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Methodologies for Considering Technical Energy Issues in Urban Transportation Planning

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Cost-Effectiveness Model for Ranking Transportation Energy Conservation Strategies

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ABSTRACT

An analytical methodology was developed to establish priorities for a set of transportation energy conservation (TEC) strategies within an urban environment. Such a methodology is needed because of the high cost and long-term shortage of energy, the lack of an effective and comprehensive TEC evaluation tool, and the requirement for optimal allocation of limited transportation funds. The objectives of this research were to (a) develop a cost-effectiveness methodology for evaluating and ranking the various TEC strategies under given situations and (b) apply the developed methodology to a real-world situation to demonstrate its usefulness and practicability. Among the desirable features incorporated into the methodology are (a) a comprehensive accounting of all relevant effects of TEC strategies, (b) an approach to assure compatibility among tangible and intangible effects, (c) linkage of the theoretical framework to the decision-making process, (d) application of multiattribute utility theory to subjective impact assessment, and (e) the use of cost-effectiveness concepts. The case study of the Salt Lake City Metropolitan Area in Utah has demonstrated the methodology's utility, ease of application, and acceptance by decision makers and responsible agencies.

Despite the call for increased conservation of fossil fuels after the 1973-1974 Arab oil embargo, the United States is still dependent on foreign supplies of oil. Because of the unstable nature of world politics, reliance on this undependable and costly petroleum increases the chances of critical internal disruption. Urban transportation, specifically automobile travel, accounts for a major share of the consumption of petroleum energy and thus offers a tremendous opportunity to reduce energy costs and the reliance on foreign oil supplies.

A variety of strategies is available for transportation energy conservation (TEC). To ensure that transportation agencies have information to make intelligent and consistent appraisals pertaining to TEC investments, many types of factors must be fully considered. Consideration should be given not only to conserving energy, but also to relevant effects and consequences on the community as a whole. In response to a recent nationwide survey, many transportation agencies indicated that they have only considered each TEC strategy on its own merit and have not tried to select strategies in order of cost-effectiveness (1). Many methods for cost-benefit analysis and for alternative analysis have been developed. These methods, however, were developed for evaluating alternatives for improving transportation in general; energy conservation has usually been of secondary concern and not a major factor in ranking projects. There are no known methodologies specifically developed to assist individual locales in ranking alternative strategies. Therefore, research is needed to develop an effective and practical tool to be used in the public decision-making process for selecting optimal TEC strategies for various local situations.

The principal objectives of this study were to (a) develop a cost-effectiveness methodology for ranking TEC strategies for a given urban environment and (b) apply the developed methodology to a real-world situation (i.e., the Salt Lake City Metropolitan Area in Utah) to demonstrate its usefulness and practicability.

A cost-effectiveness model was developed to

1. Provide a means to rank a given set of TEC strategies effectively and efficiently,
2. Consider both tangible and intangible effects of TEC strategies on a compatibility basis,
3. Assure the maximum economic return from the expenditures invested in the TEC strategy,
4. Exhibit sensitivity to the environment in which the strategy is to be applied,
5. Account for the values of individual political decision makers in order to maintain consistency with the real world, and
6. Provide a computer-based model to facilitate actual applications.

Accordingly, this study is expected to make a significant contribution to formulating effective TEC programs for local jurisdictions.

DEVELOPMENT OF THE MODEL

In general, the cost-effectiveness analysis on which the model is based was intended to provide a framework for comparing alternatives. This was done to provide a common basis for decision makers in selecting a course of action for complex situations. It is an optimization process in which the total effectiveness within a given budget constraint is maximized or the total cost for obtaining a certain level of effectiveness is minimized. Therefore, it is believed that this method of cost-effectiveness analysis is a powerful tool for solving the complex problems associated with selecting an urban TEC strategy.

In these times of government austerity and related budget cutting, there is a greater emphasis on improved resource allocation techniques that assure the optimal distribution of limited funds. Consideration must be given to greater economic efficiency in the selection of strategies for implementation. Thus, the central feature of this model is its inclusion of the economic efficiency ratio as the objective measure of the effects of a strategy. This ratio is expressed as the strategy cost divided by the estimated energy savings accruing from implementing the strategy divided by the total cost of the strategy. This attribute of the model is important to decision makers, the transportation agency, and the public in assuring the maximum return for each dollar spent.

The model also incorporates the values of the decision makers into an analysis of the subjective effects of the strategies. First, decision makers need to decide the importance of objective considerations relative to the importance of subjective ones. Second, decision makers have the responsibility of determining the relative importance of subjective impacts of TEC strategies, such as socioeconomic, political, and environmental effects. Decision makers are in the best position to assess these subjective impacts because they are normally sensitive to the concerns and opinions of their constituents. On the other hand, transportation analysts are responsible for the technical assessment of all impacts associated with the implementation of TEC strategies. In addition, the model features a mechanism termed the critical factor that eliminates infeasible strategies by determining whether the strategy has satisfied the minimum requirements of the community involved.

The selection of a TEC strategy involves many objective as well as subjective decisions to provide the community with the greatest net advantage. The model accounts for objective and subjective impacts of a TEC strategy by quantifying these impacts into dimensionless indices (2). Also, complementary decision weight variables are assigned to objective and subjective impacts to reflect their relative importance. The objective and subjective measures, along with their decision weights, are combined to produce a single composite measure of effectiveness for the strategy.

The mathematical relationship is stated as

$$CMOE_i = CFM_i \times [(W_o \times OIM_i) + (W_s \times SIM_i)] \quad (1)$$

where

- CMOE = composite measure of effectiveness of strategy i,
- CFM_i = critical factor measure of strategy i (CFM_i = 0 or 1),
- OIM_i = objective impact measure of strategy i ($0 < OIM_i < 1$ and $\sum_i OIM = 1$),
- SIM_i = subjective impact measure of strategy i ($0 < SIM_i < 1$ and $\sum_i SIM = 1$),
- W_o = objective impact decision weight ($0 < W_o < 1$), and
- W_s = subjective impact decision weight ($0 < W_s < 1$ and $W_o + W_s = 1$).

The CMOE values are used as a basis for assessing the relative worth of a strategy compared to all other strategies considered. Strategies with higher CMOE values are preferred over those with lower values. The CMOE values of TEC strategies will vary from one urban area to another depending on local conditions.

Based on a three-stage process consisting of search, screening, and consolidation procedures presented in a research report by Yu and Pang (3), significant objective and subjective impact measures were identified for inclusion in the model and are given in Table 1. Functions of the measure of critical factors and the measures of objective and subjective impacts (from the standpoint of the model structure) are discussed in the following sections.

Critical Factor Measure

As an initial step in evaluating TEC strategies, critical factors are established on the basis of local conditions. These factors will eliminate any strategy that has one or more negative impacts at an unacceptable level. For example, if a strategy is clearly too costly for the jurisdictional area, the financial critical factor would eliminate that strategy from further consideration. The critical factor measure is assigned a value of 1 or 0. If the strategy has met the minimum requirements for implementation with respect to all critical factors, it is assigned the value 1. If not, then according to Equation 1 both CFM_i and $CMOE_i$ drop to 0, thus indicating that the strategy should be excluded from any further consideration. The critical factor is defined as

$$CFM_i = \prod_k CFM_{ik} \quad (2)$$

where CFM_{ik} is the critical factor measure for strategy i with respect to critical factor k.

Determination of these critical factors is based on the examination of both tangible and intangible impacts and selecting those that are critical in determining whether or not the strategy is obviously feasible. The critical factors include the following:

1. Economic efficiency. The strategy is excluded from further consideration if the benefit-cost ratio for the strategy is less than 1. However, strategies with marginal ratios just below 1 may still be considered because nonmonetary factors may make these strategies attractive.
2. Budgetary constraints. The strategy is eliminated if its cost presents too much of a burden on the budget allocated for TEC strategies by an agency or community.
3. Technical or physical constraints. The strategy is excluded if its construction or implementation would not be feasible from a technical or physical standpoint.
4. Policy considerations. The strategy is excluded from further consideration if its implementation is contradictory to the policy of the decision maker or the controlling agency.
5. Environmental concerns. If the strategy produces significant detrimental effects to the environment, it is eliminated from consideration.

TABLE 1 Selected Impact Measures for Evaluating Transportation Energy Conservation Strategies

Impact Measure	Type of Measure
Energy conservation:	
Reduction in fuel and electrical energy consumption	Objective
Attainment of local, regional, state, or national energy goals	Subjective
Implementation and postimplementation costs:	
Capital, maintenance, and operating costs	Objective
Quality of transportation service:	
Reduction of congestion, travel comfort and convenience, responsiveness to transportation needs, and service to disadvantaged	Subjective
Public safety:	
Accident prevention and personal security	Subjective
Economic impacts:	
Business relocations, employment, employer productivity, and changes in tax base	Subjective
Environmental impacts:	
Aesthetics, vehicle emissions, and noise levels; impact on natural, historical, and archaelogical sites	Subjective
Social impacts:	
Residences displaced and effect on neighborhood stability and cohesion	Subjective
Financial impacts:	
Impact on budget and equity of financial burden	Subjective
Land use impacts:	
Accessibility, intensity of land use, and changes in land use patterns	Subjective

6. Opportunity. The strategy is excluded if the existing conditions are not conducive for the enactment of the strategy or the time required to implement a particular strategy is considered too long to provide solutions for the current needs.

Measures of Objective Impacts

All objective impacts are classified as being measurable in monetary terms and are direct concerns of implementing the strategy. The cost of the strategy and the worth of energy savings resulting from the strategy are the two basic elements. When expressed as a ratio, these impacts represent the tangible effects of a strategy. To ensure compatibility between the measures of objective and subjective impacts, measures of objective impacts are converted to dimensionless indices. Normally the economic efficiency ratio is the result of dividing the savings of a tangible benefit (energy savings) by cost; however, to conform to the mathematical structure of this model, it is expressed here as the reciprocal of the conventional ratio (i.e., cost divided by benefit).

Mathematically the measure of the objective impact for strategy i of the model is defined as

$$OIM_i = EE_i / \sum_i EE_i \qquad (3)$$

where EE_i (the economic efficiency of strategy i) is the ratio of the annual cost for strategy i to the annual estimated energy savings from strategy i in dollars. Restrictions associated with Equation 3 include (a) the strategy with the minimum cost-effectiveness value must have the highest OIM value, and (b) the sum of the OIM values for all strategies must be equal to 1.

The equivalent uniform annual cost (EUAC) method has been used for a long time in economic studies to determine the preferred choice from a set of possible alternatives. The comparison is made by computing the equivalent uniform cost of all the cost factors for each of the alternatives being analyzed. The EUAC method is used to annualize strategy costs so that they will be comparable with the energy savings estimates, which are also on an annual basis.

Estimates of strategy costs are readily available either through historical information from implementing strategies in other locations or through current information on the component costs of the strategy as broken down by materials, labor, and equipment. Also, life-cycle costs are used to compare alternative TEC strategies. Estimates of the amount of energy conserved as a result of implementing given strategies are much more difficult to obtain. Amounts conserved depend on the type of TEC strategy, level of implementation, number of users involved, and so forth.

Measures of Subjective Impacts

Subjective impacts are usually difficult and sometimes impossible to quantify in dollars and are considered as indirect effects of implementing a strategy. As given in Table 1, the selected subjective impacts include energy conservation, quality of transportation service, public safety, economic impacts, environmental impacts, social impacts, financial impacts, and land use impacts. The subjective impact measure for a given strategy i is a function of two quantities: (a) the relative weight of each subjective impact as compared to all the subjective impacts and (b) the relative weight of each strategy for a given subjective impact.

Mathematically the subjective impact measure of strategy i in the model is given as

$$SIM_i = \sum_k (SIW_k \times SW_{ik}) \qquad (4)$$

where SIW_k is the weight of subjective impact k relative to all subjective impacts and SW_{ik} is the weight of strategy i relative to all strategies for a given subjective impact k.

A member of a decision-making body might want to see one or more objectives accomplished to a greater extent than others. This can be expressed by having that member assign weights to the different objectives. The individual subjective impact weights, SIW_k, are determined from ratings obtained through a decision-making body such as a city mayor, council, or a transportation commission. Each member of the decision-making body assigns weights to each of the subjective impacts in accordance with his or her own perception so that the relative importance of the impact can be reflected. For each member, the sum of the weights assigned to all impacts considered is a total of 100 points. The average ratings of each subjective impact is calculated and divided by 100 to normalize the number within a range of 0 to 1. The matrix for weighting subjective impacts is given in Table 2.

As a supplement to this approach, the Delphi technique can be applied to influence further the weights assigned by each member. After each member has assigned the numerical weights, the average of the weights for each impact is computed as indicated. However, each member may be asked to reconsider his or her response if his or her rating varied ±25 percent from the mean impact weight (4). When this second round is completed, the set of weights is again normalized so that the sum of the weights is equal to 1.

The subjective impacts of a specific TEC strategy vary with each community in magnitude, intensity, scope, importance, acceptability, and in other values. The subjective strategy weights, SW_{ik}, are established by the transportation agency through technical analyses to assess the degree of impact of the TEC strategies being studied. A multiattribute utility theory approach is used to express the estimated magnitude of each impact category (2). This involves (a) assessing utility functions for each of the subimpacts, which constitute the individual subjective impact, (b) predicting anticipated impact levels for each strategy and finding the corresponding utility associated with that level, (c) estimating the scope of the strategy (i.e., the proportion of the population affected by the strategy), and (d) combining the utility of the subimpacts and the scope of the strategy by using a multiattribute utility function to arrive at the impact rating. To obtain the strategy weight, the impact rating is divided by the sum of the ratings for all strategies for each subjective impact. This computational procedure is illustrated in Table 3.

The decision weights, W_o and W_s, measure the relative importance of objective and subjective impacts, respectively. The sum of decision weights must be equal to 1 (i.e., $W_o + W_s = 1$) and the value of each weight ranges between 0 and 1. The values of W_o and W_s are obtained from the decision-making body by using an approach similar to that used in determining the subjective impact weight. Each member of the decision-making body assigns a value for W_o and W_s. The values are then averaged to obtain the final value for the decision weights. The matrix for weighting decisions is given in Table 4. The Delphi technique, which was described earlier, may also be used as an option to increase the value of the decision weights.

TABLE 2 Matrix for Weighting Subjective Impacts

Subjective Impact, k [a]	Respondent 1	2	3	. . .	n	Average	Subjective Impact Weight
1	W_{11}[b]	W_{12}	W_{13}	. . .	W_{1n}	$\frac{\sum_{i=1}^{n} W_{1i}}{n}$	$\frac{\sum_{i=1}^{n} W_{1i}}{100n}$
2	W_{21}	W_{22}	W_{23}	. . .	W_{2n}	$\frac{\sum_{i=1}^{n} W_{2i}}{n}$	$\frac{\sum_{i=1}^{n} W_{2i}}{100n}$
3	W_{31}	W_{32}	W_{33}	. . .	W_{3n}	"	"
4	W_{41}	W_{42}	W_{43}	. . .	W_{4n}	"	"
5	W_{51}	W_{52}	W_{53}	. . .	W_{5n}	"	"
6	W_{61}	W_{62}	W_{63}	. . .	W_{6n}	"	"
7	W_{71}	W_{72}	W_{73}	. . .	W_{7n}	"	"
8	W_{81}	W_{82}	W_{83}	. . .	W_{8n}	"	"
Total	100	100	100	. . .	100	100	1

[a] For the assumed case k = 8

[b] W_{kn} = Weight assigned to each subjective impact k by respondent n ($\sum_{k=1}^{8} W_{kn}$ = 100 for each respondent n and $0 \leq W_{kn} \leq 100$)

TABLE 3 Matrix for Weighting Strategies

Subjective Impact k [a]	Strategy 1: Rating	Normalized Rating	Strategy Weight	. . .	Strategy i: Rating	Normalized Rating	Strategy Weight	Row Total
1	R_{11}[b]	$R'_{11} = \frac{R_{11}}{6} + 0.5$	$\frac{R'_{11}}{R_1}$	. . .	R_{i1}	$R'_{i1} = \frac{R_{i1}}{6} + 0.5$	$\frac{R'_{i1}}{R_1}$	$R_1 = \sum_i R_{i1}$
2	R_{12}	$R'_{12} = \frac{R_{12}}{6} + 0.5$	$\frac{R'_{12}}{R_2}$	. . .	R_{i2}	$R'_{i2} = \frac{R_{i2}}{6} + 0.5$	$\frac{R'_{i2}}{R_2}$	$R_2 = \sum_i R_{i2}$
3	.	.	.	. . .	.	. .	.	.
4	.	.	.	. . .	.	. .	.	.
5	.	.	.	. . .	.	. .	.	.
6	.	.	.	. . .	.	. .	.	.
7	.	.	.	. . .	.	. .	.	.
8	R_{18}	$R'_{18} = \frac{R_{18}}{6} + 0.5$	$\frac{R'_{18}}{R_8}$	. . .	R_{i8}	$R'_{i8} = \frac{R_{18}}{6} + 0.5$	$\frac{R'_{18}}{R_8}$	$R_8 = \sum_i R_{18}$

[a] For the assumed case k = 8

[b] R_{ik} = Strategy impact rating which assesses strategy i with respect to subjective impact k ($-3 \leq R_{ik} \leq +3$).

TABLE 4 Matrix for Weighting Decisions

Decision Weight	Respondent 1	2	3	. . .	n	Average
W_o	D_{o1}[a]	D_{o2}	D_{o3}	. . .	D_{on}	$\sum_{i=1}^{n} D_{oi}/n$
W_s	D_{s1}[b]	D_{s2}	D_{s3}	. . .	D_{sn}	$\sum_{i=1}^{n} D_{si}/n$
Column Totals	1	1	1	. . .	1	1

[a] D = Objective impact decision weight assigned by respondent n

[b] D_{sn} = Subjective impact decision weight assigned by respondent n

($D_{on} + D_{sn}$ = 1 for each respondent m and $0 \leq D_{on}, D_{sn} \leq 1$)

An important consideration in the process of weighting the objective and subjective impacts should be pointed out here. In general, the primary purposes of most transportation improvement projects are to relieve traffic congestion and reduce safety hazards. Realistically this major concern for transportation services may surpass that of energy conservation. In this study the effects of reducing congestion and increasing safety are treated as part of subjective impacts (i.e., quality of transportation service and public safety). Therefore, the decision maker should take into account the importance of these significant impacts in assigning relative weights between the objective and subjective impacts for comparing strategies.

MODELING PROCESS

The modeling process is schematically illustrated by the flowchart shown in Figure 1. Basically there are

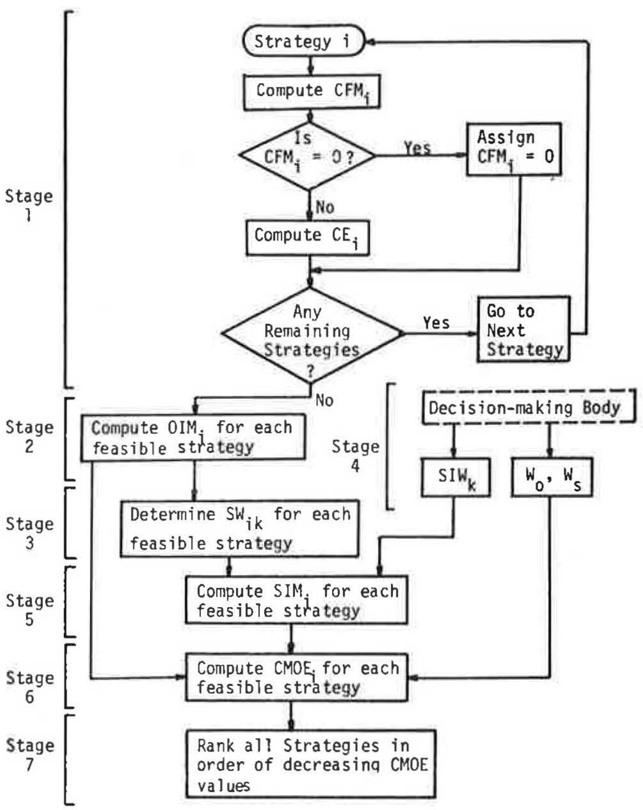

FIGURE 1 Flowchart of the modeling process.

seven stages in the evaluation process encompassed by the model.

1. Infeasible strategies are eliminated by the critical factor analysis.
2. The objective impact measure, expressed by the ratio of annual strategy energy savings to annual costs, is determined for each feasible strategy.
3. The weight of a given feasible strategy, relative to all other feasible strategies, is determined by rating each subjective impact for each given strategy.
4. The decision-making body weights each of the subjective impacts relative to one another and also assigns the objective and subjective impact decision weights.
5. Strategy weights and the subjective impact weights are multiplied to yield the subjective impact measure for each strategy.
6. Now that all pertinent elements of the model have been determined, the CMOE is computed by Equation 1.
7. CMOE values are used to rank the individual TEC strategies.

The modeling process is computerized for practical application. The computer model, Transportation Energy Conservation Strategy Evaluation Model (TECSEM), is written in FORTRAN 77 (FORTRAN V). The computer program listing, including a user's guide, is currently available (3).

STRATEGY ADOPTION PROCESS

The use of the computerized cost-effectiveness model is only one step in the process of selecting the optimal TEC program for a given urban area; the entire strategy adoption process, shown in Figure 2, involves several preliminary and subsequent steps, which are described in the following subsections.

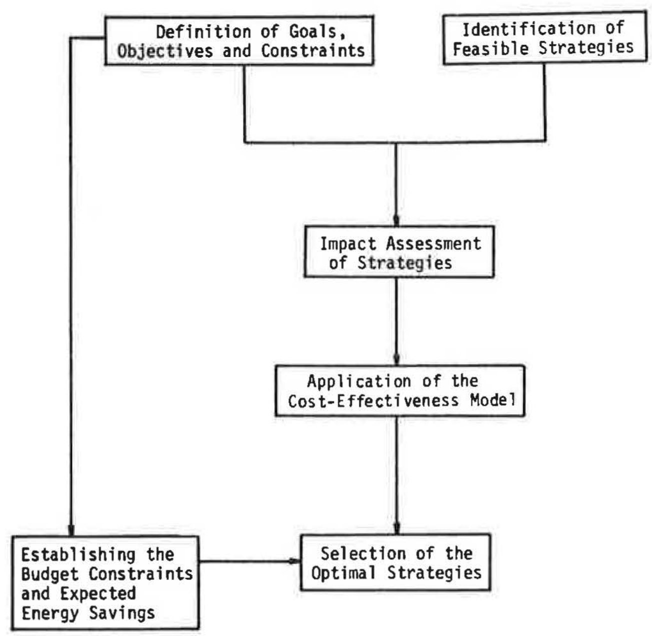

FIGURE 2 Transportation energy conservation strategy adoption process.

Definition of Goals, Objectives, and Constraints

To guide the evaluation process to a successful outcome, it is customary to specify community goals and objectives that should be satisfied generally by the optimal selection of strategies. In addition, it is also necessary to identify constraints that set bounds on all governing factors and limit the TEC strategies that can be considered. The yearly budget level allocated for TEC efforts and the energy-conserving objective of a given community must be established first. Whether the TEC strategy analysis is to be conducted under the assumption of a fixed-budget constraint or a fixed-effectiveness requirement or whether the analysis is to determine the most cost-effective strategy for various possible budget and effectiveness combinations should also be clarified.

Information on budget constraints is necessary to ensure that the projected expenditures for the selected strategies will not exceed the available or anticipated funding level. As with energy objectives, the budget allocation for energy conservation will vary from locale to locale. If concrete figures are not available, an estimate of funds can be made by surveying and evaluating available funding resources (e.g., federal, state, county, and local matching funds). A review of past budget allocations also can be made. Because many TEC strategies are related to transportation system management (TSM) actions, TSM funding sources may be used to finance conservation strategies. TSM funding can also be considered in establishing budget constraints.

The energy-conserving objectives would indicate the acceptable minimum reduction in energy use expected from a given TEC program for a given time period. This expected energy saving will vary from community to community depending on its size, desired energy conservation goals, current status of conservation efforts, prevailing political climate, and other factors. One method for deriving the expected minimum energy savings level is given by the following equation:

$$MES_t \geq W_o C_t \qquad (5)$$

where

MES_t = minimum energy savings during time period t (e.g., dollars per year),
W_o = objective decision weight or the weight of objective impacts relative to that of subjective impacts ($0 < W_o < 1$), and
C_t = total available budget allocation for strategy implementation during the same time period t.

Equation 5 implies that the higher the weight assigned to objective impacts by the decision maker, the greater will be the level of minimum energy reduction at a given budget level.

Identification of Strategies

If a community wants to achieve effective TEC, the important characteristics of all possible TEC strategies must be available. [A large number of TEC strategies involving diverse technologies have been identified by past studies (3,5-7).] Because of the general nature of TEC strategies, each strategy must be specified to assure that it is applicable to a given urban environment. This involves engineering and judgmental ability on the part of the transportation agency in establishing specific strategies for the study area. Usually a large city would have an extensive transportation network and, accordingly, the strategy established for that area should be proportionally large. A given metropolitan area may desire to improve certain aspects of travel service (e.g., reduce commuting time or improve safety). The size of a given strategy then can be established to address that improvement as well as to address energy conservation. Before the strategy-selection process is begun, however, needs and feasibility studies should be made to determine the scope of these strategies.

Assessment of Strategy Impacts

To apply the cost-effectiveness model effectively, both the objective and subjective impacts associated with each strategy must be assessed. Estimating the potential impacts of a TEC strategy is an extremely difficult task, and needs to be improved before it the model can be used accurately. As indicated previously, because objective impacts involve concrete facts and figures they should be assessed by the technical analyst. Subjective impacts, which are important to the social well-being of a community, are the responsibility of the decision maker.

The assessment of objective impacts can be based on historical accounting records, data from other localities, and field survey information. The cost of implementing the strategy is usually estimated by experienced personnel. Energy savings can be estimated by employing methods available in the literature (3,5- 11). Subjective impacts are much more difficult to determine; however, a rating scheme, such as the multiattribute utility function approach, can assist in assessing subjective impacts. When the strategies are actually implemented, it is imperative to collect and analyze data pertaining to their impacts, both objective and subjective. This information is useful for selecting subsequent strategies whether in the same urban environment or elsewhere.

Application of the Model

The large number of TEC strategies and the diversity of impact measures make the comparison of individual strategies a complex process. However, the computerized cost-effectiveness model, TECSEM, will greatly facilitate the comparison of various strategies. Before application of TECSEM, the following need to be identified: (a) a list of TEC strategies; (b) for each strategy, an assessment of the objective and subjective impacts, including costs, energy savings, and weights for each of the subjective impacts; and (c) the relative weights of the objective and subjective impacts.

TECSEM is easy to use and efficient. It is also a flexible model because almost any number of TEC strategies with the accompanying objective and subjective impacts can be analyzed. The output is a list of TEC strategies ranked, taking into consideration their total cost-effectiveness, according to their CMOE value.

Because selecting TEC strategies is invariably concerned with the future and estimates of both costs and other prevailing conditions, no TEC program can ever be prescribed that will result in absolute success. The approach to this uncertainty is to perform a sensitivity analysis, in which computations are repeated for an imprecisely known parameter for each of several assumed values. A comparison of results can reveal which parameters have the greatest effect and where the regions of the greatest sensitivity lie.

Adoption of Optimal Strategies

The adoption of TEC strategies for implementation involves consideration of budget constraints and the expected minimum energy savings set by a given community. Basically the process consists of proceeding down the list of strategies ranked in order of decreasing CMOE values and including all high-ranked strategies as part of the implementation package. The costs of the individual strategies selected are taken into account; and when the cumulative cost of the selected strategies is at a maximum without exceeding the available budget, the adoption process ceases. The strategies chosen at that point qualify for implementation because the sum of their costs falls within the predetermined or estimated budget constraint. In addition, a check should be made to determine whether the cumulative energy savings of the strategies selected for implementation exceeds the expected minimum energy savings. If it does, the constraint is upheld. Otherwise, it will be necessary to (a) pursue the possibility of increasing the budget, (b) determine whether the minimum level of energy savings is realistic and adjust as necessary, or (c) increase the scope of strategies identified as being highly effective in energy conservation.

THE CASE STUDY

To demonstrate the methodology, a real-world case is examined to determine how it is formulated and analyzed. The Salt Lake City Metropolitan Area (SLCMA), Utah, was selected for this test case. The SLCMA is one of many jurisdictions that expressed interest in developing an energy conservation plan as part of the nationwide conservation effort. A mayor's energy advisory committee has been formed and has already initiated a number of local projects related to energy conservation, such as a ridesharing program and a downtown computerized traffic signal system. However, it has been recognized that there is still a great potential for implementing other projects to minimize energy consumption.

Goals, Objectives, and Constraints

The first step in executing the methodology was to identify the city's goals and objectives, as well as constraints, related to TEC. One goal established by a regional transportation committee was to assign high priority to efficiency in planning future transportation development (12). Thus, all transportation projects should provide incentives for more efficient use of private automobiles and transit systems. Another goal developed by the staff of the metropolitan planning organization indicates that minimum energy consumption is an essential element in developing metropolitan area transportation (13). In response to the questionnaire for this case study, the mayor and council members indicated considerable interest in a citywide TEC effort. Therefore, there was a desire to implement effective TEC strategies in the SLCMA. The Salt Lake City Transportation Department indicated that an annual budget of about $25,000 would be available for the TSM-type projects which, in turn, relate to TEC efforts. This figure was based on the current matching funds available for federal-aid projects, the expected portion of urban federal monies usually allocated to the city, and the anticipated percentage of funds devoted to TSM projects within the next few years.

Feasibility of Strategies

Twenty-two potential TEC strategies given in Table 5 were initially considered for possible application to the Salt Lake City area. On the basis of knowledge of the existing transportation system, ranging from its transportation network characteristics to its current transportation-related goals and policies, the most suitable strategies were identified. Using the critical factor analysis, 10 of the original 22 potential strategies were considered feasible, were evaluated further, and were ranked by the cost-effectiveness model. Most of the projects selected for the TEC strategies have actually been proposed and are being considered by the Salt Lake City Transportation Department. The 10 feasible TEC strategies and their descriptions are as follows:

TABLE 5 Selected Transportation Energy Conservation Strategies for the Case Study

Vehicle flow improvements
Traffic signal system improvements
Special parking restrictions
One-way streets
Reversible lanes
Right turn on red after stop
Freeway traffic management
Traffic signal removal
Traffic signal flashing operation
Preferential treatment of high-occupancy vehicles
Ridesharing program
Bus and carpool lanes
Improved mass transit operations
Bus preemption of traffic signals
Fringe parking facilities
Modification of travel behavior
Work-hour rescheduling
Congestion pricing
Increased compliance with the 55 mph speed limit
Driver efficiency training
Promotion of non-auto use
Improved bicycle facilities
Improved pedestrian facilities
Land use policies
Electrical energy reduction
Sodium street lights
Replacement of street lights by reflective devices

1. Traffic signal system improvements. Salt Lake City is in the process of installing a centrally controlled computerized signal system. The majority of Salt Lake City's signalized intersections will be controlled by this system (14). Many signalized intersections, however, are outside the system and several of these are isolated. Time-based coordination by sophisticated time clocks was proposed for six of these locations. Some of the existing controllers will need to be replaced in the process.
2. Special parking restrictions. Thirteenth East Street from 900 South to 2100 South has one lane of traffic in each direction with parking allowed on both sides. It was proposed that parking be prohibited during the peak hour to provide an additional travel lane. This is a collector road with a volume-to-capacity ratio of 0.94 in the 7:00-to-9:00 a.m. peak period.
3. Reversible lanes. Fifth East Street from 400 South to 2700 South Streets is a four-lane road with approximately an 80 to 20 directional split in the peak hours. Three northbound lanes and one southbound lane were proposed in the morning peak period and the reverse in the afternoon peak period.
4. Traffic signal removal. Three intersections in the study area apparently no longer warrant traffic signals. They are Highland Drive and Simpson Avenue, 400 East Street and 1700 South Street, and 700 South Street and 500 East Street.
5. Traffic signal flashing operation. There are 83 signalized intersections in Salt Lake City that are currently being considered for flashing operation. It was proposed that the signals operate in the flashing mode between the hours of 1:00 and 6:00 a.m. daily.
6. Bus and carpool lanes. Use the parking lanes on 700 East Street from 400 South to 3900 South Streets as exclusive bus and carpool lanes. There are currently three lanes and a parking lane in each direction separated by a raised median. Parking is prohibited in the peak period to allow a fourth

TABLE 6 Estimates of the Objective Impacts of Feasible Strategies for Salt Lake City, Utah

Strategy	Equivalent[a] Annual Cost($)	Annual[b] Energy Savings($)
Traffic signal system improvement	1,574	54,264
Special parking restrictions	1,639	10,624
Reversible lanes	7,575	12,475
Traffic signal removal	885	20,098
Traffic signal flashing operation	442	25,448
Bus and carpool lanes	2,747	99,614
Work-hour rescheduling	7,079	156,600
Improved bicycle facilities	5,894	5,794
Improved pedestrian facilities	6,028	5,064
Sodium street lights	5,966	9,876

[a]Based on 10-year project life and 12 percent annual interest rate.
[b]Based on the energy-savings estimation models from Yu and Pang *(3)*, $1.20 per gallon of gasoline, and $7.80 per month for a 159-watt sodium vapor light.

travel lane. This proposal would eliminate parking at all times so the curb lane could be continually used by buses and high-occupancy vehicles.

7. Work-hour rescheduling. A publicity program is planned to inform the public and, more specifically, employers of the benefits of a 4/40 (4 days and 40 hours per week) program. With the encouragement of this program it is anticipated that a substantial number of organizations will voluntarily convert to the 4/40 work schedule.

8. Improved bicycle facilities. A type-I bike route is proposed along the grass median of 600 East Street from South Temple to Liberty Park. The type-I bike route would extend through the park and a type-II route would continue from 1300 South to 2700 South Streets. With access to the park, this 4-mile bike route would accommodate recreational trips as well as work trips.

TABLE 7 Matrix of Subjective Impact Weights for Salt Lake City, Utah

Subjective Impact	Respondent 1	2	3	4	5	6	7	8	Average	Subjective Impact Weight (SIW_k)
1. Energy conservation	10	11	5	10	10	9	12	11	9.8	0.098
2. Quality of transportation service	10	20	12	10	10	15	11	12	12.5	0.125
3. Public safety	25	10	18	15	10	20	19	20	17.1	0.171
4. Economic impacts	15	9	10	5	10	7	13	12	10.1	0.101
5. Environmental impacts	5	20	10	15	10	13	9	12	11.8	0.118
6. Social impacts	10	15	22	20	25	15	15	15	17.1	0.171
7. Financial impacts	20	10	18	5	10	11	11	10	11.9	0.119
8. Land use impacts	5	5	5	20	15	10	10	8	9.8	0.098
Total (rounded)	100	100	100	100	100	100	100	100	100	1.000

TABLE 8 Matrix of Decision Weights for Salt Lake City, Utah

Decision Weight	Respondent 1	2	3	4	5	6	7	8	Average
Objective impact (W_o)	60	80	70	40	50	60	60	70	61.25
Subjective impact (W_s)	40	20	30	60	50	40	40	30	38.75
Total	100	100	100	100	100	100	100	100	100

TABLE 9 Matrix of Strategy Weights for Salt Lake City, Utah

Subjective Impact, k	SIW_k[a]	Strategy 1 IR[b]	1 SW_{ik}[c]	2 IR	2 SW_{2k}	3 IR	3 SW_{3k}	4 IR	4 SW_{4k}	5 IR	5 SW_{5k}
1. Energy conservation	.098	.134	.087	.166	.108	.166	.108	.166	.108	.134	.087
2. Quality of transportation service	.125	.112	.091	.138	.113	.112	.081	.112	.091	.138	.113
3. Public safety	.171	.122	.122	.122	.122	.060	.060	.091	.091	.060	.060
4. Economic impacts	.101	.077	.091	.051	.060	.077	.091	.077	.091	.077	.091
5. Environmental impacts	.118	.128	.105	.128	.105	.077	.079	.103	.105	.103	.105
6. Social impacts	.171	.080	.091	.053	.060	.080	.091	.080	.091	.080	.091
7. Financial impacts	.119	.087	.120	.087	.120	.087	.120	.087	.120	.087	.120
8. Land use impacts	.098	.099	.111	.074	.083	.074	.083	.074	.083	.074	.083

[a]SIW_k = Subjective impact weight.
[b]IR = Impact rating.
[c]SW_{ik} = Strategy weight of strategy i relative to subjective impact k.

9. Improved pedestrian facilities. An elevated walkway across State Street between Social Hall Avenue and the ZCMI mall at 50 South was proposed to eliminate pedestrian accidents at the existing at-grade crossing. This skyway would enhance pedestrian safety and is expected to increase the volume of pedestrian activity and, consequently, reduce vehicle trips.

10. Sodium street lights. Salt Lake City currently leases one hundred fifty-nine 620-watt incandescent street lights from Utah Power and Light Company. It was proposed that these be replaced with 15-watt sodium vapor lights. This would yield an energy savings of 1720 kwh per year per fixture.

Impact Assessment

The next concern was assessing the impacts of the individual feasible strategies. First, the objective impact measures--the equivalent annualized cost of the strategy and annual energy savings resulting from implementing the strategy--were estimated and are given in Table 6. The cost estimates of strategies were based on the most current data from similar projects implemented in the Salt Lake City area or elsewhere. Project costs were broken down into capital, operating, and maintenance. The initial implementation costs were established by quotations from suppliers and contractors. Operating and maintenance costs were obtained from the accounting records of agencies that have operated and maintained similar projects. Annualized costs were derived from the assumed project life (10 years) and interest rate (12 percent).

Energy savings were determined by using a set of estimation equations developed by the authors (3). These equations are a simplified tool for quick-response estimates; however, they provide a reasonable level of accuracy.

To obtain relative weights of all eight subjective impacts, as well as objective versus subjective impacts, an opinion questionnaire was sent to the decision-making body (i.e., the seven-member Salt Lake City Council and the mayor). Each of the respondents was asked to assign relative weights. The results of subjective impact weights and objective versus subjective decision weights are given in Tables 7 and 8. Such a survey was not difficult and full cooperation was obtained from all of these decision makers.

To weight the 10 feasible strategies in terms of the subjective impacts, a set of utility functions was developed and used. A panel of technical experts consisting of state and local professionals was used to establish composite utility curves.

Based on estimates of strategy impact levels and strategy scope, the ratings given in Table 9 for each strategy relative to a given subjective impact were determined. The ratings were converted to strategy weights by dividing the individual rating by the sums of all ratings for all of the strategies.

Use of the Cost-Effectiveness Model

After all necessary inputs had been compiled, application of the computerized cost-effectiveness model began. With minimal computer time, TECSEM produced the strategy ranking results. The data in Table 10 indicate the strategy ranking in decreasing order of CMOE values of individual TEC strategies. The most favorable strategy was traffic signal flashing operations. The second, third, fourth, and fifth best are bus and carpool lanes, traffic signal system improvement, work-hour rescheduling, and traffic signal removal, respectively. All top five strategies have a CMOE value at or above 0.113 and are far superior to the other strategies. Improved bicycle and pedestrian facilities have much lower CMOE values and also have an economic efficiency ratio value (energy savings divided by cost) of less than 1. They could initially be eliminated by the critical factor analysis but were retained to determine if nonmonetary factors might justify their implementation. Under either circumstance, they should not be considered for implementation. The fact that one strategy (reversible lane), which had an economic efficiency ratio above 1, was ranked below a strategy with a ratio below 1 illustrates an example where, for a given strategy, the subjective impact measures dominate the objective impact measure, resulting in a higher overall CMOE value.

By using the computer model, a sensitivity analysis can be performed to determine whether the margin of error for the different variables will be such that it would affect the rank of TEC strategies. For this case study, sensitivity analyses of the CMOE values to changes in interest rates, project life span, energy saving estimates, and decision weights were performed; however, they are too lengthy to be discussed in this paper.

6		7		8		9		10		Total
IR	SW_{6k}	IR	SW_{7k}	IR	SW_{8k}	IR	SW_{9k}	IR	SW_{10k}	IR
.200	.130	.166	.108	.134	.087	.134	.087	.134	.087	1.534
.138	.113	.167	.136	.083	.068	.112	.091	.112	.091	1.223
.081	.091	.122	.122	.060	.060	.122	.122	.151	.151	1.000
.103	.122	.103	.122	.077	.091	.103	.122	.103	.122	0.847
.103	.105	.077	.079	.103	.105	.103	.105	.103	.105	0.978
.080	.091	.080	.091	.080	.122	.107	.122	.133	.151	0.880
.107	.161	.053	.079	.053	.079	.027	.041	.027	.041	0.667
.123	.138	.074	.083	.099	.111	.099	.111	.099	.111	0.890

TABLE 10 Composite Measure of Effectiveness and Ranking of Salt Lake City Feasible Strategies

Strategy	Objective Impact Measure	Subjective Impact Measure	Composite Measure of Effective-ness	Rank
Traffic signal flashing operation	.311	.093	.227	1
Bus and carpool lanes	.196	.115	.165	2
Traffic signal system improvement	.187	.103	.154	3
Work-hour rescheduling	.120	.103	.113	4
Traffic signal removal	.123	.097	.113	5
Special parking restrictions	.035	.097	.059	6
Sodium street lights	.009	.112	.049	7
Improved pedestrian facilities	.005	.102	.042	8
Reversible lanes	.009	.089	.040	9
Improved bicycle facilities	.005	.090	.038	10

Note: Based on 10-year project life and 12 percent annual interest rate.

TABLE 11 Cumulative Costs and Energy Savings of Salt Lake City Feasible Strategies

Strategy	Rank	Annual Cost ($)	Cumu-lative Cost ($)	Annual Energy Savings ($)	Cumu-lative Energy Savings ($)
Traffic signal flashing operations[a]	1	442	442	25,448	25,448
Bus and carpool lanes[a]	2	2,747	3,189	99,614	125,062
Traffic signal system improvement[a]	3	1,574	4,763	54,264	179,326
Work-hour rescheduling[a]	4	7,079	11,842	156,600	335,926
Traffic signal removal[a]	5	885	12,727	20,098	356,024
Special parking restriction[a]	6	1,639	14,366	10,624	366,648
Sodium street lights[a]	7	5,966	20,332	9,876	376,524
Improved pedestrian facilities	8	6,028	26,360	5,064	381,588
Reversible lanes	9	7,575	33,935	12,975	394,563
Improved bicycle facilities	10	5,894	39,829	5,794	400,357

[a]Strategies within budget constraints.

Strategy Adoption

Strategies to be implmented must remain within the boundary of budgetary constraints of a local government. In the strategy adoption process, the top-ranked strategies are included in the implementation package until the available budget amount is exhausted. At that point, a check is made as to whether the selected strategies meet the minimum energy savings as established by local goals and objectives.

As indicated previously, an annual limitation of $25,000 for TEC projects was used for the city's budget allocation as project matching funds. The minimum expected energy saving was determined by using Equation 5. With W_o = 61.25 percent (from Table 8) and C_t = $25,000 for 1 year, the energy savings should be at least $15,313. In selecting the highest ranked strategies that fall within the allowable budget of $25,000, it was found that the first seven strategies met this criterion, as indicated in Table 10. With the total cost of the seven strategies equal to $20,332, there is a surplus of funds amounting to $4,668. There are two options in this case: either return the $4,668 to the funding source or reduce the scope of the next-ranked strategy such that its annual cost is $4,668 or less.

Now it is necessary to determine whether the minimum energy savings has been achieved. As given in Table 11, the expected savings from the first seven strategies is $376,524, which is well above the established minimum of $15,313. Therefore, the set of seven top-ranked strategies qualifies for implementation based on the given budget limitations and the minimum expected energy savings level.

The ranking of the alternative strategies can assist in determining the priorities in Salt Lake City for programming future projects. Also, the results of the strategy adoption process can serve as supporting justification for grants or other support provided by the state and federal governments.

CONCLUSIONS

An effective model for the development of a TEC program that is fully responsive to the typical environment of urban areas is presented in this paper. Emphasis was placed on simplicity and practicality. The model computes a CMOE value for each potential strategy based on its subjective and objective impacts and the relative weights assigned to each class of impacts. The relative values of these CMOEs are used to rank the individual strategies. From the ranking, strategies are selected for implementation based on the budget allocation for TEC strategies and the minimum expected energy savings expressed by a given community. Sensitivity analyses may be performed to determine the interplay of the various parameters in the model.

The case study described in this paper illustrates the usefulness, practicality, and ease of application associated with the developed methodology. The use of a preprogrammed computer-based model greatly facilitated the execution of the methodology without undue time or cost. It was found that data requirements for use of the model were not excessive. Full cooperation was received from local and regional agencies for the case study. There was a general consensus of all public officials and technical personnel involved in this study that the suggested approach is quite realistic in the existing public decision-making process and is reasonable for the currently available technical resources of the local government.

The suggested approach is expected to contribute to TEC effort by filling a void that currently exists in the evaluation and ranking of TEC alternatives. The success of applying this approach is, of course, dependent on the user's ability to gauge the needs and concerns of the urban area. Without this insight, the most important consideration is overlooked, that is, the citizen, the taxpaper, and the community.

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Rail Rapid Transit and Energy: A Reexamination of Current Conventional Wisdom

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ABSTRACT

Rail rapid transit is often advocated as a major part of solutions to the energy problems of urban transportation. In the wake of Lave's energy analysis of the BART system in San Francisco and Oakland and the Congressional Budget Office study, in conventional wisdom the view is reflected that new rail transit systems often expend more energy than they save. Lave's analysis is reexamined in this study. Energy costs are calculated for six energy categories (propulsive, construction, maintenance, vehicle manufacture, calorific, and miscellaneous) for BART and a freeway alternative. The results indicate that BART uses 3.6 percent more energy annually than the freeway alternative when all energy costs are annualized. This is not a significant difference. Differences in key assumptions account for the difference in results. An alternate analysis using the assumptions of Usowicz and Hawley is discussed to show the sensitivity of an analysis of this type to the assumptions used. The notion that new rail transit construction wastes energy is not supported by the available evidence.

It is generally believed that new rail transit systems are energy wasters. Studies and articles by Healy and Dick (1), Lave (2), and the Congressional Budget Office (3) have found that the energy used to construct a rail transit system outweighs the marginal energy savings resulting from its operation. Despite occasional dissenting opinions [see the discussions following Lave's article (4-7), and Pushkarev and Zupan (8)], these findings are generally considered current thinking on the subject.

Construction of the Bay Area Rapid Transit (BART) system was examined as a case study for an UMTA-funded project concerning the relative importance of indirect energy considerations. The energy costs (in terms of energy consumed) associated with the construction and operation of the BART system are compared to those of a freeway alternative. The approach used by Lave is followed generally in this paper, and special attention is paid to the assumptions necessary for this type of analysis. Many of Lave's energy factors, which were taken from a previous study by Fels (9), are also used in this paper. Results obtained here are compared to Lave's findings; there is a considerable difference, explained primarily by the assumptions chosen. As an example of the sensitivity of an analysis of this type to the assumptions employed, results of an alternate analysis based on Usowicz and Hawley (7) are also presented.

CATEGORY OF ENERGY COSTS

Following the format of the larger report from which this paper is taken (10), energy consumed (energy costs) is analyzed by category of energy use. Propulsive or direct energy is the energy used to propel BART vehicles or automobiles. Indirect energy categories include construction, maintenance, vehicle manufacture, and calorific. Construction energy is the energy needed to operate construction machinery and perform related activities at the construction site; it also includes energy needed to transport construction materials to the site and the energy required to convert raw materials into a usable form. Maintenance energy is that needed to maintain roadways, guideways, and vehicles. The energy used in the manufacture of automobiles, buses, and BART vehicles is vehicle manufacturing energy. Finally, calorific energy is the potential energy of a material (such as asphalt) that may be used as a fuel, and it measures the heat energy released when the material is completely burned.

BART also requires energy to operate the stations, and the freeway alternative requires energy for the construction of additional parking garages to accommodate increased automobile traffic in the central business district (CBD). These energy costs fall outside the categories defined earlier, so they are placed in an "other energy costs" category.

Lave's analysis is presented in metric units. For simplicity, metric units are also used for the calculations in this paper, and the results for each energy type are converted to billions of British thermal units (BBtu).

Propulsive Energy

Lave uses 65.5 megajoules (MJ) per vehicle kilometer for the marginal operating power factor for BART; this is based on studies from 1975 and 1976. Because it was presumed that BART's energy efficiency would improve over time, more recent articles and data were consulted. In a 1979 article, Chomitz reported the traction energy of BART as 14.8 MJ per car kilometer (11), or 71 percent of total energy. Assuming a 30 percent efficiency in generating and transmitting electricity, the energy actually required is 14.8/0.3 or 49.3 MJ per vehicle kilometer. The most recent Section 15 report indicates an annual energy use of 171,430,000 kilowatt hours (kwh) for BART's fiscal year 1981 and 28 million car miles (12). This energy use reflects only vehicle propulsive energy; energy costs for station operations are addressed later. Converted to metric units, the result is

BART propulsive energy factor
= (171,430,000 kwh x 3.6 MJ/kwh/0.3 efficiency)/ 28 million vehicle miles x 1.6 km/mile
= 45.9 MJ/vehicle km.

This latter figure is comparable to Chomitz' factor, so the annual propulsive energy cost for BART is the numerator of the previous equation, which expressed in BBtu's is 171,430,000 kwh x 3,413 Btu/kwh/0.3 efficiency = 1,950 BBtu.

To calculate the freeway propulsive energy costs, Lave first divided the energy used to produce a liter (L) of gasoline by the energy efficiency of an automobile. This number is adjusted for automobile occupancy to produce an MJ-per-passenger-kilometer factor for the automobile mode. The same was done for buses. BART's passenger kilometers were then divided between automobile and bus in proportion to the former mode used by BART passengers. Input data were derived from the Section 15 report (12), Environmental Protection Agency (EPA) over-the-road mileage (13), the Caltrans energy study (14), and Lave (2). Because transit efficiency was derived for fiscal year 1981, automobile efficiency should be an average of the 1980 and 1981 mile-per-gallon (mpg) figures, in according with the principle of giving equal consideration to both modes. The following data were used in the calculations:

- Energy in gasoline was 37.3 MJ/L (2), which includes energy lost in the refining process.
- Automobile fuel efficiency was (15.78 + 16.34)/2 mpg/2.35 mpg/km/L, which equals 6.8 km/L (2,13).
- BART passenger kilometers for fiscal year 1981 were 624,749,000 passenger miles x 1.6 km/mile, which equals 1 billion passenger km (12); 46.5 percent of these were attributed to former automobile users and 53.5 percent to former bus users (2).
- Automobile occupancy was 1.3 passengers per vehicle (2).
- Bus fuel efficiency was 0.234 gallon per mile or 0.550 L/km (14) (1/0.55, which equals 1.82 km/L).
- Energy in diesel fuel was estimated to be 41.2 MJ/L (2), which includes energy lost in the refining process.

The marginal operating power used for automobiles and buses was

- Automobile propulsive factor = 37.3 MJ/L/6.8 km/L = 5.49 MJ/vehicle km/1.3 passengers/vehicle = 4.22 MJ/passenger km and
- Bus propulsive factor = 41.2 MJ/L/1.82 km/L = 22.6 MJ/vehicle km/11.5 passengers/vehicle = 1.97 MJ/passenger km.

Therefore, propulsive energy costs can be calculated as follows:

- Automobile propulsive energy = (1 billion x 0.465) passenger km x 4.22 MJ/passenger km x 948 Btu/MJ = 1,860 BBtu,
- Bus propulsive energy = (1 billion x 0.535) passenger km x 1.97 MJ/passenger km x 948 Btu/MJ = 999 BBtu, and
- Total propulsive energy costs for the freeway alternative = 1,860 + 999 = 2,859 BBtu.

Construction Energy

Lave estimated that BART cost $2.119 billion in 1974 dollars to construct (not including the cost of purchasing vehicles), and his analysis uses a factor of 81.9 MJ per dollar, which was taken from Healy and Dick's input-output analysis of BART (1,2). As Usowicz and Hawley point out in their discussion (7), however, this 81.9 MJ per dollar figure is based on 1963 dollars. Lave argues that energy per current dollar tends to rise, but it appears spurious to apply a factor based on 1963 dollars to 1974 costs. The implicit price deflator developed by the Bureau of Labor Statistics (BLS) was used to estimate BART costs in 1963 dollars (15):

BART costs in 1963 dollars
= $2.119 billion x (71.67/114.92)
= $1.322 billion.

The construction energy for BART is then $1.322 billion x 81.9 MJ/dollar x 948 Btu/MJ = 102,642 BBtu.

Healy and Dick assume a useful service life of 50 years for BART (1). This may be low in light of experience in other American cities but was used in this analysis as a conservative assumption. Annualized construction energy costs then would be 2,053 BBtu.

For the freeway alternative, Lave calculated the lane kilometers of highway needed if BART were not available by estimating the number of peak-hour automobile and bus trips diverted to BART and calculating the additional highway capacity needed in the peak hours to accommodate these vehicles. Factors for dollar cost per lane kilometer and energy cost per dollar are used to determine total construction costs.

For fiscal year 1981, BART's ridership was 50,294,000 unlinked passenger trips (12). Assuming that 10 percent of these unlinked trips were transfers, there were 45,264,600 linked trips per year. Lave estimates that 59 percent of BART's patronage rides in the peak hours (2). Assuming 300 travel days per year, the following calculations can be made:

- BART daily trips = 45,264,600 annual trips/300 days/yr = 150,000 trips.
- Trip length = 1 billion passenger km/45,264,600 trips = 22.1 km/trip (13.8 miles/trip).
- Daily peak-period automobile trips diverted to BART = (150,000 x 0.59) peak-period BART trips x 0.465 automobile share/1.3 passengers/automobile = 31,650 trips.
- Highway needed for automobiles
  = (31,650 peak-period automobile trips x 22.1 km/trip)/4 hr/peak period x 2,000 automobiles/lane hour
  = 87.4 lane km.

For former bus trips, Lave uses a peak-load factor of 25 persons per bus, a diversion factor of 0.535 (i.e., 53.5 percent of BART riders were former bus users), and a capacity factor of 1,200 buses per lane hour. List points out that this capacity factor is too high; he cites the Highway Capacity Manual figure of 690 and the highest achieved value of 490 buses per lane hour (6). In this analysis 600 buses per lane hour was used. The bus calculations are

- Daily peak-period bus trips diverted to BART = (150,000 x 0.59) peak BART trips x 0.535 = 47,350 trips,
- Highway needed for buses
  = (47,350 peak bus person trips x 22.1 km/trip)/25 persons/bus x 4 hr/peak x 600 buses/lane hour
  = 17.4 lane km, and
- Total highway needed = 87.4 + 17.4 = 104.8 lane km (65.5 lane miles).

This is approximately 40 percent greater than Lave's estimate.

Lave uses a 1974 dollar cost that must be converted to 1963 dollars to match the energy-per-1963-dollar factor. The BLS implicit price deflator factors (15) used again here are

- Freeway costs per lane km in 1963 dollars = $579,000 x (71.67/114.92) = $361,000, and
- Construction energy costs for freeways = 104.8 lane km x $361,000/lane km x 118 MJ/dollar x 948 Btu/MJ = 4,232 BBtu.

A 25-year service life is assumed for roadways. Although at first glance this may appear to violate the principle of equal treatment of modes in cross-modal comparisons, it is an accurate reflection of reality because rapid rail structures last longer than roadways. Thus annualized construction energy costs for roadways would be 169 BBtu.

The preceding calculations measure the energy costs for constructing 65.5 lane miles of roadway in lieu of BART. They do not address the need for a trans-Bay bridge or the need for widening an existing bridge nor do they consider the necessity of tunneling under Berkeley Hills. A freeway alternative providing equivalent trans-Bay capacity would need a bridge and tunnel, and their construction energy costs should be included in this analysis.

Usowicz and Hawley (7) and Lave (2) argue over the width of the necessary bridge and tunnel. An assumption was made here that a two-lane bridge and a two-lane tunnel would be built as part of the freeway alternative. This is essentially the minimum feasible construction. It is unlikely, however, that such a narrow bridge would be built; a wider facility capable of handling future travel increases could be expected. Nonetheless, a two-lane width is used as a conservative assumption for both bridge and tunnel.

Usowicz and Hawley estimate the cost of a trans-Bay bridge as $27.04 million per lane in 1963 dollars. Berkeley Hills tunnel costs were derived from actual BART costs, which were $24.01 million (1963 dollars) for a double tube. Using the highway energy conversion ratio of 118 MJ/dollar and a service life of 30 years, calculations for bridge construction were

Bridge construction energy costs
= $27.04 million/lane x 2 lanes x 118 MJ/dollar x 948 Btu/MJ
= 6,050 BBtu/30 years, or
= 201.7 BBtu annually.

Because tunneling for a highway is similar to the BART construction work, the BART energy conversion ratio of 81.9 MJ/dollar was used and a service life of 50 years was assumed:

Tunnel construction energy costs
= $24.01 million/double tube x 81.9 MJ/dollar x 948 Btu/MJ
= 1,864 BBtu/50 years, or
= 37.3 BBtu annually.

The total construction energy cost for the freeway alternative is the sum of the roadway, bridge, and tunnel construction energy costs (i.e., 169 + 202 + 37 or 408 BBtu).

Maintenance Energy

Lave does not address maintenance energy. Chomitz reports that 5 percent of total electricity consumed by BART is used for maintenance, whereas propulsive energy accounts for 71 percent of total electricity (11). It was assumed that this 5 percent of total electricity used for maintenance includes guideway and vehicle maintenance. Using the propulsive energy costs of 1,950 BBtu calculated earlier, the calculation for BART annual maintenance energy was (1,950 BBtu/0.71) x 0.05, which equals 137 BBtu.

For the freeway alternative, vehicle and roadway maintenance must be considered. Factors obtained from the Caltrans study and Erlbaum (14,16) are 2,713 Btu per vehicle mile for automobile maintenance and 0.134 BBtu per lane mile for roadway maintenance (assuming an asphalt road). In addition, the Caltrans study cites a factor of 13,142 Btu per vehicle mile for bus maintenance (14). These are annual factors. In calculating construction energy, the number of daily peak-period automobile trips diverted to BART was derived. Here the annual number of automobile trips diverted to BART was needed. Assuming, as before, that 46.5 percent of BART riders formerly used an automobile and using factors of 150,000 BART trips per day, 1.3 persons per automobile, 300 weekday equivalents per year, and 13.8 miles per trip (22.1 km/trip), the following calculations can be made:

- Annual automobile miles diverted = (150,000 x 0.465/1.3) automobile trips/day x 300 days/yr x 13.8 miles/trip = 222,126,920 miles, then
- Freeway automobile maintenance energy = 222,126,920 vehicle miles x 2,713 Btu/vehicle mile = 603 BBtu.

The number of bus trips diverted can be calculated considering that 53.5 percent of BART riders formerly took a bus and using an overall load factor of 11.5 persons per bus. Calculation of bus miles diverted by BART annually is then:

- Annual bus miles diverted = (150,000 x 0.534) person trips/day/11.5 persons/bus x 300 days/yr x 13.8 miles/trip = 28,890,000 miles; then
- Freeway bus maintenance energy = 28,890,000 x 13,142 Btu/vehicle mile = 380 BBtu, and
- Total freeway vehicle maintenance energy = 603 + 380 = 983 BBtu.

There are 65.5 lane miles of additional roadway required under the freeway alternative; therefore,

- Freeway road maintenance energy = 65.5 lane miles x 0.134 BBtu/lane mile = 9 BBtu, and
- Total freeway maintenance energy = 983 + 9 = 992 BBtu.

Vehicle Manufacture Energy

Lave calculated the vehicle construction energy for the automobile, BART, and diesel bus in megajoules per vehicle kilometer. Instead of Lave's present and future automobile categories, a single calculation is done for the automobile assuming an average weight of 3,000 lb (1361 kg) and using a Caltrans-derived energy factor of 91.3 MJ/kg (14).

Lave assumed service lives that are much too high. Instead of his 180 000-km life for an automobile, this paper uses 160 000 km (100,000 miles), a value obtained from Caltrans (14). Lave cites 1 600 000 km as the service life of a bus; this is three to four times too high. Caltrans gives a value of 480 000 km (300,000 miles) for a standard 53-seat bus (14), and experience in New York State supports that number. In this paper the service life of a transit bus is 300,000 miles. Lave's estimate of the service life of a BART vehicle (4 480 000 km or 3,000,000 miles) is also unreasonable. Experience in New York State indicates that an appropriate service life for a rapid transit vehicle is 1,250,000 miles or 2 000 000 km. Although New York's experience is not always transferable to the BART system, this service life appears more appropriate and was used in this paper. Lave's values for manufacture energy match Caltrans figures for a standard 53-seat bus and a commuter rail car (no figures are available for a rapid transit rail car, which may be less energy intensive to build).

The factors for vehicle manufacture energy were

- BART: 4 430 000 MJ/2 000 000-km service life = 2.215 MJ/vehicle km,
- Automobile: 1361 kg x 91.3 MJ/kg/160 000-km service life = 0.777 MJ/vehicle km, and
- Bus: 1 080 000 MJ/480 000-km service life = 2.250 MJ/vehicle km.

In fiscal year 1981 BART provided 28 million vehicle miles or 44 800 000 vehicle kilometers of service. As calculated previously, BART replaced 222,126,920 automobile miles and 28,890,000 bus miles. The calculations are straightforward:

- BART vehicle manufacture energy = 44 800 000 vehicle km x 2.215 MJ/vehicle km x 948 Btu/MJ = 94 BBtu,
- Freeway automobile manufacture energy = 222,126,920 vehicle miles x 1.6 km/mile x 0.777 MJ/vehicle km x 948 Btu/MJ = 262 BBtu,
- Freeway bus manufacture energy = 28,890,000 vehicle miles x 1.6 km/mile x 2.25 MJ/vehicle km x 948 Btu/MJ = 99 BBtu, and
- Freeway total manufacture energy = 262 + 99 = 361 BBtu.

Calorific Energy

The freeway alternative involves an additional 65.5 lane miles of asphalt pavement. The calorific energy contained in this asphalt must be calculated. Assume that the lanes are 12-ft wide and the pavement is 7-in. thick. At a compacted density of 145 lb/cu ft and a 5 percent asphalt content, the amount of asphalt needed for the freeway alternative is

Tons of asphalt = 5,280 ft/mile x 65.5 lane miles x 12 ft/lane x 7/12 ft depth x (145/2,000) tons per cu ft x 0.05 asphalt content = 8,776 tons.

Halstead provides a calorific energy factor of 37,100,000 Btu per ton of asphalt (17). Assuming a 25-year pavement life, freeway calorific energy per year would equal 8,776 tons x 37,100,000 Btu/ton/25 years, or 13 BBtu. No calorific energy is associated with the transit alternative.

Other Energy

The energy cost for BART's station operations is addressed here. A parallel energy cost for the freeway alternative is also addressed (i.e., the energy cost of parking garages). Both transit stations and parking garages are necessary in using a particular mode, but their associated energy costs have not yet been taken into account. Energy cost for station operations is treated similar to maintenance energy. Chomitz reports that 24 percent of the total electricity used is for station operations (11). Propulsive energy (1,950 BBtu) makes up 71 percent of total energy; therefore, BART station operating energy would equal (1,950 BBtu/0.71) x 0.24, or 659 BBtu.

Parking garage costs are addressed in several different ways by Lave and the various discussants (2,4,7). Usowicz and Hawley imply a cost per space of $2,265 in 1963 dollars and suggest a facility construction energy factor of 65,400 Btu/dollar. For the sake of argument, Lave accepts Tennyson's approach of providing a space for each commuter automobile trip and one space for every two off-peak automobile trips (2,4). Assume that two spaces are needed for every three automobile round trips, or one space for every three trips, and assume a 30-year life, which is typical for a major structure (14,18). Then calculations would be

- Automobile trips diverted = 150,000 x 0.465/1.3 = 53,654 trips,
- Spaces needed = 53,654/3 = 17,885 spaces, and
- Freeway garage construction energy = 17,885 spaces x $2,265/space x 65,400 Btu/dollar/30 years = 88 BBtu.

It is not clear whether station maintenance energy costs are included in any energy-per-dollar figure considered thus far, so garage maintenance will not be considered.

It might be argued that the energy costs for parking lots at BART stations should also be considered, because energy costs for parking are included under the freeway alternative. Lots at the stations do not involve a structure as a CBD parking garage does. Cohen provides a factor of 1.74 gal (217,500 Btu) per space (18). BART reports 20,200 spaces at 23 stations (19). Assuming a 25-year service life, BART lot construction energy = 217,500 Btu/space x 20,200 spaces/25 years, or 0.2 BBtu. This is insignificant. Because garage maintenance was not addressed, lot maintenance energy costs were not considered.

Use of the car left home by those switching modes might also be considered in this category. A study by Gross revealed that of the energy saved by shifting from the automobile to transit 40 percent is spent by household members using the car left home (20). However, in accordance with the first principle concerning equal treatment for all alternatives, consideration should also be given to operating and vehicle manufacturing energy saved by reduced automobile ownership levels brought about by transit service. Pushkarev and Zupan argue that this energy saving is significant (8) but methods to calculate it are not well developed. Thus, neither energy consumed by the car left home nor energy savings brought about by reduced automobile ownership are considered here.

TOTAL ENERGY COSTS

Component energy costs are given in Table 1. Total annual energy costs for BART are 4,893 BBtu and for the freeway alternative 4,721 BBtu. For BART there are significant propulsive, construction, and station operating (other) energy costs, whereas propulsive and maintenance energy costs account for the bulk of the freeway energy requirements. The difference in construction energy costs is the major factor in determining relative total energy costs for the alternatives. Overall BART energy costs are 3.6 percent higher than the freeway energy costs. Given the large number of assumptions employed, a difference of less than 10 percent between alternatives cannot be considered significant.

TABLE 1 Energy Costs: BART Versus Freeway (annual BBtu's)

Energy Category	BART	Freeway
Direct		
Propulsive	1,950	2,859
Indirect		
Construction operating	2,053	408
Construction hauling	-[a]	-[a]
Maintenance	137	992
Vehicle manufacture	94	361
Processing	-[a]	-[a]
Calorific	-	13
Other	659	88
Subtotal indirect	2,943	1,862
Total	4,893	4,721

[a]Included in construction operating energy.

Lave expressed his results in number of years of operation that would be required for BART to pay back the initial energy investment. If these construction energy costs were converted to an annual basis (assuming a 50-year life for BART and a 25-year life for roadways) and petajoules were converted to BBtu's, then Lave's calculations would result in 5,385 BBtu for BART, 2,563 BBtu for the freeway alternative with a 14-mpg average for the fleet, and 1,710 BBtu for the freeway alternative with a 27.5-mpg average for the fleet. On the other hand, using Lave's approach, the analysis in this paper results in a payback period of 63 years as follows:

- BART total construction energy costs = 102,642 BBtu,
- Freeway total construction energy costs = 12,146 BBtu for construction + 2,649 BBtu for the garage, or 14,795 BBtu,
- Annual operating energy costs (including everything but construction and parking garage costs) for BART = 2,840 BBtu/yr and for the freeway option = 4,225 BBtu/yr.

The years required to recover the initial expenditure, then, are (102,642 - 14,795) BBtu initial expenditure/(4,225 - 2,840) BBtu/yr savings, or 63 yr.

Given the different service lives involved in the various components of the freeway alternative, nearly all of which are less than BART's assumed service life, this calculated figure for the energy payback period should be viewed with caution. Before the BART system reaches the end of its service life, the roadway, bridge, and parking garage will all face extensive reconstruction; the payback approach does not reflect this. A clearer picture of relative energy costs can be obtained by using annualized construction energy costs, as has been done here.

Usowicz and Hawley used several different assumptions in their analysis, described briefly in their discussion of Lave's original article (7). A summary is given in Table 2 of the differences in results obtained by this analysis, by Lave, and by Usowicz and Hawley. Obviously conclusions regarding relative energy efficiencies can be affected significantly by changing basic assumptions. For those interested in pursuing the matter further, the differences in assumptions and energy factors among the three studies are summarized in Table 3.

TABLE 2 Total Energy Costs: BART Versus Freeway, Using Three Different Methods (annual BBtu's)

	BART	Freeway
Boyle	4,893	4,721
Lave	5,385	2,563[a] 1,710[b]
Usowicz and Hawley	2,714	4,735

[a]Current automobile.
[b]Future automobile.

TABLE 3 Assumptions and Factors Used in the Three Analyses

	Boyle	Lave	Usowicz and Hawley
BART propulsive energy	(Actual kilowatt hours from Section 15 data		
MJ/passenger km	adjusted for power plant efficiency)	65.5	1.488
MJ/vehicle km		3.06	31.8
Btu/vehicle mile		99,350	48,234
Operating energy factor (includes energy lost in refining)			
Automobile			
MJ/passenger km	4.22	4.82[a] 2.45[b]	4.22
Btu/passenger mile	6,401	7,311[a] 3,716[b]	6,401
Bus			
MJ/passenger km	1.84	1.84	1.532
Btu/passenger mile	2,791	2,791	2,324
Bus efficiency			
km/liter	1.94	1.94	2.3
mpg diesel	4.5	4.5	5.4
Prior mode			
Automobile (%)	46.5	46.5	56.5
Bus (%)	53.5	54.5	43.5
BART cost ($1963, billions)	1.322	2.119[c]	0.902
BART construction energy factor			
MJ/dollar	81.9	81.9	45.5
Btu/dollar	77,641	77,641	43,134
BART trips			
Daily	150,000	130,000	150,000
Peak hour	88,500[d]	76,700[d]	29,250
Roadway needed in lieu of BART			
Lane km	104.8	74.7	198.4
Lane miles	65.5	46.7	124
Freeway cost ($1963)			
Per lane km	361,000	579,000	5441,130[e] 178,432[f]
Per lane mile	577,600	926,400	370,133 (231,333)[g]
Freeway construction energy factor			
MJ/dollar	118	118	118.4
Btu/dollar	111,864	111,864	112,243
Costs of bridge and tunnel considered?	Yes	No	Yes
Maintenance energy factor			
BART			
MJ/passenger km	(5% of total energy)[h]	–[i]	0.511
Btu/passenger mile			8,133
Automobile			
MJ/passenger km		–[i]	1.071
Btu/vehicle mile	2,713		2,112
Bus			
MJ/passenger km		–[i]	0.564
Btu/vehicle mile	13,142		9,838
Annual travel diverted			
Automobile			
Million passenger km		379	565
Million vehicle miles	222.1	182.2	271.6
Bus			
Million passenger km		436	435
Million vehicle miles	28.9	23.7	23.6
Passenger per vehicle			
Bus			
Peak period	25	25	11.5
Overall	11.5	11.5	
BART	22.3[j]	21.4	21.4
Automobile	1.3	1.3	1.3
Manufacture factor			
BART vehicle			
MJ/vehicle km	2.215	0.923	0.043
Btu/vehicle mile	3,360	1,400	1,400
Automobile			
MJ/vehicle km	0.777	0.772[a] 0.420[b]	0.654
Btu/vehicle mile	1,178	1,171[a] 637[b]	922[k]
Automobile weight			
kg	1361	1633[l]	1633[l]
lb	3,000	907[m]	907[m]
Bus			
MJ/vehicle km	2.250	0.675	0.058
Btu/vehicle mile	3,413	1,024	1,024
Service life			
BART vehicle			
km	2 000 000	4 800 000	4 800 000
miles	1,250,000	3,000,000	3,000,000
Automobile			
km	160 000	180 000	180 000
miles	100,0001	112,500	112,500
Bus			
km	480 000	1 600 000	1 600 000
miles	300,000	1,000,000	1,000,000

TABLE 3 continued

	Boyle	Lave	Usowicz and Hawley
Asphalt in freeway (tons)	8,776	–[i]	–[i]
Calorific energy of asphalt (million Btu/ton)	37.1	–[i]	–[i]
Station operating energy (% of total energy)	24[h]	(Included in operating energy)	(included in maintenance energy)
Parking spaces needed in CBD	17,885	–[i]	17,550
Cost per space ($1963)	2,265	–[i]	2,265
Parking garage energy factor ($1963)			
MJ/dollar		–[i]	69
Btu/dollar	65,400		65,400
Highway capacity (buses/lane hour)	600	1,200	1,250

[a] Current.
[b] Future.
[c] 1974 dollars not corrected to 1963.
[d] In 4 peak hours.
[e] Cost for 28.7 urban lane km.
[f] Cost for 169.7 suburban lane km.
[g] Weighted cost.
[h] Propulsive energy is 71 percent of total.
[i] Not addressed.
[j] Derived from section 15.
[k] Based on 1361 kg weight.
[l] Per 3,600 lb—current.
[m] Per 2,000 lb—future.

ENERGY IMPLICATIONS OF RAIL TRANSIT CONSTRUCTION

The wide disparity in overall energy costs calculated by different methods needs to be emphasized. Lave indicates that a rail transit system such as BART is much more energy intensive than a comparable freeway alternative. The results of this paper indicate that both alternatives are roughly equal in terms of annual energy costs. Usowicz and Hawley show BART to be much more energy efficient than the freeway alternative. The differences in results may be found in the assumptions employed, as indicated in Table 3. In almost every case energy factors and assumptions used by Usowicz and Hawley are more favorable to BART than those used in this analysis. On the other hand, Lave's assumptions tend to be less favorable to BART. Although many differences between this paper and Lave's analysis are revealed in Table 3, the key differences can be summarized as follows:

- Lave incorrectly applies an energy factor based on 1963 dollars to a cost expressed in 1974 dollars; the analysis in this paper converts all costs to 1963 dollars. Lave's defense of this facet of his analysis is not convincing.
- Actual fiscal year 1981 BART ridership was taken from the UMTA Section 15 report and was somewhat higher than that used by Lave.
- Lave does not take into account vehicle maintenance energy, nor does he consider the energy costs of additional parking structures required in the CBD under the freeway alternative.
- Lave overestimates the service life of vehicles, which affects the calculations of vehicle manufacture energy.
- The highway capacity figure of 600 buses per lane hour is based on observed traffic flows; Lave's figure is twice as high.

In addition to these differences, there is a major difference in the format used to present the results. Lave calculates the payback period, which may not be appropriate in comparing alternatives with different service lives. This analysis uses annualized energy costs, which take service lives into account, and thus provides a clearer idea of relative energy costs.

The results of this analysis do not support the belief that construction of new rail transit systems wastes energy. Using reasonable assumptions and Lave's approach, it has been shown here that the annualized energy cost of BART is only 3.6 percent higher than that of a freeway alternative. Others may fault the assumptions used here or argue that further energy considerations are needed. Trips induced by BART have not been considered here; use of the car left at home and the effects of rail transit on automobile ownership also have been ignored.

Excluding induced trips from the analysis was also a simplifying assumption made by Lave, who pointed out the difficulty in separating trips induced by normal mobility of people (who did not formerly make "this trip," but did make a similar trip from their previous location) from trips induced by BART (2). In Pushkarev and Zupan's analysis, reduction in the level of automobile ownership related to the availability of rail transit strongly affects their findings concerning the energy efficiency of rail transit (8). It is difficult to gauge the extent to which automobile ownership has been reduced; Pushkarev and Zupan use data from New York City and Long Island, which may not be transferable to San Francisco or to other areas. To balance this omission, use of the car left at home is also not considered.

Pushkarev and Zupan also claim that generalizations concerning the energy efficiency of rail transit should not be based on BART, because BART's reliance on complex technology has resulted in unusually high energy costs (8). Although it is difficult at present to evaluate this claim, new rail transit construction in Washington, D.C., Atlanta, Baltimore, and other cities will broaden the existing data base and provide a stronger foundation for energy analysis of rail transit systems.

The reputation of rail rapid transit has been damaged by its adherents who have overstated its contribution to energy conservation. The findings here agree with those of the Congressional Budget Office report and a previous New York State Department of Transportation study of transit's role in an energy-saving effort (3,21). A rail transit system is not the answer to an energy crisis; however, this is not the same as saying that construction of a rail transit system wastes energy. In reaction to the failure of transit to meet the extravagant claims made for it, conventional wisdom has swung too far in the opposite direction. The Congressional Budget Office report stated that slight variations in assumptions could lead to a conclusion that the energy impact of rapid rail transit system does not have clear-cut advantages or disadvantages in terms of energy consumption. Further studies on other new systems are needed; meanwhile, the idea that new rail transit construction wastes energy should be discarded on the grounds of insufficient evidence.

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The Influence of the Price of Gasoline on Vehicle Use in Multivehicle Households

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ABSTRACT

Two-thirds of the households in the United States that own motor vehicles own two or more. Multiple vehicle ownership permits households to substitute travel by fuel-efficient vehicles for travel by inefficient vehicles in response to higher fuel prices. Travel demand equations were estimated for one-, two-, and three-vehicle households by using disaggregate data from a monthly diary of vehicle use from April 1978 to March 1981. Three individual equations and a combined equation for small cars, large cars, and trucks were estimated. Price and fuel efficiency elasticities were allowed to vary according to the type of other vehicle owned by the household. In response to a 25 percent increase in gasoline price, the model predicts a 5 percent decline in vehicle use, but only a 0.2 percent increase in overall fuel efficiency is due to shifts to smaller vehicles.

Consumer demand for gasoline and automobile use has been extensively studied, especially since the Arab oil embargo of 1973-1974. [A review of the literature on this subject through 1978 has been compiled by Greene (1).] Many of these studies have dealt with gasoline demand in the aggregate by using either single equation, dynamic adjustment models (2,3), or systems of equations representing the demand for vehicle travel and fuel efficiency (4-8). Mellman (9) has reviewed many of the significant studies of aggregate automobile travel demand. There is considerable literature on modeling travel demand by using disaggregate household data; however, it is primarily concerned with tripmaking and choice of travel mode rather than vehicle use and total vehicle travel (e.g., 10,11). Adequate survey data for disaggregate econometric analyses of household vehicle use have been collected only recently (12,13), and as a result a few disaggregate studies of household use of highway vehicles have been published (14-16).

Both Mannering (16) and Train and Lohrer (15) specifically consider the determination of vehicle use in households owning more than one vehicle. Mannering's model, estimated for two-vehicle households, includes use of the other vehicle as an endogenous right-hand side variable in each vehicle-use equation. This structure clearly requires simultaneous equation estimation techniques. Train employs the more traditional econometric approach of expressing quantities of travel consumed as a function of prices and income (and demographic variables). Although Mannering's equation system consists of two linear simultaneous equations for two unknowns, it could have been estimated in reduced form by nonsimultaneous techniques. From the perspective of the classical economic theory of consumer demand, demands for commodities such as travel are temporally simultaneous; yet equilibrium demand equations, as functions of prices and income alone, always exist (e.g., 17). This is the approach adopted in this paper.

Both Mannering and Train include the price of gasoline in their models as a component of a cost-per-mile variable. In the context of the household production theory of consumer demand, discussed below, this results in a commodity demand equation that is a function of commodity prices. As Pollack and Wachter (18) have demonstrated, it cannot be proven that such demand equations exist. The problem is the joint determination of commodity demand and commodity prices. Recognizing this, Train used an instrumental variable to represent cost per mile. Although this solution addresses the econometric problem of joint determination, it does not address the question of existence. Finally, both studies estimate a single equation for all vehicles owned by a household. That is, estimates of parameters are not allowed to vary across number of vehicles. In this study, miles traveled by different vehicles are considered to be different from, but closely related to, commodities and parameters; in particular the responses to gasoline price changes are allowed to vary.

The focus of this paper is on changes in household vehicle use in response to changes in the price of gasoline. Disaggregate data permit quantification of the substitution of travel in fuel-efficient vehicles for travel in larger, inefficient ones and the variation of the sensitivity of travel to cost as a function of the number and types of vehicles owned. Recent panel survey data collected from April 1978 to March 1981 afford an opportunity to explore the tendencies for U.S. households that own more than one vehicle to shift vehicle-use patterns as well as reduce total travel in response to higher fuel costs (13). The data used are almost ideally suited to this purpose because each fuel purchase is recorded for every vehicle owned by a household including the price paid, gallons purchased, and the odometer reading. This permits the estimation of miles traveled for each vehicle as well as actual, realized fuel economy.

The demand for travel is modeled in the context of household production theory as a produced commodity. For one-vehicle households it is possible to investigate the hypothesis that consumers respond to the commodity price (gasoline cost per mile) instead of the goods price (the price of gasoline, which controls fuel economy). For two-vehicle households a demand equation is estimated that allows the travel response to fuel costs to vary according to the nine possible household combinations of small cars, large cars, and trucks. Because of the small sample size, it was not possible to estimate a similar equation for a three-vehicle household; however, a reasonable, simplified version was developed.

The remainder of the paper contains sections on the household production approach and functional forms of the vehicle-use models; the results of ordinary least squares estimation of the model; and shifts in vehicle use and improvements in fuel economy in response to price changes.

THEORY

Michael and Becker (19) viewed households as deriving utility from commodities produced by them using purchased market goods (durable and nondurable) and labor. Their concept is used in this analysis. Households are assumed to maximize utility (u), which is a function of the commodity vector (z), subject to a constraint that full income (s) be spent. This can be represented by the Lagrangian

$$L = u(z) - \lambda[\sum_i (wt_i + \underline{p}_i'\underline{x}_i) - s] \quad (1)$$

where w is the wage rate, $\underline{p}_i$ the price vector, $\underline{x}_i$ the vector of market goods quantities, and t_i the labor time used in producing commodity i. First order conditions require that the ratio of the marginal utilities (MU) of two commodities (i and j) equal the ratio of their marginal costs (MC) in both time and money as shown by Equation 2.

$$\begin{aligned} MU_i/MU_j &= (\partial u/\partial z_i)/(\partial u/\partial z_j) \\ &= [w(\partial t_i/\partial z_i) + p_i(\partial x_i/\partial z_i)]/ \\ &\quad [w(\partial t_j/\partial z_j) + p_j(\partial x_j/\partial z_j)] \\ &= MC_i/MC_j \end{aligned} \quad (2)$$

The marginal costs are shadow prices of the commodities (which depend on the prices of market goods), the value of time, and the productivity of each in producing z_i.

Consider a household that produces travel using two different vehicles. If both vehicles travel at the same speed, then (hedonic aspects of travel aside) the time cost component of marginal cost will be the same for both. Assume that vehicle 1 is more fuel efficient than vehicle 2 and that all other things are equal. Then

$$p(\partial x/\partial)_{z_1} < p(\partial x/\partial_{z_2}) \quad (3)$$

where z_i (i = 1 or 2) represents travel by the respective vehicle, x is fuel consumed, and p is the price of fuel. From Equations 2 and 3 it is clear that if the price of fuel increases between time periods, $P_{t+1} > P_t$, then

$$(MC_{1,t+1})/MC_{2,t+1}) < (MC_{1,t})/(MC_{2,t}) \quad (4)$$

and the relative use of vehicle 1 should increase (assuming declining marginal utilities or increasing marginal costs of travel for each vehicle).

In one-car households options are more limited. Vehicle use can be reduced or another mode of travel (e.g., walking or mass transit) can be substituted for personal vehicle travel. The ability to substitute may depend on location more than any other factor.

In three-vehicle households the opportunities for vehicle substitution are more complex. The sample size, which is only one-fifth of that for two-vehicle households, proved to be a serious limitation to exploring vehicle-use patterns in three-vehicle households. However, a model with a simplified characterization of vehicle holdings was reasonably successful.

Variables included in the models were gasoline price, own and other vehicle fuel economies in miles per gallon (MPG), household income, number of drivers, age of the vehicle (years), location (within city limits of city of 50,000 or more, outside city limits of city of 50,000 or more, or rural), quarter of the year, and region (the nine Bureau of the Census regions were used). The fuel economy assigned to a vehicle was average MPG over the entire survey period. Thus simultaneity between MPG and vehicle use was not a problem. No information was available on the division of income into wage and nonwage sources.

All models were estimated using the logarithms of all variables except age of vehicle. This formulation implies constant elasticities but exponentially declining use over time. For all vehicle ownership levels, separate equations were estimated by vehicle type (small, large, or truck) to facilitate analysis of response of vehicle use to higher fuel prices. An alternative model, which uses the translog utility function, has been applied by Aigner and Hausman (20) to disaggregate data on the use of electricity. Their formulation would require expressing gasoline price in terms of cost per mile for each vehicle. Three vehicle classes were formed by aggregating the Environmental Protection Agency (EPA) classes of vehicle size. Compact and smaller cars were considered small; larger than compact, large. Standard-sized pickup trucks, vans, and recreational vehicles were combined in the truck category, but minipickups were considered to be small cars.

RESULTS

All equations were estimated by calculating ordinary least squares regressions. The GLM procedure of the 1979 SAS User's Guide (21) was used throughout except in testing the price and MPG coefficients restriction, for which the SYSREG procedure was used. The fuel purchase data were aggregated to monthly average, and each month for each household was treated as a single observation (a description of the data and data processing is available from the authors). The dependent variable was average daily travel for the month. The large number of households prevented the use of generalized least squares techniques and at the same time tended to make them unnecessary. Results for the one-, two-, and three-vehicle household models are described in turn. In the interest of conserving space, quarterly and regional dummy variable estimates have been omitted from tables. These are available from the authors on request.

Most of the single-vehicle households in the sample owned a large car. About half as many owned a small car and relatively few owned only a truck. As the data in Table 1 indicate, the estimates for most parameters are similar for the three vehicle types. The elasticity of gasoline price for large cars and trucks is 75 percent or more higher than for small cars. Households with large cars appear to respond to the cost of gasoline per mile of travel as evidenced by the equal and oppositely signed elasticities of gasoline price and MPG. If this condition were imposed as a constraint on each equation it would be rejected in all except the large car equation.

It appears that truck owners are overly sensitive to the price of gasoline. There does not appear to be an obvious explanation for this, although there is also no requirement that household travel depend on cost per mile. In the context of household production theory, cost per mile is the commodity price of travel (or at least part of it). As Pollack and Wachter (18) have shown, commodity demand equations in terms of commodity prices do not exist, in general. Essentially this is because the commodity price depends on exactly how the household chooses to produce the commodity and how much it produces. In the case of multiple-vehicle households, it is evident that the overall gasoline cost per mile of

TABLE 1 Coefficients for Travel Demand Equations: One-Vehicle Households

Vehicle Type	Intercept	Price	MPG	Income	No. of Drivers	Age	Urban	Suburban	R^2	N
Small car	6.540	−0.184	0.302	0.288	0.081*	−0.047	−0.167	−0.121	0.107	14,916
Large car	6.078	−0.328	0.316	0.250	0.267	−0.051	−0.162	−0.050	0.124	29,281
Truck	5.743	−0.435	0.301	(−0.080)	(0.062)	−0.068	−0.163	0.226	0.135	2,020
Combined	6.400	−0.294	0.307	0.251	0.198	−0.051	−0.165	−0.059	0.119	46,217

Note: Coefficients in parentheses are not statistically significant at the 0.05 confidence level for a two-tailed test. All other estimates are significant at at least the 0.01 confidence level except one, which is indicated by an asterisk.

travel depends on which vehicle the household uses to produce the travel. For single-vehicle households it may be that truck owners are more likely to carpool or shift to other modes of travel. Unfortunately the survey data are insufficient to test this conjecture.

The estimates for MPG elasticity are remarkably consistent across vehicle types. They suggest that, within a size class, a 25 percent more efficient vehicle would receive 7 percent more use, other things being equal. Travel appears to be inelastic with respect to income; in fact, income elasticity is not significantly different from zero in the truck equation. The number of licensed drivers in a household has little effect in the truck and small car equations but substantially more in the large car equation. The effect of vehicle age is quite consistent across vehicle types, indicating approximately a 5 percent decrease in vehicle use per year for cars and almost 7 percent for trucks. Finally, the use of vehicles of all types inside the city limits of a city of 50,000 or greater is 15 percent less than of vehicles in rural areas. The effect of a suburban location varies much more across vehicle types. Caution should be used in interpreting the truck estimate because of the relatively small number of households (as opposed to monthly observations) in the sample.

A pooled estimation, using dummy variables to represent the effects of vehicle size, looks similar to an average of the three individual equations. The combined equation indicates strongly that one-vehicle households respond to gasoline cost per mile in making vehicle use decisions. An F-test for equality of slope coefficients across the three vehicle types rejects the hypothesis of equality. This same result recurs in the two- and three-vehicle models.

The two-vehicle household model recognizes the ability of households to make relative changes in vehicle use in response to higher fuel prices by allowing the price and MPG elasticities to vary according to the type of the other vehicle. Once again separate small car, large car, and truck equations were estimated. Although the MPG elasticities are relatively constant across vehicle combinations, the price elasticities vary a great deal, and generally in an interpretable pattern (Table 2). In the one-vehicle household equations the price elasticity was lowest for small cars and higher for large cars and trucks. This result tends to hold for two-car households as well. Furthermore, the elasticity of gasoline price should be expected to increase as the size of the alternative car decreases (its efficiency increases). This also appears to be reflected in the results. With the exception of trucks, price elasticity is highest when a second small car is owned. Beyond that, it appears to make little difference whether the other vehicle is a large car or a truck. The truck equation is unusual in not following these patterns. The reason may be that in most cases when a household owns a truck, the other vehicle is a large car. Note that the other two price elasticity estimates are nonsignificant. Another possibility is that these results partially reflect real differences in the way households use trucks and cars.

Another distinctive aspect of these equations is the pattern of increasing household income elastic-

TABLE 2 Coefficients for Travel Demand Equations: Two-Vehicle Households

	Small Car	Large Car	Truck	Combined
Intercept[a]	5.756	5.784	5.663	5.617[b] 5.716[c] 5.722[d]
Gasoline price if other vehicle is				
Small	−0.161	−0.301	(−0.119)	−0.225
Large	(−0.058	−0.148	−0.228	−0.137
Truck	(−0.061)	−0.144	(−0.091)	−0.118
Own MPG if other vehicle is				
Small	0.284	0.417	0.356	0.343
Large	0.354	0.346	0.286	0.328
Truck	0.328	0.354	0.479	0.372
MPG of other vehicle	(−0.012)	−0.015	0.077	(0.004)
Income	0.050	0.130	0.230	0.114
Age	−0.062	−0.053	−0.063	−0.057
Number of drivers	0.223	0.277	0.251	0.255
Urban	(−0.032)	−0.111	0.082	−0.048
Suburban	0.088	(−0.009)	0.118	0.056
R^2	0.102	0.112	0.117	0.106
N	21,814	30,354	10,394	62,562

Note: Estimated values in parentheses are not significantly different from zero at the 0.05 confidence level using a two-tailed test.

[a]Quarterly estimates and estimates of eight regional dummy variable parameters have been excluded to conserve space (available from authors on request).

[b]Small.

[c]Large.

[d]Truck.

ity from small cars to large cars to trucks. Still, motor vehicle travel is decidedly income inelastic given vehicle holdings. Unlike the one-vehicle equation set, all equations appear equally responsive to an increase in the number of drivers in the household. Going from two to three drivers would increase the use of a typical vehicle by about 10 percent. Again, unlike the one-vehicle household equations, use appears to bear no simple or consistent relationship to location. Finally, the fuel economy of the other vehicle (MPG other) does not appear to be an important factor in determining vehicle use.

For three-vehicle households, twice as many price and MPG slopes would have been required to cover all possible vehicle combinations. Because only one-fifth as many observations are available and especially because the distribution of households among vehicle combinations is not uniform, this could not be done. Instead, the two other vehicles available to the household were classified according to whether one of the other vehicles was a small car. This is believed to be reasonable because most of the differences in coefficient estimates for the two-car equation appear to be based on a small car or other distinction.

The relatively large number of insignificant coefficients (Table 3) hinders interpretation of the individual vehicle type equations. The combined equation has only one insignificant coefficient, income, and is thus easier to analyze. Although it may appear that there are more than enough observations, actually most are monthly replicates from a much smaller set of households. The panel data cover 36 months. If the average household remained in the panel only one-half that time, then the 2,487 observations used to estimate the three-vehicle household truck equation may represent only a few more than 100 households. For these reasons only the combined equation results are discussed.

The three-vehicle model continues a trend evident in the one- and two-vehicle model results. As the number of cars per household increases, the importance of household income in determining use declines and the importance of the number of drivers increases. Indeed, income is statistically insignificant in the three-vehicle model. The importance of location is also diminished. The factors that appear to matter are number of drivers, vehicle age, fuel economy, price of fuel, and household fleet composition. Use of cars in households owning at least one alternative small car is almost twice as sensitive to fuel price changes as in households that do not. Thus, the results indicate substantial willingness to substitute cheap miles for expensive ones when the choice is available.

EFFECT OF GASOLINE PRICE ON VEHICLE USE

It is clear that higher gasoline prices would cause these models to predict reduced vehicle use overall and a shift away from larger cars and trucks toward smaller cars. The effect on gasoline demand would be twofold: (a) a direct reduction through less travel and (b) a reduction proportional to the improvement in fleet fuel economy brought about by the shift in use. The quantity of vehicle travel for each category for which there is a distinct price elasticity is needed to quantify these effects. Given this, the new total travel (T_t) can be computed as follows:

$$T_t = \sum_i T_{oi} \, (P_t/P_o)^{\alpha_i} \quad (5)$$

where (P_t/P_o) is the new-to-old price ratio, T_{oi} is the initial period traveled by category i vehicles, and α_i is the appropriate price elasticities. An average price elasticity for the given price change can be computed as follows:

$$\bar{\alpha} = \ln(T_t/T_o)/\ln(P_t/P_o) \quad (6)$$

where $T_o = \sum_i T_{oi}$. Note that $\bar{\alpha}$ is not constant but depends on the price ratio.

For vehicle miles the total vehicle miles of all vehicles in each ownership level is used--vehicle type category for the entire sample period. The corresponding total fuel use is used to compute efficiencies (these data are available from the authors on request). To give the reader a rough idea of proportions, 35 percent of the total vehicle miles is by small cars, 53 percent by large cars, and about 13 percent by light trucks. By ownership level, 37 percent of vehicle miles is by one-vehicle, 49 percent by two-vehicle, and 14 percent by three-vehicle households.

A 25 percent real price increase would cause a

TABLE 3 Coefficients for Travel Demand Equations: Three-Vehicle Households

	Small Car	Large Car	Truck	Combined
Intercept[a]	5.575	4.889	5.615	5.404[b] 5.302[c]
Gasoline price if at least one other vehicle is				
Small	(-0.242)[d]	-0.517	(-0.044)	-0.343
Otherwise	(0.001)	-0.316	(-0.095)	-0.185
Own MPG if at least one other vehicle is				
Small	0.445	0.311	0.119	0.319
Otherwise	0.420	0.441	0.404	0.413
MPG of second vehicle	(0.009)	(0.046)[d]	(0.026)	0.037
MPG of third vehicle	-0.066	(-0.037)	-0.167	-0.090
Income	(0.059)	(0.025)	(0.066)	(0.027)
Age	-0.061	-0.057	-0.074	-0.062
Number of drivers	0.327	0.341	0.352	0.321
Urban	-0.100	-0.078	0.167	(-0.028)
Suburban	(-0.058)	(-0.037)	0.122	(-0.005)
R^2	0.142	0.131	0.139	0.130
N	4,424	6,437	2,487	13,348

Note: Estimates in parentheses are not significantly different from zero at the 0.05 confidence level using a two-tailed test.

[a]Quarterly estimates and estimates for eight regional dummy variable parameters have been omitted to conserve space (available from authors on request).

[b]Small vehicle.

[c]No small vehicle.

[d]Significant at the 0.1 confidence level using a two-tailed test.

4.7 percent overall decline in travel for an average elasticity for that size increase of -0.216. Such a price increase, of course, occurred in consecutive years in 1979 and 1980. One-car households are most responsive to the 25 percent increase ($\bar{\alpha}$ = -0.284), whereas two-car households are the least responsive ($\bar{\alpha}$ = -0.158). Elasticity increases again for three-car households ($\bar{\alpha}$ = -0.246).

By vehicle type, large cars have the highest price elasticity ($\bar{\alpha}$ = -0.2786); small car use is only half as high ($\bar{\alpha}$ = -0.1314); and trucks fall in between ($\bar{\alpha}$ = -0.1931). Thus a price increase will have the effect of shifting travel away from large cars toward smaller ones. This will have subtle but estimable effect on the overall vehicle fleet fuel economy. The 25 percent price increase has the effect of increasing fleet fuel economy a mere 0.2 percent. This would be less than 5 percent of the total decline in gasoline consumption caused by the price change. Of course, the possibility that households may take other actions (e.g., greater tire inflation pressures and slower speeds) to improve vehicle fuel economies has not been discussed here. Apart from these, however, reduction in travel totally dominates shifts in fuel economy in terms of the amount of gasoline used.

SUMMARY

The household production theory of consumer demand has been used to specify estimable disaggregate equations for household vehicle use. Separate sets of small car, large car, and truck equations were estimated for one-vehicle, two-vehicle, and three-vehicle households by using panel survey data from April 1978 to March 1981. The results indicate a rough consistency between gasoline price and vehicle fuel efficiency elasticities for one-vehicle households. This result suggests that one-vehicle households may base decisions about use on the cost of gasoline per mile. For multiple-vehicle households this result breaks down as households indicate an inclination to substitute more efficient for less efficient travel. Although this practice may significantly improve fuel economy for some households, the overall effect is negligible. In response to a 25 percent price increase the model predicts a 4.7 percent decline in vehicle use and a 0.2 percent improvement in fleet fuel economy induced by a shift in use. The average price elasticity of all vehicle travel associated with a 25 percent price increase was calculated to be -0.216.

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Fuel Crises, Economic Uncertainty, and Outdoor Recreational Travel

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ABSTRACT

An assessment was made of the effects of fuel availability, fuel price, and general economic conditions on attendance at national parks. The findings indicate that American propensity for outdoor recreational travel is strong enough to withstand the challenge of fuel shortage or economic uncertainty. This study demonstrates the resilience of outdoor recreational travel patterns in the decade 1973 to 1982. The challenges of two severe fuel shortages in 1974 and 1979 and periodic recessions, most notably in 1981-1982, caused only momentary and inconsistent variations in the outdoor recreational travel patterns of the American traveling public.

The focus of this study was a sample of 35 national parks selected from the list of national parks included in "The Statistical History of the National Park System" and a parallel sample of state parks selected from nine states in different regions of the country. First, a procedure is presented for considering the potential associations between attendance figures and fuel availability, fuel price, and the economy. Second, an assessment is made of the findings of a series of regression analyses, pertaining to both the national and the state samples. Third, available origin and destination information is reviewed so that the possibility of substituting closer trips to state parks for longer trips to national parks can be considered. The findings are then summarized and assessments presented.

PROCEDURE

Attendance patterns at national parks are frequently regarded as a barometer of outdoor recreational travel (1). This is in part because of the availability of a relatively consistent source of comparable data. For energy-related studies national park attendance has the additional merit of representing the choice of long-distance travel. Because travel to national parks generally requires advance planning, such travel could be deferred in response to concerns about fuel availability, fuel price, or the economy. The existing body of literature on national parks is substantial. Most of it is concerned with predicting demand for particular attractors or particular parks; for example, Cesario (2) cites and assesses numerous studies that have constructed models that use measures of park attendance as dependent variables and a variety of influencing factors as independent variables. Burton (3) reviews recreational forecasting studies in both the United States and England, and Cheung (4) assesses outdoor recreation participation models. Cheung's model incorporated population size, accessibility, alternative opportunities, and attractiveness into a regression model. No attempt is made in this study to add to this body of literature. Instead this study seeks to provide an aggregate longitudinal analysis of the impact of fuel availability, fuel price, or the economy on park attendance (5) and examine the potential for state parks as alternative attractors. [McAllister and Klett (6) introduced the effects of alternative recreational opportunities into a gravity model which would predict demand, but does not assess such impacts in a broadly based analysis of travel patterns.]

The 35 national parks in the study sample were selected from the list of national parks included in "The Statistical History of the National Park System" provided by the U.S. Department of the Interior. All facilities designated as national parks, as distinguished from national monuments, national forests, or national recreational areas, were included. An attempt was made to update and amplify the data supplied by the Interior Department through direct contact with each of the parks. Aggregate figures for 1981 and 1982 were requested as was information on the state of origin of the visitors. About 15 parks were able to provide updated aggregate attendance figures, but only 5 supplied figures on the origin of visitors and even these data were not sufficiently consistent for a statistical analysis.

Parallel data on attendance at state parks were requested from and supplied by nine states. The states were selected for inclusion on the basis of the following criteria: either they were home states for a large number of travelers to those national parks supplying data on travelers' origins or they were states with a national park within their borders. In addition, an effort was made to include representation from states in different census regions of the country: the Northeast, the South, the Midwest, the Mountain States, the Southwest, and the Far West. The states included were Arizona, California, Colorado, Florida, New York, Ohio, Pennsylvania, Texas, and Virginia.

For each state both an urban park (one within an easy day's drive of a major city) and a rural park (requiring at least an overnight trip from a major city) were included. The expectation was that these state parks could serve as alternative but closer outdoor recreational trip generators. Travel to the more rural parks was expected to approximate the national travel patterns, whereas attendance at the more urban parks was expected to rise in years with fuel or economic crisis. Within each state the urban and the rural park that drew the largest number of attendees were selected. This was to ensure that these parks would be recognized by name and have attractiveness within their respective states.

Regression analysis was used to investigate the potential association between park attendance and fuel availability, cost, and the economy. To focus on explanations for relative changes in travel patterns, increase in park attendance was used as the dependent variable. This figure controlled for differences in overall attendance among parks and directed attention to relative changes in travel to the respective parks. The independent variables required a measure that would be reflective of fuel crises and a measure that would be reflective of economic conditions. The expectation was that the average daily supply of gasoline for each year would be a better barometer of fuel crises than the more elastic figure of gasoline price but both figures were obtained, the former from Statistical Abstracts and the latter from the U.S. Department of Energy monthly energy reports. Regressions were run using each variable independently.

Rate of unemployment was used as a rough surrogate for economic level, and it indicated considerable variation in the economy within the 10-year period. Unemployment for the individual states was used in association with the parallel studies of the state parks because of a need to reflect relative economic conditions at the travelers' place of origin. Unfortunately, there was no parallel consistent measure of the availability of gasoline at the state level. Controls in the form of the state or standard metropolitan statistical area (SMSA) population were also inserted into the regression equations as appropriate. [Bowes and Bloomis (7) have suggested the need to incorporate a correction factor for uneven population zones into the travel cost models developed by Clawson and Knetsch.] Because there was no way of identifying substitution of local travelers for distant travelers except where figures on origin of the traveler were supplied, these population figures provided a rough indicator of the potential for such substitutions.

Most studies of this type also include some measure of the intangible quality of park attractiveness (8-10), such as the number of park acres, hiking trails, and so forth. However, with a diverse set of parks including beaches as well as mountain camping locations, numbers of such attributes would be inappropriate. Consequently, as a rough measure of park attractiveness, this study used an index of park recognition that was based on an international travelers survey (11). It was assumed that parks recognized abroad would also be recognized attractors within the United States. In the survey sponsored by the U.S. Travel and Tourism Administration in the fourth quarter of 1982, international air travelers were asked to identify their specific destinations. The recognition index was constructed as follows:

- Park mentioned by fewer than 100 international travelers was assigned a value of 1.
- Park mentioned by 100 to 5,000 international travelers was assigned a value of 2.
- Park mentioned by more than 5,000 international travelers was assigned a value of 3.

More index points would have generated groups too small for manipulation in what was already a relatively small number of parks. This index places such well-known parks as Grand Canyon, Yellowstone, and Yosemite in the highest category as indicated in Table 1. The expectation was that economic levels and fuel crises would have a minimum effect on determination to visit such parks. What the study indicated, however, was that the recognition index was not a consistent indicator of attendance at national or state parks in general.

TABLE 1 Recognition Index for National Parks

Park Name	Index Value	Park Name	Index Value
Arcadia	1	Isle Royale	1
Arches	1	Kings Canyon	1
Badlands	2	Lassen Volcanic	1
Big Bend	1	Mammoth Cave	1
Biscayne	1	Mesa Verde	1
Bryce Canyon	2	Mount Rainier	1
Canyonlands	1	North Cascade	1
Capitol Reef	1	Olympia	2
Carlsbad	1	Petrified Forest	2
Crater Lake	1	Redwood	2
Everglades	2	Rocky Mountains	2
Glacier	1	Sequoia	2
Grand Canyon	3	Shenandoah	2
Grand Teton	1	Theodore Roosevelt	1
Great Smokies	2	Wind Cave	1
Guadalupe Mountains	1	Yellowstone	3
Hot Springs	1	Yosemite	3
		Zion	3

FINDINGS

As indicated earlier, a series of regression programs attempted to establish an association between variation in attendance at parks and the indicators of a fuel crisis or economic uncertainty. A quick overview of attendance figures at the national parks showed considerable declines in attendance coinciding with the fuel crisis years of 1974 and 1979 and with the economic downturns in 1975 and 1982. Eighty-three percent of the national parks registered declines in 1979, 73 percent in 1974, and 51 percent in 1977. Of those parks providing data for 1982, 90 percent reported declines in attendance.

Relationships between these variables proved to be insignificant, however, when the parks were viewed in the aggregate in terms of a regression equation. A model using increase in park attendance as the dependent variable and fuel barrels available, unemployment rates, and local population as

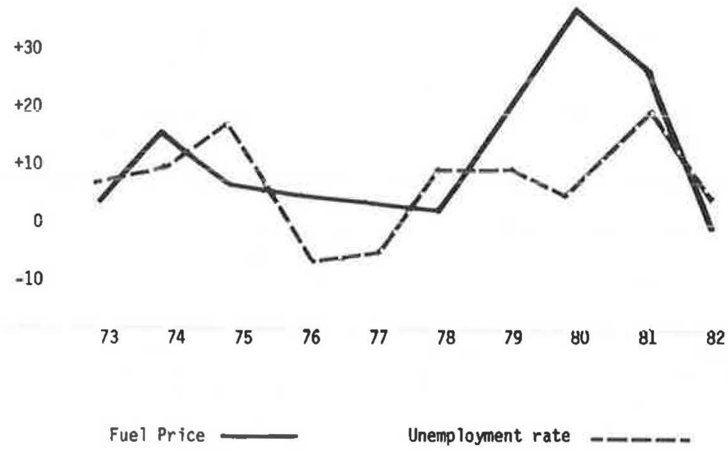

FIGURE 1 Relative increase in fuel price and unemployment rates by year.

independent variables generated an R-square value of only 0.02. For the state park sample, the same model generated only a slightly higher R-square value of 0.119. Substituting fuel price for barrels of fuel as a measure of the fuel crisis generated even lower R-square values: 0.002 for the national sample and 0.015 for the state sample, and eliminating the population figure reduced the R-square value even more.

The model was also tested by substituting changes in fuel price and unemployment rates. It was hypothesized that the traveling public might respond more to the degree of change in fuel prices and unemployment rates than to the actual numbers. The resulting R-square values were similar to those indicated previously: 0.03 for the aggregate national park sample and 0.19 for the aggregate state park sample.

A separate regression for 1979, the year with the highest percentage of decreases in park attendance, continued to yield a very low R-square value (0.06). The estimate for the intercept was 747.9 with the estimates for fuel barrels available, unemployment rates, and local population at -0.31, 43.38, and -0.01, respectively. The directionals did confirm that a decrease in fuel supply and an increase in the unemployment rate were associated with the decreased park attendance in 1979, especially where there was a lower local or state population. The F-value for the equation was, however, only 1.19--insignificant at even the 0.25 confidence level.

As Figure 1 shows, the years with the greatest increase in automobile fuel prices did not coincide with those years with the greatest increase in unemployment rates. In order to control for the possibility that the effects of one type of adverse conditions were offset by improvements in the other, individual models were developed for increases in fuel prices and increases in unemployment rates. Again, both models indicated insignificant levels of association with changes in park attendance. The correlation of changes in park attendance with changes in unemployment rates netted an R-square of only 0.04 while that associating increases in park attendance with changes in fuel prices was even lower, -0.02.

Further investigation led to an attempt to apply the model to the attendance records for each park individually. The results of this analysis indicated considerable variation among the parks. Although the model was significant at the 0.1 confidence level and produced an R-square of 0.81 for Hot Springs, Arkansas, for example, it continued to be insignificant in explaining changes in the attendance at a number of other parks. The R-square values for the model when population of the host state was included and when it was removed are indicated in Table 2 (national parks) and Table 3 (state parks). The data in both tables clearly indicate the impact of local population on attendance. For states with large populations, such as California, the number of potential local visitors was far more significant than

TABLE 2 R-Square Values for National Parks Included in the Sample

Park	R-Square with Population, Fuel, and Unemployment	R-Square with Only Fuel and Unemployment
Arcadia, Maine	.02	.008
Arches, Utah	.05	.005
Badlands, S. Dak.	.03	.01
Big Bend, Tex.	.42	.42
Biscayne, Fla.	.64	.52
Bryce Cannon, Utah	.77[a]	.46
Canyonlands, Utah	.15	.14
Capitol Reef, Utah	.47	.17
Carlsbad Caverns, N. Mex.	.49	.49
Crater Lake, Oreg.	.04	.02
Everglades, Fla.	.87[b]	.50
Glacier, Wash.	.79[a]	.42
Grand Canyon, Ariz.	.67	.28
Grand Teton, Wyo.	.64	.64[a]
Great Smokies, Tenn.	.47	.27
Guadalupe Mountains, Tex.	.37	.36
Hot Springs, Ark.	.81[a]	.80[c]
Isle Royale, Mich.	.51	.50
Kings Canyon, Calif.	.11	.03
Lassen Volcanic, Calif.	.42	.20
Mammoth Cave, Ky.	.24	.20
Mesa Verde, Colo.	.56	.42
Mt. Rainier, Wash.	.35	.30
North Cascade, Wash.	.55	.51
Olympia, Wash.	.20	.14
Petrified Forest, Ariz.	.38	.34
Redwood, Calif.	.63	.20
Rocky Mountains, Colo.	.11	.09
Sequoia, Calif.	.62	.62[a]
Shenandoah, Va.	.09	.05
Theodore Roosevelt, N. Dak.	.52	.44
Wind Cave, S. Dak.	.12	.02
Yellowstone, Wyo.	.29	.22
Yosemite, Calif.	.20	.18
Zion, Utah	.15	.13

[a]Significant at the 0.1 confidence level.
[b]Significant at the 0.05 confidence level.
[c]Significant at the 0.025 confidence level.

TABLE 3 R-Square Values for State Parks Included in the Sample

Park	Rural or Urban	R-Square with Population, Fuel, and Unemployment	R-Square with Only Fuel and Unemployment
Yuma, Ariz.	R	.90	.73
Picacho, Ariz.	U	.38	.36
Roosevelt, Pa.	U	.48	.40
Pymatuni, Pa.	R	.83	.77
Humbolt, Calif.	R	.90	.34
Huntington Beach, Calif.	U	.21	.17
Pocahontas, Va.	U	.62	.46
Hungry Mother, Va.	R	.83	.33
Cherry Creek, Colo.	U	.71	.25
Lathrop, Colo.	R	.90	.89[a]
Tyler, Tex.	U	.35	.28
LBJ, Tex.	R	.67	.39
Fugh Taylor Birch, Fla.	U	.98[b]	.90
Myakka River, Fla.	R	.27	.21
Jones Beach, N.Y.	U	.61	.26
Walkins Glen, N.Y.	R	.37	.26
Houston Wood, Ohio	U	.34	.32
Lake Hope, Ohio	R	.96[b]	.53

[a]Significant at the 0.05 confidence level.
[b]Significant at the 0.025 confidence level.

either the measure for the fuel crisis or the economy. Understandably, out-of-the-way parks in states with lower population levels were affected more by national concerns about fuel and the economy.

A quick review of Table 3 (state parks) appears to support the expectation of differences between patterns of attendance in urban and rural parks. Rural parks appear to be affected much more by fuel shortages and the economy than the more urban parks, a finding that might suggest the substitution of a trip to a nearby recreational park for a more distant one. Yet, taken as a whole, the differences between urban and rural park attendance proved to be insignificant. This was true especially when local population was removed from the model.

Clearly differences in individual parks accounted for far more of the variability in attendance records than was indicated by the aggregate model. Attendance at individual national parks, such as Grand Teton, Hot Springs, and Sequoia, appears to have been more highly affected by national concerns about fuel and the economy than attendance at less well-known, remote parks such as Arcadia and Arches. Telephone discussions and notes from those responsible for data collection at the parks helped to confirm observations about the importance of concerns specific to a given park in determining attendance. Factors, such as reports of poor fishing, road construction, marketing campaigns, and the installation of new electronic counters, were used to explain changing attendance patterns at different parks.

As indicated previously, insufficient comparable data were available to allow an assessment of changes in attendance patterns of visitors to national parks or to determine whether the use of aggregate attendance figures masked the substitution of visitors from short distances for those from long distances. Nevertheless, some preliminary observations can be made from the information supplied by five parks: Rocky Mountain, Petrified Forest, Carlsbad Caverns, Capitol Reef, and Yellowstone. Although these parks were arbitrarily selected and, therefore, observation cannot be generalized, they do represent a fairly good cross section of the parks in the national park study. They are in five different states and include two parks ranked at 1 on the recognition index, two ranked at 2, and one ranked at 3.

Because information was supplied in different forms by these parks, a simplified common method of analysis was applied to all. Visitor index scores were constructed for each park for each year for which information was supplied, and the names of the five states supplying the greatest number of visitors were noted. A value of 1 was assigned to the host state of the park, 2 to a neighboring state, 3 to another state in the same region as the park, 4 to a state in an adjacent region, and 5 to a state across the country (12). These scores were then weighted to indicate the ranking of highest down to fifth highest number of visitors. The scores for the appropriate states were then multiplied by the weights and the total scores for individual years were obtained by adding the weighted state scores.

For example, in 1980 the highest number of visitors to Capitol Reef Park in Utah was from Utah; the second highest number of visitors was from California, a state in the region; the third highest number was from Colorado, a neighboring state; the fourth highest number was from Arizona, a state in the region; and the fifth highest number was from Florida, a state across the country. Therefore the total visitor index score was 34. The procedure for assigning visitor index scores is given in Table 4.

TABLE 4 Procedure for Assigning Visitor Index Scores

State Contributing Most Visitors	Index Value		Weight		Score
Utah	1	x	5	=	5
California	3	x	4	=	12
Colorado	2	x	3	=	6
Arizona	3	x	2	=	6
Florida	5	x	1	=	5
Total visitor index score					34

Higher scores indicated a greater number of visitors from distant states. When these visitor scores were compiled for each year for which information was supplied, the scores appeared to be remarkably consistent for each park.

- The scores for Capitol Reef were 34 in 1980, 33 in 1977, 33 in 1976, and 35 in 1975.
- For Petrified Forest the scores were 47 in 1982, 41 in 1981, 48 in 1980, and 48 in 1940.

- Rocky Mountain had scores of 39 in 1975, 1974, and 1953.
- Carlsbad Caverns had scores of 38 in 1979, 37 in 1968, 38 in 1964, and 40 in 1960.
- Yellowstone showed the greatest variation: 37 in 1981, 37 in 1980, 44 in 1977, and 52 in 1976.

Only Yellowstone showed any substantial substitution of more local for more distant visitors in recent years. Generally, the variation was minor, one state replacing a neighboring state in the list of the five states providing the highest number of visitors to a particular park. With so small a sample it is impossible to detect a general trend. Nevertheless, these observations do lend support for initial statements about persistent trends in travel patterns.

CONCLUSIONS

In general, the American traveling public appears determined to pursue plans to visit national parks despite the challenges provided by fuel shortages and economic uncertainty. A closer look at individual parks indicated that the impacts of such national concerns were more apparent at some parks than at others. Additional case studies would be needed to determine why attendance at some parks has been affected more than that at others. The recognition index used in this study proved to be inconclusive in providing explanations. It was true that parks with high recognition levels, such as Grand Canyon, were not affected significantly despite remote locations, but attendance at a number of less well-known parks also proved to be affected insignificantly.

Attendance patterns at state parks generally mirrored those of national parks rather than providing any clear indication that they became alternative closer destinations when travel to national parks was more difficult. State parks near cities did not generate significantly different attendance patterns from more rural parks when the model was controlled for local population size. Again, further study would be needed to explain why some state parks seemed to be more affected than others.

A study of this type can offer no proven explanation for the apparent resilience of outdoor recreational travel patterns. Several potential explanations, however, are suggested for further study.

It is possible that in times of fuel shortages the American traveling public will make alternative provisions for in-town regular trips, such as work or shopping trips, and reserve their automobiles for planned vacations or weekend trips to state parks (13). Where public transit or carpools are viable alternatives for daily travel, this type of tradeoff might well be feasible.

The national survey conducted in connection with the Third Nationwide Outdoor Recreation Plan offered further support for the findings of this study (14). The study indicated that expenditures for recreational participation have been affected less by inflation or recession than by other types of expenditures (15). The survey was conducted in 1977 after the first major increase in fuel prices and before the second. Respondents were asked whether the increase in price of gasoline had caused them to take fewer outdoor recreational trips. Fifty percent answered no, 47 percent answered yes, and 3 percent had no opinion. When asked whether the price of gasoline caused them to make shorter trips, 49 percent answered yes, 47 percent answered no, and 4 percent had no opinion. Changing travel patterns among 49 percent of the traveling public would indeed make a difference in attendance patterns, and it is true that for most parks attendance did decline in years of crisis.

One-half of the respondents, however, indicated that they had not made fewer recreational trips. This group would not have deferred a planned trip to a national or state park. The respondents to the national survey were also asked whether doubling the fuel price would affect their future travel to outdoor recreation. Eighty percent said that it would. However, despite a doubling of the gasoline price from $0.62 in 1977 to more than $1.20 in 1982, this study revealed little actual change in recreational trips, at least not in trips to national or state parks. The focus on relative increases or decreases in attendance by park indicated that even in 1979 the level of decrease was only significant for a few parks.

Further study would be needed to indicate whether there was an increase in use of city parks during the crisis years of the 1970s. Individuals who deferred travel to national parks also might have found that travel to state parks represented too great an expenditure of fuel or funds and may have substituted a visit to a city or regional park.

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The Scenario Analysis Process and Long-Range Transportation Planning

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ABSTRACT

An 18-month study of a prototype application of a scenario planning methodology for public planning is documented. The scenario technique is intended to address concerns about long-range planning in the light of uncertainties about the future by considering the interaction of a few key variables. By assigning values to each of the variables and considering their interaction, a panel of policy makers generates several hypothetical scenarios of the future that provide a context for considering directions for future public policy. The key variables were oil supply, economic activity, and technological change. The scenario process is described and a summary is given of the substantive findings. Also the value of scenario analysis as an adjunct to the ongoing, conventional transportation planning process is assessed.

It is fairly accurate to describe long-range transportation planning as a process that projects future conditions based on existing trends and implicit assumptions about the key interrelationships between transportation and other factors, such as land use or the economy. The projected future conditions describe a set of needs on which plans and programs are based. Of course, the problem with this conventional approach is that it breaks down when the future is not a neat extension of the present or when the assumed relationships are altered. This was illustrated by the energy supply disruptions of the 1970s, which created departures from expected trends in travel behavior and gave new importance to sets of interactions that had never before been given serious attention, such as the linkage between the demand for transportation and the ability of the government to finance transportation investments. The demonstration project conducted by the Baltimore, Maryland, Regional Planning Council from fall 1981 to spring 1982 was an effort to focus more attention on unexpected changes in energy and other conditions that have a significant bearing on transportation and to consider more fully the interactions among transportation, energy, and other matters of primary importance to the region.

The project used a planning technique called multiple scenario analysis, which has been used frequently by private industry and research groups to improve planning for an uncertain future. The process consists of examining the interaction of a limited number of key factors that are expected to have a fundamental influence on future needs. By assigning several plausible but widely differing values to the selected factors and combining them in different ways, several hypothetical pictures of the future can be derived. Individually, the alternative future conditions pose unique problems and demand individualized public responses; collectively, they are intended to encompass the full range of possible futures and assure that the planning process has addressed them.

In the Baltimore study, a group of officials from the public and private sectors examined four futures (called scenarios) that were typified by variations in (a) availability of energy for transportation, (b) economic conditions, and (c) commercialization of technology. The interactions of the key variables with regional conditions brought to light a number of transportation issues (some were already part of the conventional transportation planning process and some were new) that demanded consideration of new policy and program responses and suggested important linkages between transportation and other functional areas of the regional planning process. The intent of the study was to generate discussion of these new concerns and to consider public-policy options in response to them.

STUDY CONTEXT, THE BALTIMORE REGION

The Baltimore region lies in the lower portion of the northeast corridor, which includes Boston, New

York, Philadelphia, and Washington, D.C. The region is typical of these urban areas and shares the trends and problems commonly associated with them. Most notably:

- An older central urban core with surrounding suburban areas;
- Most trips oriented toward the city center but significant amounts of travel oriented to widespread suburban locations;
- A shifting of the employment base from heavy manufacturing to service and trade industries; and
- New growth directed toward suburban areas.

The Regional Planning Council (RPC) is an association of the governments of Baltimore City and the five surrounding counties. The planning community also includes the Maryland departments of Transportation (MDOT), Natural Resources, Health and Mental Hygiene, and Planning. The RPC staff conducts various federally mandated planning programs for the region in conjunction with MDOT and carries out programs in natural resources, land use, housing, and economic development.

PROJECT RESULTS AND FINDINGS

The primary intent of the project was to bring a new perspective to long-range transportation planning, particularly in relation to varying future conditions. The results of this concern were evidenced in several specific areas.

The Energy/Transportation Futures panel recommended a number of policies to the RPC and its committees for inclusion in the 1982 General Development Plan (GDP). Many of these policies were included; however, because the GDP must be approved by a wide range of public and private organizations, it is a conservative document, and some of the more innovative policies were not adopted. For example, the panel recognized that systematic reduction in maintenance of low-volume facilities might be necessary under certain conditions, but the GDP does not reflect that concept. Also, the panel suggested establishing a regional body to encourage new industry, which would be funded through tax-base sharing. This policy was not accepted for the GDP. These policies and others that were rejected were extremely controversial; however, they were considered in the formal deliberations and they have been stated for further consideration in the conventional planning process and greater attention in the work programs of the RPC and other planning agencies.

The major findings of this study on energy use in the transportation sector did not center on conventional conservation themes. Instead, the interactions of the key factors--oil availability, economic activity, and technological innovation--emphasized fundamental relationships that pointed to more far-reaching problem areas. For example, it was clear that with adequate oil supplies and healthy economic growth, there would be pressure for suburban expansion, little inclination to reduce fuel consumption, and reduced market demand for technologies that could reduce travel or increase automobile mileage. It was determined that under these conditions, the success of public conservation programs would be minimal and that more pressing needs would center on augmenting conventional transit to serve expanding suburban areas and adapting the transportation network to the changing needs of a growing industrial base. At the other end of the spectrum, a stagnant economy and chronic fuel shortages would automatically promote conservation, reduce fuel consumption, and sharply reduce the rate of suburban growth. This scenario would yield its own set of problems that would revolve around severe shortfalls in transportation revenue caused by reduced consumption, preclude adequate maintenance of the highway system, and make it impossible to meet growing demands on the transit system.

By establishing these long-term relationships among oil availability, economic conditions, development trends, and transportation revenues, the study provided a new perspective for long-term planning and a new context for the design of specific policies and programs to be developed through ongoing planning activities.

It is impossible to predict the degree to which this one-time project will have lasting influence on transportation planning or public decision making. The issues that emerged as most significant in the course of the study receive little or no attention in existing work programs. Thus, for the issues initially voiced during the scenario exercise to receive continued attention and further development, significant changes will be required in the substance of the existing planning process.

SCENARIO PROCESS

The broad objective of the study was to reassess the future needs of the region, not in traditional terms of a single future scenario extrapolated from current conditions but by considering a number of alternative scenarios, each having its unique set of public and private responses. For the outcomes of the process to have the most lasting effect, it was vital that the government officials who participate in the decision making be involved. Thus, a panel of 17 officials from local governments, state agencies, and private organizations was recruited and became the group around which the project was structured. The exercise was divided into three meetings.

First Panel Meeting

The panel's main task in the first session was to agree on a limited number of key factors (called independent variables) that were beyond the control of the region and that would have the greatest influence on the region, especially with respect to transportation, land use, and economic development.

The panel selected three variables and assigned them general values that might occur during the coming decade.

1. Availability of oil: plentiful, stable, and shortage;
2. Economic growth: vigorous, slow, and declining; and
3. Commercialization of technology: rapid and slow.

The first session also included initial discussions of how the key factors would interact and which future conditions would be most important in considering future regional needs and problems.

Before the second session, the staff arrayed the variables to form 18 cells (skeleton scenarios) and described the history of conditions in selected cells.

Second Panel Meeting

The major business for the second meeting was to select the cells to be studied in more detail. The scenarios agreed to by the panel are given in Table 1; they were

- Scenario 5, the Trend Scenario, was considered the most likely to occur.
- Scenarios 3 and 7, Decline and Growth, were selected to represent polar conditions that would demand extreme responses of public and private policy.
- Scenario 16 shifting to Scenario 10 in the middle of the planning period was designated Transition. This combined scenario was selected so that the panel could consider the actions necessary to respond to a major, prolonged interruption of fuel supply.

The remainder of the second session focused on a discussion of other conditions in the region that could be influenced by regional actions (called dependent variables) that could be taken in each scenario. The major scenario-dependent variable interactions perceived by the panel are given in Table 2.

Finally, the panel discussed the policies that would be most appropriate to address the problems suggested by the scenarios and dependent variables. For the most part, the suggested policy actions reflected the previous discussion, but the panel

TABLE 1 Comparison of Significant Trends from Each Scenario

Scenario 3: Decline	Scenario 5: Trend	Scenario 7: Growth	Scenarios 16 and 10 Combined: Transition
Energy Use			
High prices and depressed economy reduce consumption.	Increased automobile efficiency reduces fuel consumption.	Stable prices and high levels of economic activity prevent significant reductions in consumption.	High levels of demand before interruption. Sharp reductions forced by shortfall.
Economy			
All segments of industry operating at depressed levels. Unemployment is most severe for blue-collar and semiskilled work force.	Slow economic growth. Unemployment is most severe for blue-collar and semiskilled work force.	Infusion of medical and technical light industry; some revitalization of heavy industry through plant modernization. Unemployment for blue-collar and semiskilled work force is stable.	Comparable to conditions in Growth Scenario with no protracted change following the fuel interruption.
Transportation			
Demand: Automobile travel decreases, transit and paratransit increase, coal and grain exports rise. Supply: No expansion, investment in the highway system declines, transit service cutbacks.	Demand: Automobile travel grows as a result of more nonwork trips, little change in transit and paratransit use, coal exports increase. Supply: Little expansion, investment in the highway system declines, transit cutbacks.	Demand: Automobile travel grows as a result of suburban growth and more nonwork trips, transit ridership declines with suburbanization, little change in paratransit, port tonnage and rail volumes decline as light industry assumes high portion of industrial output. Supply: Competition for funds between expansion and maintenance of the highway system, transit cutbacks.	Before interruption: Similar to Growth Scenario. After interruption: Sharp rise in coal exports, reductions in nonwork trips, sharp, temporary increases in transit and paratransit.
Government Revenue			
Sharp declines in MDOT revenue, further eroded by high inflation rates. Local government revenues decline. Reduced federal assistance.	Slow declines in MDOT revenue. Constant local government revenue. Reduced federal assistance.	Stable MDOT revenues. Modest increases in local government revenue. Reduced federal assistance.	Before interruption: Similar to Growth Scenario. After interruption: Sharp drops in MDOT revenues with slow recovery through the remainder of the period.

TABLE 2 Major Scenario-Dependent Variable Interactions

	Impact on Dependent Variable	
Independent Variable	Primary	Secondary
Oil availability and economic growth		
Plentiful and rapid	More rapid suburbanization Increased travel	Increased need for paratransit to supplement conventional transit Increased transportation revenue
Shortage and slow	Slower suburbanization Reduced travel	Increased demands on conventional transit Reduced transportation revenue
Economic Growth		
Rapid	Increased share of growth industries (service, technical)	Labor force training to match new industry needs Reduced port and rail volumes; increased airport and truck volumes
	Public infrastructure needs in suburban locations	
Slow	Declines in manufacturing	Labor force training of displaced blue-collar workers Underutilized rail and port capacity Reduced transportation revenues
	Increased need for public infrastructure to attract new industry	
Technology		
Mini cars	Need for new highway configurations	
	Reduced fuel consumption	Reduced transportation revenue
Telecommunications	Reduced travel	Reduced transportation revenue

also indicated an interest in promoting alternative fuels and developing energy contingency planning.

Before the final meeting, the staff wrote detailed scenarios based on the previous panel sessions. Also included were suggested policies and their effects on the problems and needs posed by each scenario. The panel was asked to review this material before the final meeting. Figure 1 shows a comparison of the major elements of the scenarios.

Third Panel Meeting

The third session was devoted to identifying policies that would respond to future regional needs as represented by the scenarios. The staff proposals from the written scenarios served as a basis for the panel discussion. The panel generated a large number of different potential policies. The following policies received the most attention:

1. Transportation policies
   - Conventional public transit must be considered in relation to paratransit and privately sponsored transportation programs.
   - The port and airport are dependent on adequate landside distribution and delivery systems; therefore railroads and highways must be an integral part of port and airport planning.
   - A complete halt in construction of new transportation facilities is unacceptable under any set of future conditions.
   - A regional sales tax should be implemented to fund transportation improvements.
2. Energy policies: Further study of the use and conservation of energy is needed regardless of future conditions.
3. Land development policies: Promotion by the government of centralized development and residential areas located near work is desirable; but crime, quality of schools, and racial distributions are probably overriding factors in choosing a location.
4. Economic development
   - A regional agency should be formed to coordinate efforts to attract new industry.

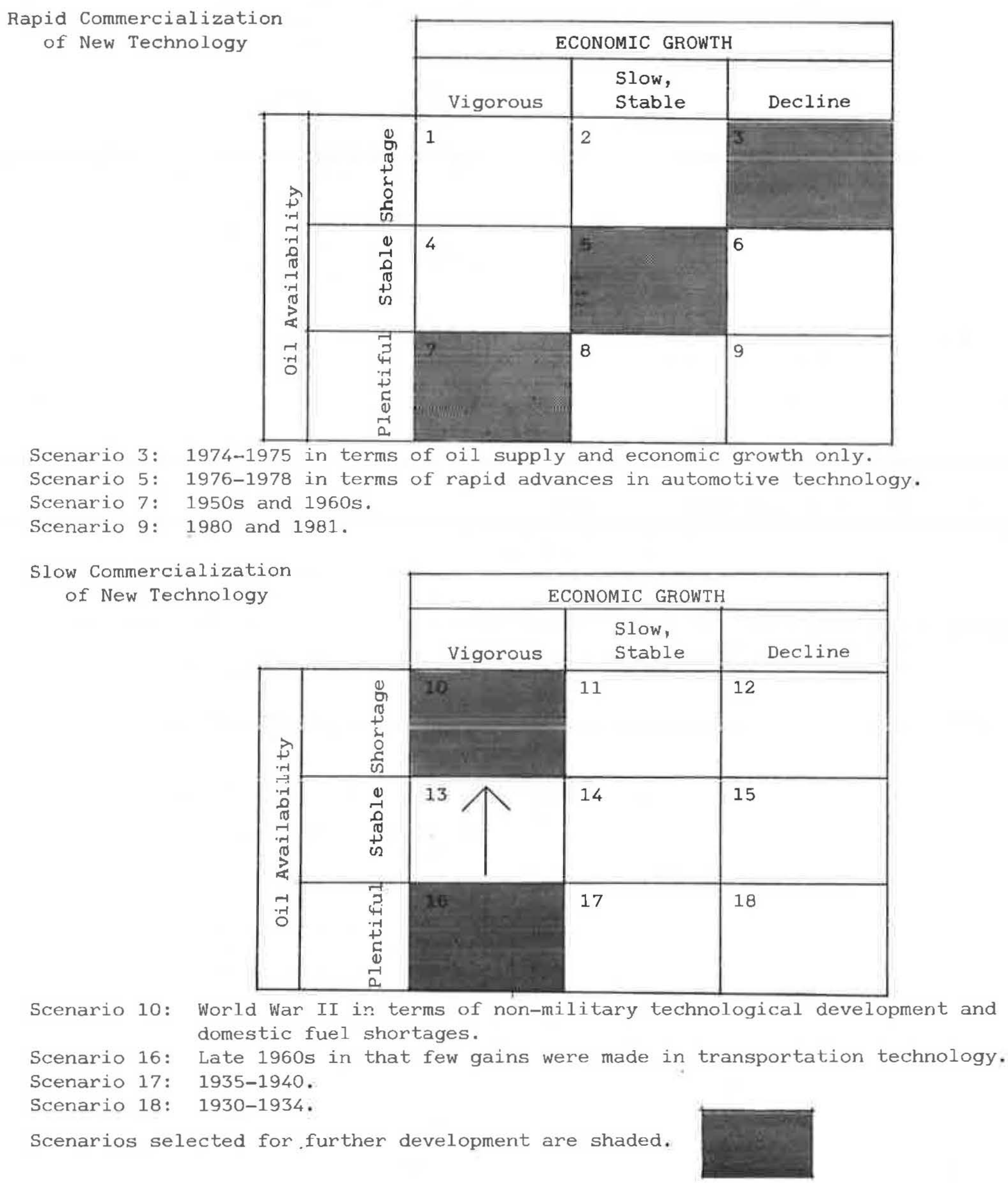

FIGURE 1 Scenario matrix.

Tax-base sharing is a potential means of pooling resources and sharing benefits of a regional approach to economic development.
- Unskilled labor and unemployed youth will be a major problem under any set of regional conditions.
- In the coming decade a joint effort by government and the private sector will be required to retrain a labor force.

Following this session, the staff prepared revised policy statements that were mailed to the panel for final review. The panel was also asked to indicate which of the policies could be recommended for the 1982 General Development Plan and which should be the subject of further study.

The final policy recommendations were presented to appropriate subcommittees of the Regional Planning Council for approval before they were included in the General Development Plan.

THE STUDY AND ONGOING PLANNING ACTIVITIES

As was the intent, the scenario exercise delved into concepts and substantive issues that are not usually covered by conventional planning. The most important of these is that the future is not necessarily an extension of the present and that existing programs and policies may not be appropriate for the future. Those concepts and the specific, substantive results of the study depart sharply from the current approach and substance of transportation planning.

Because the study concepts are innovative, they cannot be easily embraced by the conservative, well-established planning procedures and decision-making process. In practice such a change would require major changes in agency work programs that would allow a more flexible agency response to uncertain and constantly changing needs and in the attitude of decision makers to new and controversial policies.

The panel was largely comprised of individuals who will continue to be influential in policy and program development and can be expected to support the methodology and results of the futures project. Their support is essential to any substantial realignment of the planning process or change in transportation decision making. It remains to be seen whether the influence of this group will be sufficient to alter the firmly entrenched practices of the existing planning framework; therefore, the long-term benefits of scenario analysis in this context remain uncertain at this time.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.

Incorporation of Energy Analysis in the Transportation Improvement Program Process

NATHAN S. ERLBAUM and WILLIAM C. HOLTHOFF

ABSTRACT

The New York State Department of Transportation in cooperation with the Genesee Transportation Council (the metropolitan planning organization of Rochester, New York) studied ways to incorporate energy conservation in urban transportation planning and project decision making. The study evaluated the energy impact of 92 proposed transportation projects, described these findings to local officials, and examined the impact of this information on project selection.

In 1980 the transportation sector used approximately 56 percent of the nation's petroleum, and more than 97 percent of the energy used in transportation was petroleum based. Clearly, reductions in the use of energy by the transportation sector would help reduce the nation's use of petroleum and its dependence on foreign oil.

At the state and local level, limited progress has been made to incorporate concerns about energy into the urban transportation planning and project decision-making process. To investigate ways to increase concerns about energy at this level, the New York State Department of Transportation (NYSDOT) and the Genesee Transportation Council (GTC) (the metropolitan planning organization of Rochester, New York) jointly assessed the energy implications of the proposed 1983-1988 Rochester Transportation Improvement Program (TIP). (TIP is a federally mandated compilation of all transportation projects and expenditures planned for a region.) The purpose of the study was to

1. Determine the energy savings and energy costs (of construction) for all projects to be included in the 1983-1988 TIP.
2. Use these results at various points in the local area's process for setting project priorities.
3. Assess the effectiveness of the procedures, both technical and administrative.

To accomplish these goals, the study group (a) developed analysis tools for those projects for which current methods are weak or are not available; (b) monitored key energy-use and travel indices for the Rochester area; and (e) sketched future energy use in the area, accounting for the long-range plan, changes in car efficiency, employment, and population.

BACKGROUND

The Rochester, New York, metropolitan area is situated on Lake Ontario in western New York State. The area contains 1,085,000 people and 381,400 households and is basically circular shaped and focused on a strong downtown. The employment base is broad and oriented toward high technology.

Transportation planning in Rochester has followed a traditional pattern. Presently planning is conducted by a number of separate agencies, including the state DOT, GTC staff, the City of Rochester, Monroe County, the Rochester-Genesee Regional Transportation Authority, the Genesee-Finger Lakes Regional Planning Council, town planning boards, and so forth. Each of these agencies has a particular role in the overall process that is basically related to specific transportation facilities.

Smaller-scale projects usually follow a 3-year process that involves planning (alternatives analysis and consideration of all appropriate issues), design, and implementation. These are usually done by a single implementing agency, the one responsible for the system being studied. Larger-scale projects involve more participants throughout the entire process. Many require an environmental assessment and take 5 to 10 years to complete. The reduction in available funding in recent years has led to an increase in the number of short-range (1 to 5 year) solutions to transportation system problems. Funding has been spent more on rehabilitation and preservation of the existing system than on major expansion.

In evaluating projects, each agency follows the same basic steps:

1. Identify transportation problems. Establish system goals, define problem types, and monitor the transportation system or problem locations.
2. Rank problem sites. All the problem sites identified are ranked by priority, regardless of the type of problem.
3. Develop alternatives. For each problem, a number of alternative solutions, including the null, are identified.
4. Select the preferred alternative for each problem site. This is primarily based on economic efficiency or related factors.
5. Rank proposed projects in terms of priority. All selected projects are ranked by priority.
6. Apply funding constraints. Select those projects that best achieve area goals within the available budget.
7. Produce a final capital program (or TIP), organizing projects by funding category, along with more detailed narrative descriptions.
8. Implement the project. The capital project is constructed or acquired.

PLANNING

Energy planning in the Rochester area has taken the form of a series of responses to perceived crises in the availability of energy. At present, emergency energy planning focuses on the ability of the Rochester transit system to respond to an energy emergency by scheduling supervision and deploying radio-directed vehicles. The completion of the energy element of the Monroe County Comprehensive Plan is expected by mid-1983. Overall the planning process in Rochester is modally partitioned, project oriented, and well structured institutionally. In this regard it parallels the process in many other metropolitan areas.

METHODS

Based on past TIPs, a list was prepared of possible projects that implementers might propose for inclusion in the GTC 1983 to 1988 TIP. The projects listed were not only those required by federal regulations to be included in an approved TIP but also all projects in the GTC planning area that were expected to be programmed for implementation between 1983 and 1988. These additional projects are included in the GTC TIP for information purposes and to present a more complete picture of planned transportation improvements in the area. Basically, all projects contain the following components for which an energy evaluation may be necessary:

1. Vehicle or User
   - Traffic. The energy associated with changes in traffic flow speed, detours, improvements in capacity of the roadway, and so forth that change the way a vehicle is driven on, or in proximity to, the project location.
   - Pavement. The energy associated with vehicle operation that results from improvements to the pavement wearing surface or changes in speed that result from such surface changes.
2. Construction
   - Highway. The energy associated with construction activities related to the construction or rehabilitation of the roadway.
   - Structure. The energy associated with construction activities related to the rehabilitation of structural components (e.g., bridges and culverts).

The following sections describe more specifically the methods for each of these component- and project-type evaluations.

Vehicle or User Energy

Vehicle energy consumption was evaluated by the following dimensional relationship:

$$\text{Energy} = \text{AADT} \times \text{project length} \times \text{dpy} \times \Sigma_i \text{ vehicle type}_i \times \text{gpm}_i$$

where

AADT = annual average daily traffic;
Vehicle type_i = share of automobile, light trucks, heavy trucks ($i = 1,2,3$);
gpm_i = gallons per mile for each vehicle type, adjusted for the efficiency improvements for the model and year of the vehicle, speed and flow condition (free flow or stop-and-go), and grade;
Project Length = length of the project in miles; and
dpy = days per year (330 or 365).

Construction Energy

Estimates of energy used for roadway, structural, and other construction-related components were converted into equivalent gallons of gasoline by

1. Adjusting the component cost estimate to 1980 dollars, using the gross national product (GNP) implicit price deflator;
2. Multiplying the 1980 cost estimate by the appropriate construction action conversion factor [in British thermal units (Btu) per dollar] (1-4);
3. Dividing the Btu's obtained in Step 2 by 125,000 to convert the energy into equivalent gallons of gasoline; and
4. Dividing the component energy consumption by the corresponding service life to obtain annual energy estimates.

The energy analysis methods used for each of the project types contained in the GTC TIP are summarized in the three sections that follow.

Pavement Projects

The computations for vehicle energy were similar to those noted previously. Improvements to a pavement's structural condition may affect automotive fuel consumption in two additional ways:

1. Directly, through improved smoothness, which reduces rolling friction and variation in vehicle operation and
2. Indirectly, through a change in vehicle speed.

Existing literature is not definitive on the magnitude of the impact of road conditions on fuel consumption. The values range from a 30 percent increase in fuel consumption for a very rough, potholed road compared with a smooth pavement (5) to no change (6); it is believed that the latter finding was due to a defect in the design of the experiment. Currently the accepted value is a 1.5 percent increase in fuel consumption for a road rated at a pavement service rating (PSR) of 4.5 compared with a rating of 1.5.

Both changes are small; however, the change in fuel consumption that is attributable to smoothness is consistent over the whole range of PSRs (i.e., as condition improves fuel consumption drops). The change in fuel consumption that is attributable to speed has a saddle point between 25 and 35 mph (depending on the vehicle mix). Fuel consumption increases with improving pavement condition for speeds higher than the saddle point and decreases with improving condition for speeds below the saddle point. These peculiarities are due to the shape of the fuel consumption-versus-speed curve shown in Figure 1.

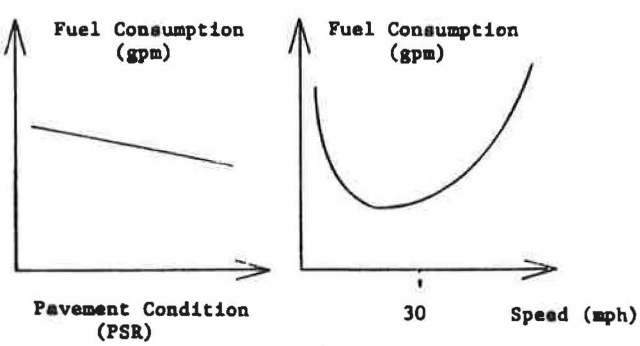

FIGURE 1 The effects of pavement condition and roadway speed on fuel consumption.

Construction components of pavement projects are evaluated as described earlier by selecting the appropriate Btu-per-dollar factor for each of the pavement actions undertaken.

Bridge Projects

Computations for vehicle energy were similar to those already noted. However, because the possibility exists that the bridge might have to be closed if unattended in its present condition, a more specific analysis was used to assess the change in energy used by vehicles during total or modified bridge closings.

1. AADT was separated into the three major vehicle components (cars, light trucks, and heavy trucks).
2. The energy impact of a total or partial vehicle detour due to a bridge closing or posting was calculated for each vehicle type as the product of the AADT x gpm x miles x days per year with respect to travel speed, flow condition, and model year efficiency improvements.
3. Geometric limitations on the bridge or its approaches often require a reduction in speed to cross the bridge or, if there is a detour, the alternate route may have a different speed. These effects are evaluated by determining the change in speed and the corresponding change in fuel consumption times the AADT for the types of vehicles affected.

Construction of the pavement and bridge portions of bridge projects is also evaluated as described earlier by selecting the appropriate Btu-per-dollar factor for each action.

TSM, Safety, and Other Projects

Construction and user impacts were computed using various methods depending on the actions undertaken. Because most of the transportation system management (TSM) projects analyzed dealt with traffic flow conditions and reducing delay, the vehicle energy computations noted previously are applicable. [Worksheets and other computation aids are documented elsewhere (7-11).]

Transit Vehicles

Transit vehicle acquisition projects result from the scheduled replacement cycle for these vehicles. The potential savings, if any, result from improvements in vehicular energy consumption. The energy consumption of both the replacement vehicles and the vehicles presently in service may each be computed, using the following dimensional relationship:

Energy = vehicles x annual mileage/mpg

Differences in vehicle efficiency (mpg) and annual mileage may work together or against each other to provide fuel savings or increases for a given vehicle replacement.

The resultant energy impact of each project was calculated, packaged along with other information concerning the project, and presented to each of the implementing agencies for use in either the internal project selection program or as part of the GTC TIP programming deliberations.

FINDINGS

The 1983-1988 GTC TIP contained 92 projects for which an energy assessment was undertaken. Figures

2-6 show these 92 projects by type, jurisdictional responsibility, and funding source. Most project types were improvements or repairs to deficiencies in the existing highway system. The transit projects represent normal scheduled replacement of vehicles, based on existing NYSDOT and UMTA performance standards and the specifications for those vehicles. Projects under the jurisdiction of New York State include all projects funded with federal dollars, as well as those using 100 percent state funds. Unlike local projects, which focus primarily on pavement rehabilitation, most New York State projects are for bridge rehabilitation. The remaining projects are

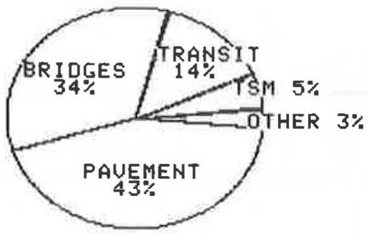

FIGURE 2 Types of projects.

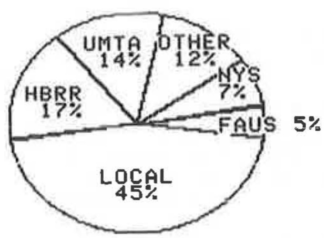

FIGURE 3 Category of funding for projects.

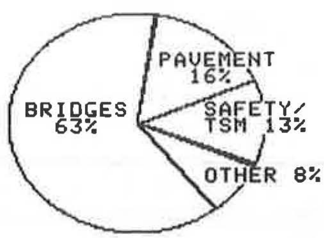

FIGURE 4 Projects for New York State jurisdiction.

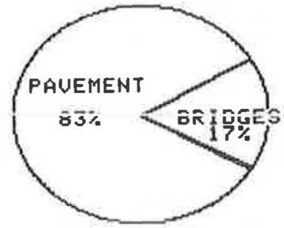

FIGURE 5 Projects for local jurisdictions.

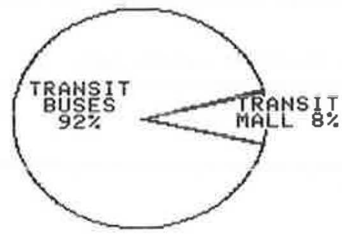

FIGURE 6 Projects for transit authority jurisdictions.

TABLE 1 Energy Analysis Findings

	Change in Average Annual Gallons (millions)
User energy	-5.9
Construction energy	2.1
Net energy	-3.8
1980 regional transportation network fuel consumption (millions of gallons)	293.2
Net energy improvement (%)	1.3
Project dollars ($1981)	198.9
Overall payback period (yr)	5.9

Note: Total number of projects is 92. Negative values imply savings.

TABLE 2 Findings of Energy Analysis Based on Project Type

			Total Annual Equivalent Gallons (000)				
Project Type	Service Life (yr)	No. of Projects	Vehicle or User	Construction	Net	Total Project Construction Energy (gal, 000)	Average Cost ($1981, millions)
Bridge	30	31	-7,272.0	528.3	-6,743.7	13,233	2.478
Pavement[e]	10	38	46.5	928.9	975.4	9,805	1.452
Speed			109.6				
Surface			-63.1				
Safety and TSM	15	5	-236.6	167.6	-69.0	2,323	3.809
New construction	30	1	1,667.5	347.3	2,014.8	7,303	17.557
Drainage	20	1	-1.3	0.1	-1.2	2	0.080
Other[f]	14.7	1	-51.4	87.5	36.1	1,674	11.511
Transit vehicle mini buses	4	33 (10)[g]	1.1	23.4	24.5	94	0.034
Standard buses	12	19 (2)[g]	20.4	13.0	33.4	156	0.163
Transit mall	30	1	-27.8	5.5	-22.3	165	11.167
All project types		92	-5,903.7[h]	2,137.2[h]	-3,766.5[h]	34,755	

Note: Negative numbers denote energy savings.
[a]Δ = difference between proposed and null alternatives.
[b]Ratios are based on the differences noted under average annual gallons.
[c]Vehicle gallons divided by construction gallons.
[d]Total project construction energy divided by annual vehicle energy.

split between correcting pavement and safety-related defects.

Local projects are primarily paving projects on the local highway system that are paid for with local funds, whereas projects proposed by New York State are primarily bridge projects that are on the federal-aid or state highway system and are generally eligible for funding from one of several federal funding sources.

The findings for all projects analyzed are summarized in Table 1. Tables 2 and 3 give summaries of the energy assessments by project type and funding category, respectively. The energy assessments described in these tables are based on the measured energy difference, or change, between the proposed project alternative and the expected null, or existing, situation. Three points should be noted when evaluating the results: (a) project type descriptions (Table 2) represent aggregated categories; (b) although there are 10 distinct funding categories (Table 3), several projects may be funded by more than one category of funds; and (c) negative numbers in Tables 1-3 represent reductions in energy use (i.e., energy savings resulting from the projects). Positive numbers represent increases in energy use (or energy losses resulting from the projects).

The general findings are as follows:

1. Projects proposed for implementation during the next 5-year period, as given in Table 1, have the potential for conserving 3.8 million gallons of gasoline annually; this is about 1.3 percent of the 293.2 million gallons of gasoline consumed on the transportation network for the region in 1980.

2. Bridge projects offer the greatest potential for energy conservation. This is due primarily to eliminating both traffic detours for bridge closings and rerouting for load limits and secondarily to improvements in flow over the structure.

3. For pavement projects, energy savings due to improvements in the pavement surface are frequently offset by increases in fuel consumption caused by increased operating speeds (Figure 1) and increased capacity gained by widening the road or improvements to the shoulder. The energy savings from surface replacement are almost always insufficient to offset the cost of the energy required to replace the pavement surface.

4. Safety and TSM projects offer the second greatest potential for energy conservation by improving traffic flow and reducing vehicle delay.

5. Purchases of transit vehicles usually increase energy use because although it is desirable to obtain more fuel-efficient replacement buses, other requirements and criteria may preclude this.

6. On the average, those projects that save energy will provide a payback of the total energy used in construction in less than 7 years in the form of annual vehicle energy savings.

7. Funding category is not indicative of energy conservation. Funding categories comprised of a significant number of bridge projects, and to a lesser extent safety and TSM projects, offer greater conservation potential.

LONG-RANGE ASSESSMENT

Energy consumed by travel on the highway system in the Rochester area is expected to change over time because of increasing vehicle efficiency, highway network improvements, and expected growth in traffic due to growth in the region. The New York State traffic simulation model was used to help determine the effect of these changes. Three separate assessments were analyzed to measure effects of both highway improvements and growth on changes in fuel consumption. The results of these three assessments are shown in Figure 7 and Table 4.

The following conclusions can be drawn from the long-range energy assessment:

1. The expected improvements in vehicle fuel efficiency between 1980 and 2000 could reduce annual highway system fuel consumption 85.7 million gallons by 1990 (29.2 percent of 1980 fuel consumption) and an additional 7.6 million gallons (2.6 percent of 1980 fuel use) by 2000. Fuel consumption between 1980 and 2000 would be reduced by 93.3 million gallons (31.8 percent).

2. The effects of traffic growth in the region would result in a fuel consumption increase of 60.4 million gallons (20.6 percent) of 1980 fuel consumption) between 1980 and 1990.

3. The net effect of these two changes could result in the saving of 25.3 million gallons by 1990 (8.6 percent of 1980 fuel consumption) and an additional savings of 9.6 million gallons (3.3 percent of 1980 fuel consumption) by 2000. The total saving

	Δ^a Average Annual Equivalent Gallons (000)						
Average Traffic (AADT)	Vehicle or User	Construction	Net	Net Gallon per Project Dollar[b]	Net Gallon per 1,000 vehicle[b]	Energy Benefit/Cost[b,c]	Payback Period (yr)[d]
13,680	-234.6	17.1	-217.5	-0.08	-48.2	-13.8	1.8
8,472	1.2	24.4	25.6	0.02	9.2	0.05	-
	2.9						
	-1.7						
13,056	-47.3	33.5	-13.8	-0.004	-3.2	-1.4	9.8
19,160	1,667.5	347.3	2,014.8	0.11	318.7	4.8	-
13,700	-1.3	0.1	-1.2	-0.01	-0.3	-9.7	2.0
54,100	-51.4	87.5	36.1	-0.003	2.0	-0.6	-32.6
-	0.033	0.710	0.743	0.022	-	0.046	-
-	1.076	0.683	1.759	0.011	-	1.576	-
-	-27.8	5.5	-22.3	0.002	-	-5.1	5.9

[e]40 projects were analyzed; however, 2 have been deleted as they are atypical and distort the vehicle energy values for this category.

[f]This project is atypical as portions of it could be categorized as bridge pavement or new construction.

[g]Number of projects.

[h]Totals include all 92 projects analyzed (see footnote e).

TABLE 3 Findings of Energy Analysis Based on Funding Source

Funding	No. of Projects	Total Annual Equivalent Gallons (000): Vehicle or User	Construction	Net	Total Project Construction Energy (gal, 000)	Average Cost ($1981, millions)
100% NYS[d]	6	-7.1	93.3	86.2	1,213	1.267
Highway bridge reconstruction	16	-3,905.5	196.8	-3,708.7	5,257	2.030
Federal-aid primary rural	2	-48.4	49.3	0.9	531	2.301
Federal-aid primary urban	1	1,667.5	347.3	2,014.8	7,303	17.557
Federal-aid urban system	5	-1,430.5	182.1	-1,248.4	2,435	3.786
Urban Interstate	3	-494.3	266.1	-228.2	6,675	12.787
UMTA[e]	13	-6.3	41.9	35.6	165[f] (414)	1.184
Interstate 4-R funds	1	-	70.2	70.2	1,104	6.867
Highway bridge reconstruction + Federal-aid urban system	3	-347.1	17.5	-329.6	468	0.910
100% local[h]	41	-1,325.3	867.2	-458.1	9,249	1.296
Hazard elimination and safety	1	-6.9	5.6	-1.3	105	1.200
All funding categories	92	-5,903.7	2,137.3	-3,766.6		

Note: For definitions of funding categories, see Section IV of "Incorporating Energy Analysis in the Transportation Improvement Process," FHWA, UMTA, U.S. Department of Transportation; U.S. Department of Energy, July 1984. Negative numbers refer to energy savings.

[a]Δ = Difference between proposed and null alternatives.

[b]Ratios are based on the differences noted under average annual gallons.

[c]Vehicle gallons divided by construction gallons.

by 2000 would be 34.9 million gallons (11.9 percent of 1980 fuel consumption).

4. The highway improvements to the transportation system contained in the 1990 GTC Transportation Plan could result in a savings of approximately 3.2 million gallons by 1990 (1.1 percent of 1980 fuel consumption).

The completion of the projects contained in the 1983-1988 TIP and 1990 GTC Transportation Plan could result in a reduction of vehicle or user energy requirements in the Rochester area of approximately

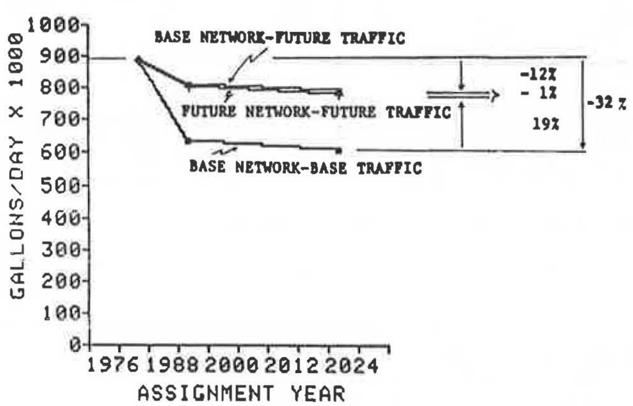

FIGURE 7 Long-range assessment.

9.1 million gallons (3.1 percent of 1980 fuel use) per year by 1990. This would be comprised of 3.2 million gallons from improvements in the 1990 plan and an additional 5.9 million gallons from TIP projects (Table 1) not already included in the network analysis of the 1990 plan. This assessment of vehicle or user energy, however, must be reduced by the capital energy costs for construction, which will offset some of the expected savings. The resultant annual construction energy expenditure would be approximately 2.4 million gallons per year.

Taking both the expected vehicle (user) energy savings and the estimate for the construction energy requirements into consideration, an overall net savings of approximately 6.7 million gallons of fuel per year (2.3 percent of 1980 fuel consumption) can be expected by 1990. When the effects of improved vehicle efficiency and increases in travel are accounted for, the total savings are 25.3 (Table 4) + 6.7 or 32.0 million gallons (10.9 percent of 1980 fuel consumption). The energy savings attributed to vehicle turnover still overshadow savings resulting from planned transportation improvements.

Based on this long-range energy assessment of improvements to the Rochester area highway system and the detailed energy assessment of the various projects included on the 1983-1988 TIP for implementation during that period, the following observations were made:

- Projects proposed for inclusion in the 1983-1988 TIP will assist (moderately) in making

TABLE 4 Network Traffic Assessments, Estimated Gallons per Year (millions)

Year	Assessment 1: Base Network Base Traffic	Change from Previous Period	Assessment 2: Base Network Future Traffic	Change from Previous Period	Assessment 3: Future Network Future Traffic	Change from Previous Period
1980	293.2	-	293.2	-	293.2	-
1990	207.5	85.7 (-29.2)[a]	267.9	25.3 (-8.6)[a]	264.7	28.5 (-9.7)[a]
2000	199.9	7.6 (-3.7)	258.3	9.6 (-3.6)	255.2	9.5 (-3.6)
Total change from 1980		93.3 (-31.8)		34.9 (-11.9)		38.0 (-13.0)

Note: Numbers may not add due to rounding.

[a]Percentages are shown in parentheses; negative values imply savings.

Average Traffic (AADT)	Δ^a Average Annual Equivalent Gallons (000)			Net Gallon per Project Dollar[b]	Net Gallon per 1,000 Vehicle[b]	Energy Benefit/Cost[b,c]	Payback Period (yr)[d]
	Vehicle or User	Construction	Net				
5,646	-1.2	15.6	14.4	0.01	7.7	-0.03	170.5
6,710	-244.1	12.3	-231.8	-0.11	-104.7	-19.8	1.3
13,850	-24.2	24.6	0.4	0.0002	0.10	-1.0	11.0
19,160	1,667.5	347.3	2,014.8	0.11	0.32	4.8	-
47,920	-286.1	36.4	-249.7	-0.07	-40.4	-7.9	1.7
79,867	-164.8	88.7	-76.1	-0.006	-2.9	-1.9	13.5
-	-0.5	3.2	2.7	0.002	-	-0.15	5.9[g]
-	-	70.2	70.2	0.01	-	-	-
14,420	-115.7	5.8	-109.8	0.12	-23.1	-19.8	1.4
8,410	-32.3	21.2	-11.2	-0.009	-4.0	-1.5	7.0
14,000	-6.9	5.6	-1.3	-0.001	-0.3	-1.2	15.2

[d]Total project construction energy divided by annual vehicle energy.

[e]The project types contained in this category are dissimilar and severely distort these values.

[f]The 13 projects include 52 buses and 1 transit mall.

[g]Payback period shown is for transit mall only.

[h]Same as footnote[e]; here 7 bridge projects are providing the savings to offset the 34 pavement projects.

progress toward the goal of reducing energy consumption.

- Improvements in vehicle operating efficiency brought about by the public buying new vehicles will alter energy consumption much more significantly than capital investments to improve or maintain the infrastructure.
- Savings due to improvements in vehicle efficiency are likely to be 12 times greater than the net savings from combined network and specific project improvements expected to be in place by 1990.

OBSERVATIONS ON INSTITUTIONAL ELEMENTS

Agency views on the usefulness and appropriateness of the project energy analysis were obtained by means of a series of meetings and questionnaires. Agencies were first asked whether they collected similar energy impact information for their project development process, whether the provided information was used, and, if so, how. They were also asked about instances in which the information was not useful because of such issues as the inappropriateness of the timing or form of the information. Each agency described the effect the information had on both the selection of individual projects and on the capital programming process as a whole and also identified specific points in the process where the information presented would be most effective.

The major results of the meetings held to discuss the energy impact information generated for projects listed in the TIP and sent to project implementers are summarized below. The reader should note that almost all of the projects examined had a positive energy impact, with an energy payback of less than 7 years. Most agencies viewed these results as supporting their previous decisions.

1. In general, energy information is more useful for larger-scale highway projects, which involve a number of location and design alternatives. In most cases energy information is developed currently when appropriate.

2. For medium- or small-scale rehabilitation and preservation, and safety and bridge projects, project energy information was judged generally not to have any bearing on the decision as to whether to fund a project.

3. For TOPICS- or TSM-type projects, the use of energy impact information as a basis for decision making is good in theory, but the reality is that in many cases these projects expand to include such additional components as moving or replacing utilities, so costs could easily expand to exceed the original energy benefits of the project.

4. Although energy information is useful in some cases at the TIP stage, it would be more useful in evaluating possible future actions at the system level and in selecting methods and materials in project design.

5. Decisions as to whether to purchase new vehicles for transit projects are based generally on the age and fleet-size standards of the transit industry and energy impact information for new vehicles is irrelevant. Energy considerations are most useful in decisions concerning vehicle options such as air-conditioning.

6. Project information might have been more useful if it had been presented at different stages in the project development process. Two possible points in the process that were identified are the policy planning stage and the project design and implementation stage.

CONCLUSION

A major finding of the study was that for medium- and small-scale roadway projects the energy impact data were not generally relevant to the decision to implement the projects. This result might be expected because almost all projects examined were found to save energy with an average payback period of less than 7 years. Several factors generally account for this result.

The first factor is the relationship between project energy benefits in general and between energy consumption and construction costs in dollars. User costs usually increase with increased congestion and with increased operating costs, both of which are positively correlated with energy use. For construction, the methods and materials used have dollar costs that correlate positively with energy costs.

The second factor is that many financial and institutional considerations surround project selection. Projects selected for inclusion in the TIP generally are designed to be the best solutions of the most serious problems in the region (and frequently the most energy efficient). The projects developed and proposed are also designed to make maximum use of outside resources. For such projects, energy concerns are not likely to be decisive; thus, few decisions to reject a project are made at the TIP stage.

The third factor is that the additional information on the energy impacts of each of these projects generally enhanced their acceptance. However, although the use of the materials often served to highlight the energy savings of proposed transportation projects it also tended to overemphasize the importance of energy savings relative to other factors.

Finally, because most of the projects already saved energy, the overall conclusion of this study was that no decisions were changed solely because of the energy impact information provided. It is the belief of the authors that when this type of energy impact information is incorporated into the TIP process on a regular basis and is presented along with other impact data, it may be more useful.

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Economic Impacts of Transportation Fuel Consumption in the Dallas-Fort Worth Area

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ABSTRACT

A mechanism is demonstrated for evaluating the impacts of transportation fuel consumption and price on a local economy. The project was derived from the observation that economic impacts of transportation actions and policies are often desired by local decision makers. It is also observed that the effect of changes in local transportation fuel expenditures on a local urban economy is generally unknown in any quantifiable form. The overall objective of this investigation is to incorporate local economic considerations into the urban transportation planning and decision-making process.

This methodology proposes that the most useful way to approach an assessment of local economic impacts is by linking the concepts of household expenditures and interindustry economics. Urban transportation planners and policy analysts have recognized for a long time that the household is the basic decision-making unit where trade-offs are made among alternative transportation services (1). The household is also the focus of decision making about expenditures for transportation fuels versus other needs and desires of the household. Therefore, in this approach, transportation, energy, and the household economy were analyzed simultaneously.

What are the effects of these changing household expenditure patterns on the overall economy of an urban area? A widely used means of answering this question is the interindustry or input-output model (2). Interindustry analysis explains how each sector of an economy is linked with every other sector. An input-output model can show, for example, what happens to all industries in an area if households reduce their consumption of gasoline. Using this approach, it is possible to quantify the effects on an urban area through aggregate measures of economic performance such as employment and income (3-5). Recently a large number of studies have been conducted at the federal level, and to some extent at the state level, that link these economic performance measures with energy consumption (6,7).

Because economies and energy situations vary from locale to locale within the United States, it should be expected that changes in transportation energy efficiency and fuel prices would have unique impacts in each area. Thus, a procedure that reflects these local differences is needed to estimate these impacts. The results of this study were published in a planning manual for local and state officials. The procedures in the manual can be used to assess quantitatively the economic impact of changes in fuel price and consumption levels. The important components of three detailed reports written for the U.S. Department of Transportation and the U.S. Department of Energy (8-10) are highlighted in this paper. The third report in this series contains a step-by-step procedure to implement the proposed methodology.

The procedures developed in this project can be used to address a number of issues of interest to state and local policy makers. Such policy questions include

1. What are the economic consequences to a particular urban area of increased gasoline prices?
2. What are the economic benefits to a local community of an increase in fuel efficiency?
3. What are the long-term effects on the household and trucking sectors of an urban area of changing fuel prices and fuel efficiency levels?
4. What is the economic impact on a local community of sanctions on roadway construction funds by the U.S. Environmental Protection Agency?

To demonstrate this planning tool, these four questions were evaluated for the Dallas-Fort Worth area.

Changing energy prices and more efficient automobiles can be expected to cause changes in household expenditure patterns. As the price of gasoline goes up, for example, households may reduce their use of the private automobile to compensate for the price increase. They may switch to alternative forms of transportation, reduce their expenditures in other areas, purchase a more fuel-efficient automobile, or choose some combination of these and other options. In linking transportation energy and economic analysis, it seems appropriate to investigate the basic trade-offs the household is making, not only in the transportation area but also among transportation and other household expenditures. The procedures and results of these interrelationships are summarized in this paper.

The three remaining sections of paper contain an overview of the methodology, a review of important planning manual components, and the results of the application of the methodology to the Dallas-Fort Worth area.

OVERVIEW OF THE METHODOLOGY

The methodology is outlined in a series of 10 steps and addresses both the household and trucking-related sectors of the economy. The procedure examines the impact on the household and trucking sectors separately. This enhances the flexibility of the analysis by allowing the planner or engineer to evaluate only those sectors that are of the most concern. The results of this study indicate the importance of evaluating the trucking sector of a local economy.

The flexibility of the procedure is also demonstrated by its applicability to any planning region. A planning area at the local, regional, or state level can undertake this method of analysis by using the area-specific factors supplied by the manual (10). The only major piece of information the manual does not supply is an input-output model for the area of interest. If a locally derived input-output model is not available, it will be necessary to obtain estimates of household expenditures by economic sector, along with economic multipliers supplied by the Bureau of Economic Analysis (11).

For some time, input-output analyses have been applied to transportation problems at the local, state, and federal levels. Goldstein highlighted a variety of applications along these lines more than a decade ago (12). More recently, the National Cooperative Highway Research Program (NCHRP) is sponsoring two handbooks for state departments of transportation. These handbooks will provide techniques useful in applying input-output concepts to the analysis of transportation policy (13). Figure 1 shows an overview of the planning approach. Each of the key elements of the approach is described below.

Step 1: Alternative Local Transportation Policies

The local policies of interest in this step are those that affect the energy consumption of the transportation system. These actions might include traffic signalization programs, ridesharing programs, fuel price changes, and so forth. Because the impact of these policies varies among urban areas, it is necessary for the local analyst to quantify the changes in energy consumption that result from a particular action.

Step 2: External Events

The local price of transportation fuels and the efficiency with which they are used are determined mostly by events and forces outside the control of local policy makers. Events such as OPEC oil price changes and domestic oil deregulation have significant impacts on fuel prices and consumption levels. Likewise, federal laws pertaining to automotive fuel economy probably have a greater effect on transportation energy efficiency than do local transportation actions. Again, it is appropriate for the local planner to determine the nature of these external factors and their influence on the local transportation situation because these values change from time to time.

Step 3: Estimated Fuel Prices and Transportation Efficiencies

Taking into consideration the local and external factors discussed in Steps 2 and 3 that affect local transportation fuel prices and transportation efficiencies, the local planner establishes fuel price and efficiency scenarios for the analysis. Background information on projected fuel prices and energy efficiency values is presented in the manual series to assist the local analyst with this activity. The goal of the analysis is to determine the economic impact of a change in fuel price, efficiency, or a combination of the two. To do this, a base condition (commonly the current situation) must be established; then prices and efficiencies that differ from the base condition are quantified for present-year or future conditions.

Step 4: Sector Energy Consumption Model

The first of two major models in this procedure is the economic sector energy consumption model. This is the central model in the planning manual. The

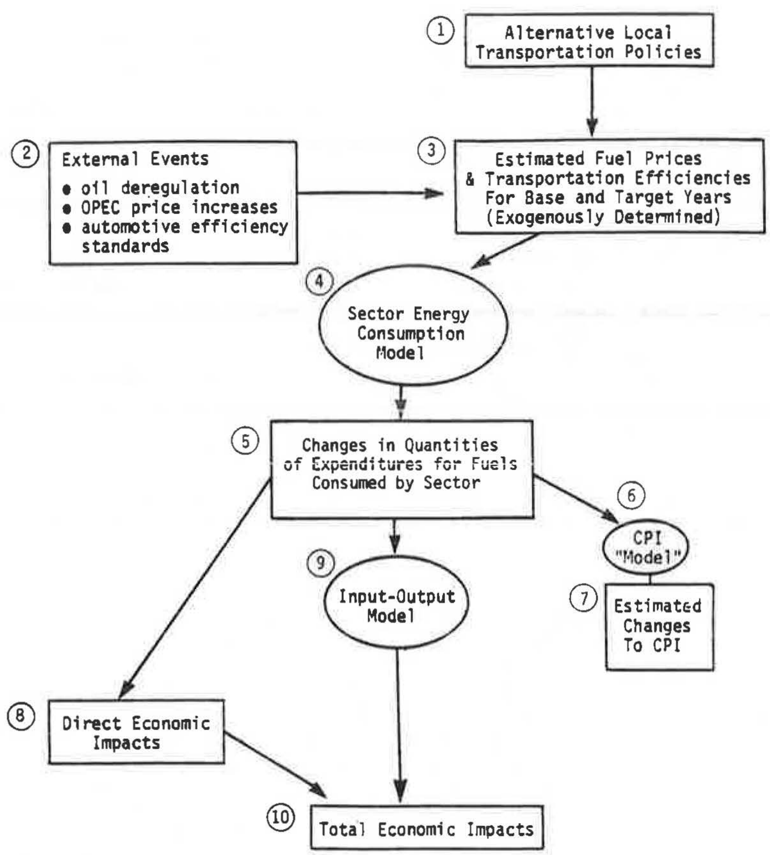

FIGURE 1 Overview of planning approach.

basic function of the model is to replicate the decisions a household makes about purchasing goods and services. When this has been accomplished, the conversion of transportation policies into economic choices can take place.

This model shows how household expenditure patterns would differ from the base condition if fuel prices or efficiencies should change as identified in Step 3. The model estimates changes in gasoline consumption, as well as other changes in household expenditures, caused by changes in gasoline purchasing patterns. The model coefficients used to simulate this change in household purchasing are based on data published by the Bureau of Labor Statistics (BLS) (14). The income/expenditure elasticity coefficients calibrated for this study were estimated by the following regression equation:

$$\ln C_{kj} = \ln a + b \ln Y_j$$

where

- ln = base of natural logarithms,
- C_{kj} = expenditures for industry sector k and jth income group,
- Y_j = income of households in the jth income group, and
- a,b = regression coefficients (b is the elasticity value for each income group and economic sector).

Household expenditure data (C_{kj}) were obtained from the BLS survey of 5,000 items aggregated into 24 household sectors. The original data contained 12 income classes, but they were aggregated into the 3 income classes (Y_j) used in this study. As a result, 72 household expenditure elasticity values were calibrated. This sensitivity to income class increases the accuracy of the study and permits the evaluation of equity concerns. The results of this model are discussed later in this paper.

Step 5: Changes in Quantities of, and Expenditures for, Fuels by Household Sector

Changes in the expenditure pattern for each sector are the output of the model. These estimates are used as input data to the steps that follow. An example of this process is presented later in this paper.

Step 6: CPI Model

The Consumer Price Index (CPI) is based on the current prices of a market basket of goods. The quantities of goods in this market basket are updated only infrequently. One of the purposes of this research is to examine the feasibility of using the CPI as a measure of transportation performance along with the more traditional measures such as volume-capacity ratio, number of accidents, emissions, and delay. By varying the prices and quantities of transportation fuels as if the market basket were updated, it is possible to estimate the impact of changes in transportation system efficiency on the CPI.

Step 7: Estimated Changes in the CPI

The output of the model would be an estimate of the change in the CPI resulting from the previous assumptions and estimates. This change in CPI is based on updated prices for a market basket of goods for the short run and updated prices and quantities for the long run. This distinction is consistent with the method currently used for estimating the CPI. Even though the incomes and benefits of some individuals are adjusted as a result of changes in the CPI (e.g., unions and some welfare programs), it is beyond the scope of this study to reintroduce revised income levels.

Step 8: Direct Economic Impacts

By aggregating the results of the sector energy consumption model, total expenditures by household sector of the economy can be estimated. Total expenditures by commercial sector are also estimated to determine the effects of price and fuel efficiency on truck travel. Changes in these initial expenditures represent the direct economic impacts.

Step 9: Input-Output Model

To determine the rippling effects of changes in household consumption patterns, an input-output model is used. This model estimates direct and total impacts. Direct impacts are defined as the initial changes in expenditures by various sectors of the economy that result from increases or decreases in fuel expenditures. Total impacts include both direct and indirect impacts and are the net effects as industries interact with each other. Indirect impacts result from an increase in demand for the output of one economic sector which indirectly increases the demand for the output of goods and services of other economic sectors that supply products to the first sector. This model is presented later in the analysis.

The altered sector expenditures are the input to the interindustry analysis. Further, the input-output analysis demonstrates any changes in employment and income. These measures are thought to represent best the vitality of the local economic climate. This method of analysis includes the indirect effects of changes in household and commercial sector expenditure.

Step 10: Total Economic Impacts

The changes in total employment and income include both direct and indirect effects. Combining the various economic impacts estimated throughout the steps in this process allows the planner or analyst to make an overall statement about the direction and magnitude of the economic impact of changes in fuel price and efficiency.

Through this analysis it is possible to determine changes in regional employment and income as a result of different transportation-related policy decisions. It is important to realize that this methodology is more accurate for the short term (i.e., less than 5 years) than the long term. To use this tool in long-term evaluations, adjustments are made to the economic multipliers because the coefficients cannot be assumed to be constant over time. Even though some of the scenarios presented for demonstration are for different years, it is suggested that the most accurate use of this methodology is to compare alternative policies for the same year. Therefore, it is recommended that the comparative versus absolute nature of the methodology be used.

A number of assumptions are included in the methodology. These assumptions (shown in Figure 2) help to identify the interrelationships among the various

	FUEL TAX		FUEL PRICE		FUEL EFFICIENCY	
NET CHANGE						
• Fuel Tax	↑	↓	-	-	-	-
• Fuel Price	-	-	↑	↓	-	-
• Fuel Efficiency	-	-	-	-	↑	↓
NET RESULT						
A) Household						
• Income	0	0	0	0	0	0
• Fuel Consumption	0(1)	0(1)	0(1)	0(1)	↓	↑
• Tax-Roadway Construction	↑	↓	0	0	0(3)	0(3)
• Purchases	↓	↑	↓	↑	↑	↓
B) Commercial/Trucking						
• Profit	0	0	0	0	0	0
• Fuel Consumption	0	0	0	0	↓	↑
• Tax-Roadway Construction	↑	↓	0	0	0(3)	0(3)
• Consumer Prices	↑	↓	↑	↓	↓	↑
C) Regional Economic Impact						
• Income/Profit	0	0	0	0	0	0
• Fuel Consumption	0(1)	0(1)	0(1)	0(1)	0(4)	0(4)
• Tax-Roadway Construction	↑(2)	↓	0	0	0(3)	0(3)
• Household Expenses	↓	↑	↓	↑	↑	↓

(1) Small change depending on elasticity
(2) Areawide policy, therefore increase in funding
(3) Localized efficiency - construction funds would not be altered
(4) Greatest impact would be to non-regional refineries

↑ represents an increase in value
↓ represents a decrease in value
0 represents no change

FIGURE 2 Major relationships and assumptions.

components of this procedure. The following is a specific example of how these assumptions are used in this approach.

If a fuel tax were increased, the following assumptions would apply to the household sector of the economy:

- Income would stay the same;
- Fuel consumption would decrease slightly depending on the fuel price elasticity, where fuel price elasticity represents the change in fuel consumption resulting from a change in fuel price;
- Fuel taxes and construction funding would increase; and
- Purchases of goods would decrease.

If a fuel tax were increased, the following assumptions would apply to the commercial trucking sectors of the economy:

- Profit would stay the same;
- Fuel consumption would remain unchanged;
- Tax and roadway construction funding would increase; and
- Costs would be passed through to the consumer in higher prices.

The net economic impact would be

- No change in income and profit would result;
- Fuel consumption would decrease slightly;
- Taxes and construction funding would increase; and
- Household expenses for goods and services would decrease because of higher user costs and higher consumer prices that would result from higher trucking costs.

Other assumptions in this methodology are

- Variable costs (i.e., gasoline, maintenance, and fuel taxes) are included in the analysis and fixed costs (e.g., insurance) are not addressed.
- Vehicle miles of travel (VMT) per household remain constant over time.
- Automobile fuel efficiency and fuel prices do not vary significantly among income groups.
- Fuel prices do not change as a result of energy efficiency improvements in the local transportation system.

REVIEW OF IMPORTANT PLANNING MANUAL COMPONENTS

To demonstrate some of the important mechanical procedures in this methodology, four steps in the process are presented in greater detail. Table 1

TABLE 1 Change in Income for Example Scenarios

	A	B	C[a]	D	E[b]	F[c]
Income Level ($)	Household Transportation Expenditures Before ($)	Household Transportation Expenditures After ($)	Change (%)	Average Income per Income Level ($)	Transportation Expenditures as a Fraction of Income	Change in Income (%)
5-Cent Increase in Fuel Tax in 1982						
Less than 10,000	977.35	997.11	+2.0	5,362.30	0.1823	-0.3645
10,000 to 19,999	1,963.37	2,000.57	+1.9	14,670.28	0.1338	-0.2543
20,000 and up	2,680.60	2,726.20	+1.7	31,023.13	0.0864	-0.1469
Longe-Range Fuel Use and Price Trends by 2000						
Less than 10,000	1,014.82	1,026.67	+1.2	5,362.30	0.1893	-0.2272
10,000 to 19,999	2,034.72	2,062.44	+1.4	14,670.28	0.1387	-0.1942
20,000 and up	2,769.99	2,814.29	+1.6	31,023.13	0.0893	-0.1429
10 Percent Reduction in Fuel Use by 1987						
Less than 10,000	943.63	896.27	-5.0	5,362.30	0.1760	+0.8799
10,000 to 19,999	1,900.52	1,807.96	-4.9	14,670.28	0.1296	+0.6348
20,000 and up	2,634.46	2,486.49	-5.6	31,023.13	0.0849	+0.4755

[a]Column C = (B - A)/A x 100.
[b]Column E = A/D.
[c]Column F = -C x E.

gives the procedure used to determine the percentage change in income that would result from various example scenarios. Notice that transportation expenditures as a fraction of income range between 8.5 percent and 18.9 percent, depending on the year and income group. This is consistent with the traditional averages for these values.

Table 2 gives the income elasticities used in the sector energy consumption model. These values are used to convert the percent change in income to change in expenditures by sector. It seems clear from a review of these values that the elasticity coefficients are reasonable when compared across income groups as well as among economic sectors. This process is demonstrated in Table 3 for a selected policy and income group. This table demonstrates the substitution decisions that a household makes when changes in its household budget are required.

Table 4 gives the results of the input-output model for the same example. The sector definitions have been altered so that they will be consistent with the national input-output model, because these technical coefficients were obtained from the Bureau of Economic Analysis for the Dallas-Fort Worth area. Adjustments are made to the employment multiplier to account for increases in real income for different years used in the analysis. The information given in Table 4 demonstrates the traditional use of an input-output model.

TABLE 2 Income Elasticities by Sector

		Income Level ($)		
Sector Number[a]	Sector Name	Less than 10,000	10,000 to 19,999	20,000 and up
29	Transportation and warehousing	0.137	0.415	1.121
30	Telephone and telegraph	0.489	0.308	0.318
31	TV, radio, and other communications	0.410	0.092	0.095
32	Gas services	0.230	0.131	0.438
33	Electric services	0.436	0.713	0.321
34	Water and sanitation services	0.364	0.543	0.356
40	Building materials, hardware, and equipment	0.315	1.002	0.438
41	Department and variety stores	0.820	0.841	0.752
42	Food stores	0.396	0.513	0.230
43	Automobile dealers and service stations	0.809	0.575	0.144
44	Apparel and accessories stores	0.724	0.728	0.521
45	Furniture and home equipment	0.725	0.659	0.589
46	Eating and drinking places	0.812	0.983	0.479
47	Other retail	0.527	0.994	0.421
48	Banking and credit agencies	1.492	1.388	0.515
49	Insurance carriers	0.677	0.556	0.234
50	Finance, insurance, and real estate	0.372	0.010	0.182
51	Legal, accounting, engineering, and professional services	0.367	3.213	0.507
52	Lodging services	1.312	1.666	1.058
53	Personal services	0.463	0.407	0.690
56	Miscellaneous repair services	0.629	1.300	0.680
57	Medical and other health services	0.411	0.662	0.336
58	Education services	1.008	1.402	0.604
59	Other services	0.560	1.181	1.007

[a]The sectors are those defined by the 1972 Dallas-Fort Worth input-output model.

RESULTS OF THE APPLICATION FOR THE DALLAS-FORT WORTH AREA

To demonstrate this procedure, the results of four examples are presented and evaluated. The first represents a change in fuel tax (i.e., fuel price), the second represents changes in fuel price and efficiency over the long term, the third represents an improvement in fuel efficiency, and the fourth evaluates the impact of sanctions on federal construction funds.

Table 5 gives background information pertaining to each example. Example 1 shows an evaluation where the base condition and alternative (i.e., 5-cent increase in fuel tax) are for the present year. This particular scenario was selected because of the possibility of an increase in state fuel taxes.

It should be recognized that increases in the pump price of gasoline can be brought about by petroleum price increases as well as taxes. The local economic impacts are different for these two types of price increases. In general, petroleum price increases will result in money being exported from the local economy, whereas tax increases may result in an increase in government expenditures in the local economy. The amount of government expenditures depends on which level of government executes

TABLE 3 Change in Group Expenditures Due to a 5-Cent-per-Gallon Tax Increase in 1982 (1977 dollars)

	A	B	C[a]	D	E[b]	F[c]	G	H[d]
Sector Number	Change in Income (%)	Income Elasticity	Change in Expenditures (%)	Fraction of Households	Change in Group Expenditures (%)	1972 Household Expenditures (000)	Population Multipliers	Change in Expenditures ($1977)
29	−0.3645	0.137	−0.049937	0.34	−0.0169786	304,966.37	1.239	−64,154.21
30	−0.3645	0.489	−0.178241	0.34	−0.0606019	125,975.61	1.239	−94,589.74
⋮								
42	−0.3645	0.396	−0.144342	0.34	−0.0490763	485,285.95	1.239	−295,080.72
⋮								
47	−0.3645	0.527	−0.192092	0.34	−0.0653113	356,455.01	1.239	−288,445.89
⋮								
59	−0.3645	0.560	−0.204120	0.34	−0.0694008	164,590.68	1.239	−141,527.56

Note: Income level is less than $10,000.

[a]Column C = A + B.
[b]Column E = C + D.
[c]Column F expenditures have been converted to 1977 dollars using values from the Dallas-Fort Worth consumer price index.
[d]Column H = (E/100) x F x G x 1,000.

TABLE 4 Results of a 5-Cent-per-Gallon Increase in 1982 (1972 dollars)

	A	B	C	D[a]	E	F[b]	G	H	I[c]
Sector Number	Change in Household Expenditures ($000)	Change in Trucking Expenditures ($000)	Final Demand Multiplier	Total Change in Expenditures ($000)	Income Multiplier	Change in Income or Revenue ($)	Employment Multiplier	Employment Adjustment	Change in Employment
1	–	−1,913.57	2.2111	−4,231.09	0.4552	−1,925,994.27	0.00011	0.84	−178
2	–	–	2.1987	0.00	0.5021	0.00	0.00011	0.84	0
3	–	–	2.2537	0.00	0.5438	0.00	0.00003	0.84	0
4	–	−25.61	1.9019	−48.71	0.2671	−13,009.82	0.00002	0.84	0
5	–	–	2.3798	0.00	0.5638	0.00	0.00005	0.84	0
6	–	−1,675.16	2.9223	−4,895.32	0.7271	−3,559,387.22	0.00008	0.84	−239
7	–	–	2.8962	0.00	0.8058	0.00	0.00009	0.84	0
8	–	−1,054.87	2.2181	−2,339.81	0.3918	−916,736.44	0.00004	0.84	−31
9	–	−247.68	2.1099	−522.58	0.4518	−236,101.66	0.00006	0.84	−12
10	–	–	2.3171	0.00	0.5329	0.00	0.00011	0.84	0
11	–	−388.06	2.3719	−920.44	0.5551	−510,935.97	0.00005	0.84	−21
12	–	–	2.7221	0.00	0.7108	0.00	0.00009	0.84	0
13	–	−805.95	2.4813	−1,999.80	0.4918	−983,503.48	0.00003	0.84	−25
14	–	–	2.3809	0.00	0.5481	0.00	0.00006	0.84	0
15	–	–	2.4207	0.00	0.5649	0.00	0.00008	0.84	0
16	–	–	2.7761	0.00	0.6398	0.00	0.00006	0.84	0
17	–	−453.31	2.2994	−1,042.34	0.5235	−545,665.52	0.00004	0.84	−18
18	–	−225.39	2.2934	−516.91	0.5127	−265,019.46	0.00005	0.84	−11
19	–	−357.98	2.4721	−884.96	0.5914	−523,366.74	0.00005	0.84	−22
20	–	−348.54	2.9584	−1,031.12	0.8005	−825,412.15	0.00008	0.84	−55
21	–	−1,803.55	2.0184	−3,640.29	0.3479	−1,266,455.26	0.00003	0.84	−32
22	–	–	3.0598	0.00	0.7926	0.00	0.00006	0.84	0
23	–	–	2.7451	0.00	0.7379	0.00	0.00008	0.84	0
24	–	–	2.6427	0.00	0.6363	0.00	0.00011	0.84	0
25	−279.55	−838.19	2.7697	−3,095.80	0.7486	−2,317,519.23	0.00006	0.84	−117
26	−458.72	–	2.2641	−1,038.59	0.5581	−579,635.94	0.00004	0.84	−19
27	−283.05	−573.13	2.2138	−1,895.41	0.3617	−685,570.26	0.00003	0.84	−17
28	–	−1,714.95	2.6366	−4,521.37	0.7256	−3,280,708.62	0.00007	0.84	−193
29	−2,990.28	−384.86	2.5959	−8,761.53	0.7326	−6,418,693.89	0.00011	0.84	−593
30	−961.99	–	2.7219	−2,618.44	0.6587	−1,724,766.81	0.00011	0.84	−159
31	−1,517.91	–	2.8677	−4,352.91	0.7041	−3,064,884.29	0.00007	0.84	−180
32	−391,74	–	3.6246	−1,419.90	1.0111	−1,435,661.70	0.00011	0.84	−133
33	−162.01	–	1.6184	−262.20	0.1747	−45,805.81	0.00002	0.84	−1
34	−332.46	–	2.7315	−908.11	0.6644	−603,351.27	0.00021	0.84	−106
35	−263.67	–	2.9928	−789.11	0.8601	−678,714.87	0.00011	0.84	−63
36	−331.25	–	2.7933	−925.28	0.7809	−722,551.64	0.00006	0.84	−36
37	−776.29	–	2.4738	−1,920.39	0.6332	−1,215,988.54	0.00007	0.84	−72
38	−1,450.99	–	2.7905	−4,048.41	0.7419	−3,003,513.30	0.00051	0.84	−1,287
39	–	–	2.4766	0.00	0.3676	0.00	0.00021	0.84	0
Total	−10,135.90	−12,810.70		−58,630.82		−37,348,954.17			−3,621

[a]Column D = (A + B) x C.
[b]Column F = D x E x 1,000.
[c]Column I = F x G x H.

TABLE 5 Four Selected Transportation Policies and Actions Evaluated for the Dallas-Fort Worth SMSA

	Variables Changed			
Type of Analysis	Energy Price	Energy Efficiency	Energy Price and Energy Efficiency	Construction Funding
Base year alternative	Example 1: Short-range impact of a 5-cent increase in state fuel tax in 1982.			Example 4: Short-range impact of Environmental Protection Agency sanctions on roadway construction.
Base year and future year projection			Example 2: Long-range price and efficiency impact between 1980 and 2000.	
Future alternative		Example 3: Medium-range 10 percent fuel efficiency improvement above anticipated 1987 levels.		

the tax. Two options are presented to demonstrate this point.

Example 2 evaluates the long-term effects of changes in fuel price and fuel efficiency over time. This scenario was selected because economic impact measures were needed to assist in formulating the year 2000 long-range plan for the Dallas-Fort Worth area. An important issue in this plan is the impact of the cost and availability of petroleum on future travel. Another key component of the plan is an estimate of the transportation revenue generated by users in 2000. Specific attention to the impact of projected fuel price increases on the trucking sector of the economy between now and 2000 is included in the long-range plan.

Example 3 evaluates the economic impact of fuel efficiency improvements. This scenario represents the maximum energy efficiency that would be obtained from the implementation of transportation control measures and transportation system management actions in the Dallas-Fort Worth area. This package of actions is being tested as a possible component of a revised State Implementation Plan for Air Quality.

Example 4 evaluates the economic impact of a sanction on federal roadway construction functions. This action may be imposed by the Environmental Protection Agency for regions where air quality standards are not being achieved.

As discussed previously, this approach is intended for use by local, regional, and state transportation planners and engineers for estimating economic impacts of transportation fuel consumption on both the household and trucking sectors of the economy. Of the 59,840,000 daily vehicle miles of travel (VMT) in the Dallas-Fort Worth Standard Metropolitan Statistical Area (SMSA) for 1977, household or personal travel composes 48,878,000 VMT per weekday (77.6 percent) and trucking travel composes 9,513,000 VMT per day (15.8 percent). The remaining 1,450,000 VMT (6.6 percent) is made up of other users consisting of public service vehicles, such as police cars and fire trucks, and business and rental cars. The methodology contained in this planning manual addresses 93.4 percent of all roadway travel. Essential services and business and rental car travel are not included in this analysis because of their relative insensitivity to fuel price and efficiency. This omission greatly reduces the number of calculations without affecting the results in any significant way.

Table 6 gives the economic impact of the example alternatives evaluated for the Dallas-Fort Worth area. Recalling that Example 1 represents a 5-cent-per-gallon state fuel tax increase, the results of this investigation show that approximately 500 jobs would be lost to the economy of the Dallas-Fort Worth SMSA. Traditionally, such tax increases are presented as an employment benefit. This information indicates that there is no improvement in employment in the Dallas-Fort Worth area if a state gasoline tax is implemented. It is estimated that the Dallas-Fort Worth area "donates" 55 percent of its fuel-tax-generated revenue to other parts of the state.

To demonstrate the economic impact of a policy that would increase local fuel taxes, a study was conducted of Example 1B. This example evaluates a policy of returning 90 percent of the revenue from fuel tax dollars to the Dallas-Fort Worth area and results in an increase of 2,700 jobs. This option is much more beneficial because of the greater return of construction funds to the local area.

Example 2 shows a loss of 34,000 jobs as a result of the long-term changes in fuel price and efficiency. This is 1.35 percent of the projected employment for the year 2000. Ninety-five percent of this employment loss is caused by increased costs being passed on to the consumer as a result of increased trucking fuel costs. The economic impact due to household travel is less than 5 percent of the total impact because the projected increase in fuel price is offset significantly by increased fuel efficiency. The 1982 Surface Transportation Assistance Act addresses some of the inefficiencies of

TABLE 6 Final Impact of Four Selected Examples in the Dallas-Fort Worth SMSA (1972 dollars)

	Change in Income or Revenue ($000)	Change in Employment	Change in Employment (%)	Change in CPI (%)
Example 1A: 5-cent increase in state fuel tax	9,700	−500	−0.03	0.25
Example 1B: 5-cent increase in state fuel tax with 90 percent return to local jurisdiction	56,700	2,700	+0.16	0.25
Example 2: Energy and efficiency changes between 1980 and 2000	−840,600	−34,100	−1.35	0.11
Example 3: 10 percent fuel efficiency improvement	172,100	13,500	+0.71	−0.39
Example 4: Construction sanctions	−175,300	−11,780	−0.71	0.00

truck travel; however, continued attention to this concern seems warranted.

Example 3 represents a 10 percent improvement in fuel efficiency over anticipated 1987 levels. This example demonstrates a local gain of approximately 13,500 jobs. Example 4 evaluates potential roadway funding sanctions of approximately $150 million per year. This example demonstrates an employment loss of almost 12,000. From the information presented for each example, it can be seen that the procedures, input data, and results used in this methodology are sensitive to policy concerns.

One benefit of this procedure is that specific sectors can be monitored throughout the methodology. Data in Table 7 indicate the economic sectors in the Dallas-Fort Worth most affected by changes in transportation user costs. This table presents those sectors that are positively and negatively affected as well as the cause of the impact, namely elective household reductions in consumption or higher prices due to increased trucking costs. This relationship is driven by the household elasticity values discussed earlier. Some sectors, like retail trade, are affected by both reduced household spending and increased prices brought on by higher trucking costs. If a scenario increased household expenditures (e.g., Example 3), the results in Table 7 would be reversed.

TABLE 7 Economic Sectors Affected by 5-Cent Increase in Fuel Tax

	Cause	
	Elective Reductions	Higher Trucking Costs
Negative		
General services to households	X	
Retail trade	X	X
Wholesale trade		X
Finance	X	
Agricultural products and services		X
Eating and drinking establishments	X	
Positive		
Construction		

In summary, the methodology established in the study is designed to be straightforward. The planning manual, on which this paper is based, is ready for use and is in a format that is flexible and comprehensive. It is hoped that this procedure can be easily applied to any geographic area in the nation, for any time frame, and across any combination of economic sectors.

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Indirect Energy Considerations in Transportation Projects

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ABSTRACT

An assessment is made of the appropriate extent of analysis of indirect energy costs and the overall importance of indirect energy considerations for various types of transportation projects. The approach focuses on the analysis of typical alternatives facing the transportation planner for projects ranging from roadway maintenance to construction of a major rail transit facility. Six categories of indirect energy are defined. Indirect energy costs, along with direct and miscellaneous energy costs, are presented for the alternatives in each case study. Among the projects considered in the case studies are highway widening, roadway construction using different types of pavements, bridge repair as opposed to abandonment, a computerized signalization project, a bus route extension, and provision of dial-a-ride services. Criteria for carrying out an energy analysis and for deciding its appropriate extent for a given project type are discussed fully. The major finding is that the importance of indirect energy costs depends in part on the purpose of the analysis. If the primary purpose is to compare the relative energy costs of two or more alternatives, then consideration of indirect energy in addition to construction energy costs is necessary only if the project involves major highway or transit construction or a choice between pavement types. On the other hand, if the primary purpose is to obtain an accurate figure for the overall energy costs of a specific project, then indirect energy costs must be considered. The paper also indicates that cost-based energy factors, which are easy to use, are as acceptable as materials-based factors. The vital importance of the assumptions made in an energy analysis is emphasized.

Analyzing energy used in transportation projects is relatively recent; it grew out of the energy crises of the past decade. Many studies were undertaken that focused on energy savings; however, they often did not include a full accounting of energy costs. There is a tendency to stop after direct energy costs have been addressed, especially when little guidance exists for treating indirect costs. The nature of indirect energy costs contributes to this tendency; at times they appear to be so removed from the project under analysis that there is a question of whether they should be considered at all. This is particularly difficult when the inclusion of certain indirect costs can change the relative energy efficiencies of alternative projects.

The purpose of this paper is to provide guidelines on the extent of energy cost analysis needed for various project types. Results from various case studies are used to illustrate both the formulation of these guidelines and their application. It should be noted at the outset that this study is primarily concerned with energy costs. No new ground is broken concerning energy factors; factors in widespread use in the literature are used and cited here. This paper indicates the types of projects for which indirect energy costs are likely to be significant and highlights which decisions concerning the approach or the depth of an energy analysis would have significant effects on bottom-line energy costs.

Three guiding principles for selecting the approach and depth of an energy analysis are

1. When alternatives are compared, the energy analyses should be carried out in the same depth and detail for both.
2. The criterion for deciding the appropriate content of the analysis for a given project type is that any further considerations of indirect energy would not change the relative energy efficiencies of the alternatives.
3. If the difference in total energy costs between alternatives is less than 10 percent, the second principle is overruled and a full energy analysis is recommended. This principle recognizes that site-specific circumstances have an effect on energy costs and that a typical-project approach has limited applicability if the resulting energy costs are similar.

Although these principles are logical and straightforward, their application is not always simple. In comparing across modes, for example, different types of indirect energy costs are associated with each mode. The question of which costs constitute a comparable extent of analysis does not always have an obvious answer. Also, there may be other circumstances that make it difficult to judge exactly where the line should be drawn to exclude further types of indirect energy. Nonetheless, despite occasional tricky practicalities, these principles provide sound guidelines for assessing indirect energy costs.

KEY ISSUES

Several major issues underlie the assessment of direct and indirect energy costs. One major issue, the extent of the analysis, has been addressed by the three principles stated previously. Included among the general issues are the approach to analyzing energy costs and the methods used. The question of how to account for a certain type of energy will also arise and should be addressed. The types of projects to be analyzed are also important.

Approaches to energy analysis vary between extremes. At one end, a purely incremental approach considers only the energy obviously expended on a project and ignores indirect costs and savings. At the other end, a total approach traces indirect costs back as far as possible and gives full consideration to external costs and opportunity costs associated with energy use. Most examples in the literature choose a middle ground between these extreme approaches. The principles outlined earlier argue for a middle approach that considers indirect energy costs only to the extent that they affect the relative standing of total energy expenditures for alternative projects. Studies involving systemwide energy use tend to take a total approach. Project-level analyses consider important energy effects beyond the scope of the particular project but do not pretend to be all-inclusive.

Along with the issue of what to analyze is the issue of how to analyze. The two methods most commonly used are the cost-based method (often derived from input-output analysis) and the materials-based method (sometimes called process analysis). The cost-based method is preferable when there are time or data limitations; however, the materials-based method is chosen when accuracy is the primary concern. The monetary savings often associated with actions that have lower energy costs are more obvious under the materials-based method. This is because the cost-based method measures energy cost per dollar spent, and the total dollar amount is either an aggregate estimate (for projects to be built) or a total for one alternative (for projects already finished). When the cost-based method is used it is generally not possible to obtain energy cost estimates broken down by energy type or by project component because energy costs have been expressed at an aggregate level. The materials-based method, which uses disaggregate data, calculates the energy cost per quantity of material needed for each project component; thus it provides a finer level of detail as well as a more accurate total for energy costs.

Many energy analyses measure the local or regional impact of a particular project. Certain project-related indirect energy costs may not be incurred in the region, and it is not clear that such energy costs should be charged to the region's energy accounts. For example, in several case studies the energy involved in manufacturing vehicles is included in the calculations, yet those vehicles were manufactured elsewhere. Is it proper to charge that energy to the region? Other examples are the processing energy or potential heat energy of construction materials such as asphalt or concrete. If these materials are produced in another state, are these energy costs relevant to an analysis of regional impacts? In this paper, energy costs for these categories of energy are calculated and included in project energy costs. The analyst should be aware that a case can be made for charging energy costs of this nature to the place where they are actually incurred as opposed to the place where the project is located.

A final important issue for this paper is how to categorize projects. The main purpose is to provide guidelines for the extent of energy analysis by project type; therefore, the choice of categories is important. The three principles are guidelines for analyzing alternatives. For various types of projects, energy costs are considered for typical alternatives and guidelines are presented for the extent of analysis required for each type of project. Case studies that illustrate the calculations of energy costs for each of these typical alternatives are presented and used in conjunction with other projects in the literature to form guidelines on the extent of energy analysis recommended for each project type.

Where possible, the case studies in this paper have been analyzed using the materials-based method, because a breakdown of energy costs is necessary to determine the appropriate extent of the analysis. An incremental approach is generally sufficient, although all relevant indirect energy costs are included. Before analyzing the case studies, precise definitions of the types of energy to be considered, as well as a clarification of the differences between direct and indirect energy, are necessary.

ENERGY TERMINOLOGY

There are many different ways to categorize energy. A study by Apostolos et al., done at the California Department of Transportation and referred to hereafter as the Caltrans study, distinguished between direct and indirect energy and described two types of indirect energy: central energy use and peripheral energy change (1). Erlbaum et al. followed Caltrans in distinguishing between direct and indirect energy; however, they classified three types of indirect energy: guideway, facility, and maintenance (2). The Asphalt Institute (3) and the American Concrete Paving Association (4) use four categories of energy: materials, mix composition, plant operations, and haul and place. Finally, Halstead defines four types of energy: calorific, processing, transport (hauling), and construction (5).

These examples clearly demonstrate that there is no standard categorization of energy types. Generally, the energy categories used here are a combination of Caltrans and Halstead, with some amplification. The distinction between direct and indirect energy is recognized, and (after Caltrans) direct energy is defined as the energy used to propel or operate a vehicle (1). This energy is also known as propulsive energy, and it is the only type of energy classified as direct energy. Often the actual level of propulsive energy is not of as much interest as the energy changes brought about by the specific improvement.

All types of energy other than propulsive are considered indirect. Indirect energy obviously encompasses a wide spectrum of energy uses, which can in turn be classified according to how indirect they are. Closest to direct energy is the energy used in the construction or implementation of the project. Project construction can give rise to maintenance energy requirements or to the energy use associated with necessary ancillary facilities. Also to be considered is the energy embodied in the materials used. Each category of indirect energy is defined in the following paragraphs.

Construction operating energy is the energy needed to operate construction machinery and perform related activities at the construction site. Closely related to construction operating energy is construction hauling energy. This is the energy used in transporting materials from their point of origin to their point of use. All hauling costs are placed in this separate category because proximity to raw materials is thought to affect total energy costs significantly in certain situations. This method of categorization is not always followed in other studies: often, hauling costs include only the energy cost of transporting materials from point of manufacture to point of use. Note also that although construction hauling energy is used to operate and propel vehicles, it is considered an indirect energy cost because this energy use is a by-product of the project itself not an independent use.

Energy costs arise from necessary maintenance to roadways or guideways, to vehicles, and to other necessary facilities. This is maintenance energy. There is also vehicle manufacturing energy, or the energy used in the manufacture of automobiles, buses, or construction equipment. Processing energy is the energy required to convert various raw materials into usable form. this reflects the energy embodied in a given material. There are standard energy factors for the processing energy per given quantity of asphalt, cement, steel, and so forth. Closely related to processing energy is calorific energy. Calorific energy is the potential energy of a material that could be used as fuel; it measures the heat energy released when the material is completely burned.

Other miscellaneous indirect energy costs that do not appear to fit into any of these categories arise from time to time. However, the seven types of energy (one direct, six indirect) defined here are sufficient to categorize the most important energy costs encountered in transportation projects. This method of categorization can clearly show the relative importance of each type of energy cost.

CASE STUDIES

The results of several case studies are discussed so that the appropriate extent of an energy analysis for a given project type can be determined. Although these case studies do not cover every type of project, they are sufficiently varied to provide an excellent idea of the relative impacts of various energy costs for major highway construction projects, major transit projects, and transportation system management (TSM) actions.

Each case study presents an analysis of alternative projects. The three guiding principles cited earlier are applied to each case study to determine the point at which further consideration of indirect energy does not affect the relative positions of the alternatives in terms of their energy costs. The case studies address the following seven alternatives:

- Highway widening versus "no build,"
- Highway construction: asphalt versus portland cement concrete pavement,
- Rail rapid transit versus freeway equivalent,
- Alternate highway maintenance procedures,
- Bridge repair versus abandonment,
- Highway TSM action: computerized signalization versus null option, and
- Transit service: fixed route versus demand responsive.

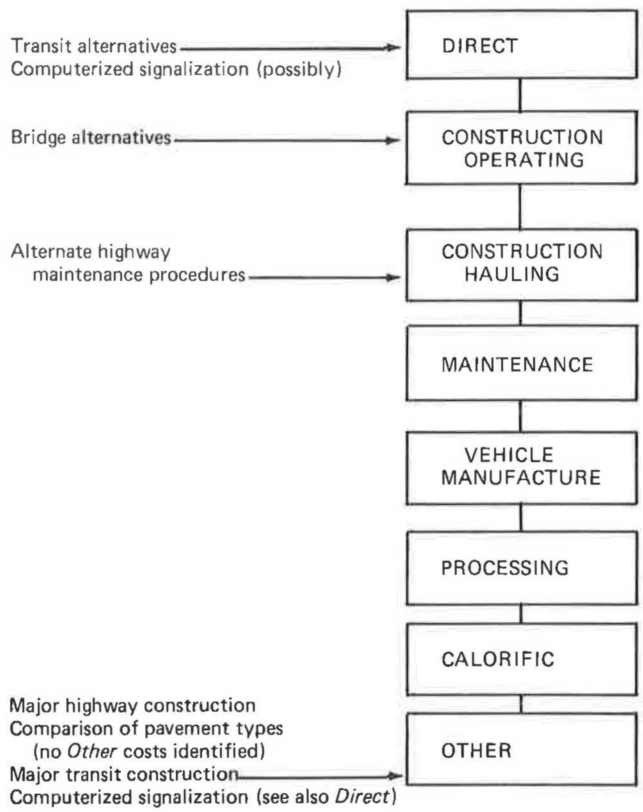
For each case study, the alternatives are described briefly, then the results of the energy calculations are discussed. A summary of annualized direct and indirect energy costs for each alternative is presented in Table 1. The relative importance of each energy category is assessed for each alternative, and the appropriate extent to which an analysis should be performed is shown in Figure 1. Consult Boyle (6) for detailed calculations.

Highway Widening Versus "No Build"

The highway widening case study was taken from the Caltrans manual (1) and involves a proposal to widen a four-lane arterial to six lanes for 5.6 miles. The alternative is to do nothing, which will mean congestion on the road in the future during peak hours. Average daily traffic (ADT) is anticipated to be 25,000 vehicles (both directions). Energy costs associated with construction and materials are much less than direct, maintenance, and vehicle manufacture energy costs. These costs primarily reflect the costs of operating a vehicle (or 25,000 vehicles in this case) and are 8 percent higher for the no-build alternative because of the increased energy costs associated with congestion. Because a difference of this magnitude cannot be considered significant, given the number of assumptions, consideration of all indirect energy costs is recommended. The soundness of this recommendation can be illustrated by examining one of the underlying assumptions more closely. If one were to assume that a 10 percent

TABLE 1 Direct and Indirect Energy Costs for the Seven Case Studies (annual BBtu's)

Case Study	Direct	Indirect	Total	Construction Related, %
Highway widening				
Widen	373.8	259.0	596.8	0.1
No-build	376.1	268.8	644.9	0.0
Highway construction				
Asphalt pavement	–	16.4	16.4	14.8
Cement pavement	–	10.7	10.7	74.2
Transit vs. highway				
BART	1,950	2,943	4,893	42.0
Freeway	2,859	1,667	4,526	3.7
Pavement maintenance				
Recycling	–	0.6	0.6	22.2
Replacement	–	0.8	0.8	20.1
Standard overlay	–	0.3	0.3	15.0
Bridge				
Repair	0	1.6	1.6	100.0
Abandonment	37.3	30.4	67.7	0.0
Traffic flow				
Computerized signalization	127.8	94.2	222.0	0.7
Null option	139.5	92.1	231.6	0.0
Transit service				
Route extension	0.8	1.1	1.9	0.0
Dial-a-ride	1.7	1.6	3.3	0.0



Note: The types of energy listed proceed from the most direct type to the least direct. For a given case study, all energy categories at or above the energy type must be considered.

FIGURE 1 Recommended extent of energy analysis for the seven case studies.

increase in ADT would result from widening the highway, total energy costs would then be 1.7 percent higher for the widening alternative (6). Similar variations in local conditions can easily cause minor shifts in the relative energy efficiencies of the alternatives under consideration; the third guiding principle is intended to guard against misleading conclusions that do not take local conditions into account.

Asphalt Versus Portland Cement Concrete Pavement

The second case study addresses the use of asphalt or cement pavements in highway construction. Data for this case study are derived from a Connecticut Department of Transportation (ConnDOT) report (7). ConnDOT studied the energy costs of standard and recycled portland cement concrete (PCC) pavements placed on I-84 near Waterbury and the energy costs of standard and recycled asphalt concrete (AC) pavements placed on Route 4 near Burlington. Because the ConnDOT study did not calculate total energy costs but instead used costs per ton or per cubic yard, the results can be adapted to a project of a given size. This case study examines the energy costs of paving a four-lane highway for 10 miles with conventional asphalt concrete and with conventional portland cement concrete.

Roadway maintenance and calorific energy costs are significant for the asphalt alternative; however, the high processing energy requirements of portland cement concrete account for most of the energy costs in the PCC alternative. If the analysis were limited to processing energy, the AC pavement would have a lower energy cost (2.7 percent lower than the energy cost of the PCC pavement). Consideration of the calorific energy in the asphalt, however, makes the total energy cost of the AC pavement 54 percent higher than that of the PCC pavement.

It should be noted that there is considerable debate between the Asphalt Institute and the American Concrete Paving Association (ACPA) over the appropriate treatment of calorific energy costs (3,4). The Asphalt Institute's argument is that when the decision is made to use asphalt as a construction material rather than as a fuel, the energy it contains is no longer available and should not be considered. ACPA emphasizes the fact that calorific energy is available in asphalt and argues that decisions on how to use asphalt do not change that fact.

Many studies concerned with the marginal energy costs associated with a specific project or with localized energy effects do not consider calorific energy costs; the ConnDOT report from which this case study is adapted is among those studies. A complete accounting of indirect energy costs, however, should include calorific energy, particularly when it can change the relative energy costs of two alternatives; therefore, a full energy analysis is recommended.

Rail Rapid Transit Versus Freeway Equivalent

The third case study addresses the energy costs associated with the construction of BART in San Francisco. The alternative to BART is referred to as the freeway alternative, and it takes into account the energy costs of freeway construction and automobile travel presumed to take place in the absence of BART. This case study is based on a study by Lave of the energy impact of BART (8), even though some of Lave's assumptions were found to be untenable and have been changed (6). Because of the difficulty in obtaining accurate totals of quantities of materials used in rapid rail construction as well as energy factors associated with each material, Lave's cost-based methodology is followed. The construction of BART was so energy intensive that it overshadowed savings in propulsive, maintenance, and vehicle manufacture energy. However, the difference in total energy costs between the alternatives is only 8 percent, indicating that local factors are likely to determine the relative energy efficiencies of rail transit versus new freeway construction. A full energy analysis is, therefore, recommended.

Others argue that further energy considerations or different assumptions can actually make transit's energy costs lower than those of the freeway alternative. Usowicz and Hawley argue that the energy required to construct BART was not nearly as great as reported by Lave and was also lower than the figure used here (9). Pushkarev and Zupan claim that BART's energy costs were unusually high because of a reliance on complex technology and that construction of a rail transit system can save energy over the medium term (10).

This wide disparity in estimates of energy used needs to be emphasized. Lave indicates that a rail transit system such as BART is much more energy intensive than a comparable freeway alternative. This analysis indicates that both alternatives are roughly equal in terms of annual energy costs. Usowicz and Hawley show BART to be much more energy efficient than the freeway alternative. Pushkarev and Zupan argue that rail transit is energy efficient, but that BART is not the system to prove it. This disparity reflects the heavy reliance of each analysis on assumptions necessitated by the absence of a good data base.

It is no surprise that Lave reaches a conclusion completely opposite from that of Usowicz and Hawley when one analysis estimates that 74.7 lane kilometers of roadway are necessary in lieu of BART and the other estimates 198.4 lane kilometers of roadway plus a bridge and a tunnel. New rail transit construction in Washington, D.C., Baltimore, Atlanta, and other cities should broaden the data base and lead to a standardization of assumptions.

Alternative Highway Maintenance Procedures

The fourth case study analyzes the energy costs of three alternative maintenance procedures and is drawn from a study carried out in Sherburne, Vermont (11). The first alternative is to recycle the top 4 in. of asphalt pavement surface. The second alternative involves removal, disposal, and replacement of 3 in. of pavement. The third alternative is to use standard maintenance procedure and overlay 1.5 in. of asphalt pavement. These alternatives are applied to a 1.5-mile stretch of US-4, a 40-ft-wide roadway.

The relative energy efficiency of the three alternatives is identical for each category of energy: standard maintenance procedure has the lowest energy cost, followed by recycling and replacement. The total energy cost of replacement is 30 percent higher than that of recycling, which in turn is more than twice the energy cost of the standard maintenance procedure. Consideration of construction operating and hauling energy costs is sufficient to determine relative overall energy costs for maintenance alternatives. The energy costs depend ultimately on the amount of asphalt or AC pavement required. Thus, even through calorific energy costs account for the bulk of overall energy costs, their exclusion would not change the results in terms of overall energy efficiency. As the Vermont report states, in order for the costs (both monetary and energy) of the recycled alternative to be justified, it must reduce future maintenance requirements.

Bridge Repair Versus Abandonment

The fifth case study is drawn from an FHWA report prepared jointly by the New York State Department of Transportation (NYSDOT) and the Genesee Transportation Council (Rochester, New York) (12) and involves a bridge over the New York State Thruway (I-90) in Monroe County. The bridge, originally built in 1953 and repaired several times since, has deteriorated to the point where further maintenance is considered pointless. The first alternative is to repair the bridge; the second is to close the bridge and divert traffic. The detour would result in an additional travel distance of 1.85 miles. Average speed is 45 miles per hour and annual ADT is 13,000 vehicles, 5 percent of which are trucks (4 percent light trucks and 1 percent heavy trucks are assumed). Because details on quantities of materials used on the bridge structure are unavailable and difficult to synthesize, the cost-based method is used in this case study. Energy-per-dollar factors have been developed in a previous NYSDOT report (2). This case study provides an excellent example of how to proceed when reliable estimates of materials and quantities used are not available. In addition, this case study differs from the others in that it focuses principally on marginal energy costs.

Results of the analysis indicate that the propulsive energy costs of the abandonment alternative are much greater than the annualized construction costs of the repair alternative. The relative energy costs become clear when construction operating energy is taken into consideration. It appears that unless the detour is very short and construction costs very high, the additional propulsive energy induced by a bridge closing is likely to outweigh the energy needed to rehabilitate the bridge.

Computerized Signalization Versus Null Option

The sixth case study examines a highway-related TSM action and is drawn from a report prepared by NYSDOT for UMTA (13). An urban radial arterial 3.7 miles long has its noninterconnected pretimed signals replaced by an advanced computer-based control system. There are 10 signals on this length of the arterial. Daily vehicle miles of travel (VMT) is 64,786 and daily vehicle hours traveled (VHT) is 3,714. The improvement will decrease travel time by 25 percent and induce 5 percent additional traffic. The project is proposed for 1983 with a cost in 1980 dollars of $2.5 million. The alternative to the signalization project is to do nothing. Although propulsive, maintenance, and vehicle manufacture energy costs are all slightly higher for the null option, there is only a 4 percent difference in overall energy costs.

The third guiding principle dictates that the results are too close to allow a clear statement of relative energy efficiencies, so a full energy analysis is recommended for projects similar to this case study. However, it is interesting to note that there is only a slight absolute difference [2 billion British thermal units (BBtu's)] in indirect energy costs between the two alternatives. Additionally, both maintenance and vehicle manufacture energy costs are dependent on the same factors that influence propulsive energy. Together these facts imply that the difference in propulsive energy costs is the most significant factor in determining overall relative energy efficiency.

Fixed Route Versus Demand Responsive

The final case study examines alternatives for expansion of transit service to growing suburban developments. The first alternative is to extend an existing transit route for a distance of 2.5 miles. The second alternative is to provide dial-a-ride service, which can act as a feeder to the existing transit line as well as provide intrasuburban mobility. The suburban town has a population of 21,000; 15,000 people are within 0.25 mile of the main arterial along which fixed-route service would operate. Fixed-route services would be offered on a 15-min headway in peak periods, a 30-min headway in the off peak, and a 60-min headway in the evening. The dial-a-ride service would operate several 10-seat vehicles over the course of the day.

Vehicle requirements, anticipated ridership, and additional VMT have been calculated using techniques developed by Alan M. Voorhees and Associates (14). When these have been determined, energy calculations may be carried out. Overall energy costs for the dial-a-ride option are 75 percent greater than energy costs for the route extension alternative. Propulsive energy is the major category of energy costs for both alternatives, and only propulsive energy need be considered in an analysis of alternatives of this type.

SUMMARY

The appropriate extent of analysis of indirect energy costs for various types of transportation projects has been addressed in this paper. An approach was adopted that focused on the analysis of typical alternatives facing the transportation planner for projects ranging from roadway maintenance to construction of a major rail transit facility. Although the difficulty of isolating typical alternatives and projects is recognized, it was believed that providing examples of alternative analyses would be more useful in providing a context for the analysis than simply examining individual projects.

This document is a synthesis of existing work. It has the advantage of applying standardized methods and factors to case studies drawn from a variety of reports, but these methods and factors are not original. Caltrans (1), the Asphalt Institute (3), Halstead (5), and previous NYSDOT studies (2,15,16) are the primary sources for these methods and factors. A complete list of factors may be found in Boyle (6). The point that energy assumptions play a key role in the analysis cannot be overstated; indeed, it deserves to be the first conclusion drawn in this study.

Extent of Energy Analysis

The appropriate extent of energy analysis for each case study is summarized in Figure 1. Indirect energy costs should receive full consideration in the analysis of major highway and major transit construction projects and in cases where the alternatives involve use of different pavement types. In the widening, pavement type, and BART case studies of relative energy efficiencies, consideration of indirect energy costs led to a conclusion different from that indicated by consideration of direct energy costs only.

Consideration of indirect energy costs for minor highway projects is marginal. Although calorific energy was a major component of total energy costs for all three alternatives in the roadway maintenance case study, its exclusion does not change the outcome of the analysis. Therefore, relative energy efficiencies can be clearly established by considering only propulsive and construction energy costs. In the signalization case study, consideration of indirect energy costs beyond construction energy does not influence the results. The results indicate that there is no significant difference between the alternatives in energy terms; direct and construction energy costs are sufficient for determining the relative efficiency of the alternatives.

Indirect energy costs beyond construction energy do not need to be considered in bridge rehabilitation and minor transit projects. For the bridge rehabilitation versus abandonment case study, length of the detour, traffic volume, and construction costs are sufficient to determine relative energy costs. In minor transit projects of a TSM nature that do not involve construction, the change in transit VMT appears to be the determining factor.

Relative Importance of Indirect Energy

Table 1 gives the direct and indirect energy costs associated with the alternatives considered in the seven case studies. In each case study, indirect energy accounts for at least 40 percent of overall energy costs for at least one alternative. This indicates that indirect energy costs account for a significant portion of total energy costs.

This conclusion appears to contradict previous conclusions that view indirect energy as marginal or irrelevant in all except major construction projects and those involving a choice between pavement types. A closer examination of Table 1 reveals that although indirect energy costs are often large, their effect on the relative energy costs of the alternatives in a given project is important less often. This can be seen in Figure 1, which shows the recommended extent of analysis for each case study. In many cases, maintenance and vehicle manufacture energy are the major components of indirect energy costs (6). Energy costs of maintenance and vehicle manufacture are affected by the same factors that affect direct energy costs (principally VMT). Thus, when examining the relative energy costs of alternatives, consideration of maintenance and vehicle manufacture energy tends to reinforce the relative direct energy costs and indirect energy does not appear to be important. However, when examining the absolute energy costs of alternatives, maintenance and vehicle manufacture energy costs account for a significant portion of overall energy costs and appear to be important. This leads to the conclusion that the importance of including indirect energy depends on the purpose of the analysis. In a relative analysis, indirect energy costs are important under the conditions outlined previously. In an absolute analysis of the bottom-line energy cost of a specific project, indirect energy costs are important.

The final column of Table 1 gives the percentage of total energy costs accounted for by construction operating, construction hauling, and processing energy. This column highlights the discussion earlier in this paper of the benefits of the materials-based and cost-based methods of analysis. Recall that under the cost-based method, these three energy categories were combined in a single Btu-per-dollar construction energy factor, whereas the materials-based method treats each separately. The materials-based method is considered more reliable; however, the cost-based method is easier to use.

The final column in Table 1 indicates that construction energy (including the three categories of construction operating, construction hauling, and processing energy) is not generally a significant component in overall energy costs. Construction energy accounts for more than 25 percent of total energy in only three of the fifteen alternate projects considered in the case studies. Moreover, for two of these three projects, the cost-based method was used because of the lack of detailed data on quantities of materials used. Construction energy was a significant portion of total energy costs in only one of the seven alternatives where the materials-based method was used. This suggests that, when construction energy costs are low, the increased accuracy derived from use of the materials-based method may not be worth the additional effort and that, for most purposes, the cost-based method and the materials-based method are equally acceptable for calculating construction-related energy costs. This supports previous studies by Caltrans (1) and Erlbaum (2), both of which used cost-based energy factors exclusively.

CONCLUSIONS

A summary of conclusions follows.

1. The importance of indirect energy costs depends in part on the purpose of the analysis.
2. In an analysis that compares the relative energy costs of two or more alternatives, indirect energy costs are important for major highway and transit construction projects and for projects involving alternative types of pavement. In these situations, a full energy analysis that encompasses all forms of indirect energy is recommended. For other types of projects, consideration of indirect energy beyond construction energy costs is not necessary.
3. In an analysis of overall energy costs of a specific project or projects, indirect energy costs are important and must be considered.
4. The cost-based method and the materials-based method are equally acceptable for calculating construction-related energy costs.
5. Because of the rudimentary nature of an energy analysis, the assumptions made are vitally important. Care must be taken to ensure that the most reasonable assumptions are made.

There is always the question of whether a given case study or a given alternative is indeed typical. Although the range of projects considered here is fairly broad, there are certainly many alternatives that either do not fall neatly into one of the case studies analyzed here or have atypical characteristics. The informed analyst can recognize problems such as these and make the necessary adjustments in the course of the analysis. With the various energy methods and factors provided by Boyle (6), the analyst should be able to perform the necessary energy calculations for those atypical projects and alternatives.

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