Methodology for Evaluating Urban Transportation Energy-Environment Strategies: Case Study for Bangkok

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Finding and sustaining an acceptable level of environmental quality in the world's largest cities requires the adoption of major policies to address transportation investments and transportation demand management, including consideration of energy use and pollutant emissions. A methodology for evaluating urban transportation energy-environment strategies is presented. The methodology is designed to address urban development patterns, transportation system structure and modal mix, and vehicle emission and energy use characteristics. Bangkok, Thailand, is experiencing a rapid degradation of its environment and is used as a case study to demonstrate the application of the methodology. The case study develops a series of policy options to address the growing environmental problems. These policy options for responding to urban energy use and air quality degradation are compared and briefly evaluated.

The growth of global population has been the source of much attention and anxiety among those concerned about the future of the global environment. More recently, attention has focused on the massive urbanization that is a product of population growth, the increase in economic opportunity in urban areas as development occurs, and the limited ability of a fixed land base to support people in rural agriculture.

The growth in the demand for motorized travel is well understood (*1,2*). As urban areas expand, available land is generally at the edges of the urban area and in areas previously considered unsuitable for development. As the distance of residential and commercial locations from the city center or other subcenters increases, so does the need for motorized travel. Motorized travel, often in private vehicles, supplants traditional modes—in particular walking, various bicycle forms, water travel, and even mass transit. The need is necessitated by the decrease in population densities with distance from urban centers and by the dispersal of travel destinations.

The evolution of the form of urban areas is driven by the growth of income and accompanying increases in the acquisition of private motor vehicles and changes in travel habits. It is also influenced by public policy toward land use, housing, and transportation infrastructure. Even though the proportion of middle- and upper-income households in developing and newly industrialized countries that are able to afford automobiles and motorcycles is lower than in industrialized nations, the number of private vehicles still becomes very large as the middle- and upper-income groups grow. The number of vehicles and levels of congestion are comparable to or exceed those for major cities of industrialized countries. With the increase in motorized travel and congestion comes increases in energy use, emissions, and air pollution.

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The development of Bangkok described in major recent studies—such as the *Medium to Long Term Road Improvement Plan: Main Report* by the Japan International Cooperation Agency (JICA) and the *Seventh Plan Urban and Regional Transport* (SPURT) by the Office of the National Economic and Social Development Board—follows the general development path described (*3–6*). In particular, these studies indicate that unless some policy measures are taken to alleviate the situation, the number of person trips, the amount of energy use, the amount of emissions, and the level of air pollution will double or triple between 1989 and 2006. In addition, unless transportation demand is managed and large investment made in well-targeted transportation infrastructure, the extreme levels of congestion will increase.

TRANSPORTATION INFRASTRUCTURE CONSIDERATIONS

Overlaid on and intimately associated with this development pattern is the transportation infrastructure. The level of infrastructure provision relative to the population density, income, and transportation pricing and other policies determines the level of congestion. For Bangkok, high population densities, rapidly increasing income levels, low fuel prices, moderate vehicle prices (except for passenger car prices, which are fairly high), and a relatively limited transportation infrastructure have resulted in severe congestion. The rapid growth in population and economic activity is pushing both the population and various urban subcenters outward, in a combination of a linear and a polynucleated or multinucleated pattern. Vehicle flow and congestion are also expanding outward.

Within this context, further growth in travel in the more central urban area will not be possible without added infrastructure. This is strikingly shown in recent data that suggest that traffic volume is decreasing in central areas while it is growing dramatically closer to the periphery (*3*). Evidence of this pattern is shown in Figure 1.

If infrastructure is added in the central areas of Bangkok, the SPURT and JICA studies agree that traffic volumes will increase so as to maintain congestion levels, except over more lane kilometers. The implication for air pollution is that it

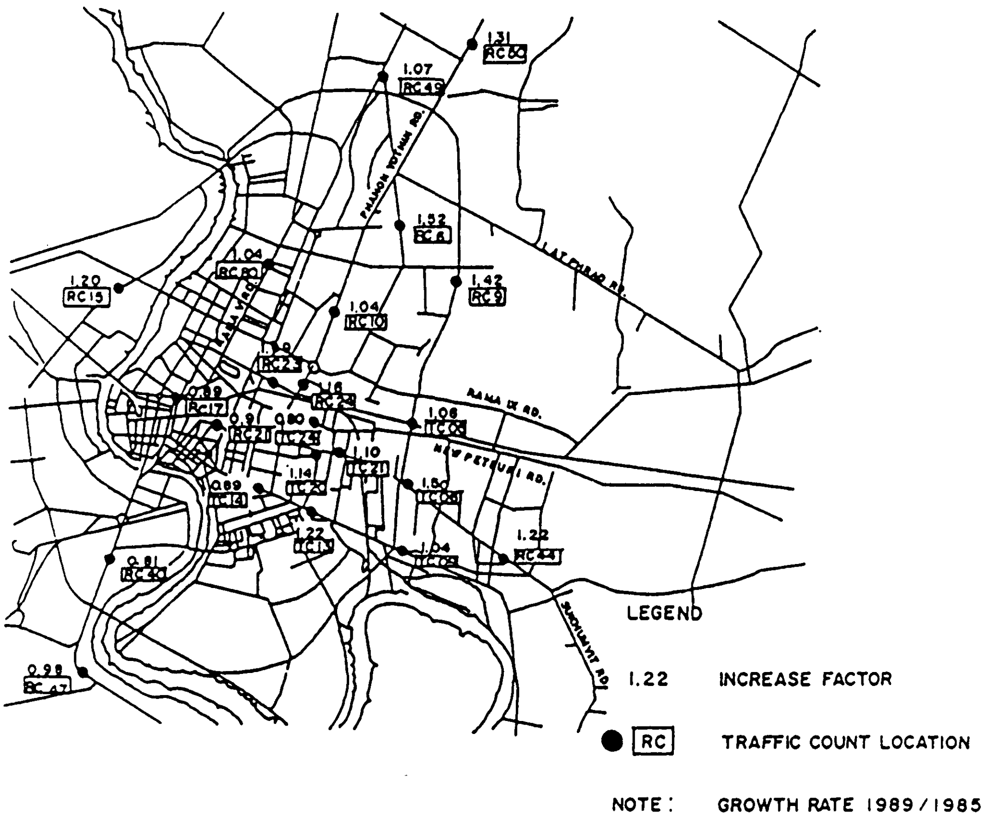

FIGURE 1 Twelve-hour traffic volume growth factor (3).

will increase (approximately) proportionally to the roadway lane kilometers provided and vehicle kilometers traveled. To provide, with the proposed new infrastructure, a higher level of service and prevent air pollution concentrations and energy use from doubling or more by the year 2006, demand management and other pollution control policy measures are required.

URBAN TRANSPORTATION AIR POLLUTION

Bangkok exhibits the vehicle-based air pollution problems typical of large industrial cities. Concentrations of various pollutants are high enough along major travel arteries to pose a significant concern for human health. Air pollution in the future, without some corrective measures, will encompass a much larger geographic area.

Lead, carbon monoxide (CO), ambient acid aerosols [from sulfur dioxide (SO_2) and nitrogen oxide (NO_x emissions], particulates (SPM), and products of incomplete combustion from diesel and two-stroke motorcycle engines are primary pollutants of concern from transportation. However, directly related fuel combustion residuals and fuel evaporation constituents are also concerns at much lower concentrations. These include—among others—1,3 butadiene; ethylene dibromide; and dichlorides; and gasoline's various aromatic hydrocarbon (HC) elements, including benzenes, xylenes, and toluene.

The photochemical oxidants (e.g., ozone) that result from extended reactions between ambient NO_x and HC have not yet proved to be pollutants of immediate concern in the Bangkok metropolitan area. Apparently, during the critical hot and dry months, the dominant winds flow steadily from the gulf on most days. In addition, the vertical instability typical of tropical cities at sea level assists in dispersing the reactants. Finally, the very low speed traffic conditions and high levels of HC emissions suggest a NO_x-limited chemical environment that tends to slow ozone reaction cycles.

Tetra-ethyl lead, introduced as a gasoline octane enhancer during the 1920s, is a multiple pathway toxin that causes retarded development in children and general system poisoning. Where leaded gasoline remains the dominant automotive fuel type, lead and lead scavenger exposure overshadow all other acute toxins for total population health risk.

Like exposure to lead, exposure to the combustion product CO is a localized concern. Elevated levels of ambient CO cause an extended loss of the capability of the blood to fully transmit oxygen to critical body tissues. At higher concentrations, CO can rapidly poison the system and cause death by asphyxiation. Chronic exposure levels usually cause headache, dizziness, and productivity losses associated with impaired perception, slowed thinking, and dulled reflexes.

Emissions of CO from vehicle engines are heightened under conditions of extended idling and operation distant from the engine design optimum—that is, at low speeds with frequent stops and starts. These are the conditions typical of large urban metropolitan areas such as Bangkok.

Particulate matter from motor vehicles come from three sources: engine exhaust, mechanical wear, and reentrainment (throwing of roadway dust). The smoke from diesel engines is probably the most obvious urban pollutant, but it may be unseen particles in conjunction with the smoky exhaust that, like lead, cause the highest health hazard.

Like diesel engines, small two-stroke motorcycle engines result in significant particulate emissions. Unlike well-tuned diesel engines, the highly visible emissions are dominantly unburned HC instead of elemental carbon. Two-stroke engines emit four to eight times the HC and many times the particulates of equivalently sized four-stroke engines. Engine design and exhaust treatment modifications are available to reduce the typical high emission rates for new equipment.

In many urban areas, high volatile organic compounds (nonmethane HC) emissions have the most negative health impacts from photochemical oxidants (ozone or smog). A typical HC constituent of gasoline that exemplifies these concerns is benzene. Extended epidemiologic studies of benzene show a strong linkage to increased incidence of leukemia, a common and usually fatal blood and bone marrow cancer.

In the urban environment, acid aerosols (NO_x and SO_2) contribute to four environmental problems: respiratory problems for sensitive populations, visibility limitations, local vegetation and materials damage, and acid rain.

METHODOLOGY FOR EVALUATING TRANSPORTATION POLICY OPTIONS FOR ENERGY-ENVIRONMENT MANAGEMENT

To understand the growth of travel, energy use, and emissions, as well as to identify and evaluate various policy measures, a transportation model was developed partly on the basis of previous modeling work (*1*). An important feature of the modeling approach is that it uses the existing, extensive travel data base and models used in infrastructure planning.

In many of the largest, rapidly growing cities of the developing world, considerable work has been done in transportation studies, including origin and destination surveys, for the purpose of infrastructure planning. Such studies have frequently been associated with major loans from the World Bank and other international lenders. Despite the wealth of information that these studies provide, they are rarely used for environmental and energy studies or policy. This is the case in Bangkok, with major studies being undertaken under the auspices of the World Bank and JICA.

Several major energy and environmental policies have been adopted at either a national or urban level in developing and industrialized countries [a review of energy measures in developing countries is given elsewhere (*7*)]. To be useful in considering and comparing policy options, a model must be able to be used in representing the impact of these policies. The major energy and environmental policies of interest address technology and behavioral choices, including

- Technological change
  - –Emission standards,
  - –Fuel treatment (e.g., lead removal, sulfur removal, and reformulation), and
  - –Fuel economy standards.
- Behavioral change:
  - –Vehicle, road, and fuel pricing policies to influence vehicle choice and use;
  - –Bans of certain vehicle types;
  - –Zonal restrictions (e.g., pedestrian zones);
  - –Infrastructure provisions to encourage choice of less polluting modes;
  - –Time-based vehicle use restrictions; and
  - –Land use policies.

The greatest experience to date in large-scale policy intervention in industrialized countries has been in the area of technological change. However for developing countries faced with an enormous potential transformation from a significantly nonmotorized to a largely motorized transportation situation, addressing behavioral issues is critical.

Modeling Framework

To provide a flexible model framework for incorporating data and travel projections from existing studies and to include input from existing emissions models, a flexible spreadsheet-based model for estimating energy use and emissions was developed. The geographic basis of the model is 19 travel analysis zones identified in the JICA Bangkok study shown in Figure 2 (*3*).

Energy use and emissions are estimated for each of these 19 zones as well as in aggregate. The calculation procedure follows a conventional approach of trip generation, modal split, trip distribution, and vehicle loading. This series of calculations results in an estimate of vehicle kilometers by mode emanating from each of the 19 zones for the years 1989 and 2006. The modes treated in the model are automobiles, taxis, pickup trucks, buses, minibuses, motorcycles, motorcycles used as taxis, samlors, silors, and nonmotorized movements (walking and bicycles). Energy use and emissions by mode for each of the zones are projected using the estimates of vehicle kilometers, vehicle speed, and coefficients of energy use and emissions per kilometer. Demographic and economic projections, critical components for making future projections, are already resident in the JICA travel projections. As will be described in the discussion of policy options, long-run price

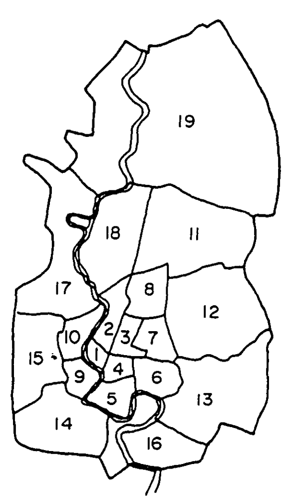

FIGURE 2 Zone division inside study area.

elasticities are treated in this study through adjustments in fuel economy. (A price response in terms of reduced travel rates could also be included, but it has not been included in this version of the model.)

It is important to note that the energy use and emissions assigned to each of the 19 zones are for personal transportation only; freight movements are not treated in this analysis. In addition, energy and emissions are assigned to zones according to trips originating in the zone even when the trip destination is outside of the zone. Thus, zonal projections may overstate or understate actual energy use and emissions occurring in the zone if the travel of residents of the zone in other zones is greater or lesser than travel by outside residents in the particular zone. Aggregate estimates, however, will be accurate to the inherent limits of the data.

The coefficients of energy use are taken from an extensive survey and study in 1987 by Diener et al. (*8*). The average fuel economy levels by mode are adjusted to approximate mean speed in each of the 19 zones by setting the speed to 8, 16, or 24 km/hr, based on JICA projections and the authors' judgment. Fuel consumption rates vary significantly with speed, as discussed in the next section.

The emissions coefficients are based on Technology Type 2 vehicle controls (i.e., very modest engine improvement and limited controls, but without catalytic converters or other add-on devices) which are based on the Environmental Protection Agency MOBILE4 model (*9*) and the California Air Resources Board EMFAC model (*10*).

Bangkok Data

The baseline information used in the model for evaluating energy and air pollution consists of

1. JICA model and travel projections (*3*) and
2. Data base and forecasting model for energy demand in the transport sector (*8*).

Given the use of the JICA report, a few observations are made on the suitability of the JICA projections as a basis for analysis. An important observation is that the JICA projections of vehicle ownership growth and the number of person trips and vehicle trips appear to be very conservative for the economic and demographic assumptions used. The number of private vehicles roughly doubles between 1989 and 2006. This outcome is a function of the logistic functions used for anticipating future ownership patterns for automobiles and motorcycles. The ownership assumptions may have been made because of the untenable levels of traffic that would result without saturation functions on ownership built into the models. For a different view on private vehicle ownership, SPURT (*4–6*) estimates that the vehicle fleet will grow by a factor of 3 to 4 during that same period.

Whereas the limits on vehicle ownership growth suppress the number of passenger trips in the JICA study, the large increase projected in average trip length may exaggerate the number of vehicle kilometers projected for the year 2006. If trip lengths remain constant, as has been the case in large urban areas in the United States (*11*), then the potential underestimate of trip numbers and overestimate in trip length may compensate each other in projecting future travel levels. No estimates of error are provided in the JICA study.

Within these limitations, we believe the JICA report is a reasonable basis for the analysis of energy and emissions levels and policies. Because JICA excludes some trips and treats trips with more than one mode as a single trip, we increased the number of (single-mode) trips to calibrate the model to estimates of vehicle kilometers and energy use.

Emissions Methodology and Data Base

Each of the policy options considered affects fleetwide emissions somewhat differently. They necessitate the capability to model expected in-use emissions for different vehicle and fuel types at different speeds and with different pollution control equipment.

No existing model is comprehensive enough to treat all the vehicles and conditions. The model used for estimating emissions for automobiles, pickup trucks, motorcycles, and light- and heavy-duty diesel vehicles is MOBILE4 (*9*). The model was applied using a 1976 U.S. emissions rate reference fleet (pre–catalytic control technology or Tech-2) and a 1990 U.S. emissions reference fleet to reflect the effect of catalytic converter controls technologies (Tech-4). These are used to represent fleet emissions characteristics before and after controls requirements.

Additional information for sulfur and particulate matter emissions and for efficiency changes at low speeds are taken from the California EMFAC7 model (*10*) and the U.S. National Acid Precipitation Assessment Program emissions inventory literature. The EMFAC7 model was developed in California to model emissions from its fleet. California has a more stringent emissions standard than the U.S. standard, reflecting the particularly difficult motor vehicle–based air pollution problems of the Los Angeles area. Alternative-fueled vehicle information comes from the emerging literature on alternative-fueled vehicles (*12,13*). These sources were used to estimate emissions for vehicles with and without specified levels of emissions controls.

An important determinant of emissions rate is vehicle speed. Thus, emissions rates were calculated at idle, 8-, 16-, 24-, and 32-km/hr average speeds using the model both with and without catalytic converters for specific vehicle modes. Estimated emissions rates under these conditions are shown in Table 1 for CO. The differences in emissions levels between the Tech-2 and Tech-4 technologies are shown by comparing the left and right sides of Table 1. (Similar tables for HC, NO_x, SPM, SO_2, lead, and benzene are available from the authors as space did not allow for their publication.)

POLICY OPTIONS AND EVALUATION

The transportation model facilitates the evaluation of a large set of energy and pollution reduction measures. A broad set of measures were considered in the study of Bangkok (*14*). Some of these, outlined in Table 2, are used to demonstrate some of the capabilities of the transportation model for policy evaluation.

The base case is in some respects a do-nothing policy: because nothing is done to constrain energy use and emissions,

TABLE 1 Emissions Factors by Fuel/Vehicle Combination

Adjusted for Average Speed of Zone in Urban Environment

(Grams/Mile)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	980	310	150	100	80	297	108	55	37	29
	4 Stroke Motorcycle	-	280	130	70	50	40	165	113	54	35	26
	2 Stroke Motorcycle	-	238	111	60	43	34	140	96	46	30	22
LPG:	Small 3 & 4 Wheel	-	21.0	13.0	10.5	7.5	6.0	10.5	6.5	5.3	3.8	3.0
	Taxis	-	49.0	23.3	15.0	10.0	8.0	24.5	11.6	7.5	5.0	4.0
Diesel:	LD Cars, Trucks, Vans	-	19.0	6.0	4.0	3.0	2.0	22.3	4.8	3.3	2.3	2.0
	HD Trucks & Buses	-	53.0	41.0	28.0	20.0	15.0	49.5	32.0	22.0	16.0	12.0
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					24.5	11.6	7.5	5.0	4.0
	HD	-	Base Case assumes no use of CNG.					36.8	29.1	26.3	22.5	18.0

(Grams/Kilometer)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	609	193	93	62	50	184	67	34	23	18
	4 Stroke Motorcycle	-	174	81	43	31	25	102	70	34	22	16
	2 Stroke Motorcycle	-	148	69	37	26	21	87	60	29	18	14
LPG:	Small 3 & 4 Wheel	-	13.0	8.1	6.5	4.7	3.7	6.5	4.0	3.3	2.3	1.9
	Taxis	-	30.4	14.4	9.3	6.2	5.0	15.2	7.2	4.7	3.1	2.5
Diesel:	LD Cars, Trucks, Vans	-	11.8	3.7	2.5	1.9	1.2	13.9	3.0	2.0	1.4	1.2
	HD Trucks & Buses	-	32.9	25.5	17.4	12.4	9.3	30.7	19.9	13.7	9.9	7.5
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					15.2	7.2	4.7	3.1	2.5
	HD	-	Base Case assumes no use of CNG.					22.8	18.1	16.3	14	11.2

TABLE 2 Transportation Policy Options Structure

Policy		Option
P1	Base Case:	new infrastructure as indicated in SPURT and JICA reports; no energy conservation or emissions controls policies
P2	Controls:	lead and sulfur removed from transportation fuels; type 4 emission controls adopted for most vehicle types
P3	Standards:	emission controls required and fuel economy standards adopted for automobiles and light trucks: from 11.0 to 8.0 liter/100 km @24 kmh
P4	Pricing:	emission controls required and fuel price is doubled due to external events or taxation policy: price elasticity assumed to be -.46 and response in terms of purchase of more efficient automobiles and light trucks resulting in 8 liter/100 km @24 kmh
P5	Area Control:	emission controls required and automobile, pickup truck, motorcycle, and samlor traffic is limited in the CBD (central business district) by means of a toll/permit system; infrastructure for rail, walking, and bicycles developed including reintroduction of pedicabs
P6	Use restrictions:	emission controls required and automobiles pickup trucks, and motorcycles are prohibited from use for two days per week

both grow dramatically between the base year 1989 and the year 2006.

Policy P2 is an emissions control policy for all new vehicles that requires, for cars, motorcycles, and pickup trucks, the use of catalytic converters common in Japan and the United States. The policy necessitates the introduction of lead-free (unleaded) gasoline for use in all new gasoline-powered vehicles. The policy also assumes the elimination of most of the sulfur from transportation fuels to allow for diesel particulate control in the form of either particulate traps or catalytic converters.

Policies P3 and P4 are energy efficiency policies that are adopted simultaneously with Policy P2. The policies are intended to result in a Bangkok automobile fleet that is slightly more efficient than the U.S. new car standards with a level of emissions equivalent to U.S. new car standards.

Policies P5 and P6 probe the use of demand management policies to improve environmental conditions and conserve energy. Policy P5 focuses on an area control initiative that is similar to the one described in JICA and that is implemented in Singapore. An important feature of this policy is the shift of infrastructure investment in this area into rail or "skytrain" technologies, pedestrian paths, and bicycle paths. Policy P6 is based on a program now in use in Mexico City, which has almost the same congestion and even worse air pollution than Bangkok.

Evaluation of Policy Measures in Bangkok

Energy conservation and air pollution reduction offer large potential benefits to Thailand. Within the context of transportation, there are important and necessary benefits provided by the transportation system. The challenge to policy makers is determining the optimal mix of transportation services, energy conservation, and environmental protection. Failure to provide necessary transportation infrastructure can choke the economy, as can failure to protect the environment, particularly in a country that has a large tourism sector.

In this section, the strategies outlined are considered in terms of

- Cost of implementation,
- Effect on energy use and travel time,
- Effect on emissions and general air pollution, and
- Other important implementation considerations.

Energy, time, and emissions comparisons are based on model results. The point of comparison is the base case or Policy P1 as described in Table 2. In using these results for policy evaluation, we stress that the results for 1989 have a range of uncertainty on the order of 15 percent. The results for the year 2006 are obviously subject to great uncertainty. The policy analyses, however, are internally consistent and provide a valid basis for comparing policy options.

Policy Options

Policy P1: Base Projection

The results of Policy P1 in terms of energy use and overall emissions in 1989 and 2006 are shown in Table 3. Energy use increases by a factor of 3 during the period. Contributing to the increase in energy use is the continuing shift to private motor vehicles due to the rapid growth in the Thai economy.

TABLE 3 Base Case Energy Use

Summary Table:	Total Energy Use (1,000 Metric Ton Oil Equivalent)		Energy Use/MM P-Km (Metric Ton Oil Equivalent/ Million Passenger-Kilometers)	
	1989	2006	1989	2006
By Fuel Type	2,181	6,520	42	53
Premium Gasoline	620	2,175	12	18
Regular Gasoline	370	1,241	7	10
Diesel	1,015	2,817	19	23
LPG	174	286	3	2
By Mode	2,181	6,520	42	53
Private Car	592	2,082	61	70
Pick-up Truck	668	2,350	65	74
MC	330	1,162	35	40
MC-Taxi	28	47	42	47
Bus-Minibus	378	576	19	20
Taxi	153	251	105	120
Samlor	15	25	40	46
Silor	16	27	39	45

Emission levels increase by more than a factor of 3 for CO, HC, and particulates and by more than a factor of 2 for NO_x, as shown in Table 4. Because of the lead reduction currently planned, lead emissions grow by only 14 percent. Emissions grow at greater levels than travel because of the greater areal extent of congestion and the greater reliance on private motor vehicles, which, as indicated, are much more energy-intensive than public transit.

Because Bangkok already exceeds World Health Organization guidelines for air pollution, certainly for street-level CO and ambient particulate matter and most likely for lead, it may be concluded from these results that air pollution by 2006 will more regularly exceed acceptable levels. Higher peak concentrations will occur over a broader geographic area and will affect a much larger exposed population. Only the adoption of pollution-limiting policies will prevent this.

Policy P2: Emissions Controls

An important strategic approach for reducing transportation polluton emissions is an emissions control equipment requirement for all new vehicles. This policy has been vigorously applied in Canada, Japan, and the United States and is being adopted in much of Europe and other parts of the world. This strategy necessitates a refinery-level modification of gasoline and diesel fuel that directly reduces acid gas and lead emissions from the motor vehicle fleet. In turn, removal of these exhaust stream contaminants allows for the use of advanced pollution control technology on motor vehicles to reduce volatile and reactive HC (including benzene and other toxics), CO, particulate matter and NO_x emissions. The strategy can be viewed as either a stand-alone option or one to use in conjunction with various demand-management or fuel switching policies.

New vehicle emission standards result in modest on-engine control equipment combined with catalytic converter investment. This control level costs \$600 to \$800 per typical new gasoline automobile assuming that no taxes are placed on pollution control equipment and ignoring potential efficiency gains from redesign that would reduce the cost of fuel over the lifetime of the vehicle. The fiscal implications for compliance certification can be minimized if specific engine class and control equipment combinations used in other countries are required.

This policy affects local and regional air pollutant emissions, concentrations, and deposition. The emissions modeling by 19 urban zones shows a significant air quality improvement for the regional acid gases and reactive hydrocarbons (nonmethane), along with more localized CO, lead, particulate matter, and benzene/toxics air quality improvement.

The results of Policy P2 are summarized in terms of aggregate emissions in Table 4. SO_x and lead emissions fall drastically despite the extreme growth of travel and energy use. HC also shows a modest reduction from the 1989 levels. CO shows a large reduction from uncontrolled 2006 levels due to the controls but still is twice the 1989 level. NO_x and particulates also have significantly reduced emission levels compared to the 2006 levels without controls but nevertheless show a major increase relative to 1989.

The conclusion to be drawn from this scenario is that a new vehicle standards controls policy is very effective in reducing emissions. However, even considering this effectiveness, CO and particulate matter will continue to present a serious and growing problem for air quality in Bangkok.

TABLE 4 Transportation Emissions Under Policies P1 Through P6 (in thousands of metric tons)

	1989	P1(Base) 2006	P2 2006	P3 2006	P4 2006	P5 2006	P6 2006
CO	1,075	3,830	2,081	2,081	2,081	1,835	850
HC	275	935	250	250	250	227	136
NOx	46	104	71	71	71	66	58
SPM	116	376	261	215	215	236	198
SOx	23	11	11	9	9	10	8
Pb	.501	.570	.057	.047	.047	.052	.042

Policies P3 and P4: Standards and Pricing

Policies P3 and P4 are discussed together because they are designed to accomplish the same objective of reducing energy use in the Bangkok urban transportation system. The policies are geared toward the most energy-intensive aspect of the systems—the automobiles, pickup trucks, and taxis as shown in Columns 3 and 4 of Table 3. P3 accomplishes a 20 to 30 percent reduction in energy use in these vehicles and an 18 percent reduction in all passenger transport energy use by imposing a fuel economy standard of 8 L/100 km on new vehicles. For comparison, automobiles using premium gasoline in 1984 achieved 11.0 L/100 km (*8*).

An alternative means of achieving equal savings of energy is through fuel pricing policy. If Thai drivers responded to fuel price increases in the long run by adjusting the efficiency of the vehicle they purchase (this would certainly be part of any response), then some price exists that would result in an 8 L/100 km efficiency if gasoline prices in Thailand were doubled from 8.45 to 16.9 baht per liter (the same real prices as in 1982). An elasticity of -0.46 results in a nominal 8 L/100 km efficiency. Although in our opinion it is optimistic, this elasticity is used for analysis purposes.

Either efficiency improvement strategy may prove to be politically difficult to adopt. The difficulty with the standards is that the government would have to set up a testing center for certifying vehicles and would have to find an agreement with the domestic vehicle assembly industry. A substantial penalty for noncompliance would have to be set and enforced.

As noted, the impact of a fuel economy standard (and a doubling in the price of fuel if the elasticity assumed is accurate) is an 18 percent reduction in energy use in the year 2006 compared to the case without controls (P1). Either policy would have minor direct costs to the government or to individuals, and in the case of a pricing policy, in which the underlying cost of oil is not the source of the doubling, the policy could net the government a large amount of revenue. Vehicle owners, on the other hand, would incur increased fuel cost.

Policies P5 and P6: Area Controls and Use Restrictions

These strategies are a direct policy response to a major metropolitan dilemma. The dilemma is that it is highly desirable to reduce congestion on Bangkok roads but enough roadway cannot be provided to reduce congestion levels. Congestion relief would result in shorter travel times (for a fixed set of trips), higher fuel economies, and lower pollutant emissions rates. Demand management policies could be implemented to reduce congestion.

Policy P5 borrows a policy pioneered in Singapore and now adopted in a number of cities such as Athens and Oslo, which is to charge a fee (using tolls or a sticker system) to enter the central portion of the city. The objective is to reduce the vehicle kilometers by motorized vehicles by some combination of carpooling, shifting from private vehicles to mass transit, and shifting from private vehicles and mass transit to walking and bicycles. Policy P5 sets a schedule of fees for various types of vehicles so as to result in a 40 percent decline in vehicle kilometers and an increase in average speed to 24 km/hr in an area roughly corresponding to Zones 1 and 4 identified in the JICA study.

To reduce the vehicle kilometers and provide for access, investment would be required to increase mass transit. In addition, investment would be required for pedestrian paths to provide for unserved walking demand. Some improvements in the sois (the narrow local streets that often dead-end at the canals), including bridges at selected locations, are required to provide for access to mass transit by means of bicycles and pedicabs, which would be reintroduced into this area of Bangkok. Motor vehicles would be banned on many of the sois for most hours. Finally, borrowing on the extremely successful experience of many cities in Europe over the last two decades, certain important central shopping and cultural areas would be designated as pedestrian-only zones. The overall purpose of the policy is to provide for what might be termed a quiet zone with a high level of access under pleasant conditions.

The quiet-area policy would require considerable will and vision. Because of the reduction in congestion, large travel time savings would occur within the area. The results of the quiet-area policy are a decline in energy use and CO emissions in Bangkok of 9 and 12 percent, respectively, compared with Case P2. Energy use and emissions in the targeted area, Bangkok's most congested, fall precipitously by more than 50 percent.

Policy P6 is a more drastic policy; it adopts a policy pioneered in Mexico City to ban the use of all private vehicles used in Bangkok for 2 days each week (the Mexico City experiment is for 1 day). This policy runs on a sticker system that would allocate the reduction of traffic over 7 days. The objective is to reduce the number of automobiles, pickup trucks, and motorcycles by 29 percent on any given day and increase average vehicle speed in all zones.

The impact of the vehicle use restriction policy for all of Bangkok is a reduction of 43 percent in energy use and 59 percent in CO emissions. These dramatic results assume that the policy is adopted and strictly enforced and that higher-income vehicle owners do not purchase additional vehicles to circumvent the ban. They point out the large impact of congestion on energy use and emissions. To the degree that the vehicle speed effects are overestimated (the assumption is an 8-km/hr improvement in each zone), these reductions will be overstated.

METHODOLOGICAL AND POLICY RECOMMENDATIONS

The analysis of transportation energy use and resultant emissions reveals disturbing trends for environmental conditions and the quality of life in Bangkok. Current air quality conditions in Bangkok are near failing or have failed national and international standards for health despite favorable local meteorology that helps disperse air pollutants.

Air quality may be worse in other major cities around the globe, for example, Mexico City, Los Angeles, and Cairo, but the prospects for further rapid growth in Bangkok pose an extremely serious challenge. Beyond basic environmental and health issues, there are the related issues of Bangkok's future as a tourist destination and a financial center. If recreational and investment prospects are not already dimmed by existing conditions, they are likely to be challenged by future conditions without a comprehensive mitigation strategy to address the deteriorating environmental condition.

The flexible modeling framework used and the general scenarios developed provide a basis for comparing some of the foremost air pollution management policies available to Thailand. On the basis of the results of these scenarios and additional sensitivity studies, a set of preliminary policy recommendations has been developed (*14,15*).

Before these recommendations are considered, a few observations on methodology will be made. First, where large survey-based origin-destination studies have been conducted, as in the case of Bangkok, these studies provide a major opportunity for systematically exploring energy and air pollution implications. The massive amount of route assignment data can be ignored for the purposes of exploring energy and emissions use by zone. This simplification results in an analysis that is amenable to microcomputer-based conventional spreadsheet software.

This research benefited from the availability of a recent survey of vehicle owners to establish fuel economy levels and load factors. It would have further benefited if a similar survey had been available for emissions levels from vehicles. Thus, the adequacy of the assumption of emissions levels using a U.S. pre–catalytic converter is untested. The error here, however, will tend to understate emissions levels and therefore is conservative.

The large reduction in projected emissions for 2000 brought about by emissions controls combined with the recommended refinery modifications (Scenario P2) makes this policy the highest priority for consideration. This strategy would reduce lead and sulfur emissions in Bangkok and Thailand as a whole compared to 1989 levels. Though CO emissions drop significantly from projected levels, the frequency of ambient concentrations in Bangkok above international health standards would still increase significantly relative to 1989 levels because of the enormous energy demand increase. The fact that CO emissions and ambient levels increase despite the effectiveness of controls is indicative of how large the emerging air pollution problem is becoming.

Both the Thai government and the private fuel refiners have committed to a substantial investment in the refining sector for the Seventh Plan. That effort will upgrade existing facilities and add substantial new capacity and will include most of the capital necessary for processing unleaded gasoline and desulfurizing diesel and fuel oils.

In addition to a basic emissions control policy founded on vehicle technology and fuel quality requirements, Bangkok has four main options for improving environmental quality and energy efficiency that can be considered in various combinations:

- Congestion reduction policies,
- Infrastructure capacity additions,
- Technical energy efficiency improvements, and
- A fuel switching policy.

Any policy that results in a significant reduction in congestion brings about large improvements in emissions and energy efficiency, as was shown by the striking results of Scenarios P5 and P6. The difficulty is identifying proposals that policy makers are willing to implement. Any demand management policies adopted require ongoing experimentation, management, and adjustment.

Electrically powered mass transit on separate grades is one of the most promising public infrastructure investments. These transit systems add capacity to the overall transportation system with energy-related emissions occurring at power plants. Not only can these emissions be better controlled, but the plants are located away from dense population centers. The systematic development of pedestrian paths, bridges, and bicycle ways is also promising. The advantage of these investments is that they provide for considerable mobility without the accompanying energy use and emissions. The use of exclusion zones may be necessary to return many of the sois to bicycle and pedicab use and to improve the immediate environment so as to make walking and bicycling attractive options.

Fuel efficiency improvements (at any specified level of congestion) can be made in Thailand's vehicle fleet over the long run. Because of its relative energy intensiveness, the automobile and pickup truck fleets (when used primarily for passenger movement) are the main targets for fuel efficiency improvement. Substantial fuel taxes as in Japan, Korea, and most of Europe could also be imposed to attempt to achieve a similar result as an efficiency standard on new vehicles.

Although the congestion, energy use, and emissions problems facing Bangkok are enormous, it is also evident that a large number of potentially effective responses exist. The methodology described here, using the case study of Bangkok, provides a flexible means for exploring and evaluating these and other options.

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