STUDY OF THE EFFECT OF VEHICLE DRIVER BEHAVIOUR ON VEHICLE EMISSIONS OF CARBON MONOXIDE AT SIGNALIZED INTERSECTIONS

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ABSTRACT

Considerable concentrations of vehicular emissions at signalized intersections and streets, in urban area are health-related issues of concern to society in general. This paper presents an examination for the effect of vehicle driver behaviour on vehicular excess CO emissions. The examination process based on site observations.

Four signalized intersections in Erbil City which, satisfy the objectives and specifications of this study selected, and the necessary traffic behaviour and vehicle exhaust emission data collected. The traffic data were collected using video recording technique and the Analytical Mobile Gaseous Emissions CART P8334 machine used to measure vehicle exhaust emission data.

The required traffic data abstracted from video play back using **EVENT** computer program, which provide coded digital representation for the requisite traffic activities. The abstracted data stored on floppy disks in the form of digital computer files. These files processed using computer programs developed for this purpose to abstract the necessary information from the raw data.

Among the obtained traffic information are vehicle data classified according to the type of fuel used into two classes. The first class is gasoline powered vehicles which consisted of taxis and private cars covering different model year, engine condition and size, type of fuel injection system, number of cylinders. These data observed under different ambient air temperatures. The second class is the diesel-powered vehicles, which consists mainly of truck type vehicles.

Following the processing stage, the obtained data presented and analyzed statistically to evaluate the relationship between driver behaviour and vehicle excess of CO emission. Among the driver behaviours studied is queuing driver behaviour, which showed reasonably good relationship with the excess CO emissions.

The results of this study are useful for the Local Authorities, traffic engineers and transportation planners. This is because, the obtained results assist in the adoption of suitable method of intersection control for the purpose of reduction of CO emissions and hence, reduce level of this type of air pollution.

الخلاصة

التراكيز العالية نسبيا للغازات الملوثة للهواء الناتجة عن احتراق الوقود المستخدم لمحركات المركبات التي تمر بالتقاطعات العاملة بالاشارة الضوئية و تلك التي تسير على الطرق في المناطق الحضرية ذات تأثير سلبي على صحة الانسان مما جعلها تحظى باهتمام عموم المجتمع.

تقدم ورقة البحث دراسة لتأثير سلوكية سائق المركبة على مقدار غاز أول أوكسيد الكاربون المنبعث من عادم المركبات المختلفة. اعتمدت الدراسة على بيانات حقلية جمعت من قبل الباحثين حيث تم اختيار أربعة

تقاطعات عاملة بالاشارة الضوئية في مدينة أربيل لهذا الغرض بعد أن تم التأكد من صلاحية هذه التقاطعات في تحقيق أهداف الدراسة. جمعت البيانات المرورية باستخدام جهاز الفيديو أما البيانات المتعلقة بالغازات المنبعثة من عادم المركبات فقد جمعت باستخدام جهاز Analytical Mobile Gaseous Emissions .CART P 8334

بعد الانتهاء من عملية التصوير تم استخلاص البيانات المرورية المطلوبة من أفلام الفيديو و ذلك بإعادة عرض الافلام على شاشة التلفاز و باستخدام البرنامج الحاسبي (EVENT) تم تحويل الفعاليات المرورية الى صيغة رقمية خزنت بشكل ملفات. حفظت هذه الملفات على أقراص مرنة وتم استخدام نظام ترميز في تسمية الملفات بحيث يمكن الاستدلال على محتوى الملف من أسمه. الخطوة اللاحقة كانت تطوير برامج حاسبية لغرض معالجة البيانات لاستخراج المعلومات المطلوبة لغرض البحث. من ضمن المعلومات التي تم جمعها بيانات عن الأنواع المختلفة من المركبات مصنفة حسب نوع الوقود المستخدم ديزل أو بنزين ، طبيعة استخدام المركبة خاص أو أجرة ، سنة التصنيع، حالة المحرك، عدد الاسطوانات و درجة حرارتها و لدرجات حرارة الهواء المحيط المختلفة.

بعد الانتهاء من مرحلة معالجة البيانات، تم عرض المعلومات بشكل جداول و مخططات مع تقديم تحليل إحصائي أولي لتقييم العلاقات بين سلوكيات سائق المركبة و مقدار الانبعاث الاضافي لغاز أول أوكسيد الكاربون من عادم محركات المركبات. من بين نتائج هذه الدراسة اظهر طول الطابور علاقة جيدة مع كمية غاز اول اوكسيد الكاربون الاضافي المنبعث. ان نتائج هذه الدراسة تفيد دوائر امانة بغداد و البلديات و مهندسي المرور و مخططي النقل في اختيار نظام إدارة مرورية للتقاطع بحيث يؤدي الى للتقليل من كمية غاز اول اوكسيد الكاربون المنبعث من المركبات في التقاطعات المزودة بالاضوية المرورية.

KEY WORDS

Impact of traffic movement at intersections on environment, effect of traffic movement at intersections on air pollution. CO emission as a result of traffic at intersections.

INTRODUCTION

Air pollution is a new set of air pollutants which result from mobile, industrial, and domestic uses in urban society(our use of energy) (Al-Jamr (1997)). The use of vehicles as mode of transportation introduced a great service for the humanity. It played a major role in the development of the economical; political, and social aspects of the human life. However, the increase in the use of vehicle automobile resulted in problems to the humanity. The vehicular emissions are one of the major dangers facing the human being life, especially in congested urban areas.

To provide an insight into the increase in dependency on vehicle use, consider the statistics regarding the growth in vehicle number over the years. **Table (1)**, provides statistics for the number of registered vehicles over the period 1980-1993 in some of the world countries. The data may suggest that Iraq has one of highest number of vehicles in comparison with the other countries appeared in the **Table (1).** The implication for this growth is increase in fuel consumption. This is indicated by examination of the data presented in **Table (2),** which shows comparison between fuel consumed in transportation for the year 1989. The presented data indicates that Iraq ranked as the third country in fuel consumption for transportation purposes.

Table (1), The growth in number of vehicles (*1000) in some of the ESCWA countries (Al-Ananie 1997)

	Year					
Country	1980	1985	1990	1991	1992	1993
Bahrain	65.4	104.1	122.7	132.0	141.7	152.6
Iraq	304.8	684.1	1020.9	992.5	1007.7	1050.8
Jordan	126.0	191.2	215.1	247.5	262.5	255.5
Oman	100.2	227.3	209.9	236.2	254.9	273.8
Qatar	98.5		159.8	179.8	192.8	205.8
Saudi	2068.1	4171.8	4956.5	5117.4	5528.5	5588.0
Syria	146.3	155.7	329.4	316.6	356.2	390.1
Yaman	127.7	548.3	285.2	291.9	328.2	

Table (2), Some ESCWA countries ranked according to the fuel consumed in transportation at the end of the year 1989 (Al-Ananie 1997)

Country	Fuel consumed (Toe/10^6)
Lebanon	185.0
UAE	183.3
Iraq	174.3
Libya	162.2
Luxembourg	152.2
Jordan	117.2
USA	112.6
Argentina	103.2
EEC	80.4
Rest of the world	61.9

At present fuel consumption is one of the serious problems facing traffic and environmental engineers, and transportation planners from the standpoint of the amount of air pollutants, which result from the operations of traffic movements. This is because of the agreed world wide requirement that certain standards for CO and other exhaust gases concentrations be met (Matzoros (1988)) to minimize the harmful effect of these chemicals on human life.

The most important pollutant gases present in the air of the world's cities, namely, sulfur dioxide (SO_2), nitrogen oxides (NO or NO_2), carbon monoxide (CO), and non-methane hydrocarbons (NMHC). Natural sources (exception of volcanoes) emissions do not fluctuate from year to year. Man's made emissions, are steadily increasing as population and industry expand (Al-Jamr (1997)). For CO the figures are 1970- 79%; 1979- 89%. Thus vehicle CO emissions have been increasing as a proportion of total emissions, and they have also been increasing in absolute term's. Typical gaseous exhaust emission contents are listed in **Table (3)**, for gasoline and diesel engines. Exhaust CO emission arises as a result of incomplete combustion. It is difficult to achieve complete oxidation in practice so, instead of the products been simply water and CO_2, there are other products (Case 1982).

Table (3), Typical exhaust emissions for gasoline and diesel engines (Samara (1997))

Emissions	Gasoline engines %vol.	Diesel engines %vol.
CO	4	7.1
HC	0.03 – 0.004	0.004 – 0.002
NO_x	0.2 – 0.06	0.15 – 0.04
CO_2	9	9
O_2	4	9
SO_2	0.06	0.02

Of all vehicle types, petrol-engine cars attracted more attention in relation to emission studies and control. The reason is, car numbers more numerous and pollutant than diesel-engine vehicles. In addition car used for personal mobility easiest to control in comparison with the other types of the existing total vehicle fleet sector. This argument suggest that traffic engineers has room for maneuver and should not base their evaluation only on measures such as traffic accident reduction and vehicle, congestion, delay, number of stops, and speed. The environmental impact issue result from vehicle movement should also addressed and considered as a measure of effectiveness of particular importance when design and/or improve urban and rural traffic network operations.
To conclude the above argument, the presented data and discussion suggest that, there is need for control and regulations to restrain the increasing demand for car ownership and fuel consumption for the purpose of transportation.

LITERATURE REVIEW

The Harmful Effect of Transport Generated Co Pollutant

Man inhales about 7500 liters of air each day, so lungs and respiratory system is in direct contact with whatever harmful substances present in the air. Continuous exposure to low levels could have harmful physiological effects on human beings, whereas short exposure to high levels of CO can be lethal (Singh et. al.(1990)). At sufficiently high concentrations CO can be fatal to humans. It aggravates cardiovascular diseases and may impair psychomotor functions (e.g. reaction time, depth perception, and peripheral vision).
The adverse health effects of CO are caused by its ability to reduced the quantity of oxygen (O_2) that is delivered to the tissues by the blood and possibly to inhibit the utilization of O_2 within the tissues. CO combines with the hemoglobin of the blood to form carboxy-hemoglobin, thereby displacing O_2 from the hemoglobin molecule and reducing the blood's ability to carry O_2. It also inhibits O_2 that is bound to hemoglobin from being released to the tissues (Matzoros (1988)).
In addition to that, CO is one pollutant which produces a change in human physiology that can be directly related to concentrations which the subject was exposed; blood carboxy-hemoglobin (COHb) can be predicted from atmospheric CO concentration. CO primarily affects the cardiovascular and central nervous system. It can cause or contribute to severe cardiovascular damage or sudden death to individuals with arteriosclerotic diseases. Its potential effects on the central nervous system include changes in vigilance, sensory function and psychomotor function. The main significance of those nervous system effects is that they occur at or near carboxy-hemoglobin concentrations that can be experienced by drivers in heavy traffic. Hence, there is a possibility that it impairs driving ability and, thereby, contributes to the occurrence of traffic accidents. The clinical studies conducted, however, have found contradictory results, so that the extent to which CO exposure may impair driving abilities is still not clear (Matzoros (1988)).
Death occurs in humans exposed to concentrations around **1000 ppm** corresponding to blood levels of **60%** COHb, impaired blood function may occur at much lower levels between **10** to **20%**. Reasonable correlation between daily mortality levels and CO, in addition heart function has been shown to be altered by elevated COHb, because CO blocks the transport of O_2 in the blood stream.

Comparison of CO Sources

It is estimated that motor vehicles contribute approximately **55%** of the total anthropogenic emissions in US cities. Even in cities like Delhi, vehicular traffic is significant source of CO. The urban area of Delhi has a high pollution potential during winter especially during November to January. In the U.K. the transport in general accounts for over **90%** of total CO emissions and over **20%** of CO_2, and road transport accounts for **99%** of CO (Singh et. al.(1990)).

Signal Control Intersections and the Increase in Vehicular CO Emissions

The use of traffic signals at road intersections controls vehicle movements by allocating time intervals during which separate traffic demands make use of the available road space. Signal equipment and control techniques have evolved to cope with wide range of intersection layouts and complex traffic demands- including pedestrians crossing.

One characteristic of the transport pollutant emissions of major interest to traffic managers, is the fact that they are very much influenced by the operating mode of the engine. This, in simple terms, means that a vehicle emits different quantities of pollutants per unit time or distance, when it accelerates, decelerates, idles or cruises at a steady speed. Matzoros (1988) mentioned it is widely reported in the literature that interrupted traffic flow produces more pollution than freely moving traffic flow. This is the case of traffic flow at junctions in general and signalized intersections in particular.

In a number of papers, Patterson and Meyer (1975) has investigated the use of traffic queuing models at signalized intersections in an attempt to estimate the non-constant emission profiles caused by stop-and-go traffic at the stop line. Although subject to the limitations described below, Patterson's work indicates that the queuing process is a copious source of CO near the stop line. Thus, most CO will be emitted near the stop line while automobiles are stopped for a red light. The result is that the emissions profile will be sharply peaked at the stop line and fall off rapidly toward mid-block, leading, under most wind conditions, to a similar non-uniformity in pollution levels between stop line and mid-block.

There are, however, some limitations in Patterson's approach. The queuing model considered assume either constant or uniformly distributed arrivals to and departures from the queue. These assumptions are often violated in the field. Examples include right turn on red unprotected left turns, pedestrian blockages of left-or right-turning traffic, buses dwelling at near-side bus stop, and platoons arrivals. The inclusion of such effects requires much more comprehensive model as reported by Matzoros (1988).

Claggett et. al. (1988), measured CO, traffic and meteorology during a six week period near a signalized intersection at an arterial intersection in Melrose park, Illinois, a suburban of Chicago. Ambient air samples were collected in the queue, acceleration/deceleration, and mid-block cruise zones. Measured concentrations were highest in the zone of traffic queue and lowest at mid block. The data indicates that CO concentration may be higher at urban intersection than the near freeways that have 2-3 times higher traffic volumes.

Matzoros (1988) developed a computer model to tackle the problem of transport air pollution from urban networks. It consists of queuing, emission and dispersion models and takes vehicle-operating modes (accelerating, decelerating, and idling and constant speed) and their variable emission rates into account. The model was applied under varying conditions and it was found that, CO emissions and concentration distributions show the highest spatial variation than other pollutants.

Lee (1983), used the TEXAS-II model in series of designated experiments to obtain quantitative estimates of the effects of various traffic and intersection factors on emissions, fuel consumption, traffic delays and queue lengths.

The TEXAS-II model was used to estimate, with respect to time and location, the source of CO, HC and NO_x emissions as well as the amount of fuel consumed by individually characterized vehicles as they pass through an intersection environment which can be described accurately in terms of its geometric features, traffic control and traffic stream characteristics. He concluded that:

1- Additional emissions and fuel consumption result from interrupted traffic flow on the intersection legs and in the intersection proper, as compared with uninterrupted flow.
2- Improvements in intersection geometry and traffic signal operation generally reduce excess emissions and fuel consumption more on the inbound intersection lanes than in the intersection proper or on the outbound lanes.

3- For the practical range of cycle times and traffic volumes used in the experiment, longer cycle times cause more emissions and fuel consumption on the inbound lanes but less in the intersection proper.

DATA COLLECTION

The selection of intersections for the purpose of this study is critical, as there are various conditions (e.g. geometry, traffic and timing) which directly affect the local traffic operation. In order to fulfil the objectives of the data collection, it was necessary to collect statistically sufficient and representative data, which should represent a range of vehicle flow, signal timing, and intersection geometry and vehicle emissions.

To achieve the above objectives, it was necessary to collect data about drivers' behavior during the various aspects of the signal cycle and the hours of the day at different intersection locations and geometric. This is to allow for the impact of these parameters on driver behavior to be observed. It was also necessary to collect data about the tailpipe emissions of different types of vehicles (diesel and petrol and private and taxi) for different transient modes (idling, acceleration and deceleration). The observed data may be summarized as below:

1- Vehicle data
2- Signal data
3- Intersection and road layout data
4- Tailpipe emission data

Four intersections, which satisfied the requirements of this study and representing a range of locational, vehicle and signal timings on Kurdistan ring road in the city of Erbil, were selected. Traffic at the selected intersections was controlled by uncoordinated fixed time signal plans. At the observed intersections there was no signal control on right turn traffic movement. **Table (4)** presents some of the main traffic and geometric characteristics of the four selected intersections.

Table (4). The main traffic and geometric features observed at the selected sites

Item	Description
Roadway system	Two-way street
Type of traffic control	Pretimed control
Observed range of cycle time	70 – 80 seconds
percentage of buses	0.5 – 13 percent
percentage of trucks	0.5 – 9.5 percent
Condition of pavement marking	No marking
Grade percent	0

The data collection made during the period 7:30 AM to 8:30 AM. This is because the observed levels of traffic activities during the morning peak periods produce data, which is statistically meaningful. In addition to that, the data collected in sessions of one-hour duration for each intersection in days of good weather conditions during the spring of the year 1999.

The video recorded data were as listed below:

1- Signal timing data.
2- Vehicle arrival data.
3- Vehicle departure data.
4- Incidents that could affect the observed listed as above data.

Lane and approach widths were measured manually using tape measurement at the stop line of each approach to obtain the accurate width. While the signal phasing was obtained using a stopwatch to measure time duration of the phases at site when it was not possible to get these information from the video recording.

Data abstractions were based on sessions of 30-minute periods of recorded data. When the videotape was replayed for a period of data abstraction, the sound signal was used as a reference point for all data sets. This sound technique is useful and essential to ensure that as long as there is need to replay the recording of one session to abstract all the required data, the abstraction process start and finish at the same points in time. The recorded data were abstracted using software developed for personal computer.

The data abstraction process is mainly achieved with the aid of a computer program named EVENT developed by Al-Neami (2000). The program was developed using C-language. The accuracy of the abstracted traffic data using this program is about up to 0.01 second.

Using the developed computer programs the abstracted data from EVENT files were processed. These programs calculate the given below traffic parameters:

1- The time headway between successive arriving vehicles.
2- The time headway between successive departing vehicles in queue.
3- The travel time for successive departing vehicles in queue.
4- Saturation flow data were calculated by taking the reciprocal of the average headway.
5- Calculates the frequency distribution of the video observed departure and arrival headways
6- The average video observed delay of an approach.
7- Duration of video observed data session.
8- Vehicle arrival and departure flow.

Remark

It should be noted that not all listed as above data used in this paper.

The link speeds data for the links between the surveyed intersections were measured by observations made from a moving vehicle during the morning peaks. This is because this method is efficient and practical, and is particularly suitable when a general evaluation of traffic conditions on a network of streets required (McShane and Roess (1990)).

The observers in the test car made a number of test runs (at least 6) for each link and they record their journey times, count opposing traffic, and keep a tally of overtaking and overtaken vehicles. From these observations, the mean speeds and numbers of vehicles passing along a street can be obtained for all classes of selected vehicles.

The vehicle emission data were collected using ANALYTICAL MOBILE GASEOUS EMISSION CART P 8334. The observed samples were 100 diesel engine buses and trucks, and 600 gasoline cars were tested at ambient temperature between 20 – 25 °C for transient modes (idling, accelerating and decelerating). Most of the vehicles were at cold start situation.

In this research, the intention was to produce typical emission values for the existing vehicle traffic composition in Erbil City. Therefore, the observed vehicles were mostly of models in the range of 1975-1990, with kilometers traveled between 100000 and 400000 km at the time period of surveys. A few older models with higher mileage vehicles also included in the survey for the observed data to be representative.

PRESENTATION AND ANALYSIS OF OBSERVED DATA

The abstracted data were analyzed statistically. The statistical analysis performed using SPSS statistical package. The traffic parameters analyzed are those of driver behaviour which initially assumed to have an effect on amount of car exhaust emission.

Observed emissions rate data

The idle vehicle emission data obtained by direct measurement of CO and HC emission from the vehicle exhaust. Emission data for other modes of vehicle operation obtained from the conducted surveys of moving car method. Achieved results of data collection of the observed various modes of vehicle operation presented in **Table (5).**

The idle vehicle emissions data, used in the analysis of the effect of driver perception-reaction behaviour on air pollution at the onset of green for vehicles. Emission data for dynamic mode of vehicle operation used in the analysis of driver behaviour during intergreen periods in relation to air pollution and in the development of emission models for vehicle queue and delay. Examination of the presented data indicates that on average, kinematics and dynamic modes of operation of gasoline engine vehicles have the highest CO and HC emission rates.

Table (5), Observed CO and HC emission data

Operating mode	CO & HC Emissions (* 10^{-3} g/sec)							
	Gasoline vehicles						Diesel Vehicles	
	Taxi Cars		Private Cars		Average			
	CO	HC	CO	HC	CO	HC	CO	HC
Cruise (50 kph)	37	15	36.7	15	36.9	55	11*	3*
Deceleration (50-0) kph	147	38	142	37	145	37.6		
Idle	134	17	131	16.6	132.8	16.8		
Acceleration (0-50) kph	139	28	136	27.3	137.8	55.7		

* FOR ALL OPERATING MODES

Observed Effect of Driver Behaviour on Vehicular CO Emissions

Driver starting delay time behaviour

Driver starting delay defined as the time lag between the start of green indication for stopped vehicles and the movement of first vehicle in queue. This time lag depends primarily on waiting driver perception – reaction time. **Table (6)**, provides a summary for the results of the descriptive statistical analysis performed. The observed data covers the behaviour of 1986 driver. The presented statistics indicates the existence of substantial difference in perception-reaction times among the observed drivers as may be inferred from the range of the data.

The obtained data presented graphically in **Fig.(1).** This Figure is a scatter plot used to examine the relation between starting delay and the excess vehicular CO emissions. The presented data suggest that as the starting delay increase the excess vehicular CO emission increase. This trend may be attributed for two reasons. The first is that the perception component of the starting delay time increases the idling time of the vehicle engine and hence, the CO emission. The second reason attributed to the reaction – action time component of the starting delay behaviour.

Table (6), Results of descriptive statistical analysis of the observed starting delay behaviour

Sample size	Minimum	Maximum	Mean	Standard deviation
1985	0.22	9.61	2.13	1.14

During this time interval the driver change his vehicle state from kinematics to moving condition to cross the stop-line. This has the implication of increase the excess CO emission as a result of the difference in time between the two modes of vehicle condition of idling and moving at constant speed before passing over the stop line.

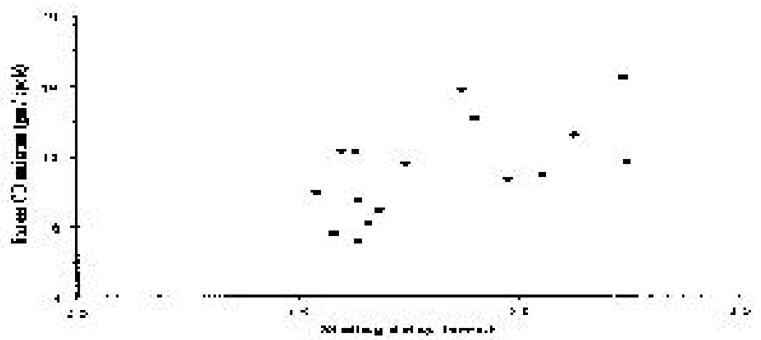

Fig. (1), Effect of observed mean driver starting delay behaviour on excess CO emission

Based on the above obtained result and argument, it is decided to examine the distribution of observed drivers starting delay behaviour. The obtained distribution presented in **Fig.(2)**, in the form of a standardized frequency polygon.

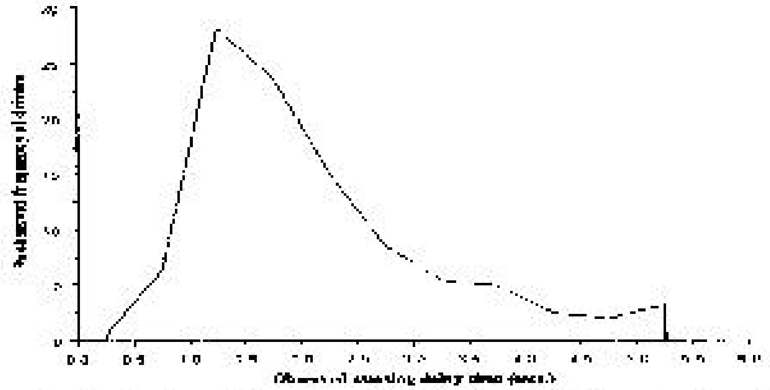

Fig.(2), Observed standardized frequency distribution of driver starting delay behaviour

The shape of the frequency polygon suggests that the observed driver behaviour skewed to the right. This indicates that the majority of drivers have starting delay times greater than the observed mean value of 2.13 seconds. This conclusion is consistent with the observed range of starting delay values presented in Table-6-. However, it should be noted that driver behaviour is not the only factor which contribute to the mean starting delay value. Type of vehicle has also an effect on starting delay value. An indication to this can be found by examination of the data presented in **Table (7)-** below. The presented data indicate that passenger car and truck-trailer type of vehicles have the lowest and highest mean starting delay of 1.692 and 3.953 seconds respectively. The reason for this substantial difference is attributed to the variation in kinematics characteristics between vehicles.

Table (7). Observed mean starting delay values for different types of vehicles

Type of vehicle	Mean starting delay	Observed sample size
Mixed traffic	2.129	1985
Passenger car	1.692	1497
Mini bus	3.005	60
Normal bus	3.185	36
Truck	3.034	43
Truck-trailer	3.953	20
Tractor	3.104	7
Total	3648	

Average vehicle queue length

The number of vehicles waiting at the commencement of green is usually referred to as vehicle queue length. This number depends on traffic factors such as vehicle arrival flow, saturation flow, phasing, cycle time and duration of red indication. The time required for vehicle queue to discharge has a substantial effect on the excess vehicular CO emissions. The increase in queue length can cause an increase in excess vehicular CO emission. An indication to this can be found by examination of the data presented in **Fig. (3).**

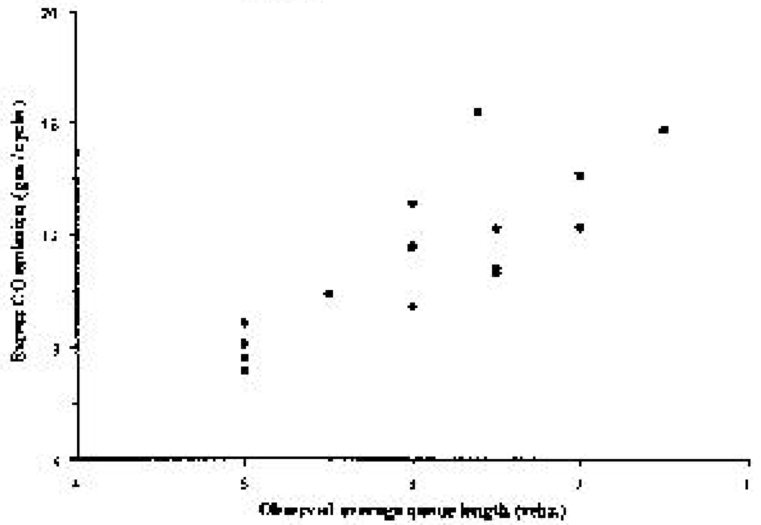

Fig. (**4**). Effect of average vehicle queue length on excess CO emissions

This is attributed for two major reasons. Firstly, an increase in the queue length means increase in the number of CO emitters, and hence, in the amount of CO gas. Secondly, an increase in queue length result in an increase in the time required for vehicles to dissipate during green. This has the implication of increase CO emissions while queuing vehicles are in idle, kinematics and dynamic modes of movement.

By contrast, vehicle queue length can result in decrease in vehicle discharge headway with the increase in vehicle position in queue. An indication to this can be found by observing the data presented in **Table (8).** As a consequence of this driver behaviour, it is possible to argue that vehicle CO emission decrease with the increase in vehicle queue length. This decrease in vehicle discharge headway with the increase in vehicle position in queue can be attributed to the decrease in driver perception-reaction time. This decrease can result from the possible impact of queuing time on driver.

However, the resultant effect of vehicle queue length is that CO emission increase with the increase in the average queue length.

Table (8)-, Effect of vehicle position in queue on vehicle discharge headway

Vehicle position in queue	2	3	4	5	6	7	8	9	10
Discharge headway	2.53	2.45	2.35	2.22	2.01	1.89	1.65	1.70	1.32
Total	**1882**	**1675**	**1315**	**899**	**500**	**229**	**71**	**15**	**3**

Percent Stopped Vehicles

As the percent stopped vehicles increases the excess vehicular CO emission also increase. This is clear in **Fig.(4),** which is a scatter plot of percent stopped vehicles and the excess vehicular CO emissions. The reason may be attributed for fact that as the percent stopped vehicles increases the idling, accelerating and decelerating times increase and the constant speed time decrease. Hence, the difference in CO emission rates between these modes namely the excess CO emission increase with the increase in percent stopped vehicles.

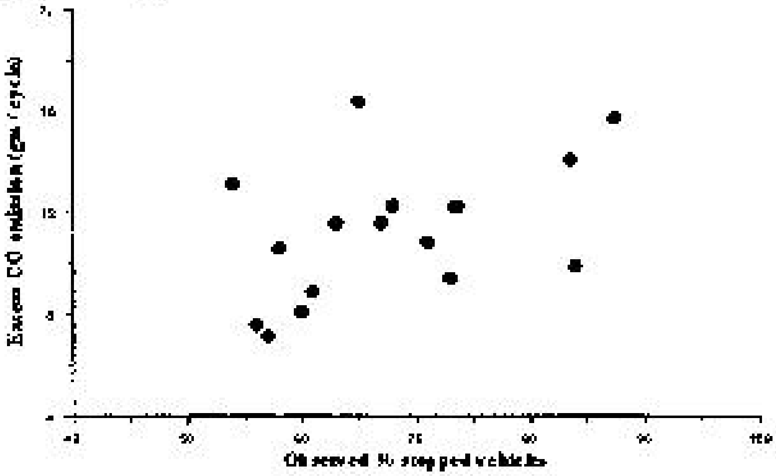

Fig.(4), Effect of percent stopped vehicles on vehicle excess CO emissions

Driver end lost time

The amber signal indication period follow the green signal used to provide the driver with a safe transition interval before the signal change into red. Therefore drivers arriving during this interval face the situation of either, decelerate to stop the vehicle before the stop-line or continue movement and accelerate if necessary to cross the intersection area before the commencement of the red signal. The choice of the proper action can vary between drivers. The end lost time defined as the unused portion of the amber interval result from the behaviour of those drivers who choose to stop during amber.

The effect of end lost time on vehicular CO emission is similar to that described for the effect of vehicle starting delay, that is CO emission increase with the increase in vehicle end lost time. Indication to this trend can be found by examination of the data presented in **Fig.(5)**. This trend in the data can be attributed for reasons similar to that described as above in the section of effect of driver start lost time on excess CO emissions.

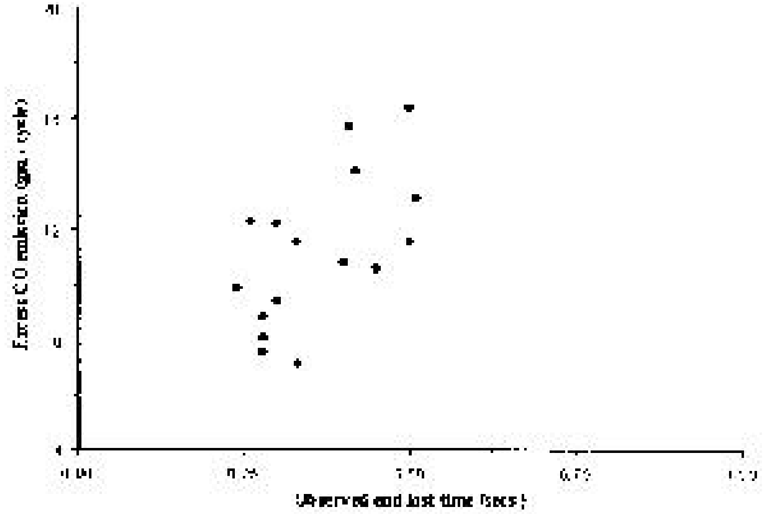

Fig. (5), Observed effect of driver behaviour during amber on CO emissions

Driver behaviour during amber is further examined by observation of the effect of time since start of amber on driver decision. Result of the statistical analysis made presented graphically in **Fig. (6)**, in the form of a standardized frequency polygon. The presented data indicate that the majority of the observed drivers pass over the stop-line when they arrive during the first 1.5 seconds following the start of amber. However, this behaviour vary with the type of vehicle observed. An indication to this variation can be seen by examination of the data presented in **Table (9).**

Table (9). Observed variation of amber mean time used by vehicles with type of vehicle

Type of vehicle	Observed No. of vehicles	Mean time used by vehicles since start of amber
Passenger car	644	1.06
Small truck	52	1.46
Mini bus	42	1.20
Normal bus	39	1.52
Large truck	14	1.65
Tractor	8	1.34

In general excess CO emission increases with the increase in end lost time and the majority of the observed drivers pass over the stop-line when they arrive during the first half of the amber period.

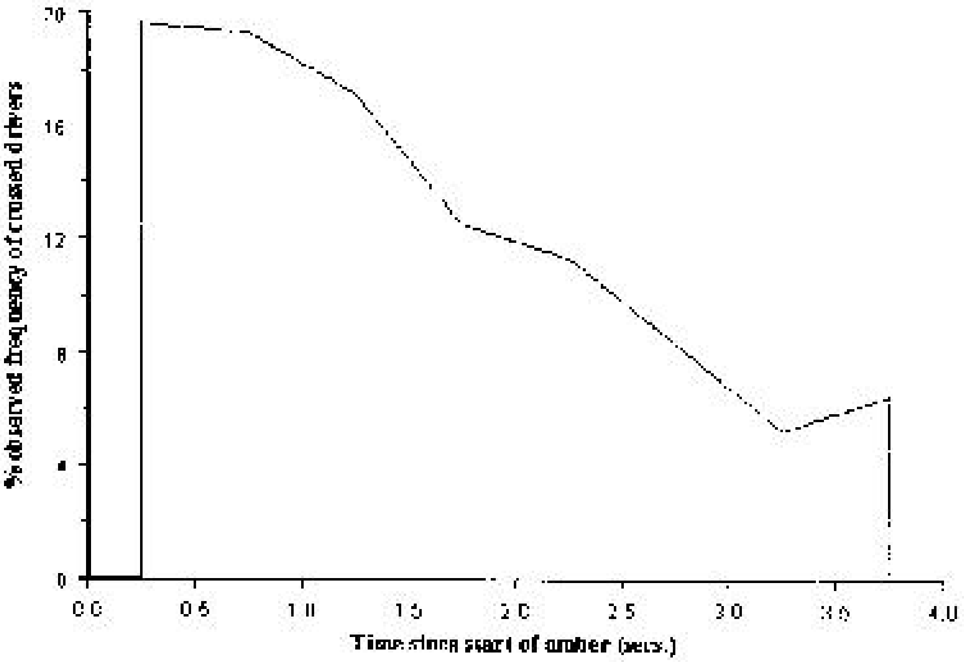

Fig.(6). Variation of excess CO emissions with the used time by vehicles since start of amber

Concluding remarks

The obtained results of this research work summarized as below:

1- Transient modes have substantial effect on CO emission rates, with decelerating mode having the highest CO emission rate. This conclusion is in agreement with that reported by the presented literature.

2- Gasoline powered vehicles emit higher percentages of CO emissions than diesel powered vehicles.

3- The obtained emission rates are based on the observed driver behaviours and vehicle types. It is rather unlikely that different vehicle compositions would produce similar results.

4- High driver precipitation-reaction time values, can result in an increase in vehicle excess CO emission rates.

5- Vehicle average queue length has a considerable effect on vehicle excess CO emissions, which increases with the increase in average queue length.
6- Improve vehicle movement during amber period can result in reduction in the excess CO emissions if safety can be maintained.

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