A CASE STUDY OF MITIGATING AIR POLLUTION EMISSIONS AT TRAFFIC LIGHT JUNCTIONS

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Summary

Air pollution due to transportation is the result of the discharge of unburnt and partially burnt engine fuels together with the by-products of complete combustion. The major components of air pollution due to transportation are carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbon (HC), lead, and particulate matter. The concentration and relative mixtures of these pollutants depends on vehicle speed, acceleration, deceleration, the amount of time vehicles spend idling, stopping and waiting, especially at major junction in urban areas. However, due to an increase in traffic volume, improper junction geometry, improper signal phasing and also due to inadequate signal timing, motorists are spending substantial amount of their time idling and waiting at junctions. Traffic light junctions that are designed according to proper standards will minimize delay and thus reduce the amount of pollutants emitted from idling vehicles. In this paper, the effects of signal coordination and minor geometric improvement to

traffic light junction upon the amount of pollutant emitted are investigated. The study shows that provision of signal coordination together with provision of appropriate turning lanes and approaches to junctions significantly reduces the amount of pollutants emitted at traffic light junctions. A case study of traffic light junctions in Ipoh city was conducted to determine the percentage of pollution reduction as a result of improvement in the design of traffic light junctions.

1. Introduction

The number of vehicles in major cities in Malaysia is increasing annually at a steady rate. In the case of Ipoh City, the annual increases in traffic volume on several road stretches are shown in Table 1. In Ipoh, traffic growth is increasing at a rate of about 10% annually, which is a typical growth rate of developing countries. As in other developing countries, increases in number of vehicles will compete with the available road space to carry them from one place to another. The inability of the road network to carry the amount of traffic generated will cause severe road congestion. There are several measures of traffic congestion that are discussed in the following chapter. Besides congestion, increase in traffic volume also causes several undesirable effects such as increase in accidents and increases in pollution.

Station	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
AR304	18,180	20,153	21,901	21,083	24,904	27,975	31,748
AR306	16,762	14,709	17,213	16,203	16,946	17,217	17,124

Source: Road Traffic Volume Malaysia 1996

Table 1: Annual traffic volume (vehicles) in Ipoh City

Previous studies had indicated that increases in traffic volumes also causes increases in traffic related accidents. There are various different types of accidents, such as head-on collision, side swipe, out-of-control, rear-end collision, angle collision, etc. Increases in traffic volume also increase the chances of occurrence of any of the accidents. The severity of the accidents will depend on the vehicle speed, type of accident, vehicle type, etc.

Increase in traffic volume causes traffic congestion in terms of increases in delays (i.e. amount of time vehicles spend idling and slowing down while traversing any stretch of road) and increases in number of stops per vehicle, especially at major road junctions in urban areas. The function of the junction is to allow vehicles to change direction onto another road without causing serious traffic conflict and avoiding major road accidents. Traffic congestion will get worsen if the junction is not designed properly and according to the appropriate standard. In this article, the effects of improvement in junction design on the amount of pollutants emitted are investigated. The pollutants emitted by the burning of vehicle fuel have been known to cause temporary effects that influence human behaviour.

In the following section, factors contributing to traffic congestion are discussed. In section 3, possible effects of major components of air pollution on human health are discussed. In section 4, the approach used to investigate air pollution emissions at traffic light junctions is discussed. Section 5 then discusses the data collection process to achieve the objective of the study. Section 6 discusses the proposed improvements to the junction under consideration. Section 7 discusses the findings of the study and finally section 8 concludes the paper.

2. Factors Contributing to Traffic Congestion

Traffic congestion is defined as a condition of deteriorating travel conditions, usually as a result of increasing traffic volume traversing a stretch of road. However, a reduced volume of traffic using the road could also experience congestion as a result of various factors such as inadequate road design, selection of inappropriate junction type, poor junction design, road maintenance and weather conditions. The level of congestion on the road usually differs from one driver to another because of the subjective nature of the traffic congestion. However, in order to evaluate the level of congestion, traffic engineers use particular measurements. In traffic engineering the most common types of measurement are average delay (amount of time drivers spend idling while waiting during congestion), duration of stops made by an average driver, ratio of traffic volume to road capacity, and number of vehicles queuing. The respective road or facility is considered to be congested whenever the average delay, average stop rates, or queuing are high. In this section, several factors contributing to traffic congestion are discussed.

Traffic Volume and Traffic Composition

As expected, higher traffic volume will usually result in higher delay and higher stop rates, thus contributing to congestion. Traffic composition also affects the level of road congestion. Traffic composition usually consists of passenger cars, motorcycles, lorries, buses, and trailers. Traffic with a high percentage of lorries, buses and trailers will experience more congestion because the respective vehicles are not only larger in size but also have slower speed. Thus, certain sections of road with a high percentage of heavy vehicles tend to be more congested.

Road Design

In designing a roadway, there are several factors that road engineers need to consider, such as number of lanes and lane width. In hilly and mountainous regions, criteria such as curve radius and road gradient also need to be considered; these certainly affect the carrying capacity of the roadway. A certain road type can carry a certain number of vehicles. With inadequate road design, the carrying capacity of the road reduces. The anticipated number of vehicles using the road is also important in planning. Without proper planning, the road will either carry more or less traffic than anticipated.

Improper road design is defined as roads that are not designed according to a proper standard. Sometimes, usually due to the economic situation, roads are not designed to the standard prevailing in the country. For example, a stretch of road that is expected to carry heavy traffic should be designed in such a way that vehicles can travel from one place to another in a short period of time. The designed parameters affecting the travel time are roadway width, number of lanes, lane configuration and lane markings. For example, with high traffic volume, wider lane width will be able to carry more traffic as compared to narrower lane width. Similarly, more lanes will enable more vehicles to be carried in a shorter length of time.

Junction Design

Along a stretch of road, the most critical places are considered to be road junctions. Usually, traffic engineers will design a road junction based on the anticipated volume of traffic that will use the junction. Severe traffic congestion can occur as a result of designing road junctions according to inappropriate standards. Increase in congestion will certainly increase the amount of pollutants being emitted.

Along an arterial road, the critical place is the road junction. Usually, the capacity of the road junction will determine the capacity of the arterial road. If the capacity of the road junction is high, then the traffic carrying capacity of the arterial is also high. There are several factors that affect the capacity of junctions that need to be taken into consideration during design, i.e. junction type, lane width, number of lanes at each approach, and gradient (if the approach is uphill or downhill).

There are three major types of road junction, i.e. priority junction, roundabout, and signalized intersection. The capacity of traffic light junctions is higher than the capacity of priority and roundabout junctions. Thus, signalised intersection should be provided whenever high traffic volume is anticipated. Junctions with more and wider lanes usually have greater capacity, and thus reduce the occurrences of traffic congestion. Uphill approaches to junctions, particularly when in combination with high numbers of heavy vehicles, will usually increase congestion.

Road Maintenance

Road congestion also occurs as a result of road maintenance. Due to the maintenance work, the carrying capacity of the road is reduced, depending on the nature of work being done. Even though the traffic volume along the road is less as a result of the maintenance work, congestion still occurs and the severity of the congestion depends on the type of road (number of lanes and lane width) and the extent of the road maintenance works. Usually, for the maintenance work to be done properly, one or more lanes are closed at any point of time, potentially resulting in road congestion.

Weather Conditions

Weather conditions also affect the degree of road congestion. Due to the bad weather, drivers usually drive their vehicle slower, often resulting in traffic congestion because the vehicles cannot flow smoothly. Heavy rain for an extended period of time can create massive congestion, particularly during peak hours when commuters head for work in the morning and back from work in the evening.

3. Effects of Air Pollution

Evaporative losses from the fuel tank and carburettor, together with pollutants emitted from exhaust gas, are the major factors causing air pollution. If oxidation were complete, water and carbon dioxide would be the only products produced from the combustion of petrol in an internal combustion engine. Neither of these products is generally considered as a pollutant, although there is considerable anxiety about the build-up of carbon dioxide in the atmosphere and its effect on global climate. In practice it is difficult to achieve complete oxidation so that carbon monoxide is formed in considerable quantities, some of the fuel remains unchanged and some is converted into other organic compounds. Thus the major components of air pollution due to traffic activities are carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbon (HC), lead, and particulate matter, as shown in Table 2.

By products of engine's fuel combustion	Remarks
Carbon dioxide (CO_2)	Not considered to be pollutants
Water vapor	
Unburnt petrol	Pollutants
Carbon monoxide (CO)	
Hydrocarbon (HC)	
Oxides of nitrogen (NO_x)	
Lead compounds	
Carbon particles (smoke)	

Table 2. By-products of the burning of vehicle fuel.

3.1. Carbon Monoxide

Carbon Monoxide will combine with haemoglobin in the blood to produce carboxy-haemoglobin (COHb). Carbon monoxide has a greater affinity for haemoglobin than oxygen and it is preferentially absorbed, even when the concentration of carbon monoxide is very low. High percentage of carboxy-haemoglobin in the blood leads to health hazards. Death will result when more than 70% of the blood haemoglobin has been converted to COHb. After a subject ceases to be exposed to non-lethal doses of carbon monoxide, the carboxy-haemoglobin content of the blood gradually declines as carbon monoxide is breathed out (reversible effect).

3.2. Oxides of Nitrogen and Hydrocarbon

Oxides of nitrogen or NO_x are produced by the combination of atmospheric nitrogen with oxygen under conditions of high temperature and pressure, such as are produced in an internal combustion engine. They are a significant health hazard, especially nitrogen dioxide. In the atmosphere, the oxides of nitrogen resulting from the combustion of petrol can react with hydrocarbon (HC) in the presence of sunlight, particularly under anticyclonic weather conditions, to produce ozone. This is a known precursor for the formation of photochemical smog. Thus, the products of vehicle fuel combustion can react with each other to produce undesirable secondary products which are all hazardous to human health.

3.3. Lead Compounds

The major sources of lead in urban areas are from vehicle exhaust gases. The lead compounds in the exhaust gas originate from the "anti-knock' agents added to leaded fuel. In Malaysia, leaded gasoline is still being widely used since there are still many old vehicles on the road. Lead emitted through vehicles' exhaust gases will eventually enter plants or will drain to watercourses. Lead enters human bodies through the consumption of food containing lead from either of the two sources. In the long-term, lead will cause health hazards in term of lead poisoning.

3.4. Smoke

The smoke emitted by vehicles consists mainly of very fine particles of carbon, which result from incomplete combustion of fuel. Smoke is usually related to vehicles with diesel engines. It consists of fine particulates, including those with aerodynamic diameter less than 10 micrometers, which can penetrate deep into the air exchange region of the human lung, thus causing a health hazard.

In addition, carbon particles may act as nuclei both for haze formation and the absorption of gases such as sulfur dioxide and nitrogen oxides which are likely to cause damage to the lung.

4. Pollutant Emissions at Traffic Light Junction

Vehicle movements at traffic light junction are regulated by traffic signals. Vehicles will accelerate and enter the junction if the signal turns green. While the signal is green, incoming vehicles enter the intersection at cruising speed or average speed. Vehicles will decelerate and come to a complete stop when the signal turns red.

The process is repeated for each cycle of traffic signal. All of the different level of vehicle movement at the junction contributes to fuel consumption and pollutant emissions. In this paper, traffic engineering software package SIDRA 5 (Akcelik and Beasley, 1996) is used to analyze the pollutant emissions at the junction. SIDRA 5 is used to estimate all traffic engineering parameters such as delay, queue, and stop rates. SIDRA 5 is also capable of estimating pollutant emissions at road junctions. SIDRA 5 employs a detailed four-mode elemental model for estimating fuel consumption and pollutant emissions.

The four-mode elemental model considers each cruise, deceleration, idling and acceleration element of the vehicle in the estimation process. The four-mode elemental model is as described by equation (1).

$$E = f_1 C + f_2 D + \left[f_3 - \left(\frac{f_2 d_h}{3600} \right) \right] H \qquad (1)$$

Where,
E = the statistic of interest, e.g. pollutant emissions and fuel consumption,
C = the amount of travel, in veh-km/h,
D = total stop-line delay in veh-h/h
d_h = acceleration-deceleration delay for a complete stop-and-go cycle in seconds,
H = total number of complete stops per hour,
f_1, f_2, f_3 = parameters associated with cruising, idling, deceleration and acceleration per complete stop.

5. Study Approach

In this study the geometric characteristics in terms of junction layout, number of movements, lane width, and approach gradient of the junction were observed. Traffic characteristics such as traffic composition and turning volumes were also observed, especially during peak hours. In this study the performance of the junction in terms of traffic delays and fuel consumption under prevailing signal operations are estimated using SIDRA 5. This is then used to estimate the cycle time and appropriate signal timing for the junction after the proposed improvements to the junction. The improvements to the junction were done in two scenarios. The first scenario looks into the effect of signal coordination between two adjacent traffic light junctions upon the amount of pollutant emitted. The second scenario investigates the effect of minor improvements to the junction while maintaining signal coordination between adjacent signalized intersections. The 'level-of–services' were estimated using the relationship established, as shown in Table 3. The pollutant emissions estimated at the traffic light junction as a result of the proposed improvements were compared with the pollutant emissions estimated for the existing junction.

Level of Service	Average Overall Delay Per Vehicle (sec)
A	$d \leq 6.5$
B	$6.5 < d \leq 19.5$
C	$19.5 < d \leq 32.5$
D	$32.5 < d \leq 52.0$
E	$52.0 < d \leq 78.0$
F	$78.0 < d$

Table 3. Level-of-service definitions based on delay

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Biographical Sketches

Nor Azam Ramli is a lecturer in Environmental Engineering at the School of Civil Engineering, Universiti Sains Malaysia. He graduated from the Universiti Sains Malaysia, but went to the University of Wales, United Kingdom, to read for an MSc in Environmental Impact Assessment (EIA) and an M.Phil in Air Pollution. He is currently pursuing his PhD in PM_{10} from traffic emission in developing townships. Although he remains interested in Environmental Impact Assessment, his simultaneous concerns are emissions from motor vehicles and human based activities which have been the major sources of pollution and play significant roles in deteriorating life quality. He is also interested in long-term changes in urban air pollution and its effects on health and building damage. His work in material damage by air pollutants has not been restricted to outdoor environments. He has written several papers on air pollution from various sources and the effect of inadequate EIA on air quality in Malaysia and Wales. He is a member of the Aerosol Society of the UK.

Wan Hashim Wan Ibrahim graduated from Purdue University, West Lafayette, Indiana in 1989 in the field of Civil Engineering. He obtained an MSc in 1991 and a Phd in Civil Engineering in 1994 from Purdue University. After obtaining his PhD, he worked as a lecturer in the school of Civil Engineering at Iniversiti Sains Malaysia. He was appointed as Dean, School of Civil Engineering at Universiti Sains Malaysia in March 2003. Actively involved in several research projects on traffic engineering areas such as developing a highway capacity manual for Malaysia and evaluating motorcycle issues with respect to Malaysian traffic conditions.