluded that roundabouts do not necessarily perform better than the other intersection type of control. They also noted that the results varied by the type of pollutant and the driver behavior.

Salamati et al. [12] suggested an empirical macroscopic model to compare the emission at roundabout intersection and signal intersection. Their method was based on vehicle specific power. Their model can estimate the rate of NO_x, CO_2, CO, and HC. The model took into account signal timing, demand-to-capacity ratio and signal progression characteristics. They concluded that roundabout intersection produces less emissions than traffic signals under low demand. However, when demand reaches capacity, signal intersection generates lower emission than roundabout.

3. MATERIAL AND METHOD

Figure 2 shows the proposed methodology that followed to compare the different intersections control types in terms of emission rates and fuel consumption. The process included data collection, dependent and independent variables identification and development models from fuel consumption and emission data.

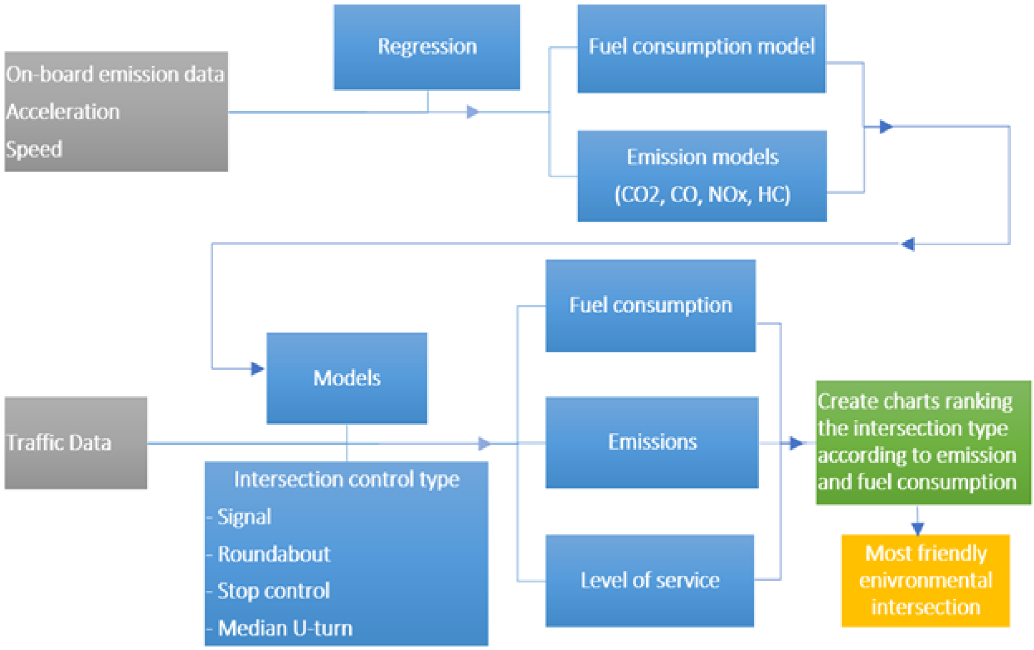


FIG 2. Proposed methodology to develop regression model

3.1 Data Collection

In developing an emission model, it is necessary to collect second-by-second emissions data from a sample of vehicles to build a model that predicts emissions for the national fleet. Compared with conventional dynamometer testing under controlled conditions, on-board data reflect real driving situations. The Data of on-board instruments can facilitate the process of emission models development. A variety of data were collected to capture emissions and vehicle activities. The field measurements were gathered bythe Egyptian Environmental Affairs Agency (EEAA)in Greater Cairo Region.

A total of four vehicles working with gasoline were recruited and tested. These four vehicles are representative of current internal combustion engine technology. The vehicle model years ranged from 1990to 2015.The vehicles were carrying equipment composed of two on-board gas analyzers, a laptop computer equipped with data software, a power supply unit, a tailpipe attachment and other accessories. These vehicles were selected in order to produce an average vehicle that is consistent with the average vehicle in terms of engine, weight, and vehicle type. The number of data points ranged from 3,800 to 11,102. The total length of the travelling trips is approximately 180.0 km along urban streets. The trips included driving through more than 200 intersections of different types of control.

The collection process used two instruments. One measures the speed profile and the other measures the tailpipe emission. The Global Positioning System (GPS) was used to record the vehicle location and speed, and the gas analyzer was used to collect the measurement of tailpipe emissions. Second-by-second measurements of nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), temperature, pressure, and fuel consumption (FC)were measured. A total reading of 34,611 gasoline exhaust points was recorded for the four vehicles.

The authors hypothesized that the results and the recommendations from this study could be applied for the other vehicles even though the magnitude of fuel consumption and emission rates would be different. The authors realize that continuous enhancements to the predicted fuel and emission models are required. It is very important to relate fuel consumption and emissions to intersection improvement projects that are used by traffic analysts to enable them to choose the proper measures that save the environment.

For a more comprehensive assessment of the relationship between intersection control type, fuel consumption, emissions, speed trajectories, and LOS,more data were collected from 19 intersections in Greater Cairo. The data covered5two-way stop control intersections, 5 roundabouts, 5 U-turns and 4traffic signals. Data over peak traffic condition in morning peak and afternoon peak from 7.00 to 9.00 and from 15.00 to 17.00 were separated.

Traffic conditions along each intersection were collected. Average emission rates were compared for the four types of traffic control. After aggregation of the instantaneous data, each intersection was characterized by the available information such as speed profile, acceleration, travel time, traffic volume, delays, and various MOEs. To isolate the effect of each intersection control type, the collected data were downloaded and integrated into a geographic information system. A constant distance of influence was identified for each intersection so that the evaluation could be consistent.

MOEs were compared over an influence distance that included a 200 m long segment consisting of 100 m upstream and 100 m downstream of the center of the intersection. Since vehicle activity varied for each intersection, varying amounts of MOE data resulted for each intersection. The authors assumed that the conditions experienced by each driver were similar because the corridors and the intersections experienced by all drivers were similar. The MOEs for each intersection were summed, resulting in the total MOEs for each intersection. A level of service (LOS) was estimated for each intersection based on delay.

3.2Dependent and Independent Variables Identification

Numerous variables influence vehicle energy and emission rates near intersections. These variables can be classified into categories as follows; travel, weather, vehicle, road, traffic and driver factors. Distance and number of trips are travel factors, while the weather factors account for temperature and wind effects. Vehicle factors account for the engine size, the condition of the engine, whether the vehicle is equipped with a catalytic converter and whether the air conditioning is working. Road slope and surface roughness are road factors, while the traffic factors account for vehicles relation and vehicles interaction. Finally, the driver factors account for differences in driver behavior.

Ding et al. [5] demonstrated that the use of average speed alone is insufficient for the estimation of vehicle emission. They proposed models that are consistent with microscopic fuel and emission models. The model's estimation is based on the vehicle instantaneous speed and acceleration. Ahn et al. [13]study indicated that the vehicle fuel consumption rate is more sensitive to cruise speed levels than to vehicle stops. The vehicle stops that are represented by the different acceleration and deceleration levels have a significant impact on vehicle emission rates. Carbon monoxide (CO) and Hydrocarbon (HC) emission rates are highly sensitive to the level of acceleration when compared to speeds in the range of 10–120 km/h. The impact of the deceleration levels on MOEs was small when compared with the other factors in their study. Also, the study demonstrated that the increase in the speed limit could have extremely negative environmental impacts.

In Egypt, the current emission models attempt to account for road, weather, and vehicle factors on emissions. These models can't capture the effect of traffic and driver factors on vehicle emissions. The models use average speed and vehicle travelled distance to estimate the emission. Consequently, the current emission models failed to evaluate the environmental impact of the operational level projects. The analysis of the collected speed data in Greater Cairo demonstrated that most vehicles are operating in acceleration and deceleration modes most of time as shown in Fig. 3. The literature review and the study reveal that all factors being constant in Cairo region conditions, speed and acceleration do have a significant impact on vehicle emission rates. The massive amounts of recorded data were further analyzed. Differences in vehicle positions with time were used to calculate vehicle speed. Differences in vehicle speed with time were used to calculate vehicle deceleration and acceleration. The fuel consumption and emission rates were provided for a range of speeds from 0 to 60 km/h and for a range of accelerations from −2 m/s2 to 3 m/s2. These data included typical driving conditions that ranged from decelerating to idling to acceleration.

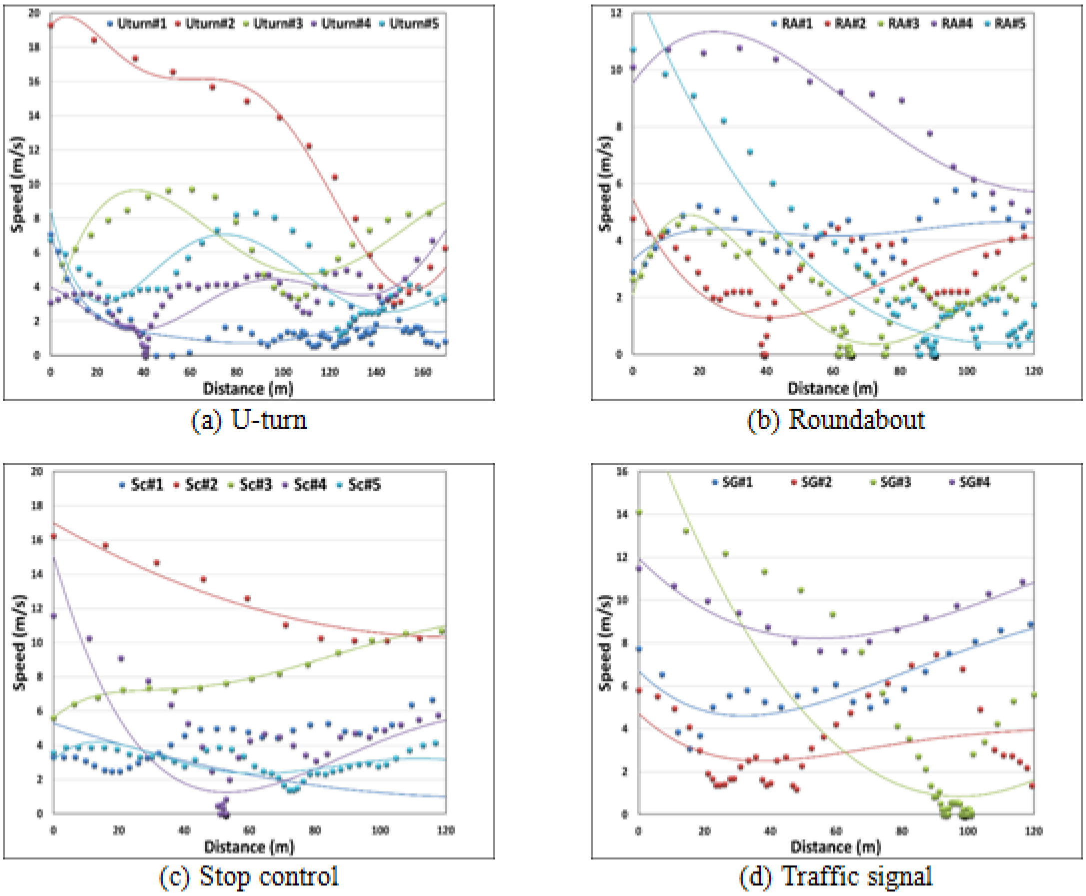


FIG 3. Speed profiles

3.3Modelling Fuel Consumption and Emission Data

Regression models in SPSS software were used to build the fuel and emission models. Linear, quadratic and cubic terms of speed and acceleration were evaluated. In these models, emissions and fuel consumptions were the dependent variables and speed and acceleration were the independent variable. The final models included third-degree polynomial equations.

4.RESULTS AND DISCUSSION

The on-board measurements for emission, fuel consumption, acceleration and speed were used to develop models for gasoline using SPSS software. After the isolation of instantaneous measurements, the data were aggregated, integrated and computed for each unique intersection. The following paragraphs provide the summary, analysis and study findings.

4.1Effect of Speed on MOEs

The first attempt to characterize the impact of traffic and vehicle characteristics was to characterize the impact of different levels of speed on MOEs. To conduct this analysis, the test cars travelled at speeds ranging from 0.0 to 60 km/hr. Second-by-second fuel consumption and emission records were used and integrated over the entire trip. The different relations between MOEs and corresponding their speed levels were plotted over a fixed section of 10.0 km/hr speed. From Fig.4we can notice the nonlinear relationship between speed and MOEs. As the value of speed increases, the fuel consumption rate and emission also increase. The figure demonstrates that the differences between the lowest and the highest fuel rates are approximately in a range of 300%.The variation in CO_2 and HC emission rates constituted a difference in the range of 300% over the 0–60 km/hr speed range. CO emissions varyby the range of 200%. The variation in NO_x emission rates is in the range of 400% over the 0–60 km/hr speed range.It is demonstrated well from Fig.4 that there is no constant relationship between speed and tailpipe emissions.

4.2Effect of Acceleration and Deceleration

To segregate the speed effect, the variation of emissions was studied at different acceleration levels .As shown in Fig.5, the accelerations that were experienced by the majority of records represented an acceleration ranging from 0.0 m/s2 to 3.0 m/s2, while the decelerations were in the range of-2.0 m/s2 to 0.0 m/s2. Idealized fuel consumption and emission rates for CO, CO_2, HC, and NO_x were plotted against average acceleration and deceleration. In general, it can be observed from the figure that emission increases with an increase in vehicle acceleration. As illustrated in Fig.5, the fuel consumption rate increased from the lowest rate at a deceleration of 2.0 m/s2 to its maximum value at an acceleration of approximately 3.0 m/s2. This implies lower emission rates at lower accelerations and higher emission rates at higher accelerations. However, emission rates in deceleration mode are very low when compared with emission rates in acceleration mode. Bokare S, Maurya A [6] declared in their study that the possible reason to understand this behavior is that the deceleration is achieved bythe application of brakes.

4.3Combined Effect of Speed, Acceleration and Deceleration

In this part, the relations between speed, fuel consumption and emissions (CO, CO_2, HC and NO_x) within a particular acceleration or deceleration range were plotted. The analysis was conducted for four acceleration levels ranging from -1 m/s2 to 2 m/s2and a speed ranging from 0–60 km/hr.

Figure 6 presents the relationships of FC, CO_2, CO, HC, and NO_x, respectively, with speed and acceleration. In general, as speed is increasing, the power needed to accelerate the vehicle is reducing, and hence the fuel consumption and emission rates are also reducing. As the level of acceleration increased, the vehicle fuel consumption and emission rates increased. It is found that at the same speed value, acceleration levels and emissions manifest a prominent relationship.Figure6 manifests a prominent variation in MOEs with the different speed ranges and acceleration level combinations. It is seen from the figure that variation in acceleration level has a significant impact, more than the impact of speed variation. Furthermore, it can be observed that the effect of acceleration on emissions is more prominent at low and medium speeds. At low-speeds, emission rates are rapidly increasing and gradually lower with an increase in speed.

Generally, at lower speeds, the engine exerts more power with more consumption of fuel and resulting in high emission rates. The results for both steady state and deceleration scenarios were very similar. Furthermore, the analysis indicated that the fuel consumption and emission rates were insensitive to the level of deceleration. The figure shows that fuel consumption and the emission of CO_2 and NO_x are more sensitive to acceleration with a direct relationship. Whereas emissions of CO and HC rates are less affected by these episodes. The fuel consumption and CO_2 emission rates demonstrated the same trends that involved an increase in their values as the level of acceleration increased. The variation in fuel consumption and the emission of CO_2 increased by 200% relative to the 0–60 km/hr speed range and increased by 400% relative to acceleration levels from -1.0 m/s2 to 2.0 m/s2. NO_x increased 400% and 800%, respectively, at the same speed and acceleration levels. CO and HC emission rates increased by 200% at similar speeds and acceleration levels. Furthermore, Fig. 6 illustrates that HC rates were more sensitive to speed values than to acceleration levels. CO emissions display a highly nonlinear nature with speed and acceleration.

4.4 Effect of Intersection Control Type on MOEs

This part aims to demonstrate the impact of intersection control type son the environment and air quality. The analyses display the relationship between LOS threshold, fuel consumption and emission rates. This analysis can inform designers and decision makers about the consequences of their intersection choice on air quality. In this study, LOS for selected intersections ranges from B (best) to F (worst). Statistical analyses were carried out on the collected data to assess the impact of intersection control type and LOS on the emission. The total amount of

MOEs for 19 intersections observation was summed. The fuel consumption and emissions data were reported and plotted. The analyses were performed for fuel consumption and four pollutants (CO_2, CO, HC, and NO_x).Figure7compares the impacts of intersection control types and LOS on MOEs for five LOS and four types of intersection control. Intersection control types manifest a prominent relationship with episodes like acceleration and deceleration levels. The study gives a general idea of the impact of intersection type and LOS on fuel consumption and emissions. However, we can't ignore the role of traffic demand either.

Figure7 shows how MOEs increase at the different types of intersections as LOS gets worse. At LOS "B" and during the non-peak hour, two-ways top control and midblock U-Turn allow vehicles to move through the intersection without significant delay, resulting in lower emissions and fuel consumption rates. However, as traffic demand increases during the peak hour, travel times and delays increase substantially. At LOS "C" and "D", roundabouts are the best choice as they allow vehicles to operate at yield conditions at a slow and constant speed instead of a complete stop. This type of intersection control allows vehicles to pass through the intersection without the need to make a complete stop, which would have a great impact on fuel consumption and emissions. This behavior reduces the level of acceleration and could have a great effect on fuel consumption and emissions. As the traffic demand increases, the delay increases, and LOS gets worse for all types of intersection controls. At LOS "E" and "F", the demand is highly increased and the signal intersections minimize the total delay, which consequently lowers fuel consumption and emission rates.

The results demonstrate that roundabouts can only operate effectively when the traffic demand is relatively low. Moreover, if the demand increases, the signal intersection becomes the most appropriate intersection type. The study shows that the impact of LOS on emissions and fuel consumption is significant. The results from this study show a very strong relationship between intersection control type, LOS, and the quantity of all pollutants. Furthermore, the results show that fuel consumption, CO_2 and NO_x emissions are more sensitive to LOS rather than other emissions. In both cases of CO and HC emissions, the general trend is almost constant with various LOS.At relatively low demand, fuel consumption, HC, CO, and CO_2 are higher for signal intersections than for other types of control. Considering NO_x emission, it is seen that signal control produces lower emissions than the roundabout. Similar to the base condition in low demand, two-way stop control and midblock U-Turn generate the least value for all emissions. In this case, two-way stop control and midblock U-Turn intersections are the most suitable types for this environment

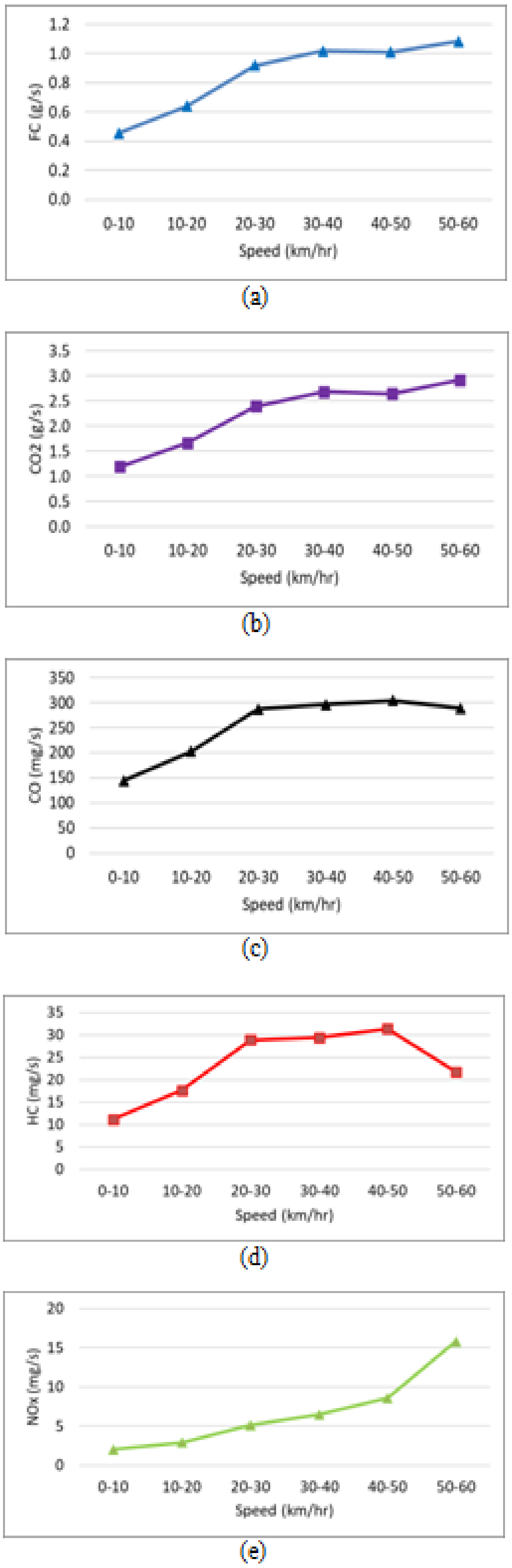


FIG 4. Relation between speed and MOEs

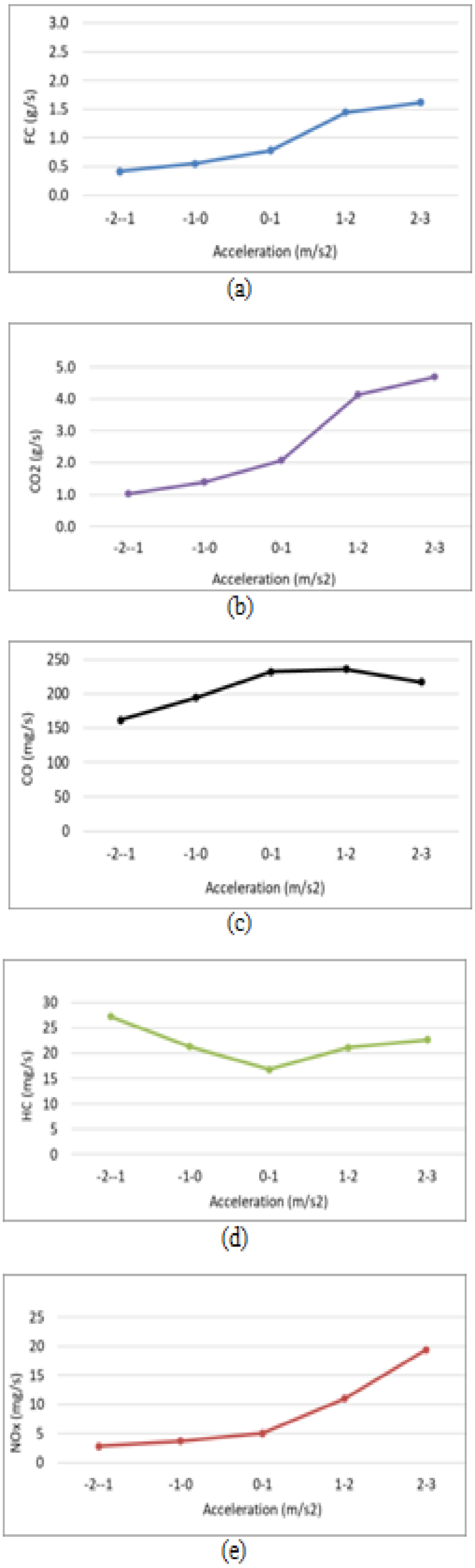


FIG 5. Relation between acceleration and MOEs

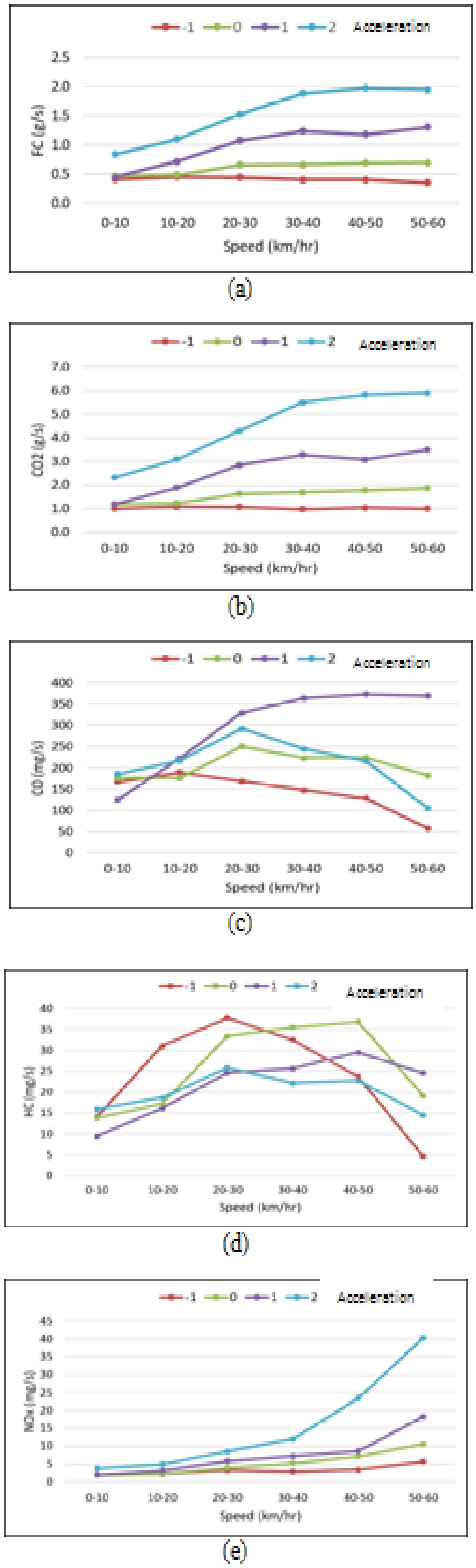


FIG 6. Relation between speed, acceleration levels and MOEs

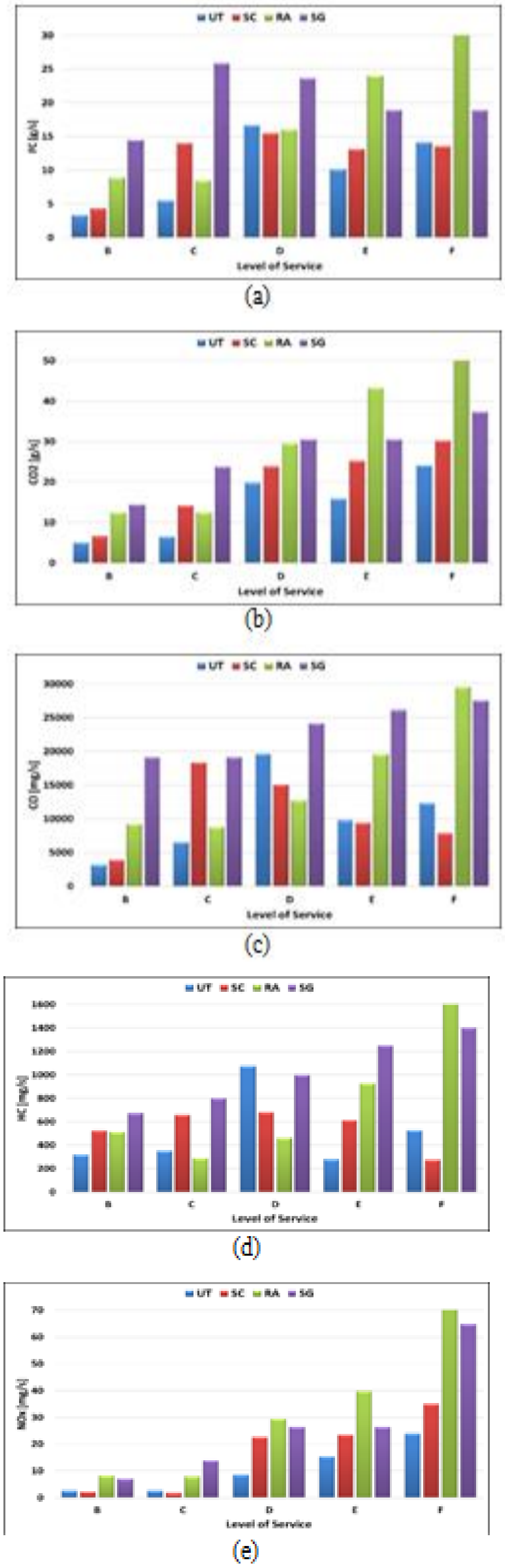


FIG 7. Intersection type, LOS and MOEs relation

5. CONCLUSION

The main object of this study is to compare each type of intersection control in terms of the environmental influences. The study investigated four types of intersections; two-way stop control, midblock U-turn, roundabout and traffic signal. The intersections have been compared in terms of fuel consumption and emission rates of four pollutants; CO_2, CO, HC and NO_x based on data instantaneous real-world measurements. The on-board measurements for emission, fuel consumption, acceleration and speed were used to develop models for gasoline using SPSS software. After the isolation of instantaneous measurements, the data were aggregated, integrated and computed for each unique intersection.

MOEs were compared for each intersection over its influence distance. From analysis we can conclude the followings ;two-waystop control and midblock U-turn intersections are more friendly for environment in low traffic volumes. In medium traffic volumes, the roundabout would be the suitable alternative. As traffic volume increases, the roundabout experiences a significant increase in delays, fuel consumption, and emissions compared to the signal intersection. The complexity of the problem under consideration needs further research. In this study, only four drivers were involved, and this didn't allow us to explore the full range of behaviors in the real world.

REFERENCES

[1]. Pandian, S., Gokhale, S., Ghoshal, A.K., 2009. Evaluating Effects of Traffic and Vehicle Characteristics on Vehicular Emissions Near Traffic
Intersections. Transp. Res. Part D Transp. Environ.

[2]. Federal Highway Administration, 2010. Roundabouts: Technical Summary. FHWA-SA-10-006. U.S. Department of Transportation.

[3]. AhnK, Rakha H, TraniA, Van M (2002) Estimating vehicle fuel consumption and emissions based on instantaneous speed and acceleration levels, Journal of Transportation Engineering.

[4]. Rakha H, Van M, Ahn K, Trani A (2000) Requirements for Evaluation of Environmental Impacts of Intelligent Transportation Systems using Speed and Acceleration Data, Presented at the Transportation Research Board 79th Annual Meeting, Washington DC, January, CD-ROM [Paper # 00-1133].

[5]. Ding Y, Rakha H (2002) Trip-Based Explanatory Variables for Estimating Vehicle Fuel Consumption and Emission Rates. Water, Air, & Soil Pollution.

[6]. Bokare S, Maurya A (2013) Study of effect of speed, acceleration and deceleration of small petrol car on its tail pipe emission, International Journal for Traffic and Transport Engineering, 3 (4): 465-478.

[7]. Sharma S, Mathew T (2016) Developing speed dependent emission factors using on-board emission measuring equipment in India, International Journal for Traffic and Transport Engineering, 6(3): 265 – 279.

[8]. Boubaker S, Rehimi F, Kalboussi A (2016) Impact of intersection type and a vehicular fleet’s hybridization level on energy consumption and emissions, Journal of Traffic and Transportation Engineering.

[9]. Anh K, Kronprasert N (2009) Energy and Environmental Assessment of High-Speed Roundabout. Transportation Research Record Journal of the Transportation Research Board. 2123. 54-65. 10.3141/2123-07.

[10]. Meneguzzer C, Gastaldi M, Giancristofaro R (2018) Before-and-After Field Investigation of the Effects on Pollutant Emissions of Replacing a Signal-Controlled Road Intersection with a Roundabout. Journal of Advanced Transportation. 2018. 1-15. 10.1155/2018/3940362.

[11]. Hallmark S, Wang B, Mudgal A, Isebrands H (2011) On-road evaluation of emission impacts of roundabouts. Transportation Research Record.

[12]. Salamati K, Rouphail N, Frey H, Liu B, Schroeder B (2015) Simplified Method for Comparing Emissions in Roundabouts and at Signalized Intersections. Transportation Research Record, 2517, 48 - 60.

[13]. Ahn K, Rakha H, Van M (1999) Microscopic Fuel Consumption and Emission Models. 79th Annual Meeting, Transportation Research Board, Washington.

[14]. Osses M, Henríquez A, Triviño R (2002) Positive mean acceleration for the determination of traffic emissions. In Proceedings of the 11th International Symposium Transport and Air Pollution, Graz. 65-72.

[15]. Sturm P, Boulter P, DeHaan P et al (1998) Instantaneous Emission Data and Their Use in Estimating Passenger Car Emissions. MEET Deliverable 6, COST 319 Final Report A2, Technische Universitaet Graz, Graz, Austria.

[16]. Wang J, Dixon K, Li H, Ogle J (2004) Normal Acceleration Behaviors of Passenger Vehicles Starting from Rest at All-Way Stop-Controlled Intersections, Transportation Research Record: Journal of the Transportation Research Board. DOI: http://dx.doi.org/10.3141/1883- 18, 1883(2004).

[17]. Wang M, Daamen W, Hoogendoorn S, Arem B (2011) Estimating Acceleration, Fuel Consumption, and Emissions from Macroscopic Traffic Flow Data, Transportation Research Record: Journal of the Transportation Research Board. DOI: http://dx.doi.org/10.3141/2260- 14, 2260(2011).