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# Effect of traffic volume on air pollution in urban areas - case study in Jordan

T.I. Al-Suleiman, G.G. Al-Khateeb, A.Z. Rabi, A.R. Awad

*Department of Civil Engineering, Jordan University of Science and Technology, P.O. Box 3030, Irbid-Jordan*

## ABSTRACT

This paper presents an evaluation and modelling of air pollution in urban areas. To achieve the objective of this paper, eighteen major sites (eight signalized intersections and ten main rotaries) were selected in Irbid City-Jordan and taken as a case study. The traffic counts at these sites were performed during peak and off-peak hours taking into consideration the seasonal variations. Special technical equipment were used to measure the concentration of the following air pollutants: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), Nitrogen Oxides (NOx), and particulate. The results showed that the effect of volume of Gasoline-Powered Vehicles on CO, NOx and particulate were statistically significant. While, the $SO_2$ was found more correlated with the volume of Diesel-Powered Vehicles. In general, the predicted levels of air pollution at the signalized intersections were found higher than those at the rotaries.

## INTRODUCTION

Air pollution in urban areas arises from several sources. The importance of a particular type of source depends to a certain extent on the location and climate. As stated by the World Health Organization [1], no matter where an urban area is situated, it has in its air a mixture of pollutants from different sources, including industrial plants, vehicles, and other transport media. Pacyna [2] mentioned that the basic component in any research of air pollution in urban areas is the inventories. They provide the basis for planning air pollution reduction strategies, modeling and evaluating their results.

Haikalis and Jordan [3] performed an analysis for the revised 1982 state air quality plans for New York and New Jersey throughout the use of specified transportation measures. They showed that improved public transit service to the business district

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produced less pollution and increased economic activity. Hanssen et al [4] examined the effect of traffic densities in four different geographical areas in Norway. It was shown that traffic volume is the most serious environmental problem in Norwegian urban towns and built-up areas. Matzoroz and Van Vliet [5] developed non-linear regression models to predict air pollution and concentrations from urban road networks. Several factors were taken into consideration; link flow, capacity, location of the receptor points, wind speed and direction, and the cycle time of signalized junctions. It was found that the most significant independent variables affected the concentrations were the link flow and capacity.

## MOTIVATION FOR THIS RESEARCH

Because of the fast expansion of road network and operating vehicles in developing countries, the environmental problems have significantly arised to become the most critical factor that influences the human kind. Jordan as one of the developing countries is expected to suffer from environmental problems especially those related to air pollution. Irbid city in the north of Jordan has a road network carrying a relatively high traffic volume compared to its population which may result in environmental and health problems. The mobile source represented by traffic volume is the main contributor to air pollution in the city. In addition, the road network of the city has no separate-grade intersections, no bridges, no tunnels, and no rail-roads, but rather all its intersections are at-grade intersections. The problem becomes more complex due to the fact that most of these intersections and rotaries, carrying high traffic volume, are located in residential areas where inhabitants are negatively affected, or commercial areas where people shopping are disturbed too. This research is considered the first in Jordan that examines the direct relationship between air pollution and traffic volume during peak and off-peak hours in both Spring and Summer seasons.

## METHODOLOGY AND DATA BASE

Eighteen major sites (eight signalized intersections and ten main rotaries) were selected based upon the following criteria:

a. To cover all the districts in the city which represent the differences in traffic volume.
b. The locations of monitoring sites were selected to be far enough from the influence of other sources of air pollution.

The data base included the following elements:

1- Air pollutants: CO concentration in parts per million (ppm), NO concentration (ppm), $NO_2$ concentration (ppm), $SO_2$ concentration (ppm), and particulate concentration (PTCONC) in micro gram per cubic meter ($\mu g/m^3$).
2. Traffic Volume: volume of Gasoline-Powered Vehicles (Vg) and volume of Diesel-Powered Vehicles (Vd) were obtained at all approaches of the monitored intersections and rotaries.

The data were collected during two seasons; Spring (from February-27-93 to April-4-93) and Summer (from June-20-93 to July-28-93) in the peak and off-peak hours.

## STATISTICAL MODELING AND RESULTS

The collected data were used to develop the statistical models that express the air pollutants as a function of traffic volume. These models would help in predicting the air pollution at any level of traffic flow. The first stage of model development was the establishment of statistical correlation matrix for the different variables included in the study. The correlation matrix is used to select the independent variables that highly correlated with the dependent variable and to investigate the multicollinearity among the independent variables. From the correlation matrix, it was found that CO, NO, $NO_2$, and PTCONC had high correlation coefficients with Vg. While, $SO_2$ was found more correlated with Vd. The second stage of model development was to determine the general trends of the considered variables and the suitable statistical transformation required in each model.

The regression models corresponding to the peak hours were developed as shown in the following equations:

$$CO=-1.943+0.006*Vg-2.219*Type+1.689*SEA \quad (1)$$

$$NO=0.000137*Vg-0.037*Type+0.056*SEA \quad (2)$$

$$NO2=-0.709+0.245\ Log(Vg)-0.007*Type+0.017*SEA \quad (3)$$

$$PTCONC=-5680+1850\ Log(Vg)-72.7*Type+171.4*SEA \quad (4)$$

$$SO_2=-0.031+0.00019*Vd+0.017*Type+0.017*SEA \quad (5)$$

Where:

Type = type of monitoring intersection (intersection = 0, rotary =1).

SEA = Season of the year (Spring = 0, Summer =1).

It is worth mentioning herein that Type and SEA were considered qualitative (dummy) variables. The other variables in these models which are defined previously

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were considered quantitative.

On the other hand, the following regression models were developed corresponding to the off-peak hours:

$$CO=(4.619*10^{-3})*10^{-0.028(Type)}*10^{0.015(SEA)}*Vg^{0.993} \quad (6)$$

$$NO=(1.524*10^{-4})*10^{-0.015(Type)}*10^{0.010(SEA)}*Vg^{0.949} \quad (7)$$

$$NO2=(3.928*10^{-5})*10^{-0.010(Type)}*10^{-0.014(SEA)}*Vg^{1.008} \quad (8)$$

$$PTCONC=-2507.7+873.4\ \log(Vg)-14.5*Type+22.7*SEA \quad (9)$$

$$SO2=-0.332+0.154\log(Vd)-0.004*Type-0.002*SEA \quad (10)$$

The effects of independent variables on air pollutants were found highly significant (level of $\alpha$ less than 0.10) in the developed models. Since that vehicles were found the primary source of CO and $SO_2$ in urban areas, the effect of traffic volume on these pollutants was more investigated. The statistical characteristics of the models in Equations 1, 5, 6, and 10 are summarized in Tables 1, 2, 3, and 4, respectively. The values of coefficient of multiple determination ($R^2$) for the models in these equations were found 0.845, 0.761, 0.991, and 0.987, respectively.

Table 1: Statistical Characteristics of the Model in Equation 1.

| Parameter | Parameter Estimate | Standard Error | t-Value | Level of $\alpha$ |
|---|---|---|---|---|
| Intercept | -1.9427 | 1.0184 | -1.9080 | 0.0655 |
| Vg | 0.0060 | 0.0006 | 10.4420 | 0.0001 |
| Type | -2.2188 | 0.5080 | -4.3670 | 0.0001 |
| SEA | 1.6894 | 0.4845 | -3.4870 | 0.0014 |

Table 2: Statistical Characteristics of the Model in Equation 5.

| Parameter | Parameter Estimate | Standard Error | t-Value | Level of $\alpha$ |
|---|---|---|---|---|
| Intercept | -0.03105 | 0.01422 | -2.1830 | 0.0365 |
| Vd | 0.00019 | 0.000022 | 8.4810 | 0.0001 |
| Type | 0.01655 | 0.00710 | 2.3320 | 0.0262 |
| SEA | 0.01723 | 0.00727 | 2.3700 | 0.0240 |

Table 3: Statistical Characteristics of the Model in Equation 6.

| Parameter | Parameter Estimate | Standard Error | t-Value | Level of $\alpha$ |
|---|---|---|---|---|
| Intercept | -2.3355 | 0.0564 | -41.401 | 0.0001 |
| Log (Vg) | 0.9929 | 0.0186 | 53.391 | 0.0001 |
| Type | -0.0280 | 0.0029 | -9.725 | 0.0001 |
| SEA | 0.0151 | 0.0031 | 4.955 | 0.0001 |

Table 4: Statistical Characteristics of the Model in Equation 10

| Parameter | Parameter Estimate | Standard Error | t-Value | Level of $\alpha$ |
|---|---|---|---|---|
| Intercept | -0.33189 | 0.01175 | -28.256 | 0.0001 |
| Vd | 0.15447 | 0.00491 | 31.443 | 0.0001 |
| Type | -0.00389 | 0.00061 | - 6.369 | 0.0001 |
| SEA | -0.00163 | 0.00069 | - 2.358 | 0.0253 |

Figures 1 through 4 show the applications of the models in Equations 1, 5, 6, and 10, respectively. Figures 1 and 3, shows that during the peak and off-peak hours, the type of monitoring site (Type) and the season (SEA) entered the models significantly. The negative sign for Type variable indicated that the CO concentration at intersections were higher than that at rotaries. On the other hand, the positive sign for SEA variable showed that the CO concentration during Summer were higher than that during Spring in spite of temperature rise in Summer, because of higher traffic volume.

Figure 2 shows that during the peak hours the $SO_2$ concentration at rotaries was higher than that at intersections. This finding could be explained by the fact that the Diesel-Powered Vehicles suffer from "stop and go" pattern at rotaries more than the Gasoline-Powered Vehicles. Moreover, the $SO_2$ concentration in Summer peak hours was higher than that in Spring peak hours due to higher traffic volumes in summer. As shown in Figure 4, the $SO_2$ concentration at intersections was higher than that at rotaries during the off-peak hours. This is because rotaries during off-peak hours serve

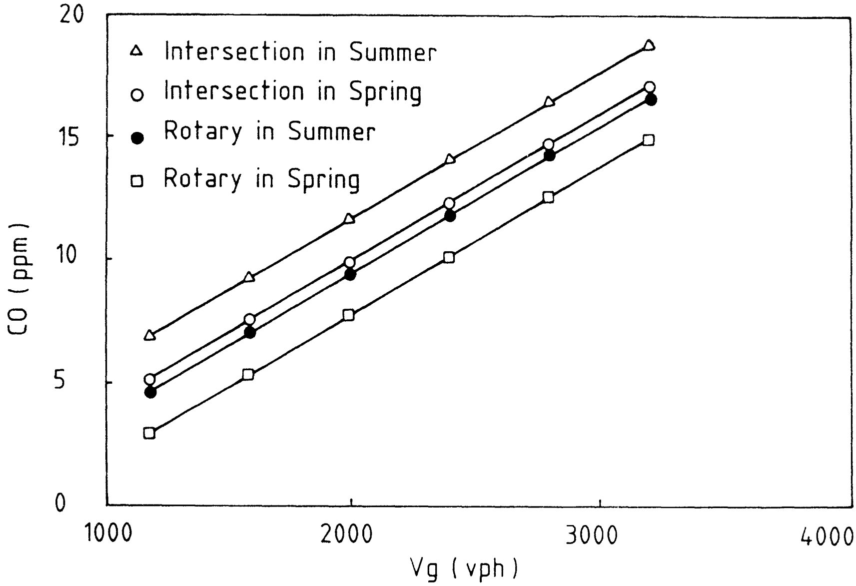


Figure 1: Estimated CO Concentration During Peak Hours.

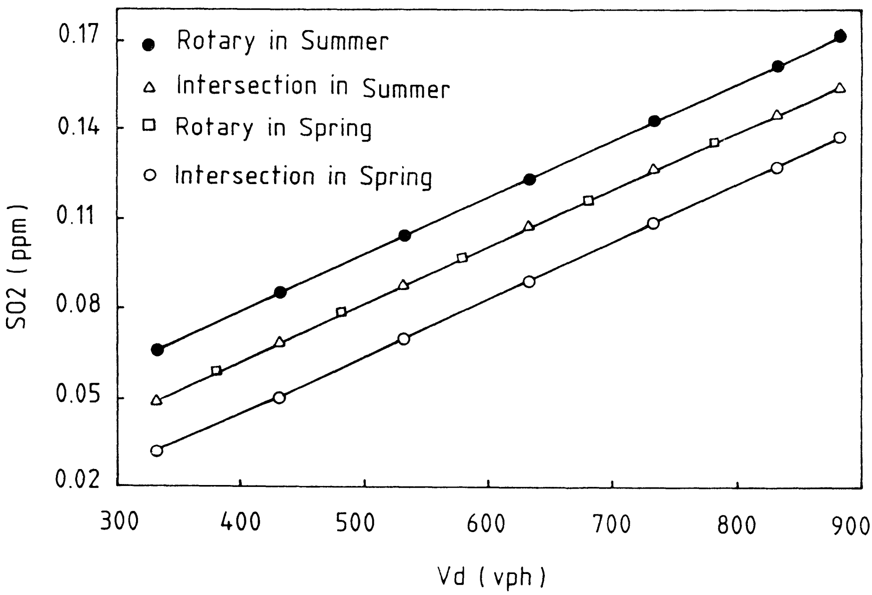


Figure 2: Estimated SO2 Concentration During Peak Hours.

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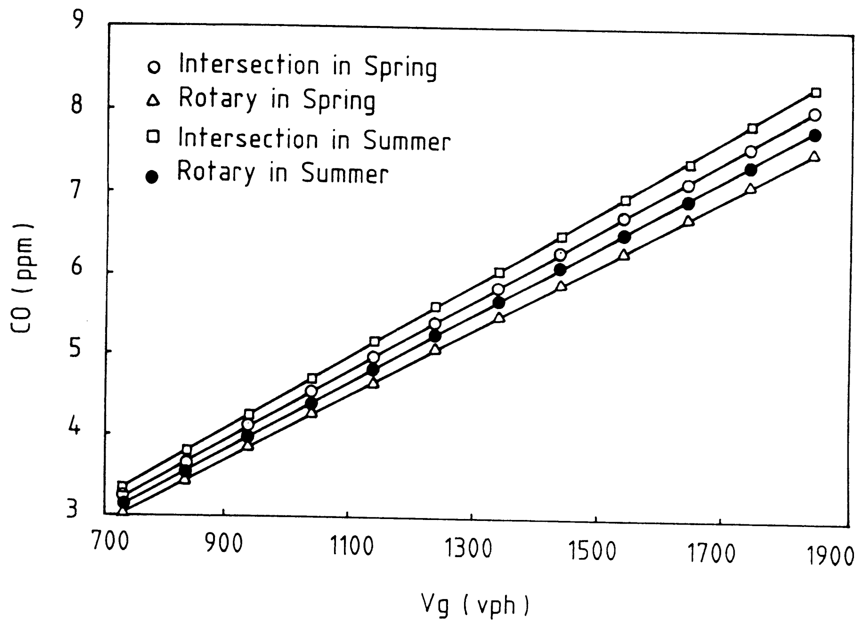


Figure 3 : Estimated CO Concentration During Off-Peak Hours.

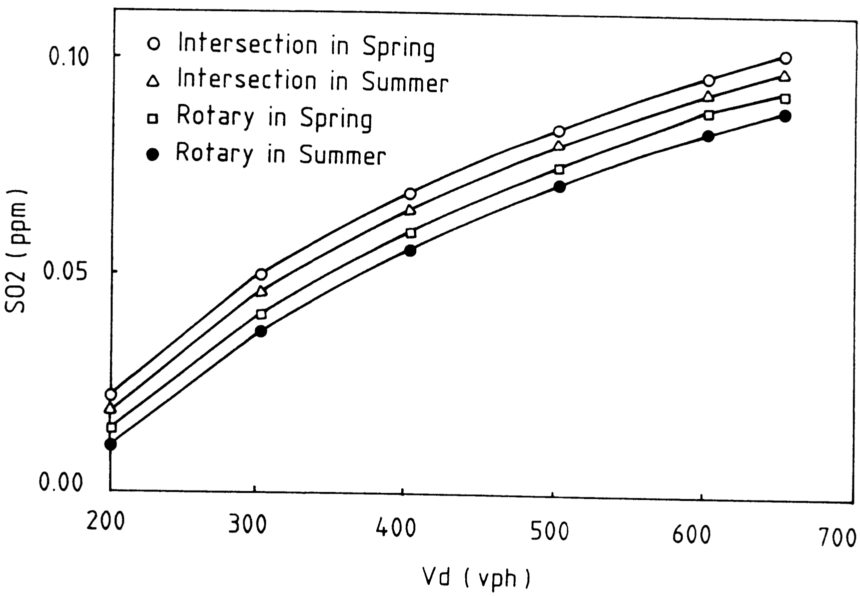


Figure 4 : Estimated SO2 Concentration During Off-Peak Hours.

less Diesel-Powered Vehicles than intersections. In addition, the heavy vehicles are not allowed to enter the CBD during the peak hours. Therefore, their volume is higher at the rotaries which are mainly located at the entries of the city.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were drawn based upon the results of this research:

1- In general, the concentrations of air pollutants were found higher at signalized intersections than at rotaries and higher in Summer than in Spring due to higher traffic volumes.
2- The relationship between the volume of Gasoline-Powered Vehicles (Vg) and the levels of CO, NOx, and particulate was found statistically significant.
3- The volume of Diesel-Powered Vehicles (Vd) and the $SO_2$ concentration were significantly correlated.
4- To reduce air pollution, several strategies are recommended including the following: improved public transit, bicycling encouragement, private cars restrictions such as institution of parking tax and fee surcharge for vehicles entering the CBD, and removing older vehicles from service.
5- In order to make the vehicles flow more freely, it is recommended that on-street parking as well as pedestrian movement should be controlled.

## REFERENCES

1- "Urban Air Pollution (1973-1980)." Global Environment Monitoring System prepared in cooperation with the Monitoring and Assessment Research Center, Chelsea, University of London, England, World Health Organization, Geneva, PP. 1-5, 1984.
2- Pacyna, M. J. "Methods for Air Pollution Abatement." Proceedings of the Conference on Atmospheric Pollution, Arab School of Science and Technology, Damascus, Syria, PP. 58-68, 1985.
3- Haikalis, G. and Jordan, J. D. "Stringent Transportation Measures to Reduce Vehicular Emissions in the New York city Metropolitan Area." Transportation Research Record 963, Transportation Research Board, National Research Council, Washington, D.C., PP. 45-52, 1984.
4- Hanssen, J., Kolbenstvedt, M., Klaeboe, R., Aas, H., Bakketeig, L. S., Larssen, S., Clench-Aas, J., and Solberg, S. "Traffic and the Environment." A Trans-Institutional Research Programme for Road Traffic, the Environment and

Health in Urban Areas, Simen Ensby, Royal Norwegian Council for Scientific and Industrial Research (NTNF), Norway, PP. 4-12, 1991.

5- Matzoroz, A. and Van Vliet, D. "A Model of Air Pollution from Road Traffic, Based on the Characteristics of Interrupted Flow and Junction Control: Part II-Model Results." Transportation Research, An International Journal, Part A: Policy and practice, Vol. 26A, No. 4, Pergamon Press Ltd., Oxford, England, PP. 331-355, 1992.