TRAFFIC POLLUTANTS LEVELS AT DIFFERENT DESIGNS OF KING FAHD ROAD, SAUDI ARABIA: COMPARATIVE STUDY

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Abstract: Dammam and Khobar governorates constructed tunnels and bridges on King Fahd road. This study aimed at comparing traffic pollutants' levels on normally designed parts and at about 50m from the portals of tunnels and bridges. This study was conducted during March to August 2009. Particulate matter; traffic vapors and gases; and noise were measured at roadside level at the three designs of King Fahd Road in the two governorates. Levels of particulate matter, total volatile organic compounds, sulfur dioxide, carbon monoxide, and noise at the normally designed parts of King Fahd road [687(25.4)μg/m^3, 1.0(1.0)] 0.1(0.2), 4.0(5.0) ppm and 76.5(6.3)dB] were higher than that at tunneled [359.1(231.0), 1.0(1.0), ND(0.1), 2.0(2.0) and 72.8(5.3)] and bridged parts [420.4(259.8), ND(1.0), ND(0.0), 1.0(2.0) and 72.2(5.3)] respectively. Therefore, it can be concluded that traffic pollutants at tunneled and bridged parts of King Fahd road were lower than that at normally designed parts.

Key Words: Carbon monoxide, particulate matter, road re-design, sulfur dioxide, total volatile organic compounds, traffic gases, traffic pollution, traffic vapors.

1. INTRODUCTION

In the past, the major sources of poor air pollution were industrial activities and domestic heating. Nowadays; traffic pollution is predominant and significantly contributes in the urban air quality problems especially in roads of condensed traffic. Traffic congestion contributes to traffic pollution, and hence affects public health, and may cause annoyance particularly for those live, or work in heavy traffic roads. Traffic emissions and noise levels are higher in congested, stop-and-go and idling traffic than they are when traffic is moving at a steady speed (Balbus et al., 2010; Ingle, Wagh, Pachpande, Patel, & Attarde, 2005; Kassomenos, Karakitsios, & Papaloukas, 2006; Potoglou & Kanaroglou, 2005).

Traffic pollution is a drastic public health problem in both developed and developing nations (Issever et al., 2005). It is usually associated with human health hazards including asthma exacerbations and other cardiovascular illness (de Kok, Driece, Hogervorst, & Briede, 2006; Linn & Gong, 1999). Moreover, traffic pollutants, of which particulate matter (PM), total volatile organic compounds (VOCs) sulfur dioxide (SO_2), and carbon monoxide (CO), have significant effects on emergency department visits for asthma among children less than 2 years and elderly of more than 75 years (Villeneuve, Chen, Rowe, & Coates, 2007). According to World Health Organization, 2004 atmospheric pollution is the cause of 2.4 million deaths per year worldwide (Chimonasa & Gessner, 2007). In addition to their adverse effects on public health, traffic pollutants have also great impact on the environment that causes public health problems. These environmental impacts include depletion of ozone layer, generation of tropospheric ozone, greenhouse effects and acid deposition phenomenon (EPA, 2004; Fenger, 2009).

Dammam is the capital of the Eastern Province of Saudi Arabia. It is about 400 km away from Riyadh. It is the major seaport of the region. Khobar is another large city in the Eastern Province. It is one of the main commercial centers. In addition, there is increase in the migration of people to Dammam and Khobar governorates for getting job and studying. King Fahd Road is one of the heavy traffic roads that connects the two governorates Dammam and Khobar and penetrates them deeply. The two fractions of the road penetrate Dammam and Khobar are characterized by length, multiple activities, and heavy traffic. There are industries, universities and different governmental and commercial centers in the King Fahd Road. Hence, air pollution abatement will remain a challenge because of increasing demands for transportation (Potoglou & Kanaroglou, 2005). Recently, increasing traffic flow on Dammam and Khobar roads leads to traffic congestion that necessitates developing and implementing transportation control strategies, of which road redesign is one of the important strategies (NG, 2000; Orubu, 2004).

So, the two governorates implemented projects of re-designing King Fahd Road. Their objectives were to ease and speed up the transportation and reduce travelling time and time wasted at intersections (UNITED NATIONS, 2002). This took place by considering the two fractions in the road penetrate Dammam and Khobar governorates. Then, each road fraction was divided into three parts. The first part was left with normal design (normally designed parts). The second and third parts were re-designed by construction of tunnels and bridges (tunneled and bridged parts). On each of the tunneled and bridged parts the road was divided into two alternative pathways, one of which was the tunnel or bridge (below or above the roadside level) and the other was the normal road (at the roadside level). Hence, vehicles at the modified parts of King Fahd road were distributed between the two alternative pathways. Consequently, traffic congestion and idling traffic was greatly reduced and traffic flow was increased.

The research questions were whether the traffic pollutants at the roadside level on normally designed parts and at re-designed parts at about 50 m from the portals of tunnels or bridges are similar or not? And which road design is the best from air pollution and public health points of view? So this study aims at comparing traffic pollutants' levels on normally designed parts of King Fahd road and at about50 m from the portals tunnels and bridges at the roadside level and thus recommending the best design from air pollution and public health points of view.

2. MATERIAL AND METHODS

The study was conducted during March to August 2009 (after nearly one year of completing construction of tunnels and bridges under study) at the fractions of King Fahd road penetrate deeply in Dammam and Khobar governorates.

The sampling stations were located on the Curbside at the roadside level on the normally parts and at 50 m from the portals of both tunnels and bridges to be away from intersections and the portals of tunnels and bridges. The first parts in each fraction represented normally designed parts of road in both Dammam and Khobar (two sampling stations). The second and third parts represented parts of road modified by constructing tunnels and bridges in the two governorates (four sampling stations). Therefore, six sampling stations were included in the two governorates. Sampling occurred during the morning rush hours (6 am – 8 am) at the working days (Saturday – Wednesday).

Four traffic pollutants were measured during the present study including: particulate matter (PM) which was measured in micrograms per cubic meter ($\mu g/m^3$); total volatile organic compounds (VOCs), sulfur dioxide (SO_2), and carbon monoxide (CO) which were measured in parts per million (ppm); in addition to noise levels in decibel (dB). The EntryRAE (PGM-3000) Multi-Gas Monitor was used for measurement of VOCs and the VRAE Hand Held 5 Gas Surveyor (Model 7800 Monitor) was used for measurement of SO_2 and CO. For Quality Assurance purposes, data of the two gas monitors were calibrated against known concentrations of these gases. Noise levels were measured using Sound Level Meter Model CA832 calibrated at 114 dB. At each sampling station, 25 readings (over two-hour period) were directly recorded on the basis of 5 minutes averages for each gaseous pollutant and noise levels. Therefore, in the present study, there were 6000 records for each of the VOCs, SO_2, CO and noise levels. Half of the 6000 records were taken from Dammam and the other half from Khobar.

Particulate Matters were sampled on 60 mm diameter glass fiber filters by the pre-calibrated Hand Held Battery Portable air sampler on the basis of two- hour samples. After sampling, the filters were transferred to the Occupational Health and Air Pollution Research Unit Laboratories in High Institute of Public Health, Alexandria University, for further gravimetric determination and calculation of PM concentrations in $\mu g/m^3$. Therefore, there were 600 PM records, 300 of which from Dammam and the other 300 from Khobar.

Statistical Analysis

Data entry, statistical analysis and graphical presentation of data were done at High Institute of Public Health, Alexandria University using SPSS-16 package (Chicago, Illinois, 2007). The used statistical analysis were: Kolmogorov-Smirov and Shapiro- Wilk tests of normality, descriptive statistics (median and interquartile range), Kruskal Wallis test as a significance test of more than two independent samples and Mann Whitney Test as a significance test of two independent samples.

3. RESULTS AND DISCUSSION

Traffic pollutants levels at roadside on normally designed parts of King Fahd Road were higher than that at 50 m from the portals of tunnels and bridges. The total volatile organic compounds (VOCs), sulfur dioxide (SO_2) and carbon monoxide (CO) showed highly significant Kolmogrov-Smirnov and Shapiro-Wilk tests of normality ($p<0.05$ at 95% C.I). Therefore, VOCs, SO_2 and CO were non-parametric variables (did not follow normal distribution). Particulate matter (PM) and noise levels proved non-significant Kolmogrov-Smirnov and Shapiro-Wilk tests ($p>0.05$ at 95%C.I). Hence, they were parametric variables (follow normal distribution). For simplification, all numeric variables were assumed to be non-parametric(Glasser, 2005). Therefore, the data were expressed as [median (Inter-quartile range IQR)] and the tests of significance used were the non-parametric tests (Kruskal-Wallis and Mann Whitney tests).

3.1. Traffic Pollutants at the Two Governorates

The levels of PM [545.2(210.6) $\mu g/m^3$], VOCs [1.0(2.0) ppm], SO_2 [0.1(0.1) ppm], CO [3.0(3.0) ppm], and noise [74.5(5.9)dB] on King Fahd road in Dammam were higher than that in Khobar [287.9(428.6)$\mu g/m^3$], [Non-detected ND (1.0) ppm], [ND(0.1) ppm], [2.0(2.8) ppm], and [73.1(6.4) dB] respectively (table 1). This may be attributed to higher traffic volume as a result of higher commercial activities and presence of educational institutions on King Fahd road in Dammam. Mann-Whitney test revealed the highly significant differences of the five traffic pollutants' levels between the two governorates. This means that differences of traffic pollutants’ levels between the two governorates were not due to chance.

Table 1. Comparison of medians of PM, vocs, SO_2, CO and noise at fractions of King Fahd Road in Dammam and Khobar Governorates during the period from during March to August 2009

	Dammam					Khobar					Mann-Whitney Test
	No	Median	Q1	Q3	IQR	No	Median	Q1	Q3	IQR	
PM	30	545.2	476.86	687.4775	210.6	30	287.9	245.2	673.9	428.6	<0.05
VOCs	300	1.0	ND	2.0	2.0	300	ND	ND	1.0	1.0	<0.05
SO_2	300	0.10	ND	0.1	0.1	300	ND	ND	0.1	0.1	<0.05
CO	300	3.0	1.0	4.0	3.0	300	2.0	1.0	3.8	2.8	<0.05
Noise	300	74.5	71.8	77.7	5.9	300	73.1	69.6	76.0	6.4	<0.05

PM	Concentration of particulate matter (μg/m^3)	CO	Concentration of carbon monoxide (ppm)
VOCs	Concentration of total volatile organic compounds (ppm)	Noise	Noise level (dB)
SO_2	Concentration of sulfur dioxide (ppm)	IQR	Inter-quartile range = Q3 – Q1
ND	Non-detected		

3.2. Traffic Pollutants at Normally Designed and Modified Parts of the Road

The levels of PM, VOCs, SO_2, CO, , and noise levels at the normally designed parts of road [687(25.4)μg/m^3, 1.0(1.0) 0.1(0.2), 4.0(5.0), ppm and 76.5(6.3)dB respectively] were higher than that at tunneled [359.1(231.0) μg/m^3, 1.0(1.0), ND(0.1), 2.0(2.0) ppm, and 72.8(5.3) dB] and bridged parts [420.4(259.8) μg/m^3, ND(1.0), ND(0.0), 1.0(2.0) ppm and 72.2(5.3) dB respectively] (figures.1, 2, 3, 4, 5). This may be due to different designs of King Fahd road in which the vehicles on tunneled or bridged parts were distributed between the two alternative pathways. This may reduce both traffic congestion, and idling and increase traffic flow. Hence, traffic pollutants at tunneled and bridged parts were consequently reduced [(4)].These findings were supported by two studies in Trento (Heimann et al., 2007), and Sydney(NSW, 2010) [(18)]. which concluded that emissions released from bridges and tunnels respectively reduce surface traffic congestion and improve roadside air quality(LightHouse, 2007).

It is also clear from figure 1 that at the roadside level, PM at tunneled parts of road [359.1(231.0)μg/m^3] were lower than that at bridged parts [420.4(259.8) μg/m^3) (NSW, 2010)[(18)]. In addition, PM levels at tunneled and bridged parts were 52% and 61% of that at normally designed parts respectively. This may be attributed to the aerodynamic diameter and collision of PM with walls and ceilings of the tunnels that may enhance settling at tunneled parts and consequently, reduce PM concentrations at the roadside level. In addition, PM excitation and dispersion at bridged parts of road reduce the settling velocity and enhance suspension in the atmosphere consequently increase PM concentrations at the roadside level(EPA, 2010). Kruskal Wallis test indicated the highly significant variation of PM among the three designs ($p<0.05$, at 95% C.I). Mann Whitney test showed significant differences between PM concentrations at the roadside levels of normal and tunneled, normal and bridged and tunneled and bridged parts of King Fahd Road ($p<0.05$, at 95% C.I). This indicated that the observed differences of PM concentrations at different road designs were realistic and were not due to chance.

Considering traffic vapors (VOCs), figure2 indicates the same VOCs levels at the roadside of tunneled and bridged parts. At bridged parts, the better vertical and horizontal diffusion and dilution of VOCs as a result of higher sources' heights reduce VOCs concentrations at roadside level while at tunneled parts the ceilings and walls of tunnels may absorb VOCs and hence, reduce their concentrations at roadside level (Heimann, et al., 2007 ; TAN, Vergel, & Camagay, 2006). Kruskal Wallis test indicated the highly significant variation in VOCs levels among the three road designs ($p<0.05$, at 95% C.I). Further analysis using Mann Whitney test revealed highly significant differences of VOCs at the roadside level between normal and tunneled and normal and bridged parts ($p<0.05$, at 95% C.I.) and non-significant difference between tunneled and bridged parts ($p>0.05$). This means that the observed variations were not due to chance.

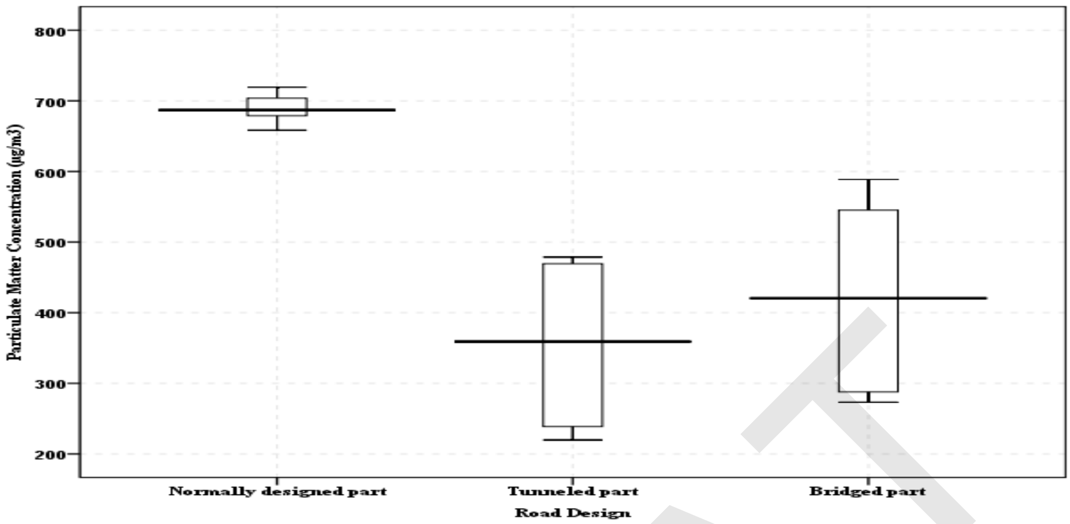

Figure (1). Particulate matter levels at normally designed parts and at 50m from the portals of tunnels and bridges on King Fahd Road in Dammam and Khobar Governorates during the period from March to August 2009

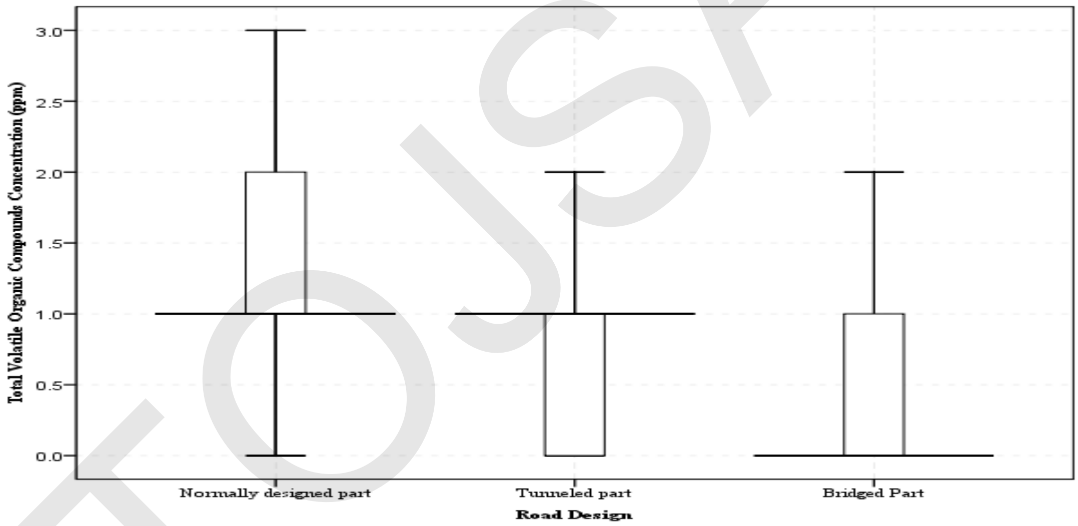

Figure (2). Total volatile organic compounds levels at normally designed parts and at 50m from the portals of tunnels and bridges on King Fahd Road in Dammam and Khobar Governorates during the period from March to August 2009

Regarding traffic gases, SO_2 at the roadside level confirmed higher levels at tunneled [ND (0.1) ppm] than at bridged parts [ND (0.0) ppm] (figure 3). This may be due to the lower vertical and horizontal diffusion and hence lower dilution at tunneled than that at bridged parts. Kruskal Wallis test, indicated the highly significant variation of SO_2 levels among the three road designs ($p<0.05$, at 95% C.I). Further analysis using Mann Whitney test revealed highly significant differences of SO_2 levels between normal and tunneled, normal and bridged and tunneled and bridged parts ($p<0.05$, at 95% C.I). Therefore, the observed differences were realistic and were not due to chance.

The lower levels of CO at bridged [2.0(2.0ppm)] than at tunneled parts [1.0(2.0)] of road were owing to higher diffusion that increased by increasing heights of emission sources (figure-4). Kruskal Wallis test revealed the highly significant variation of CO at the roadside among the three road designs ($p<0.05$, at 95% C.I). Further analysis using Mann Whitney test revealed highly significant differences of CO between normal and tunneled, normal and bridged and tunneled and bridged parts ($p<0.05$, at 95% C.I). Hence, the observed differences were not due to chance.

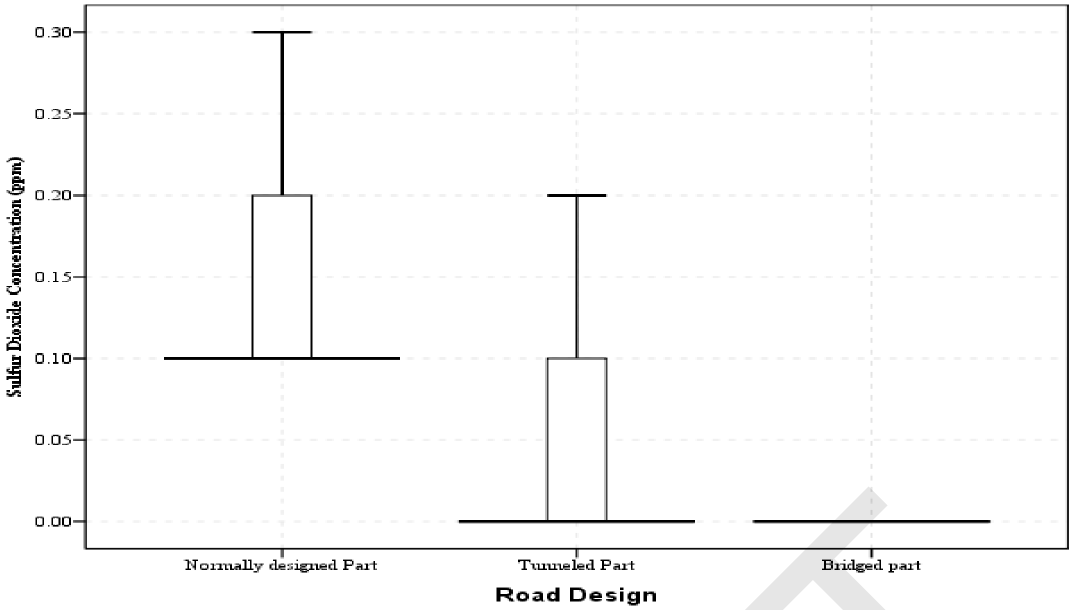

Figure (3). Sulfur dioxide levels at normally designed parts and at 50m from the portals of tunnels and bridges on King Fahd Road in Dammam and Khobar Governorates during the period from March to August 2009

Considering noise levels, figure 5 indicates that noise levels at the roadside of the bridged parts [72.8(5.3) dB] were slightly lower than that at tunneled parts [72.2(5.3) dB].This ensures that traffic is the main source of noise in King Fahd road. Kruskal Wallis test revealed the highly significant variation of noise among the three road designs ($p<0.05$, at 95% C.I). Further analysis by Mann Whitney test revealed highly significant differences of noise levels between normal and tunneled, normal and bridged and tunneled and bridged parts ($p<0.05$, at 95% C.I). Therefore, the observed differences were realistic and were not due to chance.

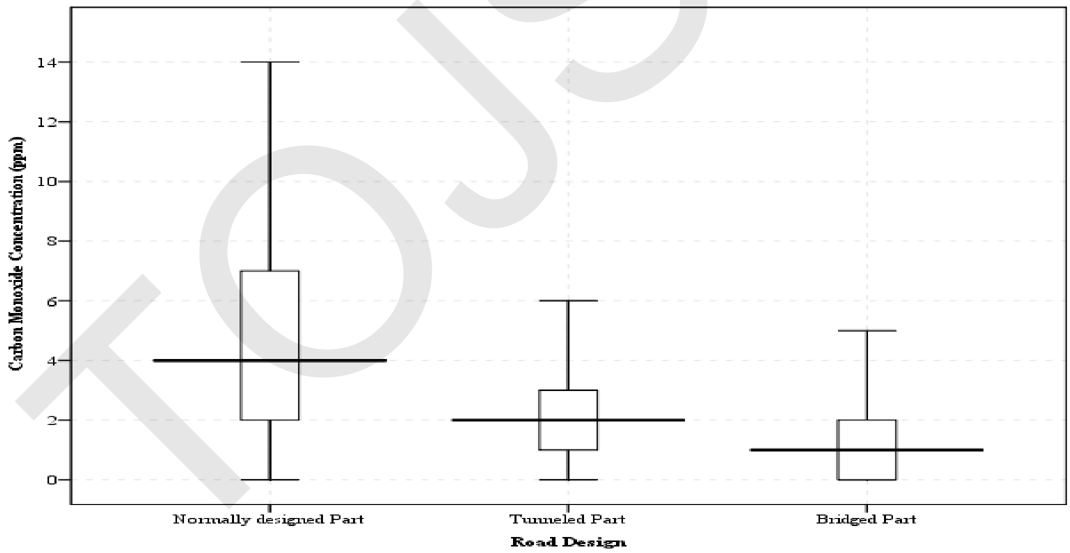

Figure (4). Carbon monoxide levels at normally designed parts and at 50m from the portals of tunnels and bridges on King Fahd Road in Dammam and Khobar Governorates during the period from March to August 2009

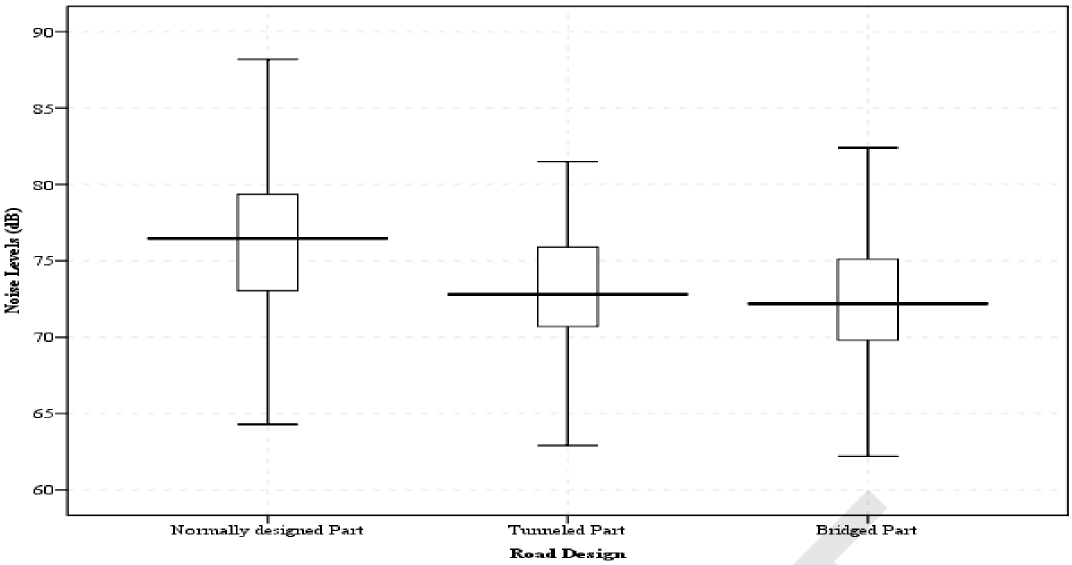

Figure (5). Noise levels at normally designed parts and at 50m from the portals of tunnels and bridges on King Fahd Road in Dammam and Khobar Governorates during the period from March to August 2009

All of the above results indicate the positive impact of the alternative roads on reducing traffic congestion and traffic pollutants levels. Both tunnels and bridges improve air quality at roadside level. The choice between tunnels and bridges depends mainly on the nature of traffic pollutants That is to say, in case of higher PM concentrations, tunnels are more recommended while in case of higher traffic gases and noise levels bridges are more recommended.

3.3. CONCLUSIONS

Traffic pollutants at the roadside level of tunneled and bridged parts of King Fahd road were lower than that at normally designed parts. Particulate matters (PM) at tunneled parts were lower than that at bridged parts. Traffic gases (SO_2, CO), and noise levels were lower at bridged than at tunneled parts. Traffic vapors (VOCs) levels were similar at both tunneled and bridged parts.

It is recommended to design and implement tunnels and/or bridges as one of the transportation control strategies in heavy traffic roads to reduce traffic congestion and mitigate traffic pollution. This mainly has positive impacts on the public health.

Further studies are recommended to assess the importance and effect of using other emission control technologies (catalytic converter, and electric transport; continuous maintenance of vehicles and transformation into cleaner fuel) on reduction of traffic pollutants on roads. In addition, improvement of public transportation and encouragement of their use may also lead to reduction of traffic density and traffic pollutants.

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REFERENCES

Balbus, J. M., Jiménez, G. F., Landrigan, P. J., Kinney, P. L., Perera, F. P., Rom, W., Trasande, L. (2010). City hospital, health officials and environmental experts promote benefits of reducing air pollution in new york city through congestion pricing. Retrieved (2011, April 24), from http://www.nyc.gov/html/doh/html/pr2007/pr056-07.shtml

Chimonasa, M. R., & Gessner, B. D. (2007). Airborne particulate matter from primarily geologic, non-industrial sources at levels below National Ambient Air Quality Standards is associated with outpatient visits for asthma and quick-relief medication prescriptions among children less than 20 years old enrolled in Medicaid in Anchorage, Alaska. *Environmental Research, 103*(3), 397–404.

de Kok, T. M. C. M., Driece, H. A. L., Hogervorst, G. F. J., & Briede, J. J. (2006). Toxicological assessment of ambient and traffic related particulate matter: A review of recent studies. *Mutation Research, 613*(2-3), 103–122.

EPA, U. S. (2004). *EPA Information: Photochemical smog—What it means for us*. Adelaide: Government of South Australia Retrieved (2011, October 25) from http://www.epa.sa.gov.au/xstd_files/Air/Information%20sheet/info_photosmog.pdf.

EPA, U. S. (2010). BCES: Module 3 - Characteristics of Particles. Retrieved (2011, April 24), from http://www.epa.gov/eogapti1/bces/module3/

Fenger, J. (2009). Air pollution in the last 50 years – From local to global. *Atmospheric Environment, 43*(1), 13-22.

Glasser, A. N. (2005). *High Yield Biostatistics* (3rd ed.). Philadelphia, Pennsylvania: Lippincott Williams & Wilkins.

Heimann, D., Clemente, M., Olny, X., Defrance, J., Suppan, P., Castelli, S. T., . . . Obleitner, F. (2007). *Living along a transit route air pollution, noise and health in the Alps*. Trento: University of Trento, Department of Civil and Environmental Engineering. Retrived (2011, October 25), from http://www.alpnap.org/ALPNAP_Brochure_English_2007.pdf

Ingle, S. T., Wagh, N. D., Pachpande, B. G., Patel, V. S., & Attarde, S. B. (2005). The influence of workplace environment on lung function of shopkeepers working near National Highway in Jalgaon: A note. *Transportation Research Part D: Transport and Environment, 10*(6), 476-482.

Issever, H., Disci, R., Hapcioglu, B., Vatansever, S., Karan, M. A., Akkaya, V., & Erk, O. (2005). The effect of air pollution and meteorological parameters in Istanbul on hospital admissions for acute coronary syndrome. *Indoor and Built Environment.14*(2), 157-164.

Kassomenos, P., Karakitsios, S., & Papaloukas, C. (2006). Estimation of daily traffic emissions in a South-European urban agglomeration during a workday- Evaluation of several “what if” scenarios. *Science of the Total Environment, 370*(2-3), 480–490.

Light House. (2007). *BC Green building code background research: materials emissions & indoor air quality*. Vancouver, BC: Sustainable Building Centre. Retrived (2011, october 26) from http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/LightHouseSBC_IAQ-Oct07.pdf

Linn, W. S., & Gong, H. J. (1999). The 21st century environment and air quality influences on asthma. *Current Opinion in Pulmonary Medicine, 5*(1), 21-26.

NG, C. F. (2000). Effects of building construction noise on residents: a quasi-experiment. *Journal of Environmental Psychology, 20*(4), 375-385.

NSW, S. (2010). *2009–10 Annual report*. Sydney: NSW and RTA. NSW Government. Retrived (2011, October 26) from http://www.sydneyferries.info/uploads/library/about/SF%20AnnRep%202010%20-%20Final.pdf

Orubu, C. O. (2004). Using transportation control measures and economic instruments to reduce air pollution due to automobile emissions. *J. Soc. Sci., 8*(3), 227-236.

Potoglou, D., & Kanaroglou, P. S. (2005). Carbon monoxide emissions from passenger vehicles: predictive mapping with an application to Hamilton, Canada. *Transportation Research Part D: Transport and Environment, 10*(2), 97-109.

TAN, M. G., Vergel, K., & Camagay, M. (2006). Development and calibration of pollutant dispersion models for roadside air quality modeling. *Undergraduate Research Program in Civil Engineering*. Retrieved (2011, October 26) from http://ncts.upd.edu.ph/old/research/docs/research/ugrad/200704/Tan.pdf

UNITED NATIONS. (2002). *Decision concerning the third instalment of “F2” claims taken by the governing council of the United Nations compensation commission at its 115th meeting, held on 13 March 2002 at Geneva*. Geneva, (Vol. S/AC.26/Dec.152 (2002)): United Nations Compensation Commission Governing Council. Retrived (2011, October) from http://www.uncc.ch/decision/dec_152.pdf

Villeneuve, P. J., Chen, L., Rowe, B. H., & Coates, F. (2007). Outdoor air pollution and emergency department visits for asthma among children and adults: a case-crossover study in northern Alberta, Canada. *Environmental Health, 6*(3), 40-45.