Environmental Impact Analysis of Transportation in a Rapidly Developing Urban Area

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The environmental impact of transportation systems on air quality and noise levels is analyzed for the rapidly developing capital city of Riyadh, Saudi Arabia. In addition to monitoring noise and carbon monoxide during peak- and off-peak hours at heavily traveled urban arterials, physical, land use, traffic volume, and travel speed data were also collected at study locations. Findings indicated that traffic-generated noise and carbon monoxide air pollution were in excess of permissible standards by a considerable margin. Both traffic volume and travel speed demonstrated significant and positive correlations with the various statistical measures of traffic noise. Traffic volume, wind velocity and traffic speed were also significantly correlated with carbon monoxide concentrations. It appears that rapid urbanization, increased mobility and the favoring of private transportation modes by responsible authorities have combined to create a significant negative impact on the urban environment. Finally, the policies for mitigating the adverse effects of traffic noise and air pollution in developed nations are reviewed, and their applicability to the case of Saudi Arabia is discussed.

This paper reports on the findings of two research projects aimed at analyzing the environmental impacts of transportation in Riyadh, the rapidly developing capital of the Kingdom of Saudi Arabia.

Over the last two decades, the environmental impact of transportation in urban areas has become a major public concern in western industrialized nations and, as such, has received increased attention from federal, state and local governments, the private sector and the public. In response to this growing concern, governments and authorities have committed considerable resources to control these negative side-effects of transportation, and the end result has been successful to a remarkable degree (*1*).

Air and noise pollution constitute two of the most critical areas of the environmental impact of transportation. Through multidimensional and concerted efforts to improve environmental quality, the governments of Western nations have established laws and regulations (*2*,*3*). Researchers have identified sources of these pollutants and have developed measurement methodologies (*4*,*5*,*6*) and predictive models to determine the future impacts of these substances (*7*,*8*,*9*). Furthermore, they have examined the assumptions (*10*) and reliabilities of these models (*11*), and established design methods and expert systems for the mitigation of these substances (*12*,*13*) and for policy analysis (*14*). Finally, they have addressed the public's attitudes toward (*15*,*16*) and responses to these environmental impacts of transport systems (*17*,*18*,*19*).

In the Kingdom of Saudi Arabia and other nations of the Persian Gulf, the rate of socio-economic and infrastructural development over the last decade and a half has been unparalleled in the history of the modern world (*20*). From 1971 to 1987, this development has directly affected urbanization and mobility trends in these nations. The population of Riyadh grew from 350,000 to 1.3 million (*21*). The number of registered vehicles in the kingdom also increased more than 30 times during the same period (*22*). An average Saudi household in Riyadh owns nearly two autos and makes more than eight vehicle trips per day for a total of nearly 90 km of travel (*23*). A major arterial street in the city center may carry an average daily traffic volume of well in excess of 150,000 vehicles per day (vpd) (*24*). A large percentage of these daily traffic volumes consists of station wagons, minibuses, buses and heavy commercial vehicles (*25*). Despite these tremendous increases in the size of the urban population, the vehicle fleet and daily travel, recent research concerning the environmental impact of transportation in the kingdom is extremely limited.

This paper presents the findings of two funded research projects designed to monitor and analyze traffic carbon monoxide (CO) and noise pollution in Riyadh and to recommend policies for mitigating the adverse effects of these pollutants.

The objectives of these studies were to: (a) monitor CO and noise pollution levels in heavily-traveled arterial roadways in Riyadh; (b) examine the contributing power of the causal factors of traffic volume, speed and mix, roadway geometrics and meteorological characteristics on these pollutant levels; and (c) review and recommend mitigation policies applicable to urban areas of the kingdom.

EXPERIMENTAL DESIGN

Eight locations were selected for CO and noise monitoring. These roadway sites were chosen on the basis of frequent site visits and discussions with traffic officials. Location, land-use, and physical data were collected, and traffic volume was measured continuously for a period of 2 weeks at each location. Traffic speed was also measured during 6 peak hours spread over the study period (1985–1986). Table 1 presents a summary of the land use, physical, and traffic characteristics for the study arterials.

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TABLE 1 LAND USE, PHYSICAL, AND TRAFFIC CHARACTERISTICS OF THE STUDY ARTERIALS

Arterial Roadway	Major Land Use Type	Approach Width (m)	Sidewalk Width (m)	Street Aspect Ratio	Peak-Hour Volume (vph)	Peak-Hour Speed (kph)	Monitoring CO	Monitoring Noise
Al-Batha	Commercial/ Residential	12.0	4.8	0.5	3630	22.0	•	•
Al-Jameah	Gov't/ Residential	12.0	4.5	0.1	7124	21.5	•	
Al-Washem	Commercial/ Residential	12.0	5.0	0.5	6750	17.0	•	•
Al-Matar	Gov't/ Commercial	11.5	4.9	0.1	2685	21.0	•	
Al-Khleeg	Gov't/ Commercial	7.0	1.5	0.1	4388	26.0		•
Al-Aseer	Residential/ Commercial	7.5	4.5	0.8	4036	19.0	•	
Al-Madinah	Commercial/ Residential	12.0	2.7	0.4	2040	23.0	•	
Al-Senaeiah	Industrial/ Commercial	13.0	2.0	0.1	4307	27.0		•

Traffic noise was measured during 6 hr covering the morning and the evening peak periods and the off-peak hours at each location. Noise levels were recorded at 1-min intervals using the Bruel and Kjaer Sound Level Meter Type 2209 and the Sound Frequency Filter Type 1616. These instruments were calibrated before each monitoring period.

Carbon monoxide was measured at each location during 6 peak hours spread over a 3-month period (October–December) in each year. Concentration levels were recorded three times at 5-min intervals during peak hours. Concentrations of CO were also monitored continuously for a period of 10–15 days at each arterial. Ecolyzer Series 2000, together with Rustrak Recorders Model 288, were used to monitor for CO. These instruments were also calibrated before each measurement period.

TRAFFIC NOISE

Analysis of noise level measurements indicated that traffic noise was quite high at all locations and during peak and off-peak periods. Noise levels ranged mainly from the high 70s to the low 90s, and their intensities differed from location to location.

A sample of the cumulative frequency distribution of noise levels for the Al-Batha and the Al-Washem arterials is shown in Figure 1. Noise levels in the Al-Batha site fluctuated from a low of 81 dBA to a high of 96 dBA during peak and off-peak periods. The values of L_{10}, L_{50}, and L_{90} (the sound pressure levels exceeded 10, 50, and 90 percent of the time, respectively) were 91.9, 86.8 and 83.1 dBA, respectively.

At the Al-Washem site, noise levels ranged from a low of 66 dBA to a high of 95 dBA. As shown in Figure 1, this site was considerably less noisy, in general, than the Al-Batha roadway. The main reason for the higher noise levels in Al-Batha was the location of a steel flyover constructed to permit through traffic to bypass the signalized intersection with Al-Khazzan Street. In addition to the reflective noise, the through traffic over the flyover travels at a high speed, even during daily rush hours.

A summary of the L_{10}, L_{50}, L_{90}, L_{eq} (the equivalent sound level, or the sound pressure level of a constant noise that produces the same amount of acoustic energy over a given time period as the actual noise varying over time), L_{NP} (the noise pollution level) and *TNI* (the traffic noise index) for three monitoring periods and four study sites is presented in Table 2. It is important to note that traffic noise was generally

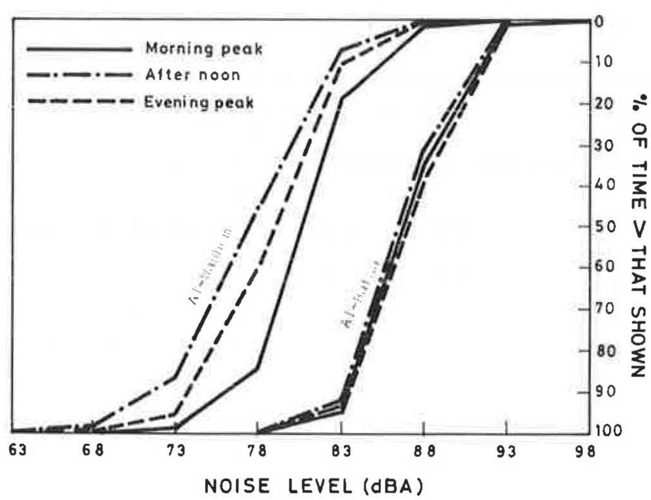

FIGURE 1 Cumulative distribution of noise levels at Al-Batha and Al-Washem.

TABLE 2 SAMPLE NOISE LEVEL MEASURES AT MAJOR ARTERIALS IN RIYADH

Study Site	Monitoring Time Period	Noise Level Measures (dBA)					
		L_{10}	L_{50}	L_{90}	L_{eq}	L_{NP}	TNI
Al-Batha	Morning Peak	92	87	84	91	97	86
	Off-Peak	91	86	83	90	96	86
	Evening Peak	92	87	83	91	97	87
Al-Washem	Morning Peak	86	81	76	84	92	84
	Off-Peak	83	78	72	82	91	81
	Evening Peak	83	79	74	83	91	85
Al-Senaeiah	Morning Peak	87	82	78	85	93	83
	Off-Peak	85	80	74	83	91	85
	Evening Peak	87	80	75	85	96	94
Al-Khaleej	Morning Peak	89	85	80	89	96	85
	Off-Peak	82	77	73	81	88	77
	Evening Peak	87	82	78	85	92	83

very high during working hours at all sites. This is clearly evident from the values of the L_{90}. The L_{90} ranged from a low of 72 dBA (off-peak period) at the Al-Washem site to a high of 84 dBA during morning peak hours at the Al-Batha location.

The L_{eq} was also calculated for each monitoring period. The resulting L_{eq} values ranged from a low of 81 dBA at the Al-Khaleej site to a high of 91 dBA at the Al-Batha location. The L_{eq} values remained nearly constant at all sites with the exception of the Al-Khaleej location, where fluctuations of traffic volumes between peak and off-peak hours were the most pronounced of all sites.

In terms of assessing the effects of noise on humans, L_{eq} is one of the most important measures of environmental noise, because experimental evidence suggests that it accurately describes the onset and progression of hearing loss. There is also considerable evidence that L_{eq} measures human annoyance attributable to noise.

Also presented in Table 2 is the calculated value of the L_{NP} for each monitoring period. The L_{NP} values were generally in the high 90s, indicating the "noisiness" of major arterial roadways in Riyadh. The L_{NP} was less than 90 dBA only during the off-peak hours at Al-Khaleej site.

The *TNI*, which records the frequencies of intruding single-event noises such as the sounds of sirens, horns and noises from heavy trucks, again indicated that although the noise levels during any period of study were generally uniform, the intruding single-event noises were sufficiently frequent to affect the values of the L_{10} (the highest-intensity noise levels). This was particularly true at the Al-Khaleej roadway, which is located next to the Military Hospital.

A comparative analysis of the *TNI* and the L_{eq} noise levels indicated that the *TNI* values are mostly larger than the L_{eq} levels. This reflects the fact that although the noise levels during any period of the day were generally constant, the intruding single-event noises were sufficiently frequent to affect the values of L_{10}, and consequently, the *TNI*.

It is of particular importance to note that in urban areas of the Middle East in general and the Kingdom of Saudi Arabia in particular, the lifestyle and the consequent variations in travel behavior assume a significantly different pattern than those of urban areas in industrialized nations. Instead of the two typical daily rush hours (start and end of daily working hours) experienced in urban areas of Western nations, traffic patterns on a given day follow four peak periods in the kingdom's cities. The usual morning peak is followed by an early afternoon (1:00 p.m.–3:00 p.m.) peak corresponding to the closing down of commercial activities and the end of the working day for government agencies and educational institutions. The third daily peak occurs at 4:00 p.m.–5:00 p.m., when commercial and private-sector institutions resume their second (evening) working period. The last, and usually the heaviest, daily traffic peak is around 8:30 p.m.–9:00 p.m., when the daily working hours end. Clearly, this pattern of daily travel significantly affects the impact of transportation on the urban environment.

Table 3 presents the results of the correlation analysis performed on traffic volumes, travel speeds and statistical measures of traffic noise. Both volume and speed of traffic demonstrated a relatively high positive correlation with the statistical measures of L_{10}, L_{50}, L_{90} and the L_{eq}. The coefficient of correlation between traffic volume and speed, however, had a negative sign, indicating a decrease in travel speed with an increase in traffic volume, as was expected.

TRAFFIC CARBON MONOXIDE

The peak hour distribution of carbon monoxide concentrations indicated that the levels of CO air pollution at all sites were generally above the standard limit. The Saudi Arabian Air Quality Standards (SAAQS) limit the concentrations of carbon monoxide to 35 ppm, for maximum 1-hour exposures and to 9 ppm for maximum 8-hour exposures (*26*).

A typical distribution of carbon monoxide concentrations during a peak hour for the two study periods is shown in Figures 2 and 3 for the Al-Batha and the Al-Jameah roadways, respectively. The CO levels represent the average levels of

TABLE 3 SIMPLE CORRELATION MATRIX

Variable	Variable L_{10}	L_{50}	L_{90}	L_{eq}	Avg. vol./hr	Avg. speed/hr
L_{10}	1.0000	.9647	.9951	.9701	.5893	.5219
L_{50}		1.0000	.9750	.9997	.4480	.4743
L_{90}			1.0000	.9800	.5065	.4175
L_{eq}				1.0000	.4534	.4331
Avg. vol./hr					1.0000	−.3107
Avg. speed/hr						1.0000

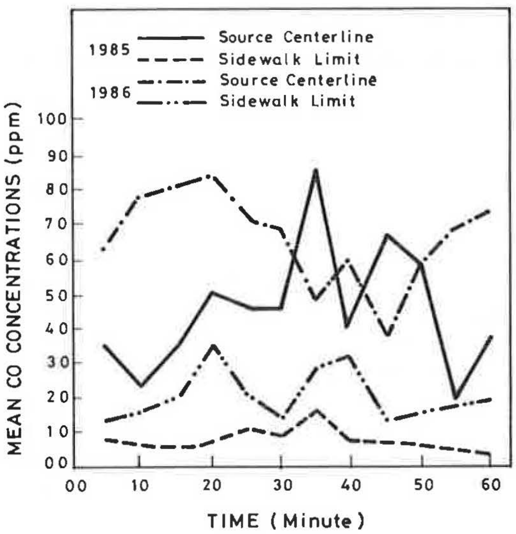

FIGURE 2 Peak hour distribution of carbon monoxide concentrations at Al-Batha.

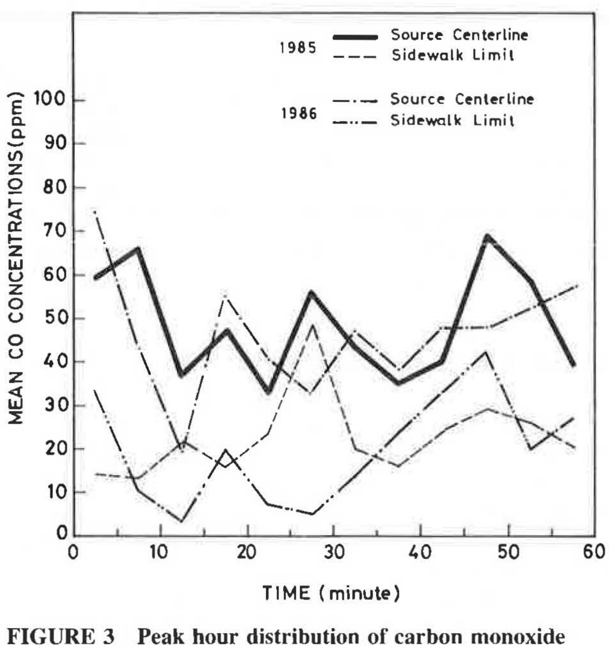

FIGURE 3 Peak hour distribution of carbon monoxide concentrations at Al-Jameah.

six peak hour periods monitored each year. The concentrations of CO increased slightly during the two study periods. This increase in CO levels was in line with the increase in the number of vehicles in Riyadh (*27*). The CO levels decreased significantly with increasing distance from the source.

The variations in the peak hour CO distributions are mainly attributable to fluctuations in traffic volume and timings of traffic signals at one end of the study sections. The construction of various urban roadways over the last decade in general, and that of the ongoing north-south cross-town expressway in particular, have resulted in numerous short- and long-term traffic detours, causing a shift in volume at or in the vicinity of the study locations. In addition, the timing of the isolated traffic signals throughout the city is frequently manually adjusted (by traffic officials) to accommodate variations in traffic volume attributable to detours or congestion during peak hours, or both. Both factors may affect CO concentrations significantly.

Factors of wind direction and velocity may also significantly contribute to these variations. Analysis of wind data for the two study periods, for example, indicated that although wind velocity varied between 5.6 and 18.5 km/hr at different monitoring days during the first study period, it changed from 1.9 to 9.3 km/hr in the second study period. The direction of wind was never the same for any corresponding monitoring day during the two study periods (*28,29*). Measurements of background CO levels at a farm 75 km from Riyadh indicated that the 1985 maximum 1-hr and 8-hr concentrations were 2.4 and 1.3 ppm, respectively.

The result of two weeks of continuous monitoring of CO taken at a height of 3 m (sidewalk limit) at each study section also indicated that the maximum 8-hr average concentration of CO exceeded the standard limit by a substantial margin at all locations. The 8-hr levels in Al-Jameah ranged from 15 to 31 ppm, for an average of 22 ppm. The CO mean 8-hr concentrations at Al-Batha and Al-Aseer were 21 and 14 ppm, respectively.

The cumulative frequency distribution curves of continuous CO measurements for the Al-Jameah and Al-Aseer sections are shown in Figure 4. These distributions indicate that the CO concentrations in Al-Jameah have, in general, a higher probability of exceeding a given level than those for the Al-Aseer roadway, especially at higher concentration levels. For example, although the concentrations of CO at Al-Jameah exceeded 22 ppm 50 percent of the time, those at the Al-Aseer roadway were less than 15 ppm. The difference in the daily CO concentration distributions between the Al-Jameah and Al-Aseer roadways is caused mainly by two factors: the average daily traffic volume and the street aspect ratio (the ratio of building height to street width). The Al-Jameah roadway is a major arterial serving a variety of commercial, educational, and residential land uses. In addition, it serves as a link connecting the newly developed districts in the northeast of the city to the CBD area. As such, this arterial roadway moves large volumes of traffic throughout the day. Al-Aseer Street, on the other hand, is a collector serving a mainly residential district with high volumes of traffic during the daily rush hours and low volumes of local traffic during off-peak hours. The street aspect ratio for Al-Aseer Street is also eight times higher than that of Al-Jameah Street (Table 1).

The mean CO concentrations measured during the 1985 and 1986 study periods were subjected to a significance test to determine whether the increases or decreases in their levels were statistically significant (*30*). As presented in Table 4, the increases in source-centerline concentrations at Al-Batha and Al-Jameah, and the decrease in CO levels at Al-Aseer over the 2-year period were not significant at the 95 percent significance level ($\alpha = 0.05$).

Analyses of correlations, performed to determine degrees of linear association between CO levels and causal factors, indicated that variables of traffic volume, wind speed and traffic speed demonstrated a significant correlation with the levels of CO concentrations. The coefficient of correlation between the peak hour traffic volume and mean 1-hour CO concentrations varied from a low of .39 at Al-Jameah, to .64 at Al-Batha, and .71 at the Al-Aseer arterial. Those for the mean wind velocity were −.28, −.46, and −.52 for the Al-Jameah, Al-Batha, and Al-Aseer roadways, respectively. The correlation coefficients between traffic speed and CO levels were −.21 for the Al-Jameah, −.36 for the Al-Batha, and −.33 for the Al-Aseer arterial. The negative signs associated with these coefficients conformed to expectations. Both traffic speed and wind velocity demonstrated a negative relationship with concentrations of CO, indicating a reduction in CO levels as the value of these variables increased (*31*).

The error associated with the sample mean of CO was calculated and a mean confidence interval was constructed using the CO sample size, the mean and the standard deviation for each sampling location. For example, the errors associated with the 1985 sample CO were ±1.7, ±1.4, and ±1.2 ppm at Al-Batha, Al-Jameah and Al-Aseer, respectively. The true mean CO concentrations at Al-Batha, for example, fell within a range of 59 to 62 ppm 95 percent of the time. Because

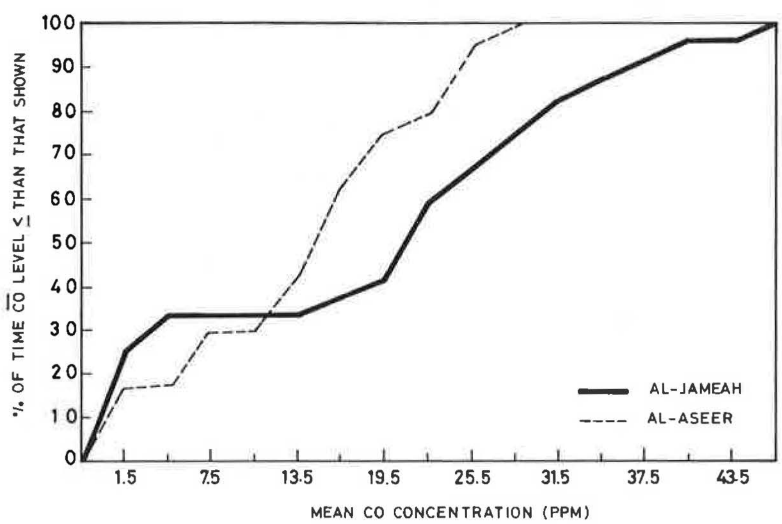

FIGURE 4 Cumulative distribution of carbon monoxide concentrations at Al-Jameah and Al-Aseer.

TABLE 4 TEST OF SIGNIFICANT DIFFERENCES IN MEAN CO CONCENTRATIONS (1985–1986) (*30*).

Arterial Roadway	1985			1986			Calculated Z Value	Hypo. Test $H_0 = \mu_1 = \mu_2$ $H_1 = \mu_1 = \mu_2$
	μ_1	σ_1	N_1	μ_2	σ_2	N_2		
Al-Batha	60.3	10.1	216	58.6	10.3	108	1.4	H = Rejected
Al-Jameah	48.4	8.4	216	54.6	8.1	108	.31	H = Rejected
Al-Aseer	50.8	9.6	216	57.5	11.7	108	-1.6	H = Rejected

NOTE: 95 percent significance level ($\alpha = .05$) used.

of the smaller sample size, the 1986 CO levels are characterized by slightly less accurate sample means than those of 1985 at all study arterials.

MITIGATION POLICIES

Western developed nations, through their pioneering in technological innovations and utilizations, have provided the developing nations with two valuable opportunities. The preventive opportunity is the opportunity to learn from mistakes and inappropriate policy decisions concerning the adverse effects of intensive use or misuse of technology. The option opportunity is the opportunity to choose (with a minimum of resource expenditures) from among a set of tested and evaluated mitigation policies, those that are best suited to a particular socioeconomic and political environment.

The widespread occurrences of similar adverse environmental impacts in many of the developing countries indicate that unfortunately, valuable advantages of the preventive opportunity have yet to be realized by these nations. In spite of several decades of advance warnings, similar mistakes are being repeated. The kingdom has assumed a pioneering role in the region by taking steps to control the adverse effects of transportation on the environment.

Mitigation and effective control of the adverse effects of traffic noise and air pollution require approaches that in many respects are complementary. A mitigation policy such as land use control, traffic management, or transit promotion that is directed toward one type of pollution often minimizes the negative impacts of the other.

Control approaches may be grouped into five categories:

1. Source emission control
2. Improved highway design noise barriers and vegetation
3. Land use control
4. Traffic management and transit promotion
5. Public education program

Source Emission Control

Source emission control requires the development of vehicles that are quieter and emit less CO air pollution. Significant progress has been made by vehicle manufacturers over the last decade to reduce both vehicle noise and CO emissions, and it continues to be made. The role of governments has been to establish and enforce noise and CO emission standards. The kingdom has adopted the CO emission standards of the United States and, through the establishment of the Vehicle Inspection Program (now 2 years into operation), enforces the 35 ppm, maximum 1-hr concentration levels. Similar efforts, however, are required to regulate levels of noise and reduce high noise pollution levels at certain locations.

Improved Highway Design and Noise Barriers

The Federal Highway Administration FHWA regulations for mitigating traffic noise in the planning and design of highways include adequate noise abatement measures to comply with the standards, and a greater attention to noise impacts in choosing the route and layout of new roadways (*32*). The regulations require that the following factors be considered during the planning and design phases of a roadway project: identification of traffic noise impacts; examination of potential mitigation measures; incorporation of reasonable and feasible noise mitigation measures into the highway project; and coordination with local officials to provide helpful information on compatible land use planning and control.

Because roadway networks of most major urban areas in the kingdom have been completed recently and very few new highways are being built within populated areas (with the exception of the north-south cross-town expressway in Riyadh), the choice of realigning or depressing the roadway is not available. The construction of noise barriers along the newly constructed urban expressways may, however, provide the most effective measure for reducing traffic noise along these corridors, where necessary.

Noise barriers may also be constructed along the existing steel flyovers and bridges within urban areas. These urban roadway sections currently experience noise levels much in excess of the permitted standards. Effective noise barriers can reduce noise levels by 10 to 15 dB, thereby cutting the loudness of roadway noise in half.

Land Use Control

Land use control is concerned primarily with establishing and enforcing regulations on land development so that noise-sensitive land uses are either prohibited next to a roadway, or so that developments are planned, designed, and constructed in a way that minimizes traffic noise impacts.

In developed nations, control of land use development is mainly the responsibility of local governments. In Saudi Arabia, however, the unified central government structure is best suited to the application of this mitigation measure because the bureaucracy and red tape involved in dealing with thousands of local governments is reduced.

Traffic Management and Transit Promotion

Options in this category include the rerouting of heavy vehicle traffic; the prohibition of trucks from certain streets and/or the assignment of a specific time period for their operation; the evaluation of traffic signal timings and their coordination to minimize frequent stops and starts; the reduction of speed limits, especially at locations with steel flyovers or bridges; the evaluation of one-way/two-way operation to lessen interruptions caused by left-turning traffic; the prohibition of on-street parking to minimize flow interruptions; and the establishment of a special lane for transit and high-occupancy vehicles to reduce the volume of traffic in noise-impacted areas.

Public Education Program

In developing nations, the level of public education and awareness concerning the adverse effects of transportation on the environment is very low. Inadequate and low-profile public education campaigns, a high rate of illiteracy (especially among older people), and a fairly recent experience with technology and mobility are among the factors contributing to this deficiency. A comprehensive educational program should aim at: improving driver behavior by discouraging the misuse of horns; increasing public awareness of air and noise pollution and its prevention; encouraging daily travel planning among family members to reduce travel demand; and promoting transit use and high-occupancy vehicle travel. The program should include a coordinated effort among all involved agencies and should extend to all segments of population.

SUMMARY AND CONCLUSIONS

The Kingdom of Saudi Arabia has recently experienced rates of socio-economic and infrastructural growth unparalleled in the history of the modern world. One particular result of increasing affluence has been the dramatic rise in the number of vehicles and a corresponding increase in urbanization and urban mobility. These developments have, in turn, led to noise and air impacts on the environment in the urban areas of the kingdom.

This paper reports on the findings of two ongoing funded research projects undertaken to analyze the noise and air impacts of transportation in Riyadh's urban environment. This information provides the necessary basis for the development of policy measures and actions required for the effective alleviation of the negative environmental impacts of urban transportation.

The findings indicated that traffic-generated noise and CO air pollution at heavily traveled roadways in Riyadh were high and exceeded permissible standards by a considerable margin.

The sample noise level measurements clearly showed that traffic noise intensity ranged from about 85 to 95 dBA. The results of a cumulative frequency distribution of noise levels showed that the intensities of the highest 10 percent (L_{10}) were very high at nearly all locations. The L_{10} is mainly affected by the frequency and the intensity of intruding single-event noises such as horns, sirens and heavy trucks.

The equivalent sound level (L_{eq}) ranged in value from a low of 81 dBA to a high of 91 dBA at the study sites. These high L_{eq} values point to the noisiness of the urban environment at these locations. This statement is further supported by high values of the traffic noise index and the noise pollution level. Both traffic volume and traffic speed demonstrated significant and positive correlations with various measures of traffic noise.

The maximum 1-hr and 8-hr mean CO levels exceeded the SAAQS of 35 and 9 ppm by a significant margin at all locations. The maximum 1-hr levels for the source centerline were 60, 40, and 51 ppm during 1985, and 59, 55, and 57 ppm during 1986, for the Al-Batha, Al-Jameah, and Al-Aseer arterials. The differences in mean CO levels for the two study periods were not statistically significant at the 95 percent level at either of the locations. The maximum 8-hr CO concentrations during 1986 were 21 ppm at the Al-Batha, 22 ppm at the Al-Jameah, and 14 ppm at the Al-Aseer roadways. Only about 1.5 ppm of these CO levels is contributed by sources (background) other than traffic in Riyadh.

Correlation analysis indicated that the variable of mean peak hour volume showed the highest degree of linear association with traffic CO. This was followed by wind velocity and traffic speed.

Five groups of mitigation approaches currently practiced in the developed nations are identified. These include source emission control, improved highway design and noise barriers, land use control, traffic management and transit promotion, and public education programs. The general applicability of these mitigation approaches is also discussed. Comprehensive and coordinated efforts will be required to minimize the adverse impacts of urban mobility on the environment.

Overall, it appears that rapid urbanization, increased mobility, and the favoring of private transportation by responsible authorities have combined to create a significant negative impact on the urban environment. As urbanization and auto ownership increase, the size and the complexity of the problems are likely to grow. Decision makers should make every effort to minimize these negative urban transportation by-products.

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