Air Quality Assessment at a Congested Urban Intersection

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ABSTRACT

Urban areas of Beirut suffer severe traffic congestion due to a deficient transportation system, resulting in significant economic losses. Grade separations are proposed at several congested intersections to alleviate this problem. Air quality, which greatly depends on the geometric configuration of an intersection, is a major environmental concern at these locations. This paper presents an air quality impact assessment at a typical urban intersection and addresses potential mitigation strategies for air quality management in urban areas. For this purpose, air quality measurements were conducted at representative locations to define existing pollutant exposure levels. Mathematical simulations were performed for several scenarios, both with and without grade separations, changes in vehicle mix, and level of service. Assessment of air quality impact significance was conducted by comparing simulated exposure levels with relevant air quality standards. Sensitivity analysis indicated that the introduction of a grade separation, changes in vehicle mix, and level of service lead to decreased exposure to air pollutants by up to 80%.

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INTRODUCTION

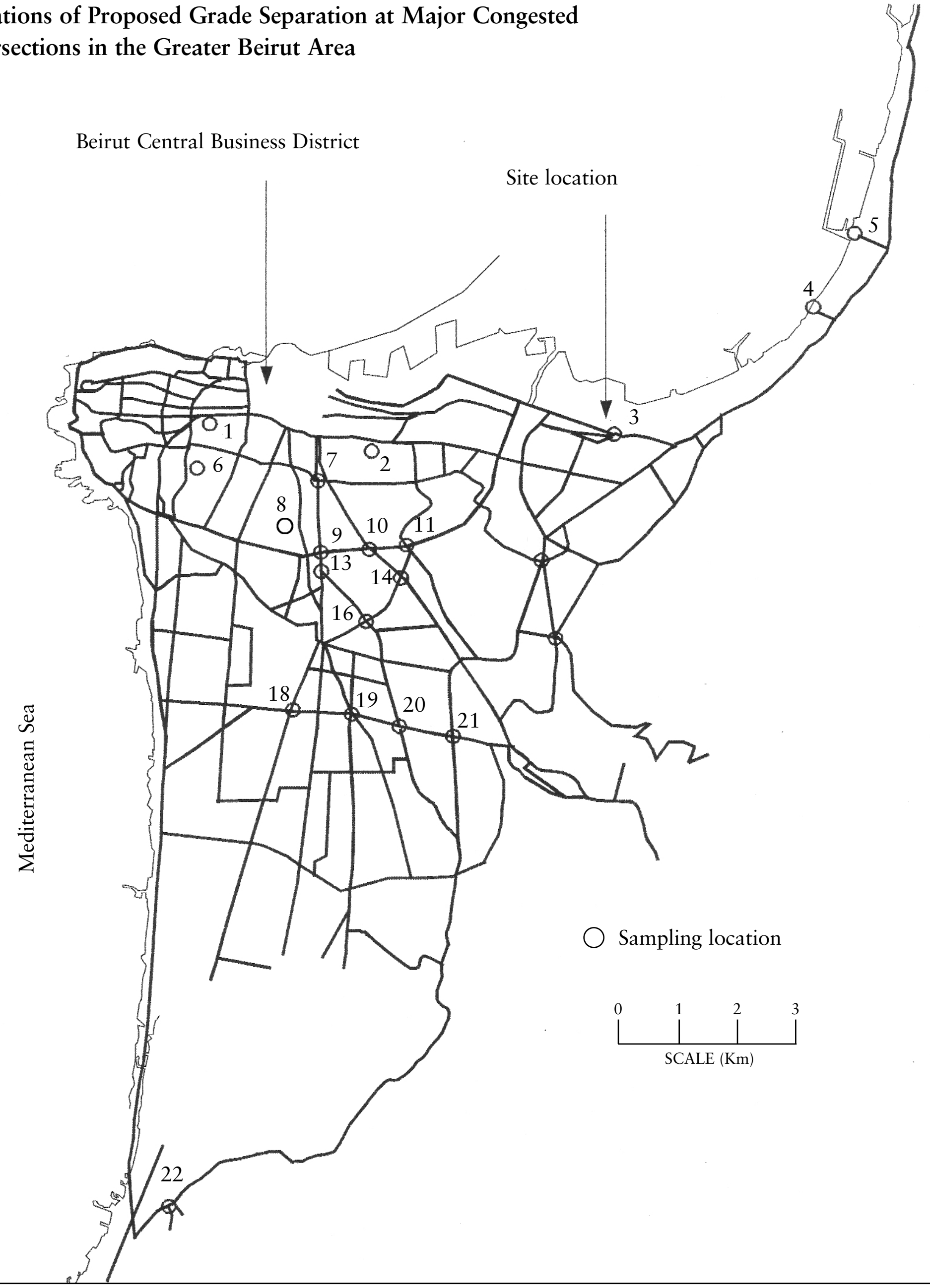
Traffic-induced emissions have been closely correlated with adverse impacts on air quality, especially in over-populated and highly congested urban areas. When industrial facilities are located away from urban centers, traffic circulation remains the most significant source of air pollutants. Urban centers are characterized by severe traffic congestion and an increased number of vehicles, leading to a longer peak-hour duration and higher air pollutant concentrations. This is particularly true in developing countries plagued with a general lack of traffic management and transport planning policies. The Greater Beirut Area (GBA) is a typical example, with 1.5 million passenger trips per day occurring on a relatively inferior road network, with a weak public transportation system, and without regulation enforcement (Staudte et al. 1997). Moreover, a relatively old and poorly maintained vehicle fleet increases the contribution of vehicle-induced emissions (TEAM International 1994). Consequently, residents are exposed to elevated concentrations of air pollutants, especially in hot summer periods when minimal air circulation and high humidity prevail.

Peak pollutant concentrations in urban areas are mostly encountered at heavily congested intersections, reflecting a high traffic volume and long delays, decreased average speeds, and a poor level of service (LOS). Vehicle-induced emissions at major intersections are dependent on many factors, including road geometry, traffic volume, vehicle fleet/fuel characteristics, driving patterns, and meteorological conditions (Hoglund 1994; Meng and Niemeier 1998; Faiz et al. 1996; Hallmark et al. 1998; Hoydysh and Dabberdt 1994). Various traffic management alternatives are used to improve traffic at congested intersections. Signalization, lane addition or lane widening, and the addition of roundabouts are among the most common traffic management alternatives. Historically, they have been implemented at intersections with various degrees of success. As congestion increases, however, these alternatives are often inadequate to accommodate the rise in traffic volume. Consequently, a grade separation or an interchange, where traffic flows without interruption in one or more directions, may be introduced.

Air quality monitoring provides the best means to characterize the state of emissions in the atmosphere, to evaluate the impact of various emission sources, and to assess the effect of new geometric configurations. However, monitoring can be inhibitively expensive to implement at every intersection. Economic considerations, coupled with the need for on-demand control and management of air pollution, have resulted in the development of a variety of guidelines and modeling techniques (mathematical algorithms) (Schattanek 1992; Schewe 1992; Zamurs et al. 1992). The most widely used models are Gaussian-based and require the definition of several factors: meteorological conditions, such as wind speed, wind direction, and atmospheric stability; emission rates, which depend on vehicle type and age, driving patterns, the type of pollution control equipment, and the level of inspection and maintenance; and the geometry of the specific intersection, including lane length and width, slope, receptor locations, and surface roughness. Some mathematical models can be used to determine fleet-average emission factors for each pollutant expressed as mass per distance traveled (grams/kilometer). Others, such as line source dispersion models, can be used to simulate atmospheric exposure levels.

This paper evaluates the impact on air quality of traffic-induced emissions at a typical intersection in a highly congested urban area. For this purpose, field measurements were first conducted to define existing pollutant exposure levels and to serve as a baseline for model calibration. The pollutants of interest were carbon monoxide (CO), nitrogen dioxide (NO_2), and total suspended particulate (TSP). The Mobile Vehicle Emissions Inventory (MVEI7G) and the California Line Dispersion Model (CALINE4), a roadside air dispersion model, were used to simulate vehicle fleet emission factors and atmospheric pollutant concentrations, respectively. Simulations were performed for worst case scenarios, including three specific factors: presence/absence of grade separations, changes in vehicle mix, and LOS. An assessment of the impact of vehicle-induced emissions was then conducted by comparing simulated pollutant concentrations to baseline air quality levels and relevant air quality standards. The overall objective was to optimize

FIGURE 1 Locations of Proposed Grade Separation at Major Congested Intersections in the Greater Beirut Area



intersection management in such a way as to minimize the impact of emissions on air quality.

Site Description

The site is one of several major intersections where a grade separation is proposed (see figure 1). The intersection under study provides the northern entrance to the future Beirut Central Business District. Traffic-counting meters were installed at these intersections to determine traffic volume at morning and afternoon peak-hour conditions. The Equilibre Multimodal-Multimodal Equilibrium (EMME/2), which models and forecasts the volume of traffic at any link based on the Multimodal Equilibrium Theory, was used to determine future traffic conditions at the intersection. EMME/2 offers the tools necessary to forecast future traffic conditions based on changes in road networks and socioeconomic conditions and is commonly used for traffic planning purposes (EMME 1998). The site layout, along with future (year 2010) peak-hour traffic volume, is depicted in figure 2.

FIGURE 2 Intersection Layout, with Projected Peak-Hour Traffic Volumes

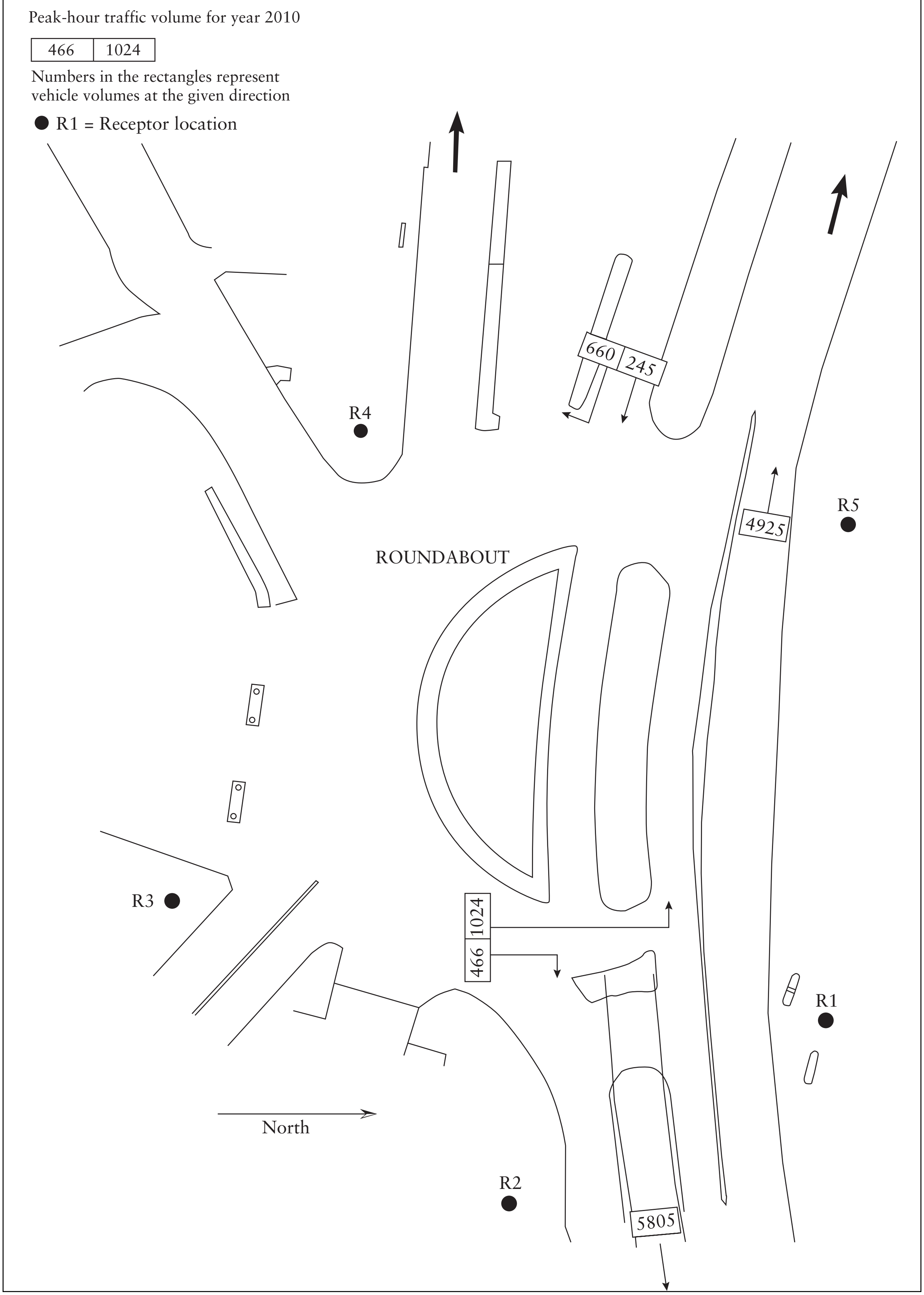


TABLE 1 Vehicle Fleet Composition, Occupancy, and Average Age

Vehicle type	Percent	Average occupancy (persons)	Average age (years)
Cars	90	1.5	14
Medium trucks	6	3	16
Heavy trucks	2	1	18
Buses	2	10	18

Sources: TEAM International 1994 and Dar Al-Handasah 1995

TABLE 2 Impact Assessment Methodology

Step	Description	Tools
1	Definition of applicable standards	Comparison with WHO and EPA standards
2	Determination of baseline conditions	■ Field measurements ■ Previous studies ■ Mathematical modeling
3	Simulation results	■ EMME: simulate vehicle volumes ■ MVEI7G: simulate emissions factors ■ CALINE4: simulate concentrations
4	Identification of potential impacts	■ Comparison with standards ■ Comparison with baseline
5	Mitigation of potential impacts	■ Regulatory ■ Technical

Traffic Fleet Characteristics

The fleet is mainly comprised of passenger cars and is characterized by relatively old and poorly maintained vehicles (see table 1). Although predictions indicate a decrease in passenger cars and an increase in bus trips resulting from the introduction of a more efficient mass transit system, implementation of such changes in infrastructure is unlikely to occur in the near future, due to minimal changes in the fuel taxation policy, weak urban planning practices, and a lack of enforcement of traffic regulations (TEAM International 1994; 1998).

IMPACT ASSESSMENT METHODOLOGY

The impact assessment methodology used consisted of the five consecutive steps identified in table 2. Applicable or relevant standards are defined first, followed by the determination of baseline conditions through field measurements, previous surveys, or mathematical modeling. In the third step, future traffic and air quality conditions are estimated using mathematical models. Potential impact is assessed in the fourth step by comparing future conditions with applicable standards and baseline conditions. Finally, mitigation measures to improve urban air quality and to achieve compliance with regulatory standards are addressed.

Using the approach described above, 13 different scenarios were developed and analyzed (see table 3). These scenarios include several variations of the three factors of interest. Scenario 1 represents the 2010 condition with no grade separation. Scenarios 2, 3, 4, and 5 represent future conditions with a grade separation coupled with or without speed improvement. The current vehicle mix was compared with two other alternatives, doubling or tripling bus ridership with or without speed improvements (scenarios 6, 7, 8, and 9). Finally, scenarios 10, 11, 12, and 13 represent the 2010 conditions under LOS E, D, C, and B, respectively (HCM 1994). Scenario 0 represents the present situation without any changes.

Definition of Applicable Air Quality Standards

Ambient air quality standards were proposed in Lebanon in the 1994 never-approved Proposed Law Number 1/52 (Ministry of Environment 1996). However, the proposed standards do not appear to have been developed on a scientific or country-specific economic basis (Staudte et al. 1997). The limit values are equal to or lower than thresholds employed in other parts of the world (see table 4) and seem to be unattainable, at least in the current regulatory and enforcement environment.

Definition of Baseline Conditions

Previous data on air quality in Beirut are practically nonexistent. Air samples were collected during the morning peak hours and analyzed for selected

TABLE 3 Description of Simulated Scenarios and Corresponding Road Traffic Conditions

Scenario	Year	Link number	Traffic volume (vehicles per hour)	Average lane speed (kph)	Purpose
0	1998	1	16	14	Definition of baseline conditions and model calibration
		2	100		
		3	3,120		
		4	126		
		5	283		
		6	3,522		
1	2010	1	660	14	Future conditions
		2	245		Implementation of proposed intersection
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
2	2010	1	660	14	Overpass
		2	245		Without speed improvement
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
3	2010	1	660	34	Overpass
		2	245		With speed improvement
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
4	2010	1	660	14	Underpass
		2	245		Without speed improvement
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
5	2010	1	660	34	Underpass
		2	245		With speed improvement
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
6	2010	1	660	14	Vehicle mix doubled bus ridership
		2	245		Without speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
7	2010	1	660	19	Vehicle mix doubled bus ridership
		2	245		With speed improvement
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
8	2010	1	660	14	Vehicle mix tripled bus ridership
		2	245		Without speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		

TABLE 3 Description of Simulated Scenarios and Corresponding Road Traffic Conditions *(continued)*

Scenario	Year	Link number	Traffic volume (vehicles per hour)	Average lane speed (kph)	Purpose
9	2010	1	660	24	Vehicle mix tripled bus ridership
		2	245		With speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
10	2010	1	660	48	LOS E
		2	245		With speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
11	2010	1	660	67	LOS D
		2	245		With speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
12	2010	1	660	75	LOS C
		2	245		With speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		
13	2010	1	660	80	LOS B
		2	245		With speed improvements
		3	4,925		
		4	466		
		5	1,024		
		6	5,805		

constituents. Table 5 contains measurements of NO_2 and TSP for the various intersections associated with the study. Measurement of CO concentrations was hindered by equipment malfunction. Generally, the results indicate the presence of greater NO_2 and TSP levels than allowed under ambient air quality standards. For example, the average measured concentration at the intersection under study for NO_2 and TSP were 28 parts per million (ppm), 581 μg/m^3 and 172.8 μg/m^3, respectively, both exceeding ambient air quality standards. Such levels are expected, due to several prevailing conditions conducive to air pollution, including:

1) the lack of periodic maintenance of the vehicle fleet,
2) a relatively old vehicle fleet,
3) the high frequency of acceleration and deceleration due to "stop-and-go" situations resulting from traffic congestion,
4) poor level of service of existing roadways,
5) the absence of regulations concerning vehicle emissions,
6) the minimal use of catalytic converters,
7) a weak and unreliable public transport system,
8) poor fuel quality, and
9) extensive construction activities (Staudte et al. 1997; TEAM International 1998).

Background levels were continuously monitored at a location away from traffic (on the campus of the American University of Beirut) for nearly one month. Average concentrations of 2 to 6 ppm (2,222 to 6,667 μg/m^3) for CO, 0.03 to 0.05 ppm (60 to 100 μg/m^3) for NO_2, and 50 to 80 μg/m^3 for PM_{10} (PM_{10} signifies particulate matter of 10 microns in diameter or smaller) were reported.

TABLE 4 Comparison of Selected Air Quality Standards

Parameter	Standard Lebanese[a] µg/m³ (ppm)	 US EPA[b] µg/m³ (ppm)	 WHO[c] µg/m³ (ppm)	 Averaging period
Nitrogen dioxide (NO_2)	200 (0.1)	NS	200 (0.1)	1 hour
	150 (0.075)	NS	150 (0.075)	24 hours
	100 (0.05)	100 (0.05)	NS	1 year
Carbon monoxide (CO)	30,000 (27)	40,000 (36)	30,000 (9)	1 hour
	10,000 (9)	10,000 (9)	10,000 (9)	8 hours
Total suspended particulate (TSP)	120	260	150-230	24 hours

NS = not specified

[a] Ministry 1996

[b] De Nevers 1995

[c] WHO 2000

TABLE 5 Summary of Average Air Quality Measurements (µg/m³)

Intersection	NO_2*	Particulate**
3	621	219.8
4	376	144.5
5	659	—[a]
7	659	176.6
10	847	151.7
11	884	136.0
12	470	194.5
13	376	101.7
14	715	192.6
16	753	130.8
17	282	165.9
18	658	179.4
19	753	291.0
20	564	207.4
21	339	139.1
22	339	160.5
Average	*581*	*172.8*

* ± 10 %

** ± 5 %

100 µg/m³ = 0.05 ppm for NO_2

[a] No data available

PM_{10} is equal to 0.55×TSP (Pearce and Crowards 1996; Vedal et al. 1987). Concentrations of 50 to 80 µg/m³ of PM_{10} correspond to 90 to 145 µg/m³ TSP), relatively high given that the measurements were collected as background readings at a non-congested location.

Emission Model: Mobile Vehicle Emissions Inventory (MVEI7G)

MVEI7G was used to determine emission factors for the Beirut fleet. The MVEI7G model, developed by the California Air Resources Board, estimates the total amount of pollutants released into the atmosphere by road transportation vehicles using statistical relationships based on emission tests for new and used vehicles. MVEI7G accounts for vehicle mix, the percentage of cold and hot starts, the existence and application of an inspection and maintenance program, the fraction of vehicles using catalytic converters, and the fraction of vehicles using gasoline or diesel. The model consists of four interrelated modules that operate together: CALIMFAC, WEIGHT, EMFAC, and BURDEN (see figure 3). The CALIMFAC and WEIGHT modules produce baseline vehicle emission rates and weighting factors for each model year, respectively. The EMFAC module uses this information, along with appropriate correction factors, to produce composite fleet emission factors. Finally, the BURDEN module combines emission factors with activity data to produce emission inventories (CARB 1996).

Emission Factors Assessment

An emission factor is the estimated average emission rate of a certain pollutant for a specific class of vehicles. Pollutants emitted from vehicles vary depending on vehicle characteristics; operating conditions; inspection and maintenance levels; fuel characteristics; and ambient conditions such as temperature, humidity, altitude, and wind speed and direction. Emission factors are strongly influenced by vehicle driving patterns, average speed, and the degree of acceleration and deceleration in the driving cycle (Garza and Graney 1996). These factors increase sharply at lower average

FIGURE 3 Flow Chart of MVEI7G Model

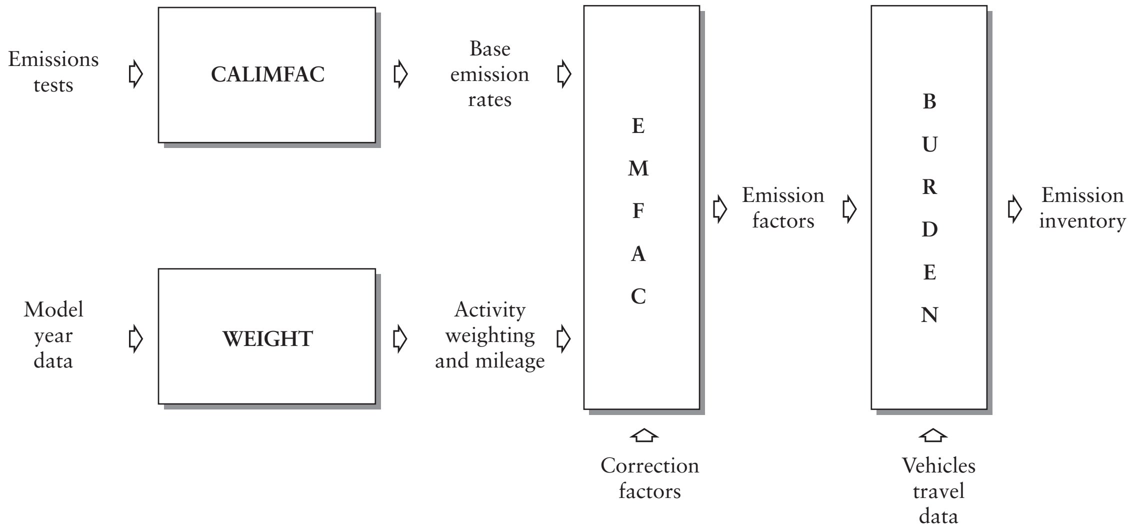


FIGURE 4 Variation of CO Emission Factor with Speed

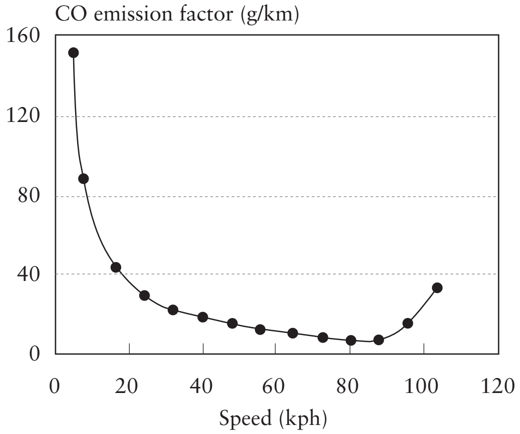
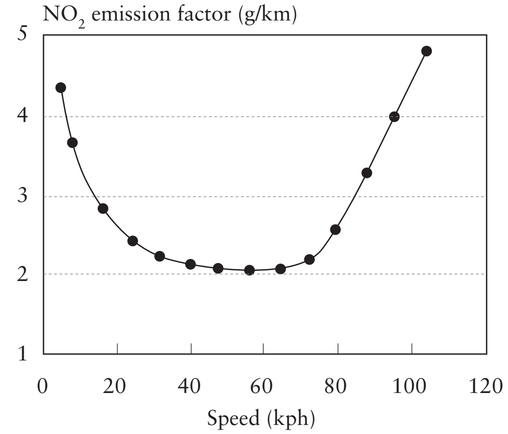


FIGURE 5 Variation of NO_2 Emission Factor with Speed



Note difference in vertical scale between figures 4 and 5.

speeds (see figures 4 and 5), typical of highly congested, stop-and-go urban driving. They decrease in free flow traffic at moderate speeds then increase again under relatively high-speed conditions (Krupnik 1991). Poorly maintained vehicles are responsible for a disproportionately higher share of total emissions (Faiz et al. 1996). Emission factors for U.S. gasoline-fueled passenger cars and medium-duty trucks equipped with different emission control technologies are presented in table 6. These factors are used as benchmark indicators in assessing emission factors of the Beirut fleet.

Model Application

MVEI7G was calibrated and applied to the Beirut area (El-Fadel and Bou-Zeid 1999). For this purpose, field surveys were conducted to measure tailpipe emissions and inspection and maintenance levels for the Lebanese fleet. Fuel composition, as well as the age distribution of the vehicle fleet, were determined and incorporated into MVEI7G. The calibration data and corresponding emission factors for selected pollutants are summarized in table 7. The estimated CO and NO_2 emission factors for the Beirut fleet fall between the noncatalyst control and the uncontrolled category of the estimated emission factors for the U.S. gasoline-fueled passenger cars. The estimated particulate emissions factor falls within the range of comparable vehicle fleets (Faiz et al. 1996).

TABLE 6 Estimated Emissions Factors for U.S. Gasoline-Fueled Vehicles

	Passenger cars		Medium-duty trucks	
Type of control	CO g/mile	NO_2 g/mile	CO g/mile	NO_2 g/mile
Advanced three-way catalyst control	9.92	0.83	16.32	0.83
Non-catalyst control	44.32	3.26	76.18	5.54
Uncontrolled	68.27	4.32	270.61	9.14

Estimated with the U.S. Environmental Protection Agency (USEPA) MOBILE5 model for a temperature of 24°C, a speed of 31 kph, gasoline Reid vapor pressure of 62 kpa, and no inspection and maintenance program in place.

Source: Faiz et al. 1996

TABLE 7 Calibration Data for MVEI7G and Emissions Factors Obtained for Vehicle Fleet

Parameter	Value
Average fleet age in years	14
Sulfur content in fuel in ppm	40
Lead content in ppm	0.3
Unleaded fuel, percent	10
Fraction of hot starts, percent	10
Fraction of cold starts, percent	10
Hot stabilized conditions, percent	80
Inspection and maintenance, percent	10
Vehicles with catalytic converters, percent	1
Temperature in degrees Celsius	30
Number of starts per day	3.5
CO emission factor in grams per mile	60
NO_2 emission factor in grams per mile	3.15
PM emission factor in grams per mile	0.05

Source: El-Fadel and Bou-Zeid 1999

Dispersion Model: CALINE4

CALINE4, developed by the California Department of Transportation (Caltrans), is an atmospheric dispersion model used for predicting air pollutant concentrations. As noted, the model uses various factors to project air pollutant concentrations away from roadway line sources. For example, it estimates the concentration of CO, NO_2, and TSP from a roadway link at monitoring points within 500 meters from the road and can simulate air quality at intersections, street canyons, or parking facilities. The model subdivides a road into segments in a way similar to a finite element analysis, then sums up the contributions of these elements to the background air pollution levels at a specified receptor location (Benson 1989). A mixing zone concept is employed to evaluate pollutant mixing due to mechanical and thermal turbulence from car exhausts. The mixing zone consists of the road width, plus a three-meter border on either side, with a height equivalent to the mixing height attainable in the region. CALINE4 requires the input of emissions factors, obtainable from actual field measurements or models similar to MVEI7G.

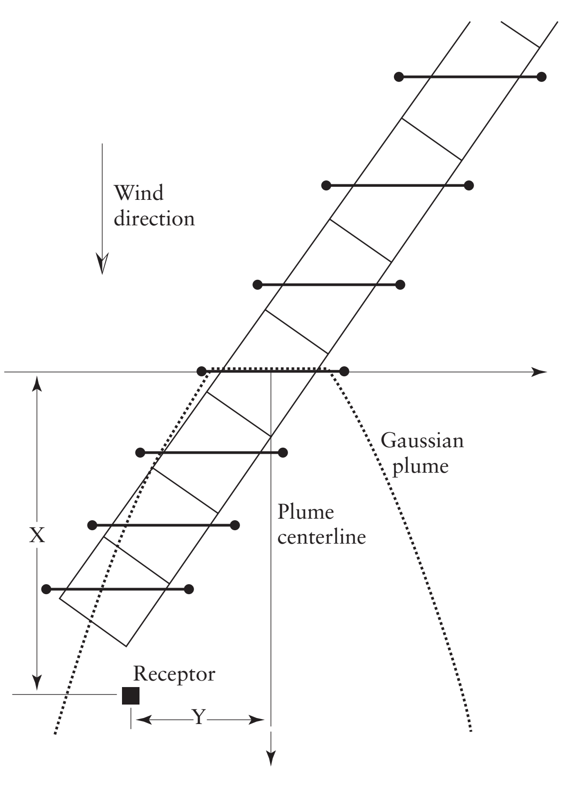
The initial step is the specification of the first roadway element, whose position is a function of the roadway-wind angle (see figure 6). The first element remains constant and equal to its position at a roadway-wind angle of 45 degrees. Subsequent elements are longer since they are less critical for the total concentration value. This length adjustment saves computational time and is within the accuracy limits of other factors in the model. Equation (1) is used to compute the length of a roadway element. Each element is perpendicular to the wind direction, and its emissions are assumed to obey the Gaussian dispersion concept expressed in equation (2). As previously noted, worst case conditions are assumed in simulating pollutant concentrations for the present study due to several factors conducive to air pollution (see table 8).

$$EL = W\left[1.1 + \frac{PHI^3}{25\times10^5}\right]^{NE} \qquad (1) \text{ and}$$

$$C(x,y,z) = \frac{q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{1}{2}\frac{y^2}{2\sigma_y^2}\right)\times$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad (2)$$

FIGURE 6 **Element Series Represented by a Series of Equivalent Finite Line Sources**



where C = pollutant concentration in grams/meter^3
EL = element length in meters
H = road height above receptor location in meters
h_m = source and receiver average height in meters
NE = element number in meters
PHI = wind-roadway angle in degrees
q = linear source strength in grams/meter^3
u = wind speed in meters per second
W = road width in meters
y_1, y_2 = distance from plume centerline to receptor in meters
z = height of receptor in meters
σ_y = horizontal dispersion parameter in meters
σ_z = vertical dispersion parameter in meters.

Mixing Height and Surface Roughness Justification

The effect of mixing height and surface roughness on CO was determined. For the present study, the critical mixing height, above which no change of pollutant concentration is observed, is 20 meters (see figure 7). The effect of surface roughness is less apparent (see figure 8), with the average value set at 100 centimeters, typically recommended as a default value.

TABLE 8 **CALINE4 Calibration Data**

Parameter	Value
Wind speed in meters per second	1
Wind direction	Worst case[a]
Wind standard deviation in degrees	5
Settling velocity of pollutants in meters per second	0
Surface roughness in centimeters	100
Mixing height in meters	20
Ambient concentration in ppm	0
Stability class[b]	G

[a] This is accounted for by the model itself.
[b] Atmospheric stability has been split into seven categories, labeled A through G, A being the most unstable and G being the most stable.

FIGURE 7 **Projected CO Concentration (2010 Baseline) Based on Mixing Height**

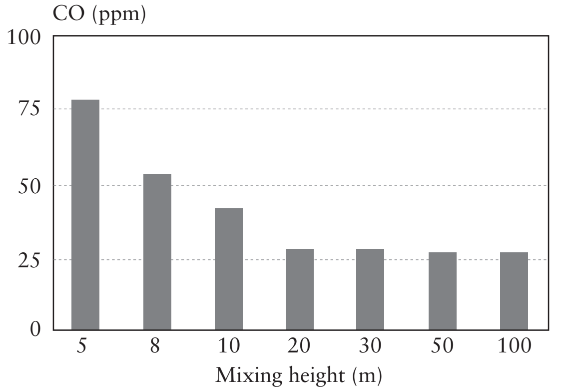
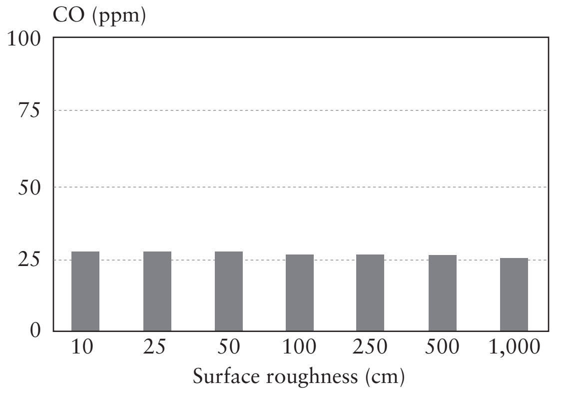


FIGURE 8 **Projected CO Concentration (2010 Baseline) Based on Surface Roughness**



Air Quality Simulations

During the operation phase, emissions are a function of the expected traffic conditions, volume and speed, at a particular location as well as the fleet characteristics. For this study, simulations were first conducted using the 1998 traffic conditions (see table 8). The simulated CO and NO_2 levels far exceed background levels where no traffic is present, indicating that traffic-induced emissions constitute the major contributor to CO and NO_2 levels. Since the simulated concentrations for NO_2 are of the same order of magnitude as those measured in the field (see table 9), this is another indication that traffic emissions are the major source of NO_2. However, the simulated TSP concentrations are far lower than field measurements, indicating that traffic is not the only contributor to particulate matter (see table 9).

Note that emissions during the road construction phase are a function of the excavation scheme and machinery used onsite. They consist primarily of particulate dust matter released as a result of earth removal activities and, to a lesser extent, of emissions from the onsite use of heavy construction equipment. While the extent of this impact cannot be reasonably quantified in a scientific manner due to the random nature of construction activities, it is typically temporary and confined to the immediate site vicinity, particularly if proper management measures are adopted to mitigate it.

Sensitivity Analysis

For the present study, model simulations were conducted to evaluate changes in the geometric configuration, vehicle mix, and LOS. Geometric changes consisted of the construction of a grade separation (overpass/underpass) to accommodate the heaviest traffic running in the north-south direction (see figure 2). Vehicle mix was modified, assuming the implementation of a mass transit system. Finally, the LOS was modified by adding an extra traffic lane along both directions of the overpass.

Type of Grade Separation

A grade separation is an effective transportation strategy aimed at increasing the average cruising speed and thereby reducing traffic delays at an intersection. Although its primary function is traffic management, a grade separation may help reduce pollutant concentrations. Pollutant emissions factors can be five to ten times higher in situations involving stop-and-go traffic due to the acceleration and deceleration processes (Faiz et al. 1996). On the other hand, increased average cruising speed can reduce emissions factors significantly (see figures 4 and 5). Note, however, that there is an upper limit of 50 and 90 kilometers per hour (kph), above which emissions factors start to increase again for NO_2 and CO, respectively. In addition, by virtue of its elevation, an overpass reduces exposure to air pollutants due to the increased time before a pollutant reaches a receptor at ground level. Similarly, an underpass confines air pollutants and, hence, reduces expo-

TABLE 9 Field and Simulated Concentrations of CO, NO_2, and TSP at Several Locations[a]

	CO		NO_2		TSP	
Intersection number[b]	Measured (ppm)	Simulated (ppm)	Measured (ppm)	Simulated (ppm)	Measured (μg/m^3)	Simulated (μg/m^3)
3	NM[c]	15.5	0.33	0.88	220	13.6
4	NM	28.9	0.20	0.51	144	27.1
19	NM	18.9	0.35	0.46	291	4.0
20	NM	8.5	0.30	0.32	207	7.6
21	NM	15.1	0.18	0.47	139	14.2

[a] The simulated values are the contribution of traffic emissions to the concentration of a particular pollutant in the air. They do not account for background levels or other potential sources in the area.

[b] See figure 1.

[c] NM = not measured because of equipment malfunction.

sure at ground level, particularly in the presence of an effective ventilation system.

In this study, concentrations of CO and NO_2 were simulated for the year 2010, given four of the different scenarios (2–5) previously described. Results are summarized in figures 9 and 10. The introduction of a grade separation reduced the concentration of both CO and NO_2. The reduction in CO concentration reached 56% and 86% for an overpass and an underpass, respectively, assuming a 20 kph increase in speed. The contribution of the geometry reached 7% and 71% for an overpass and underpass, respectively, assuming the same speed. The remaining decrease is attributed to the change in speed that directly affects emissions factors. The reduction in NO_2 concentration was less significant and reached 27% and 78% for an overpass and underpass, respectively, assuming 20 kph speed increase. Similarly, the contribution of geometry reached 7% and 70% for an overpass and underpass, respectively, assuming the same speed, with the remaining decrease attributed to the change in speed.

FIGURE 9 Effect of Grade Separation on CO Concentration

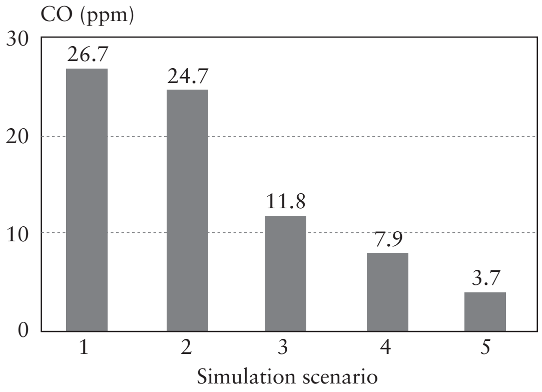
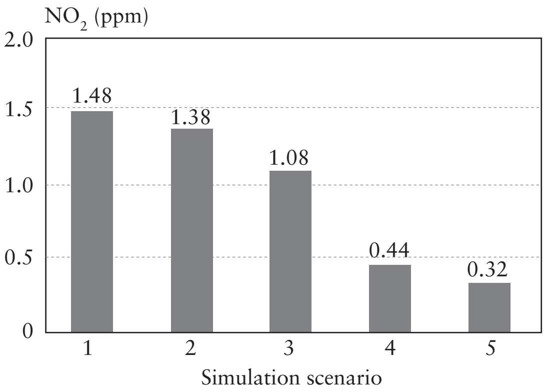


FIGURE 10 Effect of Grade Separation on NO_2 Concentration



Note difference in vertical scale between figures 9 and 10.

Vehicle Fleet Mix

Vehicle mix can have a significant effect on air quality. This is especially true when heavy vehicles, trucks and buses, are present at peak hours. In urban areas, traffic congestion relief and volume reduction can be accomplished through the expanded usage of mass transit systems. Such usage can change the vehicle mix and, hence, the extent of pollutant emissions. A traffic demand analysis indicates that the ridership share of a recently established public bus transport system in Beirut has reached 11%. The implementation of regulations and policies encouraging the use of this system can easily double this share to 22%. Assuming no additional demand for trips given the introduction of the new public transit system, the overall number of persons multiplied by trips will remain constant. The change will be in the mode of travel, with a shift from passenger cars, with average occupancy of 1.5, to buses, with average occupancy of 10 persons per vehicle trip (see table 1). It is assumed that trips gained by buses are lost from passenger cars. Doubling the percentage of buses in the fleet to account for doubling the demand for bus ridership results in reducing the traffic volume by 11.3% and increasing the average cruising speed by 5 kph. More stringent regulations can even triple the mass transit ridership share to reach 33%, reducing the traffic volume by 22.7% and increasing the average cruising speed by 10 kph. Certainly, the vehicle mix would vary if bus ridership is doubled or tripled (see table 10).

Simulation results for four alternatives, scenarios 6, 7, 8, and 9, are depicted in figures 11 and 12. The change in vehicle fleet mix has reduced CO concentrations because of traffic-volume reduction and increase in speed with a corresponding change in emissions factors. The interrelationship between these factors and emissions is illustrated in figure 13. The reduction in CO concentrations at the predefined receptor locations reached 29% and

TABLE 10 Vehicle Mix of Various Scenarios

Vehicle type	Scenario 1 bus ridership 11%	Scenario 6 bus ridership 22%	Scenario 8 bus ridership 33%
Cars	90	86.50	82.00
Medium trucks	6	4.50	7.75
Busses	2	6.75	7.75
Heavy trucks	2	2.25	2.50
Volume reduction	0	11.30	22.70

FIGURE 11 Effect of Fleet Mix on CO Concentration

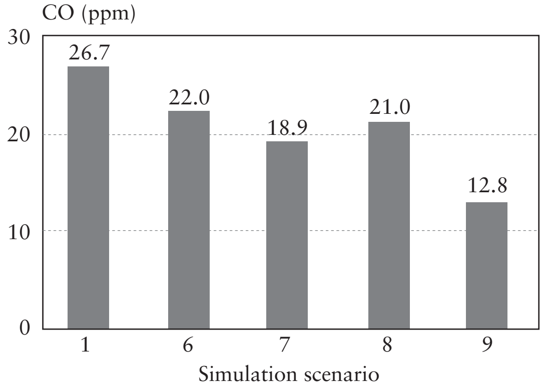
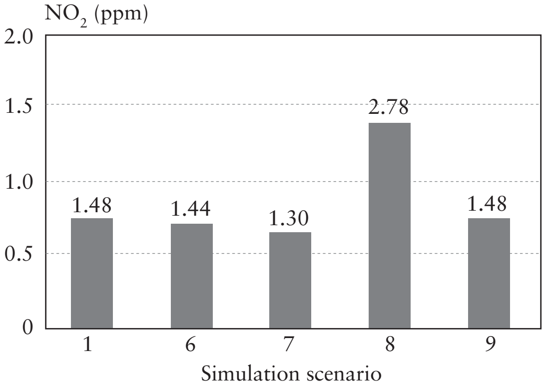


FIGURE 12 Effect of Fleet Mix on NO_2 Concentration



Note difference in vertical scale between figures 11 and 12.

52% for scenarios 7 and 9 with a 5 kph and 10 kph speed increase, respectively. As for NO_2 emissions, the situation is more complex. The contribution of fleet reduction, 11.3% and 22.7% for scenarios 6 and 8, did not reduce NO_2 concentrations. In fact, a 3% reduction, and an 89% increase in NO_2 concentrations were estimated for the 2 alternatives, scenarios 6 and 8. This can be attributed to the elevated emissions factors associated with heavy vehicles, leading to an increase in NO_2 concentrations. Moreover, the contribution of the 5 kph and 10 kph speed increase results in a net decrease of 12% and 0% in NO_2 concentrations for scenarios 7 and 9, respectively. This net reduction is not significant enough to bring the NO_2 to levels meeting air quality standards.

Level of Service (LOS)

LOS, which describes the performance of a roadway, can play a major role in establishing air quality levels. For the present study, the effect of LOS was analyzed using a slight modification to the intersection configuration. An overpass was assumed to serve the north/south traffic, the heaviest traffic flow, in both directions. The design speed for stopping sight distance (SSD) considerations is assumed to be 100 kph, with an actual average cruising speed of 60 kph (Papacostas and Prevedouros 1993). In addition, the maximum service flow (MSF) rate along the north/south direction is around 1,500 vehicle per hour per lane, which corresponds to LOS D (see table 11).

If the LOS is improved by adding another lane (both directions) in the overpass, then the facility would have an MSF of around 1,000 vehicles per hour per lane, making it eligible for both LOS C and B, corresponding to travel speeds of 75 kph and 80 kph, respectively (see table 11). Simulation results for the LOS scenarios are depicted in figures 14 and 15. Improvements in LOS reduced CO concentrations due to the increase in speed that results in a decrease in emissions factors (speed is less than 90 kph). On the other hand, changes in LOS increased NO_2 concentrations due to the increase in speed, resulting in an increase in emissions factors (speed is greater than 50 kph). This is true since for a LOS E and better, the average speed is greater than 50 kph, which falls in the range where the emissions factors increase with speed.

Assessment of Potential Air Quality Impacts

Assessment of the impact of emissions is conducted by comparing the simulated future exposure levels with existing air quality conditions and relevant local and World Health Organization (WHO)

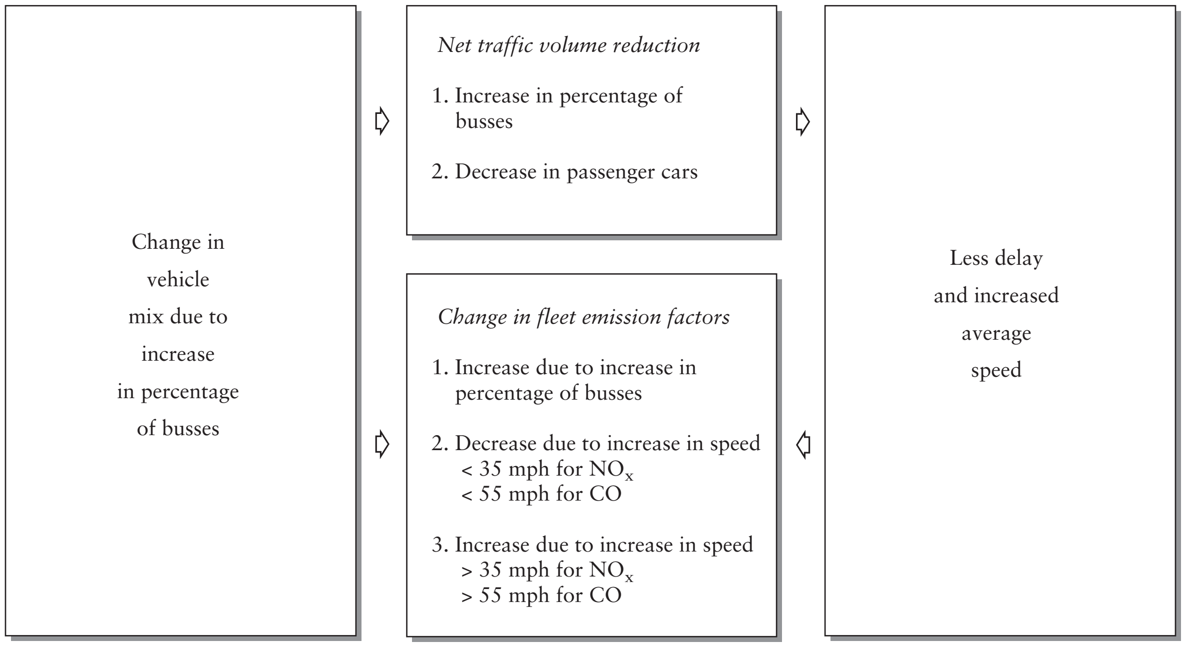


FIGURE 13 Interrelationship between the Change in Vehicle Mix and Emissions

TABLE 11 Level of Service for a 100-kph Basic Freeway Section

LOS	Density vehicle/mile/lane	Speed kph	V/c[1]	MSF[2] vehicle/hour/lane
A	≤ 12	—[3]	—	—
B	≤ 20	≥ 80	0.49	1,000
C	≤ 30	≥ 75	0.69	1,400
D	≤ 42	≥ 67	0.84	1,700
E	≤ 67	≥ 48	1.00	2,000
F	> 67	< 48	—	—

[1] Volume to capacity
[2] Maximum service flow rate
[3] No data available
Source: HCM 1994

standards. During the operational phase, which can last indefinitely, the impact on air quality will be of a continual nature. In the present study, traffic emissions alone do not cause CO concentrations to exceed the WHO standards, but the additional background concentration does result in levels exceeding those standards. On the other hand, NO_2 levels from traffic emissions alone are higher than recommended standards, regardless of background levels.

Mitigation

In Lebanon, as in many developing countries, there is a lack of institutional capacity and technical expertise to deal with environmental issues. New legislation may fail to meet its objective unless a broad mix of measures is simultaneously implemented. In this context, project-specific measures and long-term policies are needed to mitigate potential impact on air quality. While technologies that ensure the removal of air pollutants are expected to grow in importance, mitigation measures must focus on separating pollution sources

FIGURE 14 Effect of LOS Change on CO Concentration

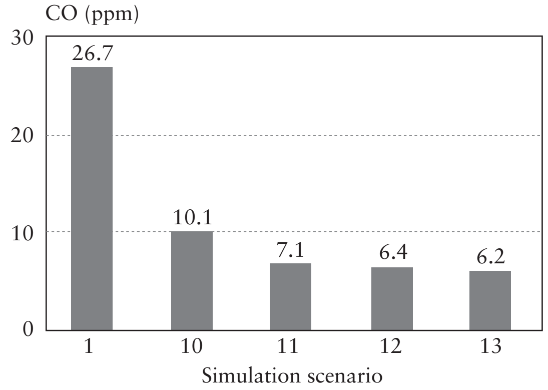
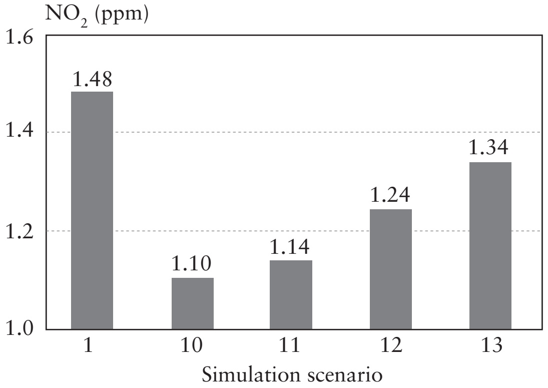


FIGURE 15 Effect of LOS Change on NO_2 Concentration



Note difference in vertical scale between figures 14 and 15.

and receptors, reducing pollution activity and its characteristics, controlling emissions with filtering devices, and adopting and enforcing proper operational procedures.

Table 12 presents possible mitigation strategies. Emissions reduction will have multi-dimensional benefits since air pollution affects both public health and the environment. With the improved status of the health of the population, there will be less absence from work because of health problems and lowered costs of health insurance. Note that mitigation measures in the context of an intersection study are related mostly to construction activities if they are to be limited to site-specific measures. The interrelation between general mitigation measures that apply at the vehicle-fleet level and an intersection study is primarily through the estimation of emission factors. The reduction of the latter is not necessarily related only to an intersection study but rather to the entire vehicle fleet and should therefore be considered in this context.

TABLE 12 Summary of Possible Mitigation Strategies

Phase	Mitigation measure
Construction	■ Site and stockpile enclosure
	■ Spraying of stockpiles with chemical bonding agents
	■ On-site mixing in enclosed or shielded areas
	■ Proper unloading operations
	■ Water damping of stockpiles when necessary (dry conditions)
	■ Sealing of completed earthworks
	■ Re-vegetation as soon as possible
	■ Medium and heavily used haul routes permanently surfaced
	■ Damping unsurfaced haul routes
	■ Keep hauling routes free of dust and regularly cleaned
	■ Minimal traffic speed on-site with proper enforcement
	■ Maintenance and repair of construction machinery
Operation	■ Diverting traffic away from heavily populated areas
	■ Converting high-use vehicles to cleaner fuels
	■ Development of a comprehensive vehicle inspection and maintenance programs
	■ Imposing emission-related taxes
	■ Development of air quality standards and monitoring plans
	■ Increasing the share of less polluting traffic modes
	■ Using fuel-efficient vehicles
	■ Installing catalytic control devices

SUMMARY

An air quality assessment was conducted for a typical congested urban intersection in Beirut. Air quality measurements were first obtained to define the existing levels of pollution. Mathematical simulations were then conducted to estimate vehicle emissions factors and to define concentrations of selected pollutants 1) with and without the grade separation, 2) with changing the fleet vehicle mix, and 3) with improvement of level of service. The simulations showed that these three factors can reduce exposure to CO concentrations in the air at ground level. Exposure to NO_2 was also reduced in most scenarios but not as significantly. Simulated TSP concentrations were far less than field measurements, indicating that traffic is not the only contributor to particulate matter. A summary of simulation results is shown in table 13, depicting the simulated concentrations and the net change in the pollutant concentration from baseline conditions. Note that in construction situations, which can arguably be a critical time for air quality, TSP concentrations are expected to exceed all standards. The extent of this impact, however, cannot be reasonably quantified in a scientific manner due to the random nature of construction activities.

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TABLE 13 Summary of Simulation Results

		Simulated concentrations		Percent change in pollutant concentration[a]	
Scenario	Description	CO	NO_2	CO	NO_2
1	Do nothing (2010)	26.72	1.48	0.0	0.0
2	Effect of type of grade separation	24.74	1.38	7.4	6.7
3		11.76	1.08	56.0	27.0
4		7.88	0.44	70.5	70.3
5		3.72	0.32	86.1	78.4
6	Effect of vehicle mix	22.04	1.44	17.5	2.7
7		18.88	1.30	29.3	12.2
8		21.02	2.78	21.3	–87.8
9		12.76	1.48	52.2	0.0
10	Effect of level of service	10.14	1.10	62.1	25.7
11		7.08	1.14	73.5	23.0
12		6.42	1.24	76.0	16.2
13		6.16	1.34	76.9	9.5

[a] Percent change in pollutant concentration from baseline conditions (Scenario 1)

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