Framework for Evaluating Transportation Control Measures: Mobility, Air Quality, and Energy Consumption Trade-Offs

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The successful implementation of a transportation control measure (TCM) and, in particular, appropriate combinations of measures may provide significant benefits to urban areas in the form of congestion reduction, improvements in air quality, and fuel savings. The effectiveness of TCMs in accomplishing these goals will most often be determined by the specific characteristics of the urban environment in which they are implemented. A macroanalysis model—a unified framework that links the transportation planning and air quality analysis models—is developed. The framework can then be used to evaluate the impact of a TCM on mobility, transportation-related emissions, and energy consumption. The results from two sample networks show that the effectiveness of a TCM depends on the characteristics of the networks. The evaluated TCMs are limited to those that affect travel time or travel costs.

Transportation planners, engineers, and air quality planners are increasingly understanding the need for coordinated efforts in providing efficient and effective transportation systems while addressing serious environmental concerns. Policy makers in the present and, particularly, those in the near future must issue policies based on broad, coordinated efforts in transportation, air quality, and energy consumption so that optimal strategies for all three components may be implemented. At present, however, transportation planning and air quality analysis models are incompatible. Emission models require detailed inputs that are not generally provided by transportation planning and analysis tools. Traditionally a set of socioeconomic variables, such as a forecast population, automobile ownership, employment, and land use, are inputs of the transportation planning model that in general comprised four steps: trip generation, trip distribution, mode choice, and network assignment. This planning process does not adequately account for the manner in which individuals make travel decisions. The only travel-related decision that can be predicted by this traditional planning method is the mode of travel, whereas transportation control measures (TCMs) affect trip generation, trip distribution, as well as route and mode choice.

Traffic flow improvement, an intended product of TCMs, may cause changes in travel patterns, for example, travel time and route changes. The traffic flow measurements given by equilibration procedures in the network assignment step are limited in estimating emissions. First, they are average values whereas the emissions estimation models usually require different values of speed, acceleration, and deceleration for different classes of vehicle. Likewise, for fuel consumption estimation, the values of speed, stop time, and number of stops are essential but are not provided by the equilibration procedures. Second, it is very difficult to include all dimensions of travel demand, and the ones that consider frequency, destination, or mode choice in addition to route choice require the use of aggregate demand models, which do not adequately capture travel behavior. Finally, the equilibration models may make large errors in estimating traffic volumes and speeds on network links. Horowitz pointed out that a 30 percent error is not unusual (*1*).

Traffic simulation models that are generally used in optimizing traffic signals and predicting delays can be used to simulate TCMs for some roadway links in a network. Most traffic simulation models track vehicle positions as they move in the network and produce information such as average speed and stop time on a link, which can be used in emissions models. However, they require traffic volume as input, except a few models that are demand responsive and thus are unable to forecast changes in traffic volume caused by a TCM.

A key in the estimation of air pollution is the conversion of traffic data into an account of pollutants. This is accomplished through the use of an emissions factor model such as the Environmental Protection Agency's (EPA's) MOBILE model. The model requires detailed inputs, which often do not correspond to what is commonly available from transportation models, as stated previously. These include various speeds and vehicle miles of travel (VMT) for different classes of vehicle, vehicle type, age of vehicle, accumulated miles of vehicle travel, maintenance program, analysis year, fuel volatility, daily ambient temperature, altitude, and humidity.

These variables, required for emissions estimations, have not been a component of transportation planning models. A methodology for combining transportation planning and analysis models with emissions factor models for predicting the effectiveness of various TCMs is needed. A matrix of strategies that produces the greatest savings in air emissions and energy consumption can then be developed. This paper presents a conceptual framework for bridging transportation planning and air quality analysis models. The framework can then be used to evaluate, comparatively, the impacts of various transportation control measures that influence

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either travel time or travel cost on transportation-related emissions and energy consumption. Two sample analyses are presented in this paper to demonstrate application of the macroframework.

FRAMEWORK

The framework, given in Figure 1, consists of five models as well as cost-benefit analysis:

1. *Mode choice model.* This model is used to predict individual decision probabilities of mode, destination, and route for various TCMs. The model should encompass all possible modes affected by TCMs. These modes include nonmotorized, drive-alone, carpool, or transit or even whether the individuals choose not to travel, as a result of telecommuting for instance.
2. *Traffic simulation model.* A traffic simulation model can be used to study effects of traffic management strategies on the system's operational performance. This performance is generally expressed in effectiveness measures such as VMT, average vehicle speeds, vehicle stops, and average and maximum queue lengths. These parameters are important in the estimation of pollutants.
3. *Emissions estimation model.* This model takes into account the factors affecting emissions, such as speed, VMT, vehicle classes, and modes of operation.
4. *Fuel consumption model.* This model estimates the fuel consumption changes as a result of TCM implementation.
5. *Dispersion model.* This model is used to estimate emissions concentration as a function of atmospheric conditions, for example, winds, temperature, and altitude.

Choice Models

The specific TCMs identified in the Clean Air Act Amendments of 1990 (CAAA) are shown in Table 1. The TCMs influence travel decisions primarily in the short term through frequency, route, and mode of travel, but they may have some long-term effects, on workplace location for example. TCMs also encompass decisions of whether an individual chooses to travel, travel to different

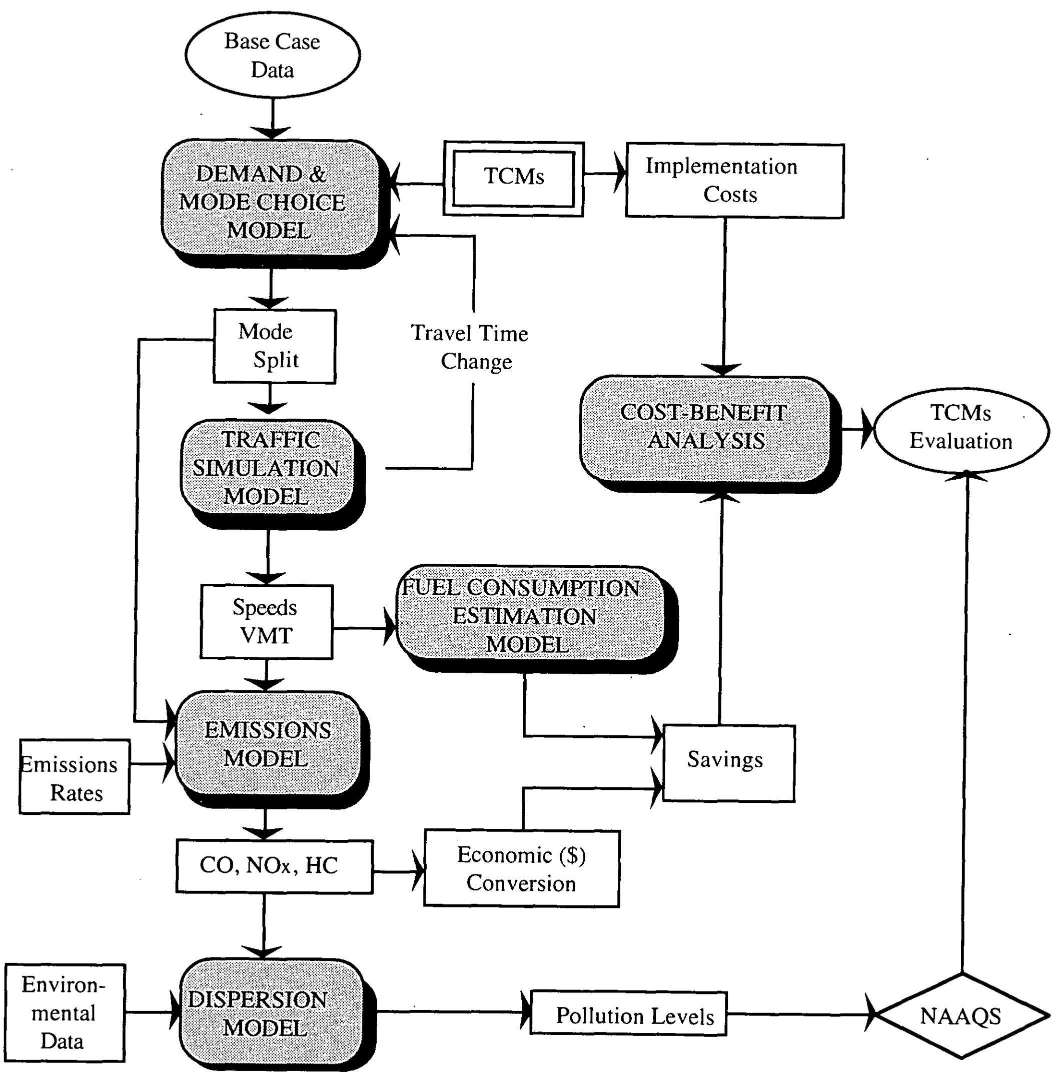

FIGURE 1 Model framework for evaluating TCMs.

TABLE 1 Available Transportation Control Measures

• Improve Public Transit	• High Occupancy Vehicle Lanes
• Employer-Based Transportation Program	• Trip Reduction Ordinances
• Traffic Flow Improvements	• Park-and-Ride/Fringe Parking
• Limit Vehicle Use in Downtown Areas	• Area-wide Ride-sharing Incentives
• Bicycle and Pedestrian Facilities	• Control of Extended Vehicle Idling
• Reduce Extreme Cold Start Emissions	• Flexible Work Schedules
• Programs for Large Activity Centers and Special Events	• Voluntary Removal of Pre-1980 Vehicles

workplace locations according to different schedules, or telecommute. The influence of TCMs on travel decisions can be explained by discrete choice models, which are flexible enough to accommodate long-, medium-, and short-term decisions.

As discussed earlier the traditional four-stage transportation planning sequence does not account for the manner in which individuals make travel decisions, particularly those in the long- and medium-term time range. As an alternative discrete choice models may be used. Figure 2 gives a broad range of behavioral decision making that may influence the traveler's decision in the long-, medium-, or short-term time range. A transportation system based on this structure was initially developed by Ben-Akiva and Atherton (*2*) to analyze potential energy conservation policies. Emissions estimated for various TCMs are merely an extended application of this model. The impacts of TCMs on air pollution should be assessed for a range of travel decisions. Use of this approach accounts for travel decisions in the long, medium, and short terms. Although this approach is more applicable than the traditional four-stage planning models, its outputs are still not sufficient in meeting the data requirements of emissions factor models that require vehicle type for work and nonwork trips and engine type (gasoline, diesel, or other fuel).

Moreover the model structure should be adaptable to inclusion of new modes into the urban transportation system. For instance if light rail is an option, the model should yield an accurate share of light rail's ridership to investigate the effectiveness of this transit investment. The model should also be able to forecast individual behavior when telecommuting, using compressed work weeks, or operating according to flexible work hours.

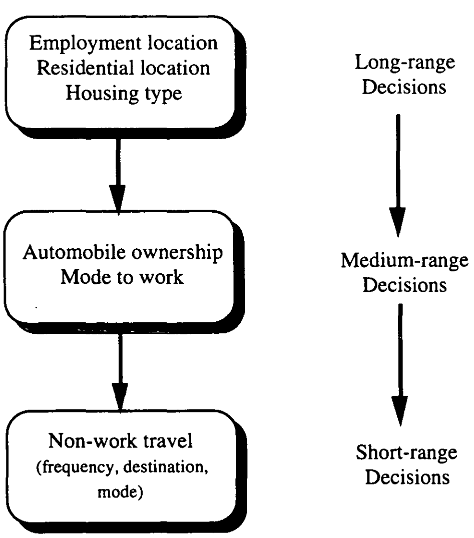

FIGURE 2 Choice hierarchy (*2*).

Significant variables in the mode choice model generally are transportation level of service and socioeconomic variables. The transportation level of service variables are travel time (disaggregated to in-vehicle time and out-of-vehicle time) and travel cost. The socioeconomic variables are income, workplace, mode availability, and employment density. Effects of a TCM enter the choice model as shown in Figure 1, changing values of the utility function variables. Some effects are given in Table 2. When route choice is predicted route length can be determined. Then one may assume for example that home-to-work trips are cold start. If the route is longer than 505 sec (the current EPA assumption) or 3.59 mi, the vehicle is in running mode. A fraction of shopping trips may be assumed to be cold start, with the remaining portion assumed to be hot start. This should result in a more accurate estimation of emissions.

Traffic Simulation Models

Several traffic simulation models are available. TRANSYT-7F (*3*) is one model that can be calibrated to study the traffic flow effects of TCMs.

TRANSYT-7F is a macroscopic model that considers platoons of vehicles, instead of individual vehicles. Inputs to TRANSYT-7F include those that can be obtained from the choice model, such as traffic volume, resulting from a change in modes. Also included as inputs are saturation flows, signal parameters, existing cruise speed, and intersection geometry. TRANSYT-7F generates travel times, delays, and stops that can be linked to an emissions estimation model. Because TRANSYT-7F is a macroscopic model its outputs indicate average values, and therefore it cannot identify specific vehicle classes, yielding less accurate emissions estimates.

The TRAF-NETSIM (*4*) traffic simulation model can accommodate traffic controls and track the positions of vehicles as they move through the network, making it possible to estimate emissions along the links. Up to 16 vehicle classes can be specified in TRAF-NETSIM, with private automobiles, trucks, buses, and carpool vehicles as the default vehicles. However, TRAF-NETSIM requires traffic volumes as an input. This means that it is unable to forecast the changes in the volumes as traffic flow improvement measures are implemented. Several TCMs, particularly the ones affecting travel time, for example, high-occupancy-vehicle (HOV) facilities, traffic signal improvements, and improved public transit, are likely to cause a change in travel time since they affect the individual choice and thus traffic volumes. This requires a number

TABLE 2 Effects of TCMs on Utility Functions in Mode Choice Model

TCMs	Effects
Improved public transit	
• Increase service frequency	Reduce transit wait time
• Extend light rail system	Reduce transit travel time
• Add new bus route	Reduce transit access time
• Add light rail and bus stations	Reduce transit access time
• Decrease fares	Reduce travel costs
Park and ride and fringe parking	Reduce transit and auto in-vehicle times Change out-of-vehicle times Change travel costs
Traffic flow improvement	
• Build new freeway and arterial	May either reduce or increase travel time
• Increase parking rate	Increase auto cost
• Increase gasoline price	Increase auto cost
• Build HOV lanes	Reduce ride-share and bus in-vehicle time
• Expand ramp metering with HOV bypass lane	Reduce ride-share and transit travel time
• Install bus-actuated traffic signals	Reduce transit travel time
Work schedule changes	
• Flextime	Reduce travel time
• Telecommuting	Affects trip decisions
Vehicle use limitations/restrictions	
• Auto-free zone	Increase travel time

of iterations to converge the average travel time value in the traffic simulation model to the value in the choice model.

NETSIM can be used to evaluate the impacts of various congestion mitigation strategies on energy consumption and air pollution. The fuel consumption and emissions calculations are based on vehicle speeds, acceleration, and deceleration. Unfortunately NETSIM measures only automotive emissions; therefore, the emissions analysis is not conclusive. Moreover NETSIM emission factors are based on earlier automobile models and it does not take into account elevation, temperature, vehicle age, and so on, as do other emissions models.

Emissions Models

A key in estimating air pollution is the conversion of VMT, vehicle speeds, and vehicle types into amount of pollutants. This is accomplished through the use of emissions factor models such as California Air Resources Board (CARB) EMFAC7E model or EPA's MOBILE model. MOBILE accounts for many variables that affect the production of emissions by motor vehicles. Important inputs for use in MOBILE include fuel volatility, daily ambient temperature, altitude, humidity, vehicle type, age of the vehicle, accumulated miles of vehicle travel, average vehicle speed, inspection and maintenance, VMT split, and analysis year.

In estimating emissions two model types are used for different applications. The microscale models determine a vehicle's instantaneous exhaust hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x) emissions per unit of time as a function of speed and acceleration, whereas the macroscale models determine total vehicle emissions or average emissions per unit of distance traveled, including trip end emissions, during an entire trip or part of a trip. In relation to the framework, both micro- and macroscale models can be used with the traffic simulation model. For example in a large urban network originating and terminating trips, such as the sink/source nodes available in TRAF-NETSIM, may be used to represent the points where trips start or end. With a known number of trips and hot soak and start-up emissions factors for vehicle type, model year, and age (or the weighted average over the model years of vehicles in the area of concern), macroscale emissions can be estimated. When only trip segments are of interest, hot soak and start-up emissions may be disregarded, thus giving microscale emissions.

Fuel Consumption Models

Fuel consumption can be estimated by the modal choice model with additional computations or by some traffic simulation models; for examples, TRAF-NETSIM and TRANSYT-7F. The latter approach has some limitations. For example in TRANSYT-7F a stepwise multiple regression is used, with the model parameters derived from a study of one test vehicle and the model coefficients adjusted to represent an "average" vehicle. In the cities in which the fuel consumption models have been calibrated to account for specific conditions such as grade, roadway geometry, mix of vehicles, and so on, the outputs from the traffic simulation can be used in that local fuel consumption model. Variables normally significant for fuel consumption estimation are travel time, stops, and stop times, which are generally provided by a traffic simulation model.

Dispersion Models

Volatile organic compound outputs from emissions factor models are one of the inputs for a dispersion model. Dispersion or diffusion models are quantitative models used for determining the relationship between emissions and atmospheric concentrations of air pollutants. The pollutants, once emitted, are dispersed by winds and may chemically react to form new compounds. An example is the ozone produced by the photochemical reaction of HCs and NO_x. EPA-approved models for the estimation of ozone levels are Empirical Kinetics Modeling Approach or the Urban Airshed Model. Emissions, temperature, winds, water vapor, initial concentrations, and the modeling period are model inputs. The models yield ozone concentrations that are compared with National Ambient Air Quality Standards.

Cost-Benefit Analysis

Finally the effectiveness of TCMs should be measured economically through benefit-cost or cost minimization analysis. The costs should include traditional expenses for new facilities or improvements, that is, HOV lanes, improved transit operations, traffic signal improvements, and so on, but should also include vehicle operating, delay, accident, and environmental costs. Small (*5*) developed a method for estimating the air pollution costs of transport modes by quantifying health and material damage. With some assumptions he arrived at the costs of different modes as shown in Table 3. These costs are based on 1974 economic conditions and technologies. More recently CARB has developed production costs per ton of pollutants for stationary source control measures in California. These going rates are given in Table 4. New estimates for pollution costs are needed for a more robust analysis. Finally some expected costs and benefits to urban transportation systems for different TCMs are given in Table 5.

SAMPLE ANALYSIS

Application of the framework is demonstrated through two examples. Two networks are created to evaluate a few strategies, namely implementation of HOV lane or increased automobile operating cost, for reducing congestion. For simplicity and illustrative comparison purposes, the sample networks are linear corridors. Evaluation of TCMs for considerably larger or more complex networks can be done by using the same procedures, provided computational time and cost as well as computer capacity are adequate. This was an inherent limitation of the present

TABLE 3 Air Pollution Emissions and Costs (*5*)

Vehicle Type	Emissions[a] (grams/km)						1974 Cost[b]
	CO	HC[c]	HC[d]	NOx	SOx	PM	¢/km
Automobiles							
Pre-1961 Model (in year 1974)	59.0	5.5	4.1	2.1	0.08	0.34	0.22
1969 Model (in year 1974)	42.3	3.1	1.6	3.2	0.08	0.34	0.21
1974 Model (new)	23.0	2.0	1.1	1.9	0.08	0.16	0.12
1974 Model (5 years old)	29.2	2.9	1.1	2.5	0.08	0.16	0.16
1974 Composite[e]	37.3	3.5	1.5	2.4	0.08	0.29	0.17
Post-1977 Model[f] (new)	1.7	0.2	1.1	0.1	0.08	0.16	0.02
Post-1977 Model (5 years old)	2.6	0.3	1.1	0.5	0.08	0.16	0.04
1995 Composite[g]	2.4	0.03	1.1	0.4	0.08	0.16	0.04
Diesel Bus or Truck							
Pre-1973 Model	13.2	2.5	--	13.4	1.7	0.81	0.60

[a] Emissions assume low altitudes and urban arterial driving at average speed of 30.6 km per hour.
[b] Costs are inflated or deflated by current-dollar gross national product per capita.
[c] Exhaust emissions.
[d] Crankcase and evaporative emissions.
[e] Exhaust emissions from 1974 and earlier models are weighted by the aggregate mileage driven on each model in 1974.
[f] Assuming enforcement of the last reductions called for in the 1970 Clean Air Act Amendments, originally scheduled for 1975 models and subsequently postponed to 1978 models.
[g] Composite exhaust emissions are calculated on the assumption of a steady-state population of post-1977 model cars, with age distribution and estimated deterioration from the U.S. Environmental Protection Agency.

TABLE 4 CARB Pollutant "Going Rates" in 1990 (*6*)

Pollutant	Average Rate (per metric ton)	Highest Rate (per metric ton)
HC	\$3,629 - \$9,073	\$19,960
CO	\$181	\$1,815
NO_X	\$1,815 - \$9,073	\$21,774

study and the reason for the simple sample networks. Therefore in these illustrative sample analyses, only microscale emissions estimations are considered.

The choice or "split" among several transportation modes depends on both the socioeconomic characteristics of the decision makers and the transportation alternatives available to them. The mode choice model used in both networks is a multinomial logit model developed by Ben-Akiva and Lerman (*7*). It is assumed that the traveler has the ability to compare all possible alternatives—in this case, car, carpool, and bus—and make the short-range decisions to select the one with the highest utility, which is viewed as the index of his or her socioeconomic attributes. To predict changes in mode split for either the HOV lane or the increased auto operating cost, one can use the choice probabilities in the base case (without TCMs) and the change in utility due only to the affected variable, travel time, or operating cost. The probability of traveler n choosing any alternative i after the implementation of either of the above two TCMs can be expressed as

$$P_n'(i) = \frac{P_n(i)e^{\Delta V_{in}}}{\sum_{j=1}^{3} P_n(j)e^{\Delta V_{jn}}}$$

where $P_n(j)$ is the choice probability in the base case; j equals 1 if automobile is selected, j equals 2 if carpool is the alternative, and j equals 3 if bus is chosen. DV_{jn} is the change of individual utility, which is formulated as

$$\Delta V_{jn} = \beta_1 \times \text{changes in travel time} + \beta_2 \times \frac{\text{changes in operating cost}}{\text{household income}}$$

The values of β_1 and β_2 are obtained from a survey. They are assumed as β_1 equal to -0.0307 and β_2 equal to -28.7 in the examples. Similarly \$28,000 is assumed as the average annual household income.

Network A

In Network A a highly congested urban street is created. The characteristics of the network and the street geometry are shown in Figure 3. All intersections are signalized. Turning volume is prescribed and constant for all cases. A total of 3,520 people are assumed to travel from Node 48 to Node 1 during peak hour. The

TABLE 5 Some Costs and Benefits Related to TCM Implementation and Air Pollution

Costs	Benefits
Improved public transit	
• Operation	• Fuel consumption reduction
• Additional initial investment	• Emissions reduction
Traffic flow improvement	
• Construction (HOV lanes)	• Fuel consumption reduction for some users
• Operation and enforcement	• Travel time savings for some users
Work schedule changes	
• Construction and operation of work satellite centers for telecommuting	• Fuel consumption reduction
• Building energy consumption	• Emissions reduction
• Telecommunication and computer use	• Office space savings and reduced parking requirements
• Congestion near satellite centers	
Park and ride and fringe parking	
• Facility construction	• Fuel consumption reduction for some users
• Traffic congestion near facilities	• Emissions reduction in CBD
• Emissions near facilities	
Road pricing	
• Travel costs for users	• Fuel consumption reduction system-wide
	• Emissions reduction
Alternative engines and fuels	
• Conversion of engines	• Emissions reduction
• Facilities for re-fueling stations	

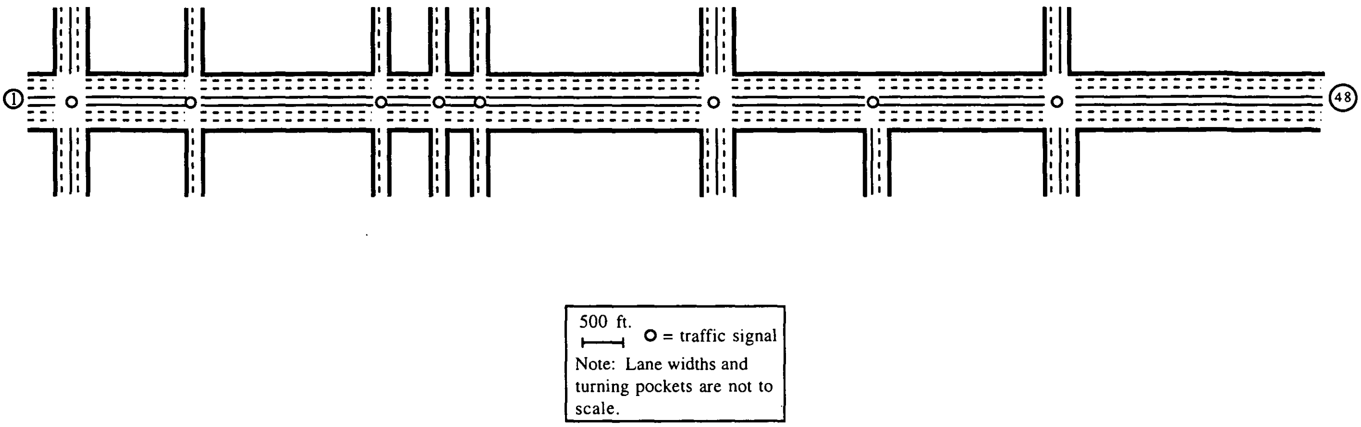

FIGURE 3 Sample Network A.

analysis is performed for the peak period, and the choice of time of day is not under consideration. Traffic volumes entering this network are assumed to be the same for all cases except that entering Node 48, which varied according to the modal splits obtained for different cases. Bus service is provided along the main street.

Six different scenarios are examined for Network A. For each case several iterations are required so that the travel time used in the utility function of the mode choice model is, within a specified tolerance level, equal to that obtained from TRAF-NETSIM. These cases are as follows:

1. *Base case.* The network geometry, traffic movements, and entering volumes were described above. The person-miles-of-travel (PMT), average speeds, and fuel consumption from TRAF-NETSIM are given in Table 6.
2. *HOV-4.* The traffic engineering data and basic geometry are the same as those in the base case except that the right lane along the main street is reserved for four-person carpools and buses.
3. *HOV-3.* Same as HOV-4 except that a three-person instead of a four-person carpool is used.
4. *Bus lane.* This case is the same as Scenarios 2 and 3, but only buses are allowed on the HOV lane.
5. *No left turn.* Left turns are not permitted along the main street in either direction.
6. *Pricing.* Operating costs for automobile and carpool are increased by 25 and 10 percent, respectively. Bus prices remain the same.

The center lane in Network A is assumed to be a reversible lane for inbound and outbound traffic for morning and afternoon peak periods. Automobile occupancy is assumed to be 1.3; carpool occupancy is 3 for all scenarios except Scenario 2, which is 4;

TABLE 6 Mobility and Fuel Consumption Results for Network A

	Base	HOV-4	HOV-3	Bus Lane	No Left	Pricing
PMT in 15 Minutes						
Auto	1,157	1,541	1,575	1,129	1,206	1,114
Carpool	548	872	860	535	561	587
Bus	313	536	529	555	290	317
Total	2,018	2,949	2,964	2,219	2,057	2,018
Average Speed (kmph)						
Auto	10.3	16.7	17.5	9.7	10.1	11.6
Carpool	10.3	26.9	25.6	9.7	10.1	11.6
Bus	9.8	26.9	25.6	26.2	8.5	10.0
All Vehicles	10.3	18.3	19.1	9.7	10.1	11.6
Fuel Consumption (liters/person-km)						
Auto	.1487	.0932	.0948	.1294	.1484	.1484
Carpool	.0306	.0179	.0223	.0266	.0303	.0348
Bus	.0108	.0066	.0066	.0066	.0111	.0111
All Vehicles (Avg.)	.0953	.0548	.0576	.0741	.0964	.0936
Mode Split (%)						
Auto	57.33	52.24	53.15	50.88	58.34	55.18
Carpool	27.16	29.58	29.01	24.11	27.14	29.11
Bus	15.51	18.18	17.84	25.01	14.02	15.71

bus occupancy is 50 for Scenarios 1, 5, and 6 and 70 for Scenarios 2, 3, and 4. The simulation time is limited to 15 min owing to the limitation of microcomputer memory.

In Scenarios 2 through 6 the speed changes in automobiles, carpools, and buses after implementation of a TCM cause the changes in the utility function and in turn yield the switch among the selection of drive-alone, carpool, and bus. The details of mode split and other traffic measurements at equilibrium are shown in Table 6.

Mobility can be evaluated subjectively by examining PMT in a unit time period or average speed. PMT is the same for all scenarios if a given level of demand is being analyzed. For example 10,560 PMT is the input value in Network A. Because of the difference in congestion levels in peak hour, however, the PMT in a unit time period (in this case, 15 min) may vary. The lower the congestion level the shorter the congestion period and in turn the larger the PMT in a unit time period during the congestion. The calculations in both networks are limited to the simulation period. All of the scenarios improve PMT during the 15-min simulation period over the base case except pricing, which remains the same. The variations in PMT in 15-min are due to the different congestion levels. The average speed improves for the HOV lane and pricing scenarios, but decreases for the bus lane and the no-left-turn scenarios. The nominal changes for the left turn outputs are primarily the result of the low percentage of left turns prescribed in the base case. From an energy standpoint all the scenarios except the no-left-turn option resulted in reduced fuel consumption. When accounting for the change in the modal split, there are some interesting results. All the scenarios except the no-left-turn option resulted in higher vehicle occupancies, that is, fewer automobile trips.

The speed and VMT outputs from NETSIM are the inputs for the emissions model. The vehicle emission results from MOBILE 4.1 are listed in Table 7. (A more recent MOBILE version is now available; however, at the time that the present analysis was conducted MOBILE 4.1 was the current version.) Compared with the results in the base case, only the implementation of the HOV lane (both HOV-3 and HOV-4) in this network resulted in effective air pollution reductions. All other strategies tested achieved minor improvements in air quality. This was because the demand largely exceeds the capacity in the network, which is reflected by the particularly slow speeds in Table 6. The inclusion of a HOV lane can improve the PMT on the HOV lane, whereas the vehicles in the other lanes of the network remain congested. This increases the denominator in calculating average emission results (on a per-person-per-mile basis) and in turn lowers average air pollution.

TABLE 7 Emissions Results for Network A (gram/person-km)

			Base	HOV-4	HOV-3	Bus Lane	No Left	Pricing
Auto								
	Running							
		HC	2.033	1.265	1.239	2.046	1.994	2.247
		CO	19.028	10.943	10.655	19.262	18.718	21.030
		NOx	0.622	0.518	0.526	0.597	0.602	0.687
	Idle							
		HC	2.119	0.797	0.968	2.109	2.065	2.111
		CO	20.311	7.638	9.280	20.216	19.797	20.233
		NOx	0.273	0.103	0.125	0.272	0.267	0.273
Carpool								
	Running							
		HC	0.877	0.308	0.413	0.886	0.883	0.870
		CO	8.201	2.456	3.316	8.337	8.281	8.146
		NOx	0.268	0.167	0.218	0.259	0.267	0.266
	Idle							
		HC	4.472	0.006	0.006	4.451	4.439	4.001
		CO	42.873	0.053	0.058	42.663	42.556	38.354
		NOx	0.578	0.001	0.001	0.575	0.574	0.517
Bus								
	Running							
		HC	0.056	0.074	0.076	0.075	0.058	0.056
		CO	0.360	0.378	0.396	0.387	0.383	0.360
		NOx	0.270	0.412	0.420	0.416	0.278	0.270
	Idle							
		HC	0.026	0.017	0.018	0.017	0.031	0.026
		CO	0.077	0.050	0.054	0.052	0.093	0.076
		NOx	0.031	0.021	0.022	0.021	0.037	0.031
Weighted Average								
	Running							
		HC	1.412	0.765	0.792	1.273	1.411	1.502
		CO	13.192	6.512	6.696	11.907	13.221	14.032
		NOx	0.471	0.395	0.418	0.470	0.463	0.499
	Idle							
		HC	2.433	0.421	0.520	2.150	2.414	2.333
		CO	23.301	4.015	4.959	20.585	23.113	22.341
		NOx	0.319	0.058	0.070	0.282	0.316	0.306
Total								
		HC	3.846	1.186	1.312	3.424	3.825	3.835
		CO	36.493	10.526	11.654	32.493	36.334	36.373
		NOx	0.789	0.453	0.489	0.752	0.779	0.805

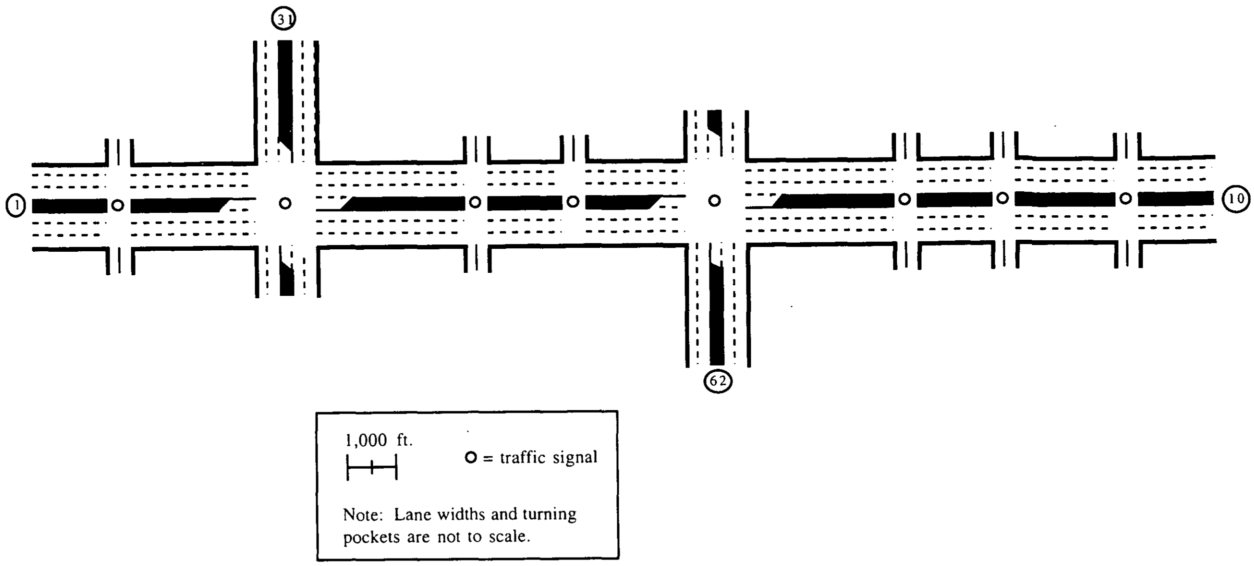

FIGURE 4 Sample Network B.

Network B

In Network B an urban arterial street with three residential zones and a central business district (CBD) is simulated. The street, shown in Figure 4, consists of nine links from west to east. The three residential zones are Node 1, Node 31, and Node 62 and the CBD is Node 10. It is assumed that the number of people living in the residential zones with the mode choice alternatives of drive-alone, carpool, and transit bus includes 3,000 people in Node 1 and 1,000 people each in Nodes 31 and 62. The assumed mode shares are listed as the base case in Table 7. There is a transit route from each residential area to the CBD. Automobile occupancy is assumed to be 1.3, carpool occupancy is 3 for all scenarios, and bus occupancy is 25 for the base scenario and 30 for the other two study cases to meet the demand. Each case was a 1-hr simulation performed on a PC486DX/50 requiring 45 to 50 min of real time.

Because of the computation time only three different cases are examined in the Network B simulation:

1. *Base case.* The base case was as described above.
2. *HOV-3.* The right lane along the main street is reserved for three-person carpools and buses.
3. *Pricing.* Operating costs for automobile and carpool are increased by 25 and 10 percent, respectively. There is no change in bus selection.

The mobility and fuel consumption measurements for the Network B scenarios are shown in Table 8. With respect to the base case, the PMT in the simulation period decreases for the HOV scenario but increases for the pricing option. Likewise there is a decrease in average speed for the HOV option and an increase for the pricing option. Average fuel consumption, however, improved (decreased) for both of the strategies relative to the base case.

The emission results in Table 9 show that the incentives to use existing mass transit systems can achieve a limited reduction in pollution. The most attractive strategy examined is the increase in the automobile operating cost, such as parking costs and gas taxes. The program reduces the emissions of HC, CO, and NO_x by 2 to 3 percent on the average per-person-per-mile basis. The exclusive HOV lane can decrease average emissions from buses by improving the traffic flow on the HOV lane. These results, however, are offset by the slower automobile movements owing to the reduction in the number of regular lanes. Furthermore the carpools that are slowed by the frequently stopped buses at the stations worsen the air pollution in the network.

CONCLUSIONS

The choice of an emissions model is critical in air quality analysis. EPA's MOBILE model takes into account elevation, temperature,

TABLE 8 Mobility and Fuel Consumption Results for Network B

	Base	HOV-3	Pricing
PMT in An Hour			
Auto	10,665	8,688	10,122
Carpool	4,201	4,485	4,426
Bus	2,248	2,818	2,688
Total	17,114	15,991	17,236
Average Speed (kmph)			
Auto	23.3	20.0	24.3
Carpool	23.3	23.2	24.3
Bus	18.6	23.2	19.6
All Vehicles	22.9	21.2	23.8
Fuel Consumption (liters/person-km)			
Auto	.169	.182	.173
Carpool	.073	.079	.076
Bus	.044	.035	.036
All Vehicles (Avg.)	.134	.130	.132
Mode Split (%)			
Auto	65.00	62.92	62.35
Carpool	25.00	25.87	26.69
Bus	10.00	11.20	10.99

operating modes, cold starts, and vehicle age, which may not be included in other emission models, yielding more accurate results. The emissions from NETSIM may result in biased conclusions; for example, the inclusion of an exclusive HOV lane in the sample Network B is plausible by NETSIM for reducing HC and CO pollution. However as shown in Table 10 this is not the case when using MOBILE. NETSIM's emissions factors are dated, and its analysis is not nearly as sophisticated as MOBILE's.

The available transportation planning tools cannot be directly used for emissions estimation. A macroanalysis framework that links the transportation planning and air quality analysis models to develop a matrix of strategies to assist decision makers in examining specific mobility strategies for an urban area has been proposed. The purpose of the paper is to illustrate a framework for identifying energy, air quality, and mobility trade-offs of various congestion mitigation strategies. On the basis of this methodological framework two sample networks were developed and evaluated in this paper. In Network A changing the pattern of vehicle flow can achieve the goal of reducing air pollution, whereas in Network B it is more effective to increase automobile operating costs. The reason for the radically different results for Networks A and B may be the extraordinary congestion in Network B, in which the choice of changing the vehicle flow pattern may still leave the roadway system congested. The results of the analyses illustrate the need for careful study before implementation of any TCM. Failure to analyze the implications of TCMs before their implementation may yield results inconsistent with environmental and energy policy objectives.

Use of the framework demonstrated in this paper clearly points to the need for additional modeling work. Existing models may be calibrated for some analyses but cannot be relied upon for directing future transportation investments. They can, however, provide some relative comparisons of TCMs. The framework presented in this paper should assist analysts in the interim while work proceeds on the development of more comprehensive transportation demand air-quality models.

TABLE 9 Emissions Results for Network B (gram/person-km)

	Base	HOV-3	Pricing
Auto			
Running			
HC	1.076	1.194	1.047
CO	8.778	10.025	8.486
NOx	0.535	0.545	0.535
Idle			
HC	0.634	0.839	0.700
CO	6.082	8.042	6.712
NOx	0.082	0.108	0.090
Carpool			
Running			
HC	0.466	0.468	0.454
CO	3.804	3.824	3.677
NOx	0.232	0.234	0.232
Idle			
HC	0.275	0.364	0.303
CO	2.636	3.485	2.909
NOx	0.036	0.047	0.039
Bus			
Running			
HC	0.086	0.063	0.067
CO	0.481	0.337	0.363
NOx	0.442	0.340	0.352
Idle			
HC	0.026	0.018	0.025
CO	0.077	0.053	0.074
NOx	0.031	0.021	0.030
Weighted Average			
Running			
HC	0.796	0.791	0.742
CO	6.465	6.579	5.985
NOx	0.449	0.422	0.429
Idle			
HC	0.466	0.561	0.493
CO	4.446	5.356	4.700
NOx	0.064	0.076	0.068
Total			
HC	1.262	1.352	1.235
CO	10.911	11.934	10.685
NOx	0.513	0.498	0.497

TABLE 10 Comparison of Emissions Results (gram/person-km)

	HC	CO	NOx
Network A			
Base			
NETSIM	0.108	1.961	0.367
MOBILE 4.1	3.846	36.493	0.789
HOV-4			
NETSIM	0.068	1.360	0.292
MOBILE 4.1	1.186	10.526	0.453
HOV-3			
NETSIM	0.072	1.445	0.310
MOBILE 4.1	1.312	11.654	0.489
Bus Lane			
NETSIM	0.094	1.727	0.322
MOBILE 4.1	3.424	32.493	0.752
No Left			
NETSIM	0.107	2.023	0.359
MOBILE 4.1	3.825	36.334	0.779
Pricing			
NETSIM	0.111	2.097	0.388
MOBILE 4.1	3.835	36.373	0.805
Network B			
Base			
NETSIM	0.169	3.623	0.786
MOBILE 4.1	1.262	10.911	0.513
HOV-3			
NETSIM	0.164	3.436	0.733
MOBILE 4.1	1.352	11.934	0.498
Pricing			
NETSIM	0.167	3.502	0.755
MOBILE 4.1	1.235	10.685	0.497

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