A Review of the Effects of Traffic, Road Characteristics, and Meteorological Conditions on Ozone Precursors from Vehicle Emissions

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***Abstract*—Traffic emissions are unarguably one of the major sources of air pollutants in developing countries. This article reviews the factors that affect the concentration of ozone precursors from vehicle emissions. It considers traffic, road characteristics, and meteorological conditions as influencing factors, particularly traffic flow, delay events, and mean speed. Road types, road structure, and atmospheric conditions are also considered important factors. Interactions among these factors determine emissions from vehicles.**

Keywords—Air Quality;Air Pollutants Concentration; Traffic Speed; Delay-events; Street Layout; Road Types; Wind Speed

I. INTRODUCTION (*Heading 1*)

Urban air pollution has become an important issue because of its harmful effects on human health and the environment. It is a concern not only in developed countries but also in developing countries. Motor vehicle emissions are one of the major sources of urban air pollution. In Malaysia, the total number of registered vehicles reached 1333749 by the end of the 2012 according to the Road Transportation Department [26]. The number of registered vehicles increased from 1 211 999 registered vehicles in 2011 [25] by an increment of 8.23%. With the increase in the number of vehicles in the country, the problem of pollution becomes more critical every year in Malaysia. In other countries, however, the number of vehicles is declining. The increasing and decreasing numbers of vehicles in a country depend on two very important factors: economic development and population growth.

Vehicle emissions consist of a complex mixture. The composition of exhaust emissions depends on the fuel used, type and operating condition of the engine, and the use of any emission control devices. The common vehicle emissions are particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), sulfur dioxide (SO_2), ozone (O_3), lead (Pb), benzene (C_6H_6), polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) [28]. These emissions must be controlled because of their harmful effects on human health and environment. According to the assessment of the World Health Organization (WHO) [31], more than 2 million premature deaths each year result from the aftereffect of urban outdoor and indoor air pollution caused by the burning of solid fuels.

The review of Han and Naeher [14] states that traffic-related air pollution exposure assessment studies are further complicated by different meteorological conditions, different traffic volumes (i.e., more motorcycles were recorded in developing countries than in developed countries), design of roadways (i.e., graded or non-graded roadways), driving habits, different kinds of maintenance conducted on vehicles, and the quality and control measures for vehicles. In recent years, a number of studies have focused on emissions from motor vehicles. However, Han and Naeher [14] also mention that, even though the number of studies on traffic-related pollution has increased, the data on this topic remain limited. The traffic-related pollution exposure assessment studies in developing countries are rather limited compared with those in developed countries. The current article reviews and discusses previous studies on the effects of traffic, road geometry, and meteorological conditions on vehicle emissions.

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II. EFFECT OF TRAFFIC CHARACTERISTICS ON VEHICLE EMISSIONS

Many traffic-related studies found that high traffic density and volume, particularly in urban areas, contribute to more traffic emissions than low traffic density and volume [12, 16, 18, 20, 22, 30]. Vehicles tend to generate emissions via acceleration, deceleration, idling, and cruising, particularly at intersections, whether signalized or unsignalized, because of delay events that consist of control delay, time in delay, and stopped delay. Delay events can cause inconvenience to drivers and congestion during peak hours if the traffic control is not handled well. In their study on the effect of arterial signalization and level of service on measured vehicle emissions, Unal, Rouphail, and Frey [30] found that emission rates are the highest during acceleration and decreased by ascending order of cruising, deceleration, and idle. Pandian, Gokhale, and Ghoshal[22] also added that sharp acceleration generates a higher level of pollutants from vehicles than steady acceleration because of the difference in fuel usage that leads to different emission rates. A change from free-flow traffic to intersection also increases traffic emissions, particularly during high traffic flow. A disturbance in traffic flow can lead to changes in speed cycle, which in turn

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increases the mean delay and queue length, which cause an increment in emission rates.

Researchers from all over the world tend to select locations with high traffic volume because these locations have proven to contribute to more traffic emissions than other locations [6, 16, 35]. Based on the study of Kimbrough, Vallero, Shores, and Mitchell [16] on using multicriteria-based site selection to measure the mobile sources of toxic air pollutants, we eliminated some candidate sites because of their low traffic volume. During peak hours, when traffic volume is high, nearly all vehicles approaching the intersection decelerate, come to a stop, and then accelerate from the stopped position. According to Zhang, Lv, and Wang [35], this speed-cycle process renders intersections the most appropriate site to study the acceleration process. In their study on the quick urban and industrial complex (QUIC) modeling of airflow and pollutant dispersion patterns, Bowker, Baldauf, Isakov, Khlystov, and Petersen [6] stated that a location with a high concentration of pollutants must be chosen if the emissions from the highway are moving over a short distance; in such case, mobile measurement is not possible, so that the median concentration value is the factor that normalizes the QUIC concentration value.

III. EFFECTOF ROAD CHARACTERISTICS ON VEHICLE EMISSIONS

Several studies on traffic-related air pollution have found that road geometry also contributes to vehicle emissions [13, 17, 21, 22, 23, 27, 29, 34]. The study of Yassin and Ohba [34] on the effect of the geometrical layout of streets on air pollution dispersion caused by traffic vehicles at an urban canyon shows that different geometrical layouts lead to different emission rates under specific atmospheric conditions. In his study on vehicle emissions and fuel consumption for street characteristics, such as road types, junctions, humps, and street configuration, Rosqvist [27] found that road geometry and road structures have a significant effect on fuel consumption and consequently vehicle emissions.

According to Rosqvist [27], driving along a large roadway rather than a small roadway generates less emission rates. Junctions and humps also lead to less emission rates because they encourage a low steady speed, which in turn decreases vehicle emissions. In their study on the influence of reducing the speed limit from 50 km/hr to 30 km/hr in a one-lane roadway,Casanova and Fonseca [7] claim that the time spent on a specific trip does not increase and fuel consumption is reduced, thereby reducing vehicle emissions. Nesamani and Subramaniam [21] also discovered that various road types, which differ in terms of traffic characteristics and number of lanes, lead to different average speeds. The classification of these roads across a city can also be based on essentially different pollutant profiles [8].

Emission rates from vehicles also increase with an increase in road grade. The research conducted by Pierson et al. [23] on real-world automotive emissions found that the level of CO and nitrogen dioxide (NO_2)from vehicle exhausts are twice higher when driving uphill (approximately 4% grade). Some research studies provide conclusive evidence that changing a signalized intersection into a roundabout decreases the production of vehicle emissions. Mandavilli, Russell, and Rys [17] state in their study that roundabouts can improve traffic flow and reduce fuel consumption and emission rates by minimizing the idle time of vehicles at intersections. Shokri, Mokhtarian, Ismail, and Rahmat [29] compared a roundabout and an intersection using aaSIDRA Software to determine the level of service between them and consequently find the most efficient design improves traffic flow and is environment friendly. In comparing the two, Shokri et al. found that a roundabout is more feasible and provides better conditions than an intersection.

IV. EFFECT OF METEOROLOGICAL CONDITIONSON VEHICLE EMISSIONS

Meteorological conditions constitute another important parameter that needs to be considered to explain the variability of the recorded concentration of traffic emissions. Fig. 1 shows the diurnal variations of O_3 and nitrogen oxide (NO_x) concentrations in four different locations in Malaysia. The locations are categorized as background, urban, suburban, and industrial areas (DoE, 2010). Air pollutants reach the receptors by transport or transformation in the atmosphere. The diurnal profile of O_3 shows an increment in its concentration during daytime and a decrease from evening until nighttime. During daytime, the NO_2 emitted from vehicle exhausts reacts with solar radiation and produces O_3. This scenario explains why concentrations of NO_2 decrease when O_3 concentrations increase, as shown in Fig. 1. During nighttime, O_3 is expected to have low concentrations because the lack of an adequate amount of ultraviolet light prevents its completion of photochemical reactions. The concentrations of O_3 in the background area are low because of the lowconcentrations of its precursors. This result is expected because background areas are located in rural areas. In their study on the impact of urban plumes on ozone pollution in downwind rural areas,Xu et al. [32]state that O_3concentration in downwind suburban areas is higher than that in urban areas. The same results have also been found in other studies [1, 3]. The urban plumes from the sources of NO_x are blown downwind to suburban areas, thereby increasing O_3 production from photochemical reaction in these areas. Meanwhile, low O_3 concentrations have been recorded in urban areas because of the titration process of NO_x on ground-level O_3 [3, 5, 10]. Wind speed also has a significant effect on the variability of air pollution concentrations. When slow-moving air passes through the pollutant source, the concentration of pollutants moving downwind is much higher than that under rapid air movement conditions. However, when obstructing objects exist, such as road structures or vegetation, near the roadway, the concentration of the pollutants register a different concentration at downwind distance.

To understand the effects of roadside barriers on the flow patterns and dispersion of pollutants from a high-traffic highway, Bowker, Baldauf, Isakov, Khlystov, and Petersen [6] conducted a study on three different types of locations: (1) a “base” case that consists of a uniform flat domain with no obstacles and no noise barrier, (2) a “noise barrier-only” case where a noise barrier is extended along the domain parallel to the line sources, and (3) a highly complex “field study” case that includes a barrier, buildings, and vegetation. In the study,

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the concentration of traffic emissions decreased at all downwind distances after passing through the trees in the "field study" case. However, different results were obtained in the "noise barrier-only" case: flow streamlines at the noise barrier moved vertically upward and over the barrier, leading to low pollutant concentration at the recirculation zone because little amount of pollutants were mixed down. However, the elevated plume that passed over the recirculation zone returned to ground level, thus increasing the pollutant concentration where the reattachment of the plume occurred. Among all the cases, the "base" case with no obstructing objects recorded the highest concentration of pollutants, but

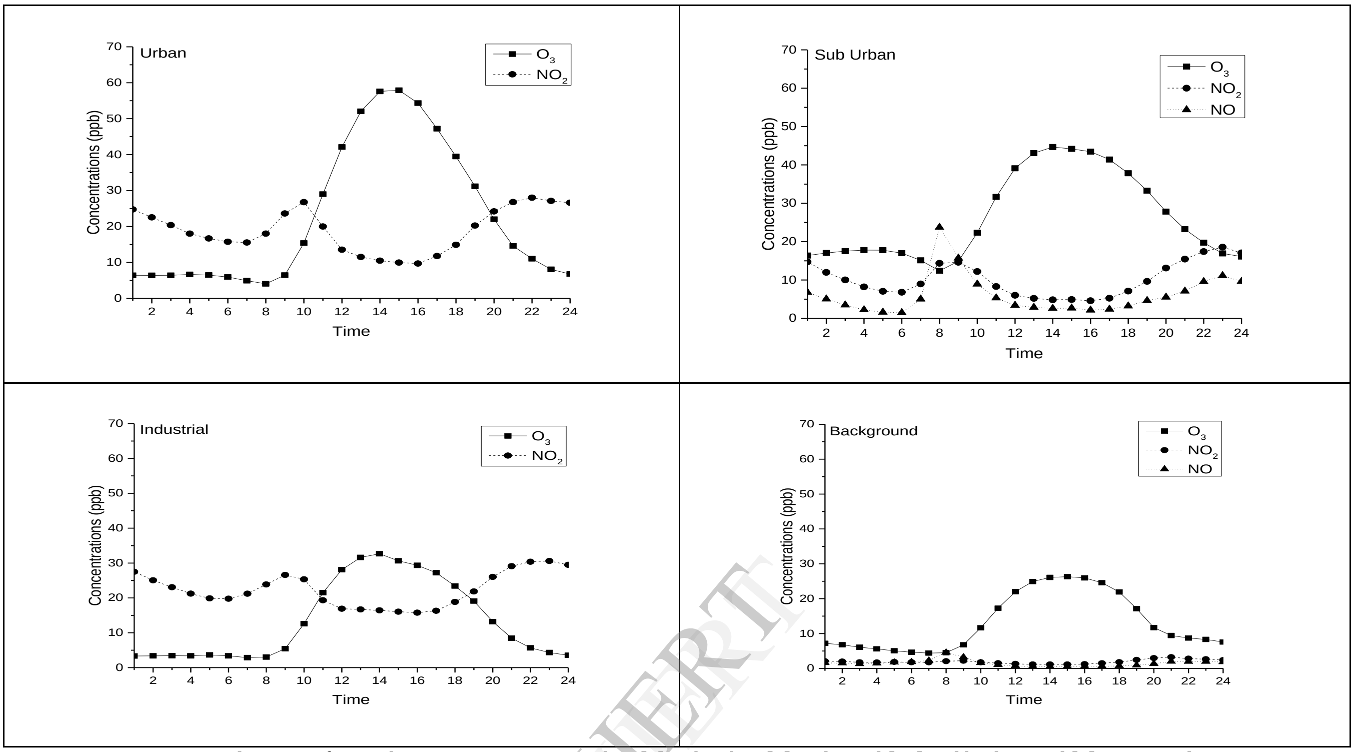

Fig. 1: Diurnal pattern of O_3 and NO_x concentration in urban [2], sub-urban [2], industrial [24] and background [3]area in Malaysia

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the concentration decreased much faster over a distance. These results show that obstruction features, such as noise barriers, buildings, and trees, can affect the initial dispersion of pollutants from roadways and influence the concentration of pollutants up to several hundreds of meters from the road.

Variations in air flows and dispersion conditions throughout the seasons also affect pollutant concentration. In their study on NO_2 and C_6H_6 in Portugal, Barros, Fontes, Silva, and Manso [4] show that the four seasons in the country affect the dispersion of traffic emission. According to the study, air quality is much worse during winter because of the limited dispersion conditions and less number of sunlight hours than during fall or spring. Sunlight promotes the photochemical reaction of NO_2 and increases the oxidation rate of C_6H_6 through the hydroxyl radical. Therefore, sunlight contributes to a low value of NO_2 and C_6H_6 concentrations, as recorded at the receptors.

The surrounding location should be considered to determine the type of location. Whether an open or enclosed area, the type of location should be considered, given that it also affects the concentration of pollutants. In the study of MohdSadullah, Yahaya, and Syed [19], the type of site locations were determined based on the criteria provided by Harrison and Perry [15]. Following these criteria, an area is considered enclosed if the top of the building subtends at an angle of more than 30° with the horizontal at the sampling location, whereas a location is considered an open area if the angle is less than 30°. The results of the study of MohdSadullah, Yahaya, and Syed [19] show that the highest CO concentration was recorded at an enclosed area for all driving modes. Buildings surrounding an enclosed zone cause a significant difference between enclosed and open areas and influence the CO concentration. The analysis of total suspended particles (TSP) emitted from motor vehicles by Yahaya and MohdSadullah [33] also followed the criteria given by Harrison and Perry [15] because of the important effect of the surrounding location on the concentration of pollutants. In this study, the TSP level in enclosed areas is higher than that in open areas, even if a larger number of motor vehicles pass by in open areas than in enclosed areas. Even though both studies [19, 33] analyzed different types of pollutants, they both conclude that enclosed areas tend to generate much higher concentrations of pollutants than open areas. The absence of obstacles justifies the relatively low concentration of pollutants in open areas. Therefore, the concentration of pollutants varies depending on traffic volume, environmental conditions, topography, and the presence of obstructing objects.

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V. CONCLUSION

Such factors as traffic, road characteristics, and meteorological conditions should be further investigated because of their significant effects on the concentration of vehicle emissions. These factors can assist researchers in formulating mitigation solutions or control measures to solve the air pollution problems at the location of interest. Even though many studies have considered these factors, they still may be considered limited because of the differences in their measuring methods, thereby rendering conclusive generalization and comparison difficult. Therefore, traffic-related pollution exposure assessment studies need to be more widely conducted in the future as they may serve as the basis for regulations and public health measures.

ACKNOWLEDGMENT

This work is part of the RUI 1001/PAWAM/811206 under the Universiti Sains Malaysia. Thanks to the Department of Environment Malaysia for providing the research data to produce Figure 1.

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