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Contents

State and Local Roles in Transportation Control Planning

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Numerous problems have arisen in the planning and implementation of transportation controls developed under the Clean Air Act. These problems include constraints imposed on the planning process by strict statutory deadlines and limited resources; uncertainties about the nature and severity of the air pollution problems facing metropolitan areas and about the effects on health and welfare of air pollution; incomplete information about the effectiveness, costs, and implementability of transportation control options; lack of explicit investigation of social and economic effects of proposed transportation control strategies; insufficient public involvement in, and understanding of, transportation control planning; and failure to adapt the transportation control planning process to the existing institutional framework. Despite these problems, transportation controls can have multiple benefits, not only improvement of air quality but also more efficient use of the existing transportation system, energy conservation, increased safety, spurred transit development and better transit services, and more rational use of scarce urban land. Thus, carefully planned transportation controls can meet multiple objectives and support community goals. Steps that can be taken by states and localities now include (a) requiring that certain decisions be made by the organization responsible for adopting a regional transportation plan; (b) coordinating the roles of all levels of government in development of transportation plans; (c) facilitating public involvement in transportation control planning; (d) requiring full impact analysis; (e) undertaking and monitoring experiments and innovations in transportation controls; and (f) requiring periodic evaluation and update of transportation control plans.

In urban areas, the automobile is the principal source of two major air pollutants, carbon monoxide and oxidants. National ambient air quality standards, established by the U.S. Environmental Protection Agency under the Clean Air Act of 1970, as amended, were exceeded for one or both of these pollutants in 66 air quality control regions (AQCRs) in 1972.

The Clean Air Act established three major approaches for achieving air quality standards:

1. Increasingly stringent emissions controls on new automobiles,
2. Performance standards for appropriate categories of new stationary emissions sources, and
3. State implementation plans (SIPs) containing any additional control regulations and measures needed to achieve the air quality standards within each state.

Transportation and land use controls are specifically mentioned in the act as means that must be used, if necessary, to meet and maintain the standards.

Although the new car emissions standards and stationary source controls have substantially reduced emissions, more than 30 AQCRs must implement transportation control measures to achieve the carbon monoxide and oxidant standards by the deadlines set by the act. In addition, new and more reliable air quality data indicate that many areas not previously required to develop transportation controls in fact may need to do so. Finally, projected growth rates in automobile use in several areas indicate that total motor vehicle emissions in these areas will increase to levels above the standards in the middle of the next decade unless countermeasures are taken. Inasmuch as the Clean Air Act requires that air quality standards be achieved in all areas and maintained permanently once achieved, transportation control measures may become necessary in these areas in the near future. Thus, transportation controls are or will be needed in a large number of AQCRs.

The Clean Air Act currently places initial responsibility for the development of SIPs, including transportation control plans, with the states but requires EPA to supplement any inadequate state plan and to formulate a plan for the state if the state fails to do so. Although some states have submitted approvable plans, EPA was required to promulgate transportation control measures in a large number of cases. However, the act permits the states to submit revised SIPs, and a number of states are taking advantage of this option to modify transportation control plans (TCPs) for their urban areas. In several cities, studies are under way to determine alternate transportation control measures to replace some of those in current TCPs. Many of these restudies have been motivated by the severe criticisms of existing TCPs.

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PROBLEMS WITH CURRENT TRANSPORTATION CONTROL PLANS

Proposals to implement transportation control measures have set off heated and often antagonistic debate in several metropolitan areas. Criticisms of and challenges to proposed measures have led to repeated plan revisions and delays in implementation in a number of cases. Controversy has been so severe in some areas that there is serious doubt that these control plans, at least as they are currently formulated, could ever be implemented and, if implemented, enforced.

A number of problems in TCP development have been identified (1).

Constraints Imposed by Deadlines and Limited Resources

Constraints have been imposed on the transportation control planning process by strict statutory deadlines and limited resources. The Clean Air Act allowed a relatively short time for the development of transportation control plans, particularly in light of the fact that there had been little experience with or information about transportation control measures. The tight deadline for plan submission was a severe constraint on the level of analysis that could be performed. In addition, several areas found that funding was not readily available for TCP development. Finally, the dates for achieving the standards were impossible to meet in a dozen areas unless those areas resorted to measures so stringent as to cause severe hardships (e.g., gas rationing).

Uncertainties About Severity of Air Pollution Problem

The nature and severity of the air pollution problems facing metropolitan areas and the effects on health and welfare of air pollution are uncertain. Although there have been great advances during the last few years in air pollution measurement and prediction, few areas have the most sophisticated models and measurements available to them. Some areas have found large discrepancies in air pollution measurements, and all but a few have had inadequate amounts of data available. In addition, the effects on health and welfare of air pollution are not fully understood, which makes it difficult to assess the impact of the pollution levels predicted. These uncertainties make it difficult to convincingly define the air pollution problems of a given area and the steps necessary to correct them.

Incomplete Information on Transportation Control Options

Information about the effectiveness, costs, and implementation of transportation control options is incomplete. A major difficulty is that the states have had practically no experience with transportation control measures. Most have been reluctant to propose potentially feasible but relatively untested measures, e.g., automobile restricted zones, because it is not always clear how to implement the measures, what their costs would be, or how useful they would be in reducing air pollution. Significant disagreements have developed over the extent to which various control measures would reduce pollution, and conflicting data and estimates even for relatively well-known strategies, such as exclusive bus lanes, have added to the confusion.

Other sources of uncertainty are the shortage of adequate models for evaluating short-range transportation control strategies and the difficulties in identifying the degree of effectiveness of any one strategy when several are interdependent. One study, for instance, indicates that, although transportation control strategies can be effective in areas where applied, air quality problems may shift to another area (2). Another study indicates that the effectiveness of car pooling in reducing air pollution depends on the extent to which cars left at home are used for trips that otherwise would not be made (3, 4). Difficulties in predicting transportation system response leave planners with unanswered questions about whether and how control strategies would work.

Lack of Explicit Investigation

Social and economic effects of proposed transportation control strategies have not been explicitly investigated, resulting in controversy over the perceived costs and benefits of the controls: In much of the reaction to transportation control plans, the issue raised, explicitly or implicitly, is, Are the benefits of improved air quality worth the costs of transportation controls?

Perhaps the major cause of controversy over transportation control plans and of delays in their implementation has been that the full range of potential impacts and the distribution of these impacts among different sectors of the public have not been adequately considered. Common objections raised have been that transportation control measures will reduce the competitive position of the central city in terms of retail sales and employment, will adversely affect contruction and other development throughout the region and cause undesirable land use shifts, will seriously reduce mobility for the average citizen, and will place a harsh financial burden for implementing and enforcing the measures on local governments. With few exceptions, there have been no sound data or analysis to adequately support or refute such charges.

Both of the major types of strategies for transportation control appear to conflict with other important social goals. Inspection-maintenance-retrofit strategies impose an economic burden on the vehicle owner, and hardest hit (in absence of public subsidy) will be the low-income automobile owner, who will have to allot an increased portion of his or her disposable income to vehicle modification and upkeep. In particular, the cost of retrofit devices may be onerous to those on a tight budget, and in some circumstances the costs may be a sizable portion of the total value of the automobile (5).

Potential losses in mobility and the effects such losses could have on employment opportunities, commerical activity, the housing market, and even social interactions have been the bases for many of the negative reactions to proposed transportation control plans. Reductions in vehicle-kilometers traveled under the transportation control plans may cause losses of mobility in the short run unless realistic alternative means of transportation are provided. Many of the plans include some practical substitutes for private automobile use; however, it is not clear whether the proposed steps are feasible, at least in the near future. In Boston, for instance, transportation officials expressed concern that the subway system could not expand services fast enough to accommodate the projected increases in riders during peak periods. Other proposed substitutes for automobile use such as bicycling and walking are suitable only for some persons (the relatively robust) and even then may be acceptable only for short distances and in good weather.

Even if a level of mobility similar to that available with unrestricted automobile use can be provided, losses will be felt. For example, using transit and car pools means less privacy and freedom of movement than the typical automobile driver has at present.

Certainly, time pressures and resource limitations have been a factor in the failure to assess these impacts, but equally important has been the lack of experience with the control measures themselves and of information about their costs, effectiveness, direct and indirect short-term and long-term effects, and implementation requirements.

Insufficient Public Involvement

Public involvement in and understanding of transportation control planning have been insufficient. In most cases, citizen involvement in the formulation of transportation control plans and explicit consideration of which interests would bear the consequences of plan implementation, especially the adverse consequences, have been minimal. Citizen input generally occurred only at the required public hearings, a forum at which information exchange tends to be stilted. One result has been that, now that plans have been promulgated, a number of revisions to mitigate hardship (or simply alternative means of reaching the clean air goals) are being suggested. This is by no means negative, but one can speculate that acceptance and implementation of control plans might have been smoother if more extensive debate and consideration of trade-offs had occurred before initial promulgation.

Another problem that may have been exacerbated by a failure to carry out active public information and participatory programs is that the public appears not to understand air quality problems and the benefits of cleaner air. Some seem to associate air pollution problems with dirty skies and bad smells, although serious problems may exist without either symptom or with such effects only minimal. Many of the effects of air pollution—increased respiratory ailments, shortened life spans, crop damage, adverse effects on domestic and wild animals, damage to real property—are cumulative and indirect and thus may not be readily apparent to the casual observer. The fact that air pollution is a contributing factor to and not necessarily the sole cause of many of these adverse effects may make it harder for persons to perceive or understand the implications of air pollution for health and welfare.

Complicating the picture is the apparent lack of understanding of how transportation controls will improve air quality. This is more probably true of control strategies such as parking management than of the transit-oriented strategies, and more debate has occurred over the former.

Under such circumstances outcry over the inconveniences and potentially harmful effects of transportation controls is hardly surprising. However, unless citizen fears can be allayed, political pressures on the state and local levels may seriously hamper the implementation of any transportation control measures. And, as a practical matter, the success of transportation control strategies will depend largely on voluntary cooperation and compliance; positive community attitudes toward the selected measures are crucial.

Inadequate Consideration of Existing Institutional Framework

The transportation control planning process has not been adapted to the existing institutional framework, resulting in inefficient use of resources and lost opportunities. In many cases, the control plan for a region is prepared outside of and somewhat independently of the institutions and political processes that will be called on to carry out the plan. This is a problem particularly for those plans developed or significantly modified by EPA, but even those plans developed by state or local agencies may not have the broad-based commitment necessary for their effectuation.

In many cases local governments and agencies that must shoulder the greatest part of the burden of carrying out transportation control plans played insignificant roles in the selection of control measures. It is not clear whether these local institutions fully support the implementation and enforcement of the control strategies, particularly since the plans sometimes conflict with previously established policies. Even if they wish to do so, local entities may lack the resources to carry out the plans because their funds and personnel resources already are stretched to the breaking point, and it is unlikely that all of the funds needed will be forthcoming from either city or state sources where environmental planning must compete with numerous other programs for scarce tax funds (6).

Failure to involve local governments also may have resulted in lost opportunities to improve air quality. Local units of government usually control many of the levers that have great potential for air quality regulation (e.g., parking, use of local streets, zoning, and development permits), and their exclusion from the transportation planning process narrowed the range of options that could be considered. Thus, involvement of the appropriate local agencies can result in significant contributions to air quality planning.

Perhaps the most serious institutional weakness in the transportation control planning process to date has been the failure, in a number of instances, to bring regional transportation and other areawide planning agencies into TCP development. The Clean Air Act requires the state to submit the SIP (including the TCP), yet TCPs are by and large an urban area need. In many cases, metropolitan planning organizations (MPOs) have been only marginally involved in controls planning, yet their support and approval of TCP measures are a prerequisite in many instances to federal funding and to successful implementation. In cases in which the MPO has not been involved significantly in transportation control planning, the result has been a parallel planning process for those transportation options that have likely air quality benefits and difficulty in obtaining funds needed for implementation of the TCPs.

RELATIONSHIP OF TRANSPORTATION CONTROL PLANS TO OTHER FEDERAL PROGRAMS

The primary purpose of transportation control plans is to achieve cleaner air and an accompanying decrease in health problems and improvements in the quality of life. However, other benefits such as more efficient use of energy, increased safety, accelerated development of transit and better transit services, and more rational use of scarce urban land may result directly or indirectly from transportation control measures.

A variety of options have been proposed for inclusion in transportation control plans. These options fall into categories: (a) those intended to reduce emissions per vehicle-kilometer traveled and (b) those intended to reduce vehicle-kilometers traveled or to increase the efficiency of traffic flow, thus decreasing total emissions. Proposed options include (7) the following. (Gasoline rationing also appears as a strategy in some control plans, although EPA's stated policy is not to require or enforce such requirements in the absence of a congressional mandate or presidential directive.)

1. Vehicle emissions inspection and maintenance

programs,

2. Retrofit of vehicle emission control devices,
3. Idling restrictions,
4. Conversion to gaseous fuels,
5. Gasoline rationing,
6. Priority treatment for high-occupancy vehicles on roadways,
7. Priority treatment for high-occupancy vehicles at signals, intersections, and toll gates,
8. Improved traffic engineering systems,
9. Paratransit and demand-activated transit services,
10. Facilitated bicycle use,
11. Improved and expanded transit service,
12. Improved pedestrian ways,
13. Parking restrictions and parking bans,
14. Vehicle-free zones and restricted use zones,
15. Congestion pricing,
16. Increased parking fees and road tolls,
17. Fringe parking at transit stations,
18. Gasoline price increases,
19. Car pooling and van pooling programs,
20. Improved goods movements, and
21. Changes in work schedules.

Of course, there are numerous possible variations of each of these options.

Many of the measures included or considered in transportation control planning for air quality purposes are being considered by other federal and state agencies because they promote other goals such as more efficient transportation system operation and energy conservation. For example, the Urban Mass Transportation Administration and the Federal Highway Administration have issued joint regulations (8) requiring the urban transportation planning agencies to develop "transportation system management elements" (TSME). Measures suggested for consideration include traffic operations improvements to manage the flow of automobiles and transit vehicles; preferential treatment for high-occupancy vehicles on highways; improved provisions for pedestrians, bicycles, and trucks; management and control of parking; changes in work schedules and peak-hour pricing; reduction of automobile use through shared rides, congestion pricing, and restrictions; improvements in transit services; and improvement in transit management efficiency. Not only are most of the options included in the TCPs suggested for inclusion in the TSMEs, but also air quality is specifically listed as one of the factors to be considered in the selection of TSM measures. Thus, this new program offers considerable opportunity for fostering greater coordination between transportation and air quality programs.

Other programs also are examining the TCP types of measures for reasons other than air quality. Several state transportation agencies are now funding and promoting common transportation control measures such as highway operations improvements, exclusive bus lanes, fringe parking lots, and car pooling as means of improving the existing transportation system level of service at low cost. The Federal Energy Administration is conducting studies of car pooling, van pooling, and other shared-ride concepts and related incentives and disincentives (parking regulations, road tolls, and so on) to determine their potential for reducing gasoline consumption (9). Social service agencies and private interest groups are promoting transportation control measures such as new or increased transit service, bicycle lanes, and improved provisions for pedestrians as means of improving mobility for the elderly, disabled, disadvantaged, and nondriving segments of the population. And numerous agencies and groups are supporting a variety of transportation control measures because of their potential safety benefits.

The consideration of TCP types of measures in a broad range of programs for a variety of purposes provides opportunities to overcome many of the problems that arose in TCP planning. By selecting those measures that meet multiple objectives (e.g., increase transit level of service while improving air quality) and are consistent with community goals (e.g., increase bicycle safety), planners can meet Clean Air Act requirements in ways that are compatible with other local needs.

RECOMMENDATIONS FOR STATE AND LOCAL ACTION

Proposed federal actions to overcome some of the problems of transportation control plans include (10) amending the Clean Air Act, modifying EPA regulations pertaining directly to transportation control plans, and modifying other federal regulations for related programs. However, the timing of federal actions is uncertain. With the exception of revised deadlines for attainment of ambient air quality standards, years may elapse before the full range of federal actions can be implemented. In the meantime, states and localities can act independently of the federal government to make transportation controls more compatible with local goals, more responsive to local opinion, and more attuned to local resources and problems. Actions that the states and local communities can take now to improve transportation control planning are discussed below.

Decision Making by Metropolitan Area Organization

Many transportation control measures are regional or local in scope and impact and should be planned and implemented by regional and local agencies, not in remote levels of the state and federal government. Measures such as exclusive bus lanes, car pooling, bikeways, and improved transit, which directly affect the regional transportation network, fall into this category and should be planned in conjunction with the established transportation planning process for the metropolitan area. The logical agency to undertake this planning is the existing metropolitan planning organization. The advantages of planning these measures on the regional level are several:

1. It uses all of the resources of the existing transportation planning agency, including established procedures for public participation, an existing data base, in-house analytical capability, contacts with other regional and local planning programs, contacts with local enforcement agencies, and available planning funds;
2. It prevents wasteful duplication of transportation planning efforts;
3. It provides for the consideration of local interests and goals in the plan formulation; and
4. It opens the TCP measures included in the regional transportation plan to a wider range of potential funding.

Coordination of Local, Regional, and State Responsibilities

Many of the transportation measures considered as transportation controls are not planned or implemented at the regional level. Some, such as inspection and maintenance, are typically handled by state agencies (if undertaken at all), while others, such as parking controls, are usually handled by local governments.

States may coordinate these disparate planning elements in one of two ways.

1. Designate a lead agency to coordinate the planning processes. The lead agency might be a state or regional agency. In either case, the lead agency's responsibility could be to identify needed input to the planning process and work out agreements with other appropriate agencies on scope and timing of those inputs, how final decisions will be made, and so on.
2. Consolidate planning responsibilities for transportation controls in one or a few agencies (e.g., by expanding the role of the MPO to include certain parking and land use planning responsibilities, assigning all transportation control planning except inspection and maintenance to the MPO, and retaining inspection and maintenance at the state level).

Whichever method is chosen for assigning responsibilities, the capabilities, authorities, and responsibilities of all relevant agencies and governments at the local, regional, and state levels must be specified. Such careful delineation and coordination of planning responsibilities maximize the likelihood that the resulting plan will be feasible, realistic within resource constraints, and implementable and also take advantage of the planning resources and capabilities available at all levels.

Public Involvement in Transportation Control

Planning public involvement programs can help to clarify for local residents the air pollution problems and the potential means of alleviating these problems. The public also may generate ideas about the kinds of control measures that are most appropriate for a given area and may assist in identifying likely impacts of control measures. Thus, public involvement is an asset to the transportation control planning process. In addition, the workability of many control options is by and large determined by the degree of public cooperation, which is fostered by full participation of the public throughout the planning process.

The organization conducting transportation control planning should identify the groups and organizations likely to be affected by measures under consideration and should meet with them to discuss likely impacts, both beneficial and adverse, and to explore ways in which adverse impacts might be mitigated. Formal public hearings are necessary but are not sufficient as the principle opportunity for public comment on control measures. Although an extensive involvement program cannot be expected to arrive at consensus on the selected measures, it can improve public understanding and help planners choose those options with greatest support.

Analysis of Full Range of Impacts

Even though there are great uncertainties about the likely effects of transportation control options, some impact prediction is always feasible. Because major concerns about many transportation control measures are their economic and social effects (particularly potential adverse effects), transportation control planners must develop information about the nature, extent, and incidence of impacts. This information will both increase public awareness of and involvement in transportation control planning and improve the information base for decisions on TCPs.

Additional Experiments and Innovations in Transportation Controls

Because uncertainty surrounds practically every aspect of TCPs, many of the strategies will be experiments. Transportation controls should be monitored carefully so that the results of accumulated experience can feed back into modifications of the TCP. Additional experiments with actions such as parking limitations and car pooling, jitneys, dial-a-ride, subscription buses, exclusive bus lanes, area traffic control schemes, parking price regulation, and service quality improvements on existing transit are needed, and it is crucial that information on the success or failure of these experiments be made widely available. The objectives are to determine ways to achieve levels of mobility close to those provided by the private automobile and to demonstrate workable options to the public and to officials; to overcome fears about the negative consequences of decreased mobility; to gain improved information about the costs, market response, and likely operating revenues (or deficits) of various transport options; and to assist in the cultural transition of local and state officials and planners from an emphasis on construction of facilities to an emphasis on operation of transport services.

Periodic Evaluation and Revision of TCPs

The dangers of undercontrol (i.e., ineffectiveness in combatting pollution) or overcontrol can be reduced if there is an ongoing planning process to deal with the dynamic needs of air quality maintenance. Also, positive response to the air quality standards is more likely when local officials and citizens see that they need not be locked into a control plan if it should prove to be unworkable. Periodic review and revisions not only help allay fears about transportation controls but also create an atmosphere in which experimentation in transportation service concepts can thrive.

GETTING STARTED

One way to get started on a transportation control planning process consistent with the recommendations listed above is to analyze all appropriate TCP measures as the first step in developing the TSME (11). An analysis of the transportation, social, economic, and environmental (including air quality) effects of the TCP measures should be performed as a normal part of the urban planning process, as reflected in each state's Action Plan. Similarly, the public participation mechanisms followed when sensitive projects are considered would apply if appropriate.

The TSME should include all acceptable TCP measures, and those measures should be programmed, if appropriate. If certain TCP measures are rejected after a thorough analysis, the next step is to explore new measures from among those suggested for consideration by the U.S. DOT. These measures should be analyzed for their potential air quality benefits, and air quality should be one criterion in selecting measures for inclusion in the TSME. Then, a recommendation should be made to add any newly identified measures to the TCP.

CONCLUSION

The success of transportation control plans may depend as much on the quality of the process through which they are adopted, implemented, and revised as on the particular actions chosen. A positive approach to this process requires recognition that the decisions being made are political as well as technical, that adverse effects may result and must be identified and dealt with, and that transportation is only one thread of the complex metropolitan fabric. Single-objective planning must be replaced by a multiple-objective process. Procedures for the ongoing development and implementation of control strategies must provide for timely public involvement and full identification of the nature and incidence of social, economic, and environmental effects (including but not restricted to air quality). This is the only way decisions on transportation controls, which involve choices among conflicting objectives and competing interests, can be made as equitably as possible.

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REFERENCES

1. E. E. Bennett and others. The Transportation Control Planning Process: Findings and Recommendations for Improved Decision-Making. Center for Transportation Studies, MIT, Cambridge, Rept. 75-4, March 27, 1975.
2. G. K. Ingram and G. R. Fauth. TASSIM: A Transportation and Air Shed Simulation Model, Vols. 1 and 2. Prepared for U.S. Department of Transportation, May 1974.
3. T. J. Adler and M. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. TRB, Transportation Research Record 569, 1976.
4. T. J. Atherton, W. A. Jessiman, J. H. Suhrbier, and A. M. Zerega. The Use of Disaggregate Travel Demand Models to Analyze Carpooling Policy Incentives. Cambridge Systematics, Inc., and Federal Energy Administration, Aug. 1975.
5. Federal Register. Vol. 38, No. 231, Dec. 3, 1973, p. 3373.
6. J. C. Fensterstock and others. Problems Associated With Air Quality Control Region Implementation Plans. In The Relationship of Land Use and Transportation Planning to Air Quality Management (G. Hagevik, ed.), Center for Urban Policy Research and Conferences Department, Rutgers, The State University of New Jersey, New Brunswick, May 1972.
7. Highways and Air Quality. HRB, Special Rept. 141, 1973.
8. U.S. Department of Transportation. Transportation Improvement Program. Federal Register, Sept. 17, 1975 (40 F.R. 42975-42984.)
9. J. H. Suhrbier. The Use of Disaggregate Travel Demand Models to Analyze the Energy Convervation Potential of Parking Restrictions Within a Metropolitan Area. Cambridge Systematics Inc., Cambridge, Mass., May 1976.
10. J. Horowitz. Transportation Controls to Reduce Automobile Use and Improve Air Quality in Cities: The Need, the Options, and Effects on Urban Activity. U.S. Environmental Protection Agency, Nov. 1974.
11. E. D. Bennett and others. Air Quality Considerations in Transportation Planning: Findings and Recommendations on Transportation Control Planning. Center for Transportation Studies, MIT, Cambridge, Rept. 75-21, Dec. 30, 1975.

Programming Highway Improvements in New Funding Environment

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Several issues have evolved in highway decision making that point to the necessity of establishing new processes and techniques for determining allocation of resources for system improvement and maintenance. These issues include the decline in highway revenues and inflation in construction cost, the uncertainty of federal highway programs and funding levels, changing public attitudes toward transportation investment costs and the probably reduced rate of investment in the future, energy efficiency, and more complex and stringent social and environmental concerns and public involvement. This paper describes the highway programming process and techniques developed in Illinois to respond to these issues and to further refine the setting of priorities and resource allocation methodologies needed to carry them out. Fundamental to the process is an inventory of transport service problems on the entire Illinois highway system. The process is essentially oriented to matching short-range priorities and solutions to existing service problems, but consideration is given to longer range goals as currently forecast fiscal resources allow. Included in the paper are discussions of deficiencies and problems of existing programming techniques, the philosophies behind the development of the Illinois process, and the development of the transportation improvement proposal information form, which provides the comprehensive information necessary for setting improvement priorities and project selection and control.

Several issues have evolved in highway program decision making that point to the need for establishing new processes and techniques to determine the allocation of resources to system improvement and maintenance. The most dramatic and severe issue confronting highway decision makers today is the cost-revenue squeeze, which has left highway organizations with fewer dollars available for improvements and maintenance. Concurrently, the purchasing power of these fewer improvement and maintenance dollars has been cut almost in half by inflated construction costs in the last 5 years.

In Illinois, for example, revenues based on the fixed-quantity tax on gasoline have leveled off to a 1 percent annual growth. Motor vehicle registration fees have also slowed in growth to about 3 percent annually. Although Illinois did not suffer an actual decrease like many states, the effect is substantially the same. Opposed to this reduction in revenues is the fact that highway construction costs ballooned 95 percent during the last 5 years.

The net result is that highway programs cannot achieve the goals and plans previously established and thought attainable. Based on the traditional concept of highway needs, the impact of this situation is amply illustrated by the fact that Illinois spent $850 million from 1970 to 1974 to retire non-Interstate highway needs on its state-maintained system. The objective of this expenditure was to reduce the large backlog of needed improvements. But, during the same period, inflation escalated the cost of meeting this 1970 backlog by $1.3 billion. Thus, the net result in 1975 was that after 5 years and the expenditure of $850 million the backlog of remaining 1970 needs is $450 million larger than when the program started out 5 years ago. To further compound it, new needs entered the picture each year because of continuing normal physical deterioration and obsolescence.

Unfortunately, the future appears to hold much of the same. At least no dramatic changes are foreseen by most economists. The situation has been temporarily eased in the short term since the formerly impounded federal highway trust funds were released. Also, some of the restrictions and rigidities attached to use of federal funds will apparently be eased. Proposals by the federal administration, various states, and AASHTO all lead in this direction. In addition, recent reports indicate that construction costs have leveled or in some instances are decreasing slightly.

None of these, however welcome in the short run, will resolve the long-run transportation funding problems. Explicit in future highway resource allocation is the dominant condition that many improvements, however desirable or productive, will not be made. In the past we could develop plans and undertake programs that would substantially meet all major highway needs. To attempt to reach those goals today means continually falling farther and farther behind in highway improvements and no hope of realizing our objectives.

Other issues, no less important, have also evolved to affect highway program decision making. These issues include more complex and stringent environmental concerns; changing public attitudes toward transportation

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investment costs and the probable reduced rate of investment in the future; increased demands for public involvement in transportation planning and programming; energy shortages, energy cost increases, and increased emphasis on efficient use of energy; multiple and sometimes conflicting goals and policies of the different modes; the frequent mismatch of planning goals, time frames, and constraints versus the goals, time frames, constraints, and priorities of the programming function; and the increasing uncertainty of federal programs and funding.

THE NEED TO REASSESS PROGRAMMING PROCESSES

The inescapable conclusion is that statewide highway programming as it has been typically practiced must be redirected if it is to effectively address the new problems that will compose the programming environment in the future. The inadequacies of current programming procedures are similar in most states. Although not all-inclusive, the following list gives major pitfalls:

1. Deficiencies and needs versus problems and solutions,
2. Separation of plans, programs, and financial resources,
3. Funding categories versus highway problems,
4. Establishing priorities and measuring success, and
5. Dealing with uncertainty.

Deficiencies and Needs Versus Problems and Solutions

Needs studies and sufficiency rating studies have been the backbone of highway programming for the last decade. They have been a fundamental tool for assessing the need for statewide highway system improvements, estimating the costs associated with these needs, apportioning funds to districts or areas, and making a case to legislators for securing adequate tax revenues. Given desired facility design or service level standards, their logic cannot be faulted. We must assess not only what the backlog of highway needs is but also what the need will be in the future.

A serious question, however, is whether the outputs of needs studies are of much value in securing solid information on the type and amount of transportation service deficiencies on existing highway systems or in formulating alternative programming solutions and recommending allocations of resources. They also typically offer limited assistance in evaluating proposed improvements. The reason for these shortcomings is twofold: They are based on (a) anticipated traffic use over the next 20 years or similar long-range time frames and (b) bringing deficient facilities up to arbitrarily established design standards irrespective of specific transport service problems.

Sufficiency rating studies are usually built around a composite of rating points for various roadway elements such as pavement width, sight distance, grades, and accident levels. Sufficiency ratings or other numerical rating indexes are used to determine the priority of a proposed highway improvement and to schedule it for construction. Again, assigning priorities to an array of candidate highway improvements in a systematic and technically sound manner is fundamental to developing a good program. An approach such as this that accomplishes the best solutions to the entire scope of highway system problems cannot be faulted.

The key to whether a sufficiency rating accomplishes this objective is in identifying the correct roadway and bridge elements to be rated and the relative importance attached to each in the rating scheme. But, regardless of how sufficiency ratings are constructed, their validity in establishing needs can be questioned in the same light as needs studies. Their contribution to effective improvement programming may well be limited to establishing priorities only after transportation service deficiencies have been identified and measured and allocations of resources to service problems have been decided. When these decisions have been made, sufficiency ratings can be applied for establishing improvement priorities and for scheduling construction.

In the new programming environment the need is not to determine an index of road deficiencies or projected needs but rather to state how the existing highway system is currently operating and to express these conditions in basic operating and geometric terms. Limited available revenues will often preclude improvements to full-design standards for a 20-year time frame, especially where it is primarily a facility deficiency and not necessarily a transportation service deficiency. Likewise, even the use of modified standards may not be the appropriate solution for some types of traffic service problems. Therefore, it is important that the identification of existing operating conditions be retained throughout the analysis and not lost in an index or rating number or in a dollar need.

Separation of Plans, Programs, and Financial Resources

In a simplified sense, planning deals with where to go, with what, and when, in the future. Programming deals with what is wrong, the funds available to fix it, and how much funds go where, currently. The problem is often that planning aims at a fixed target and programming at a moving target that is constantly reacting to changing conditions. Programming will work without planning, but it works much more wisely with it.

In the current funding environment, system plans may have little impact on what is actually programmed unless sights are lowered to fit the available money. Contingency plans are seldom available. Programming decisions in this case are driven more by funding sources, constraints, and making do with interim planning guidance until revised comprehensive plans are developed.

Funding Categories Versus Highway Problems

The categorical funding constraints imposed by federal legislation have in the past been the driving force in improvement programming. Although not ideal, this method did accomplish the goal of developing statewide systems of the various levels of highways—secondary, primary, and Interstate—and did attack specific categories of problems, e.g., safety and bridges.

Most states adopted, for convenience, a similar method of allocating moneys, usually to the point of making categorical allocations to geographic areas of highway districts. The result was that funds became the tail that wagged the highway problem dog. In more financially stable times, the method worked. In today's environment it will not work satisfactorily. Clearly, transportation service problems have to be the fundamental base on which programming solutions are built.

Establishing Priorities and Measuring Success

Establishing priorities of transportation improvement proposals is a constantly changing process. The citizen and legislative wants and decision criteria of yesterday are usually not applicable today. Evidence the effect of requirements for intensive environmental analyses of highway program makeup and construction scheduling in the last few years. Today, the same types of decision factors come in the consideration of energy factors. These are positive influences and are welcomed; programming as a dynamic process should be responsive and responsible to these concerns of users and society.

The principal problem in setting priorities that respond to these concerns is the increasing complexity of transportation goals and evaluation factors. The additional factors in all modes were essentially engineering oriented and quantifiable, tempered with administrative considerations and geographic and population equities. Setting priorities today means all of these factors plus a host of others including the roles and influences of the political executive, the legislature, the transportation administrator, the planner, and the citizen. Consideration must be given to energy efficiency and social and environmental consequences: Differences must be resolved in goals, values, and priorities within communities and metropolitan areas, as well as between local and state governments. Federal guidelines, regulations, and restrictions can also limit programming options.

Setting priorities and measuring programming success are a cyclical process, one feeding the other. Both involve efficiency, safety, cost effectiveness, user benefits, social benefits, achievement of long-range plans, adequate levels of service, balancing and integration of modal systems, serving minority and disadvantaged needs, and environmental safeguards. Clearly, no structured programming process exists to fully incorporate all of these requirements. Just as clearly, such setting of priorities and evaluation must be done in the emerging multimodal trade-off context in which resources are also scarce and many desirable improvements are being postponed.

Dealing With Uncertainty

The overriding inadequacy, however, in typical programming procedures today is the inability to deal with uncertainty. Traditional programming processes have not been designed to operate in this framework. Planning inputs have tended to be somewhat rigid long-range goals that set precise levels of facilities and offered few options. Funding and programming have tended to prescribe improvements based on developing networks or systems to design standards rather than on transportation service solution options. The current programming environment will not allow either of these concepts. Continuing them can only be detrimental to developing effective and responsive highway transportation problem solutions. Flexibility to change emphasis, to increase or decrease program scopes as conditions require, and to focus on solutions versus needs is mandatory.

DESIRABLE ATTRIBUTES OF A PROGRAMMING PROCESS

The Illinois Department of Transportation responded to this situation not by reviewing and revising then current plans and programs but by asking, What are desirable attributes of a process for producing highway improvement programs in this new environment and which process attributes are suitable to Illinois? It was decided that fundamental to the process should be analyzing existing system service and facility problems, developing alternative solution-impact-cost options, and then matching the problems and alternative solutions to fiscal resources and policy guidelines. The process should be essentially oriented toward short-range solutions to existing service problems, with an eye to longer range goals and plans as fiscal resources allow. It should provide flexibility to meet changing conditions, be responsive to local community and user wants, and be measurable against service accomplishment goals.

Major attributes of a process that would meet the above criteria are given below.

Funding-Solution Categories

An essential feature of the process was that funding sources should never lead the analysis of deficiencies or proposed solutions, nor should deficiencies or proposed solutions lead the funding allocations. Both are part of the framework within which a systematic analysis of problems is performed. Both are components of the process.

Programming Parameters

One of the most important steps in the process is establishing programming parameters. This sets the framework of limits and constraints for evaluating each mix of system deficiencies, alternative solutions, and financial allocations. Programming parameters were established. Fundamental objectives are to

1. Maintain the existing system to prevent further service deterioration,
2. Improve the existing system to increase safety and efficiency, and
3. Add to the existing system where there is a current, demonstrated need to upgrade the level of service.

The fundamental policies are to

1. Provide a minimum level of service to everyone in the state and
2. Do the most important improvements first, for these may be all that can be done with the limited available funds.

Program Structure

Another important step is the program development structure, which forms the basic strategy for analyzing problems and making statewide resource allocations. The program structure adopted and the philosophies behind each strategy are itemized below.

1. Adopt transportation service as the basic framework for preparing highway improvement programs. To put it simply, we first determine what is wrong with the service provided to the highway user. Then we ask what is wrong with the physical highway facility that is not providing the necessary service. The goal is to strictly match facilities to actual travel demands at a satisfactory level of service. Three levels of improvement are considered: (a) preservation where physical deterioration is the problem, (b) improvement where capacity or safety of the existing facility is inadequate, and (c) expansion where upgrading the existing facility is not so cost effective as constructing a new facility. The point is that, because service is the focus, facilities are not to be improved beyond their short-range match to service problems. This means that some narrow pavements will remain narrow and only be resurfaced and that some bridges will be rehabilitated to safe limits rather than replaced to modern design standards.
2. Shift from a project-by-project orientation to a

statewide system orientation aimed at producing an adequate level of service over the entire principal state highway system. The project-by-project approach was a feasible approach when it looked like funds would be available to reach the goals we had set. The revenue-cost situation no longer permits this approach or these goals. Specific projects, however desirable when they are standing alone, must now fit into the overall service goals and funding limitations for the entire statewide system.

3. Separate programs for the existing highway system and those for proposed new systems. The concept must be to get the most out of the existing system before investing large sums in new facilities. Expensive new facilities must be proved to be the most cost effective solution before money will be expended for them.

4. Separate programs for the urban highway system and those for the intercity-rural highway system. This distinction is important because the use and problems on these systems are fundamentally different as are the solutions and programs.

5. Expand the use of modified design standards in which important service improvements are obtained quicker at less cost but nonessential features are omitted. The trade-offs here are crucial. The fundamental fact today is that more solutions must be gained for the dollars invested.

6. Develop and adopt annual improvement programs within the framework of a continually updated multiyear improvement program. Revenue uncertainty demands the flexibility to shift the types and staging of projects as conditions require within the framework of a set multiyear program.

7. Identify a precise set of statewide improvement objectives, priorities, and criteria. Program objectives, priorities, and criteria must specifically set out the types of improvements that will be made and in what order and, conversely, what work cannot be undertaken, either because the proposed improvements did not solve or match the essential problems or, more probably, the money just is not going to be there.

Program Accomplishment Priorities

From the programming parameters and program structure, the following improvement priorities have been set:

1. Correct high-accident spot locations,
2. Maintain pavements to adequate surface conditions for the volume and type of traffic carried,
3. Replace or rehabilitate critically deficient bridges,
4. Widen narrow pavements, in conjunction with pavement maintenance, for the type and volume of traffic carried,
5. Improve intersections, short roadway segments, and other bottlenecks that seriously impede the flow of traffic, and
6. Construct freeways or other high types of facilities in corridors where there is a current demonstrated need.

PROGRAM DEVELOPMENT PROCESS

The Illinois process embodying these programming attributes can be generalized in seven steps. These are outlined in some detail below:

1. Start with a definitive statement of how the highway system is operating today in terms of service to users in basic operating and geometric terms and not in needs or sufficiency ratings that have standards built in. Categorize these service problems into analysis categories, e.g., narrow-rough roads, posted (or about to be posted) bridges, high-accident locations, and capacity and bottleneck problems.

2. Develop alternative solutions and associated costs and an evaluation of solution impacts (through either a subjective or objective process) for each problem category. Solutions and impact evaluation categories are listed below:

Solution	Impact Evaluation Category
Existing system	Urban, intercity, rural
Resurfacing	Functional class
Widening and resurfacing	Average daily travel
Safety	Full design (performance)
Increased capacity and efficiency	Standards and modified standards
Bridge	
New construction	Preservation, improvement, or expansion
New systems	
Interstate	
Supplemental	

3. Develop a complete picture of existing highway improvement revenues and expenditures, and perform analysis of funding options for producing additional highway revenues to develop alternative funding levels that appear feasible. Financial resources include revenues, operating expenses, diversion expenses, and net program funds. Funding options include increasing revenues through new sources or increased tax rates; or decreasing expenses by reducing operating costs or programs. These should be evaluated by funding category, whether fixed or optional, limitations, long- and short-term trends, and possible or probable short-term changes.

4. Based on the array of service problems and alternative solutions, impacts, and costs, establish programming parameters, strategies, and priorities. This includes the fundamental objectives of preservation, improvement, or expansion; the program structure; and program priorities.

5. Build alternative programs allocating resources in varying mixes of alternative solution and impact accomplishments under different levels of funding, all within overall departmental policy guidelines and fiscal restraints. Alternative solutions should be arrayed versus financial resources.

Alternative Solutions	Financial Resources
Existing or new system	Funding category
Urban, intercity, or rural	Fixed or optional
Functional class	Limitations
Average daily travel	Long- and short-term trends
Full standards or modified standards	
Preservation, improvement, and expansion	Possible or probable short-term changes

The funding options are to increase revenues and decrease expenses. Alternative programs are as follows: (a) cover minimum holding-level needs, (b) construct additional improvement concentrations, and (c) exercise funding options.

Assessment of alternative program trade-offs should include performance levels, short-term and long-term impacts, needs not addressed, funding utilization, and cost effectiveness.

6. Determine funding level, and select the desirable program. This includes satisfying objectives and accomplishment priorities and determining the investment payoff, fiscal feasibility, and political feasibility.

7. Follow through with specific project selection guidelines and an assembly process that is dedicated to the idea of accomplishments. Project selection guide-

Figure 1. Standardized transportation improvement proposal form.

LOCATION MAP

Fiscal Year/s FY 77/78
Program Category Rural Widen & Resurf.
Category Priority 2
Highway District 3
Legislative District/s 38
Congressional District/s 15
County/s Livingston
Urban Area/s
Marked Route/s Ill. 23
Key Route/s FAP 24
Functional Class Major
Location 5 miles W. of Cornell to N & W RR in Cornell
Miles 5.26
Bridge Number/s 053-0079; 053-0080; 053-0071

Improvement
Widen 18 ft. pavement to 24 ft. and 3 in. of bituminous resurfacing. Replace 1 concrete bridge and widen 1 bridge.

Number of Supplemental Sheets 9

STATEMENT

Government officials and business and service groups from the area have been extremely critical and have strongly advocated improvements on this section. This improvement will complete the upgrading of Illinois 23 to Major Highway standards between Ottawa and Pontiac. In addition, both bridges are narrow and one is a contributing factor to a high-accident location. The entire stretch of road has a high-accident rate.

ESTIMATED COST ($000)

	Prior Yrs.	FY 77	FY 78	FY 79	FY 80	FY 81
Land Acq.		150				
Structures		350				
Roadway			1,130			
Detour						
Total		500	1,130			

	Funding Source	Federal	State	Local	Total
Land Acq.	STATE		150		150
Construction	FAP	1,036	444		1,480
	Total	1,036	594		1,630

Total Cost 1,630

OPERATING CONDITIONS

Roadway	Existing	Proposed
ADT/Percent Trucks	1850 / 8	2300 / 8
Surface Condition/Type	3.8 / 19 74 / Bit.	
Pavement Width	N 24 / 18 / 24E	24
R-O-W/Roadway Width	66 / 34	100+ / 44
Number of Lanes	2	2
Level of Service	C	B
Horizontal Alignment	0.18	--
Vertical Alignment	None	--
Access Control	None	None

Structure	Existing	Proposed
Bridge Number	053-0071 1/	
Fed. SBRP Priority/Year	/	
Oper./Inv. Ratings	/ Tons	Tons
Posting Recommendation		
Width/Length	/	/

High-Accident Locations
Number of Spots: Red -- Green -- Yellow 1
Mileage of Sections: Red -- Green 1.38 Yellow --

RAILROAD CROSSING

Crossing 1 of 2
RR Name ICG RR
No. Tracks
Main 1 Passg -- Ind. 1
Maximum Speeds
Passr. -- Frt. 40 Mixed --
No. Trains Daily
Passr. -- Frt. 4 Mixed --
Protection in Place Cross bucks
Protection Proposed Flashers

DATA BANK TIE Livingston
FAP 24 / 8.10 to 13.36

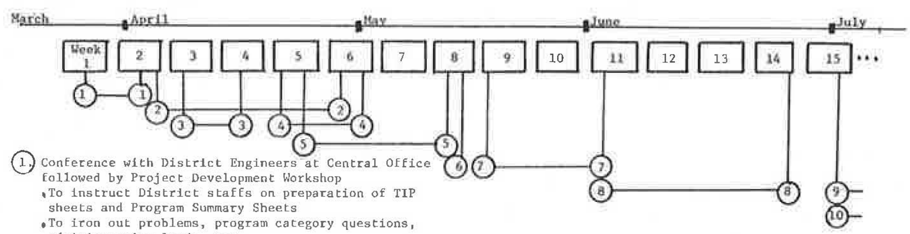
STATUS

State Job No. C-93-173-75
State Const. Sect. No. 101; 102BR; 102 B-1
Bridge Sect. No.
Standards Used Policy
Agreements
Type City - State
Status 12-15-72
Other --
Design Approval Date
FHWA 5-3-73 State --
Land Acq. Clear Date 1-1-77
Airport-Hwy Coord. Date N.A.
Letting Quarter FY 78
1st [X] 2nd [ ] 3rd [ ] 4th [ ]

COMMENTS/REVISIONS

1/ This steel I-beam structure over Vermilion River built in 1960 will remain narrow (28' wide).

Figure 2. Preparation schedule for multiyear program and fiscal year 1976 annual program.



(1.) Conference with District Engineers at Central Office followed by Project Development Workshop
- To instruct District staffs on preparation of TIP sheets and Program Summary Sheets
- To iron out problems, program category questions, administrative loads, etc.
- To give the Districts an opportunity early in the process to raise questions after District Engineer confers with his staff

(2.) District Selection of Candidate Projects and assemble candidate program and prepare TIP sheets.

(3.) Visits to each District by Programming Staff to offer assistance and clarification

(4.) District presents candidate Multi-Year Program and projects to Central Office for oral review--one day each district. Provides D.E. the opportunity to present his proposed programs in person.

(5.) Analyze and assemble Preliminary Multi-Year Program and extract out FY 76 Annual Program, incorporating adjustments worked out with District Engineer.
- Review final fiscal projections with Administration
- Final decisions on Interstate and Supplemental Freeways

(6.) Present Preliminary FY 76 Annual Program to the Secretary for review and presentation to the Governor.

(7.) Assemble Final FY 76 Annual Program.
- Make adjustments for carry-over projects
- Make adjustments considering Administrative review
- Final FY 76 Annual Program to typesetter
- Preliminary copy assembled for D.E. and Legislators

(8.) Continue analysis and assembly of Preliminary Multi-Year Program. Send to D.E. for review.

(9.) Districts review Preliminary Multi-Year Program and propose adjustments to Central Office.

(10.) Assemble Final Multi-Year Program, incorporating accepted District Engineer adjustments.

Table 1. Anticipated highway program accomplishments for fiscal years 1976 to 1980.

Program Category	Area	Project	Accomplishment	Cost ($)	Funds
Preservation	Intercity	Pavement widening and resurfacing	1840 km	185 000 000	State, FAP
		Bridge replacement or rehabilitation	296 bridges	170 000 000	State, FAP, SBRP
	Rural	Pavement widening and resurfacing	120 km	20 000 000	State, FAP, FAU
		Bridge replacement or rehabilitation	50 bridges	100 000 000	State, FAP, SBRP, FAU
Improvement	Rural	Safety improvements	550 projects	30 000 000	State, FAP, Safety
	Urban	Safety and traffic improvements	600 projects	235 000 000	State, FAP, FAU, Safety
	Intercity, rural, urban	New construction		65 000 000	State, FAP
Expansion	Intercity	Interstate highways		390 000 000	FAI
	Urban	Supplemental freeways		800 000 000	Bonds, private primage

Note: 1 km = 0.62 mile.

lines include (a) objectives, (b) criteria, (c) priorities, and (d) scheduling. Program assembly procedures are documentation, paperwork processing, and assignments and schedules.

PROGRAM IMPLEMENTATION AND MANAGEMENT TOOLS

The primary tool to implement a problem-solution programming process was the development of communication devices for use with the department's nine district engineers who are accountable for highway programming activities in this respective area.

Data given in Table 1 have been condensed from guidelines prepared for the district's use in development of the multiyear highway program. The table represents a statement of anticipated program accomplishments for fiscal year 1976 through fiscal year 1980. Specific project selection guidelines were developed for each category by the central office programming staff and accompanied Table 1. The project selection criteria included limiting values for ADT, pavement condition ratings, pavement widths, and bridge condition ratings. Highway district planning and programming personnel then selected and scheduled, by year, projects for the multiyear program.

To facilitate evaluation and assembly of a multiyear highway program, a standardized transportation improvement proposal (TIP) form was developed (Figure 1). The form was designed to accomplish several objectives:

1. To accurately portray the problem underlying a proposed transportation improvement, the type of improvement proposed, and its cost and processing status;
2. To provide a single, consolidated, concise, and common reference document within all divisions, offices, bureaus, and district offices in the department for each improvement proposed or under way; and
3. To provide a compact and readily accessible common communication tool that may be distributed to those concerned with or affected by transportation improvements.

For the district engineer, the TIP sheet provided the medium for (a) comprehensively and persuasively presenting the case for undertaking an improvement project, (b) having all central office bureaus and others referencing the same document in project communications, and (c) having at hand an immediately accessible one-page communication device for his constituency.

The front page describes the need and scope of the proposed improvement, with additional information on cost, funding source, a map, and the year(s) in which the improvement is scheduled. The statement section offers an opportunity for the district engineer to present all supplementary factors that amplify the need and benefits of the project apart from the technical justifications. Such information is of interest to the engineer and citizen alike. Thus, the front page can be used for multiple purposes, including legislative liaison and citizen information, and can serve as the basic departmental project reference document. The back page contains technical data concerning the details of the proposed improvement.

Projects were submitted to the central office on TIP sheets in district-by-district conference presentations in which the district's improvement program was presented and discussed.

Figure 2 shows the step-by-step process for submitting, adjusting, and finalizing the multiyear and immediate annual program. It illustrates again the roles of the central office and the district. The central office programming staff reviews and analyzes statewide problems, alternative solutions, and fiscal conditions and develops statewide accomplishment priorities for each program category. Working within the statewide accomplishment framework, each district proposes all appropriate projects fitting the programming category and the project selection guidelines. Each project is ranked individually in the district by priority within program category. Based on these proposals, the multiyear highway program is developed in cooperation with each district office.

It is important to note the amount of interaction, face-to-face and by TIP sheet, between the district and central offices. The process is neither centralized nor performed solely by the district. Each does the part best suited to it. The central office is closest to fiscal resources and the other statewide problems; while the district is closest to the specific problems and the appropriate priority of projects.

SUMMARY AND CONCLUSIONS

The statewide programming process described here is still under development and will continue to evolve as the department's multimodal programming process is developed and implemented. The process has proved to be a highly effective tool to date (after one annual iteration) in achieving the goals originally set out for it. The process has several important attributes:

1. Inventory of service problems on the entire system, unencumbered by arbitrary geographic allocation formulas, funding category restrictions, or fixed design standards;
2. Programming separation of existing and proposed highway systems to facilitate the cost-effective analysis of investment in new facilities;
3. Programming separation of urban and intercity-rural network problems and solutions;
4. Decision process governed by neither funding sources nor service problems but by both interacting equally;
5. Alternative solutions and funding allocations to provide flexibility to respond to changing conditions; and
6. Executive input and decisions at several stages to build a strong and decisively directed program.

The programming process as it currently operates does not have the benefit of an updated statewide plan. Such a plan is now being developed. When the plan is available, it is expected that an integrated highway planning-programming process will evolve, as a component of the department's multimodal programming process. As a closing point, it is likely that all of these planning-programming processes will possess one common attribute. They will be thinkable and workable on a human scale. Set formulas and mechanistic decision-making systems will be at a minimum. Decision-making accountability cannot be assigned to a computer.

ACKNOWLEDGMENT

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Highway Investment Analysis Package

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The highway investment analysis package (HIAP), a computerized evaluation and investment programming model, has been developed for the Federal Highway Administration to aid state, regional, and local organizations in making the best use of limited highway funds. HIAP uses microeconomic theory to analyze individual roadway sections and limited networks of sections specified by their physical, traffic, and operational characteristics. Estimates of both highway user (i.e., vehicle operating costs, travel times, and accidents) and nonuser (i.e., noise levels and air pollutant emissions) impacts are produced. HIAP develops multiperiod investment programs by selecting those improvements that maximize either user benefits or one of several accident reduction measures. The selection process permits consideration of a broad range of funding constraints, which may be tailored to the specific needs of individual organizations. Based on marginal analysis, the process allows consideration of multiple alternatives and staged improvements at each analysis site. Great flexibility in the content and format of input data is afforded the analyst. Furthermore, HIAP includes a transformation program that allows the analysis of data already available in the format used for the 1970 to 1990 highway needs study.

The nature of the highway planning process has changed significantly in the last few years because of factors such as increasing public involvement, changing statutory requirements, and spiraling construction costs. To analyze and program highway improvements effectively, today's transportation officials require the timely application of more comprehensive and responsive procedures than traditionally have been available.

The Federal Highway Administration used such comprehensive procedures in a background study (1) for the 1972 Report to Congress on the Highway Needs of the Nation. Computer models for highway improvement evaluation and programming developed for the 1972 report incorporated state-of-the-art knowledge in highway user economics. The national orientation of the study, however, made these potentially valuable tools inappropriate for direct use by individual state or regional transportation planning organizations. Consequently, the Federal Highway Administration contracted with Multisystems, Inc., to conduct the highway investment study to expand on the original study and to develop a battery of computer programs for general use by state, regional, and metropolitan transportation planning organizations for (a) systematically analyzing and evaluating proposed highway investments and (b) combining these proposed investments into efficient investment programs. The result of these efforts is a very flexible and comprehensive model called the highway investment analysis package (HIAP) (2).

HIAP fills a gap in the existing stock of highway analysis and programming procedures by providing the following capabilities:

1. Systematic analysis of the economic and safety consequences of a wide variety of highway improvements including new construction, reconstruction, resurfacing, and isolated reconstruction of hazardous areas, structures, and railroad grade crossings;
2. Prediction of noneconomic consequences of highway improvements including changes in noise levels and air pollutant emissions;
3. Analysis and budgeting of interrelated improvements, alternative improvements at a given site, and staged-construction improvements;
4. Operation over a broad range of detail in analyst-supplied data, ranging from rough estimates to very detailed descriptions of traffic and roadway characteristics;
5. Selection of investment programs that meet a broad range of financial, political, and environmental requirements; and
6. Determination of aggregate measures of benefits and cost effectiveness for highway investment programs and the corresponding ability to test the sensitivity of such measures to changes in budgetary or other constraints.

Although HIAP forms a complete analysis and investment package, it is modular in construction. This enhances its usefulness to state and regional organizations, which operate under a broad range of planning processes. HIAP recognizes that each organization's approach to planning and programming is unique and that

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the relationship between planning and programming is changing rapidly such that previous judgmental or empirical techniques are being replaced by more systematic processes.

The two major components of HIAP, improvement analysis and evaluation and investment programming, are discussed below.

IMPROVEMENT ANALYSIS AND EVALUATION

The improvement analysis and evaluation component of the model is designed both to aid planners in generating and modifying alternative proposals for meeting specific objectives and to prepare evaluation and cost measures required in selecting improvements in the investment programming process. Key features of this component are discussed below.

Section Definition and Specification

Basic analyses are performed at the individual highway section level. Depending on the degree of detail desired for a particular analysis, any roadway segment can be defined as either a single large section or a group of smaller sections.

The analyst specifies the physical and operational characteristics of the existing and one or more proposed configurations of a section by inputting the following data for all sections:

1. Functional class,
2. Area type (e.g., rural),
3. Highway type,
4. Length,
5. Number of lanes,
6. Average highway speed (weighted design speed),
7. Capacity (default value may be calculated by using lane width and either shoulder width or lateral clearance), and
8. Surface type.

For certain sections, the analyst inputs

1. Population code (urban only),
2. Terrain type (rural only),
3. Percentage of length with passing sight distance ≥ 460 m (1500 ft),
4. At-grade railroad crossings by protection type and average daily number of trains, and
5. Capital costs or detailed cost components (improvements only).

Optional data for special cases include

1. Fatal, nonfatal injury, and total accident rates,
2. Annual maintenance and administration costs,
3. Noise standard (decibels at a given observer distance),
4. Surface condition rating or index (if pavement deterioration is considered), and
5. Relocation or other data.

(Traffic data are specified independently and are discussed later.) Optional data may be supplied to override internal default values or to provide additional descriptions and impact measures for a section configuration. For example, the analyst might provide specific accident rates for a high-accident location or a strict noise standard for a section passing near a hospital.

Measurement of User Impacts

Estimates of vehicle operating costs, travel times, and expected accidents are calculated for each section. Operating costs and travel times are calculated for passenger cars and four types of trucks but are reported for automobiles, single-unit trucks, and multiunit trucks. In addition to accounting for the physical characteristics of the roadway (such as curves and grades, surface type and surface condition), HIAP also includes the effects of speed change cycles, stops, idling, and delays at railroad crossings through vehicle operating costs and travel times. These user impacts are calculated for each of six segments of the average day, representing the different levels of congestion in which traffic operates, and are aggregated to obtain average daily impacts.

Expected fatal, nonfatal injury, and total accidents (including those associated with at-grade railroad crossings) are estimated by using either rates for the specific section (supplied by the analyst) or typical rates stratified by highway design type and traffic volume.

Measurement of Nonuser Impacts

Nonuser impacts including noise and air pollution and governmental costs are also estimated by HIAP. For noise (3), the impact estimated is the maximum perceived level during the most congested portion of the day at an analyst-specified observer distance. The reported value is the level exceeded 10 percent of the time and is a function of automobile and truck volumes, travel speeds, and the steepest grade on the section. Weighted perceived noise levels and noise level distributions over the day are also calculated for informational purposes.

Air pollutant emissions (3) are calculated for automobiles and trucks by using emission rates for carbon monoxide, oxides of nitrogen, hydrocarbons, and evaporative hydrocarbons, which take into consideration average vehicle speed, increase in emissions due to vehicle age, and vehicle age composition of average traffic flows.

Estimates of governmental costs are based on the capital costs of implementing each new or improved section configuration. HIAP treats these costs as single lump sum investments to be made at the beginning of a programming period. An annual maintenance cost for each section can be either specified by the analyst or computed by using default average annual costs per 1.6 km (1 mile), which vary by functional class. If the analyst does not choose to supply annual administrative costs, the model calculates them as a percentage of the annual maintenance cost plus the average annual capital cost.

In addition to the nonuser impacts, as many as four categories of indirect effect data may be reported for each improved section.

Time-Dependent Analysis

In HIAP, the analyst establishes a planning horizon, typically 10 to 30 years, which can be subdivided into as many as four implementation or programming periods. Periods need not be the same length and can be as short as 1 year. An example with three periods is shown in Figure 1.

The model calculates the user and nonuser impacts of having each improvement alternative, including the existing condition (i.e., the null alternative), in place at the beginning of each implementation period, starting with the first period in which the particular alternative is available for implementation, and immediately after the end of the planning horizon. These measurement

Figure 1. Time-dependent analysis.

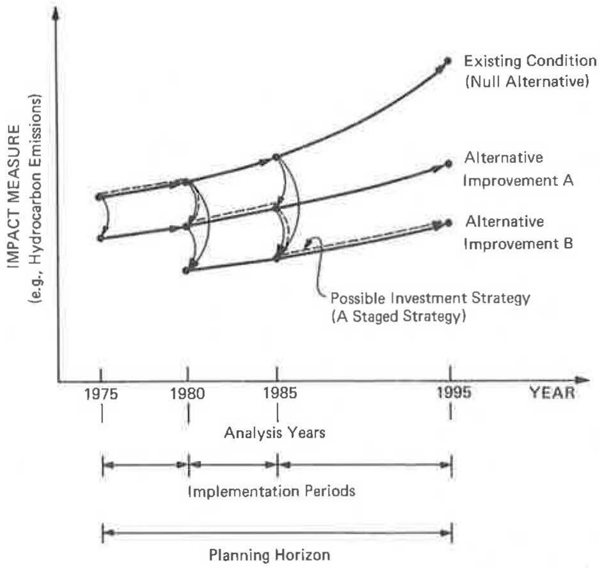


Figure 2. Analysis of interrelated improvements.

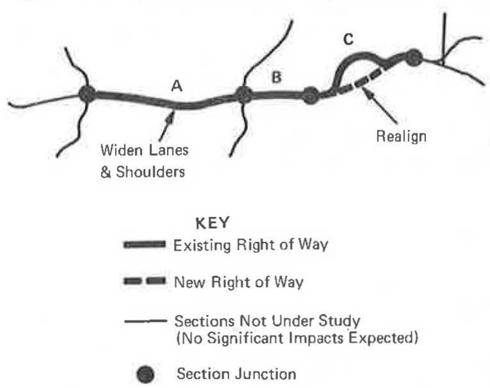
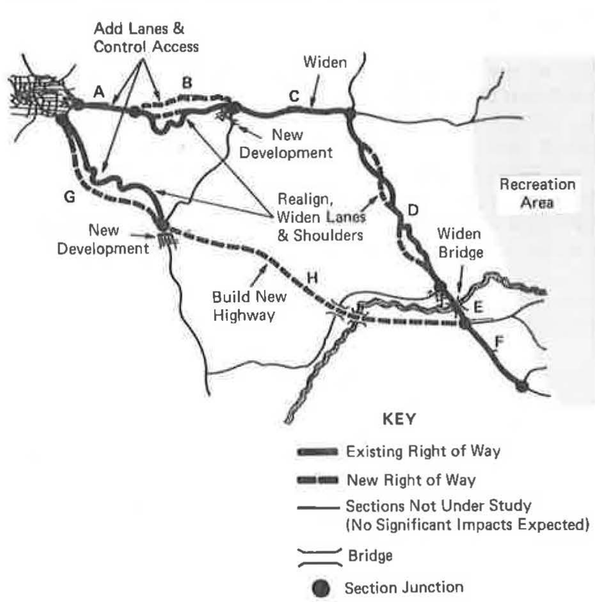


Figure 3. Analysis of multiple-alternative improvements.



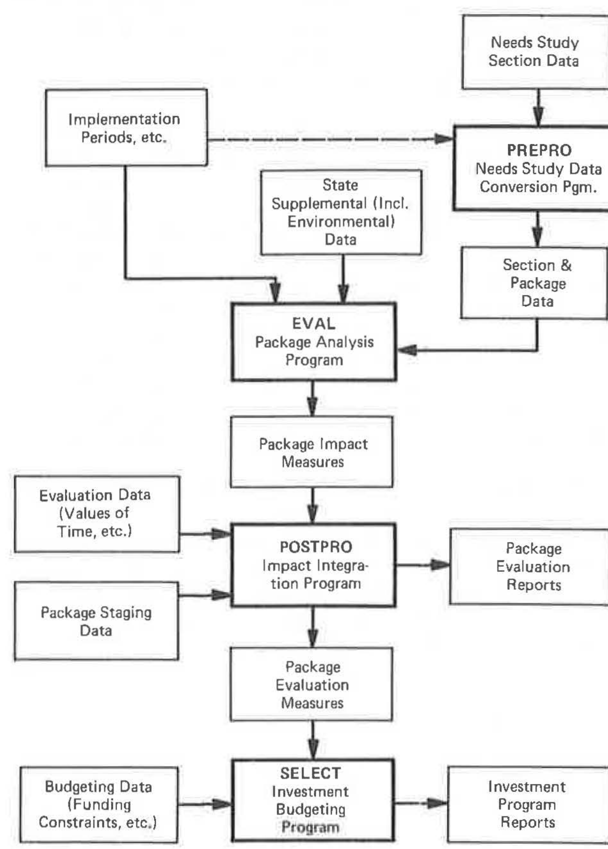
points are referred to as the analysis years; the calculated impact measures are values that would result from the section being in specific alternative configurations or physical states in an analysis year.

This analytic approach (4) yields impact estimates that are sensitive to time-dependent changes in traffic volume and composition and provides the basis for evaluating both single- and two-stage investment strategies. A single-stage investment strategy is defined as the implementation of a specific improvement in a specific period. For example, in Figure 1, the implementation of alternative improvement A (which might be the widening of a particular section from two to four lanes) in the second period would constitute a strategy. A two-stage strategy would add a further investment in a later period. The dashed line in Figure 1 indicates such a strategy in which alternative improvement B is implemented in the third period after alternative improvement A has been implemented in the second. (Alternative improvement B might call for the widening of the original section to six lanes.) The null strategy calls for the retention of the existing section throughout the planning horizon; it is the base against which all investment strategies are compared.

Analysis of Interrelated Improvements

The simplest application of HIAP occurs when a single highway section can be extracted from the highway network and analyzed in isolation. In this application, the desired objectives can be met by improving only that single section, with negligible impacts on adjoining sections. In a more typical application, objectives can be achieved only by making related improvements to adjoining sections, which cannot be analyzed realistically

Figure 4. HIAP structure.



in isolation because improvements to one section may increase traffic on adjoining sections or change traffic patterns in the immediate network.

HIAP deals with this additional complexity by calculating the impacts of proposed improvements on an entire analysis site consisting of several individual, but interrelated, roadway sections. The analyst can select combinations of section configurations, one for each section in the site. Each combination of section configurations forms a package, the basic unit of investment in HIAP. The null package, the combination of existing configurations, provides the basis for comparative analyses. In addition to improved and new sections, sections in their existing configurations can also be included in the investment packages.

Traffic data (both volume and composition) are specified for each package. In the null package, traffic data must be provided for all sections. In investment packages, these data must be provided for all new and improved configurations. In addition, revised traffic data may be provided for sections remaining in their existing configuration so that the increased congestion due to the adjacent improvements can be evaluated. The analysis site example in Figure 2 shows three serially connected sections A, B, and C. The investment package consists of improvements to sections A and C. The impacts induced on section B are included in the analysis.

Analysis of Multiple Alternative Improvements

The analysis of multiple alternative improvements for a given site is easily accomplished by building several packages, each consisting of a unique combination of possible section configurations, that describe the alternatives under consideration.

A complex situation is shown in Figure 3. The analysis site is a corridor between a major metropolis and a recreational area. In this case the three interrelated objectives are to (a) improve the accessibility of the recreational area, (b) improve the accessibility of intermediate sites, and (c) reduce the accident rates on specific sections.

The first objective can be achieved by upgrading the existing route (ABCDE) or constructing a new route (GH) or by doing both. If the new route (GH) is built, some traffic will be diverted to it from the existing route (ABCDE). This diverted traffic may be either specified by the analyst or computed internally by using diversion curves based on the ratio of travel times on the parallel routes. The second objective can be achieved by upgrading sections A, B, and G, and the third can be achieved by improving sections B, D, and E. Section F has been included in the analysis site because it will carry increased traffic when the first objective is met.

Many possible alternative packages designed to meet some or all of these objectives and covering a wide range of investments and benefits can be analyzed by HIAP. In addition, the staged implementation of these packages can be specified. For example, a first-stage package involving improvements to sections A, B, D, and E might be followed by either a package containing improvements to C plus further improvements to A or a package containing improvements to G and the construction of H.

Package Evaluation

The impacts estimated for alternative packages are compared to similar estimates for the null package. These comparisons are used to develop two categories of package evaluation measures: economic measures and effectiveness measures.

Economic Measures

HIAP calculated (a) total economic benefits (highway user plus maintenance and administration cost savings) of implementing each investment strategy and (b) corresponding net present value and benefit-cost ratios. These benefits are developed from the package impact measures in the following manner.

1. In accordance with microeconomic theory, the annual changes in consumer surplus for each section in each analysis year for travel time, vehicle operating cost, and fatal, nonfatal injury, and property-damage-only accident expectancies are calculated (assuming a linear demand curve).
2. Section benefit components (i.e., annual changes in consumer surplus) are summed into package totals, and average values of time and accidents are applied to convert these components into dollars. All package components are summed to total user benefits for the investment package in each analysis year.
3. The benefits in the years between analysis years are calculated by using linear interpolation, and benefits beyond the planning horizon are assumed to remain constant.
4. The time stream of total annual user benefits and annual maintenance and administration costs (expressed as the algebraic difference between the null and investment package costs) is discounted to the first year of the planning horizon and summed to get the total economic benefits that would result from implementation of an improvement package in the first year of the period under consideration.

Effectiveness Measures

HIAP produces the following effectiveness measures for all packages: relocations or other information input by the analyst; fatal, nonfatal injury, and total accidents; emissions of carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbons (HC); noise levels as compared to a standard and to the null package; and a daily congestion index.

Threshold Tests

The analyst may establish threshold levels against which to test the environmental impacts of each package in each analysis year. If a test is made and the package fails, the analyst has two options: (a) flag all investment strategies that include the package as having environmental problems but allow them to be included in the programming process or (b) exclude from further consideration in the programming process all investment strategies that include the package.

Investment packages may be tested against the following thresholds:

1. The percentage of increase in CO, NO_x, and HC emissions over the null package,
2. The decibel increase in maximum perceived noise levels (package noise level minus noise standard or package noise level minus null package level), and
3. The maximum acceptable value for analyst-supplied package characteristics.

INVESTMENT PROGRAMMING

The investment programming process of HIAP develops highly efficient highway investment plans subject to a large number and variety of possible expenditure constraints. Its key features are discussed below.

Evaluation Measures

HIAP makes use of much of the quantitative impact information it produces to develop evaluation measures that can be used to generate investment programs. Programs may be chosen that seek to maximize one of four evaluation measures: (a) economic benefits (i.e., travel time, vehicle operating cost, and accident benefits plus maintenance and administration cost savings) generated, (b) fatal accidents eliminated, (c) fatal plus injury-producing accidents eliminated, or (d) total accidents (of any kind) eliminated.

Flexibility

Investment plans can be developed for as many as four periods within a planning horizon. In each of these periods, HIAP allows the analyst to impose both maximum and minimum expenditure constraints. Maximum constraints restrict total expenditures within each budgetary period and are typically based on projections of future needs, revenues, and allocation policies. These constraints ensure that investments programmed in any period do not exceed realistic funding levels. This is important because a maximum constraint affects not only the choice of investments in the period for which it is specified but also the possible choices in all succeeding periods.

Minimum constraints provide the analyst with an effective mechanism for spreading expenditures over a variety of funding categories, thus ensuring that a desired balance is maintained. For example, the expenditures in each geographic, legislative, or administrative area of a state can be dispensed equitably by the proper application of minimum constraints; this precludes the possibility that so much money is spent in one area that other areas get practically none. Also, expenditures in each funding class can be constrained to ensure the optimal use of assistance from federal or other sources.

The model permits great flexibility in defining the funding categories to be constrained. Three basic categories may be defined and used in the selection process. Within each category, many individual minimum expenditures (e.g., for specific counties or administrative districts) may be specified. A fourth funding category allows the analyst to subdivide one of the three basic categories. This feature would be used, for example, if a specific allocation of funds by functional class were required within each district of a state. Without this feature, the investments in a particular functional class might all occur in only one or two districts. In the event that the analyst requires a minimum constraint structure that cannot be handled directly by HIAP, it often can be accommodated through an option facilitating sequential processing.

When comparing alternative investments, HIAP can simultaneously consider up to 99 improvement packages for each analysis site. (The total number of packages that can be handled in one period is a function of the primary computer memory available. A computer with 256 000 bytes of core can process approximately 4000 packages.) In addition, HIAP can program two-stage investments in which each stage is implemented in a different period. The second stage of the package cannot be selected unless the first stage has already been chosen in an earlier period. The second stage then must compete with all other packages still available for selection; if it is chosen, the complete staged investment is accepted.

Program Selection Process

Marginal analysis procedures were chosen as the most suitable methodology for the HIAP budgeting process because they can produce very good results at a relatively low cost and handle a large number of alternatives and expenditure constraints. This approach (5) consists of starting with no packages in an investment program and successively adding the best possible improvement package to a selected package list until the overall programming period budget is expended. The best possible improvement package at any point in the process is the one with the highest ratio of evaluation measure to cost (EM-C). If other improvement packages exist for the same analysis site, their marginal EM-C ratios are calculated and used for the remainder of the selection process. Any previously selected package for that site is replaced on the list by the latest package selected.

This process seeks to maximize the total net returns (of a particular type) of the investment program for any given expenditure level. After the analysis for a programming period is complete (i.e., the budget is expended), the evaluation measures and costs for unselected packages are adjusted to reflect the one-period delay of package implementation, and these packages are carried over into the next programming period for possible selection.

MODEL STRUCTURE

HIAP is designed to provide the analyst with a great deal of flexibility. Many program options and parameters are available that allow the analyst to tailor the improvement evaluation and program selection processes to his or her specific needs. In addition, its highly modular structure allows easy modification, substitution, or addition of components and simplifies the effort required to incorporate new technology. For example, it would be easy to update or replace the methods now used for estimating noise and air pollution when better procedures are developed.

HIAP is composed of three basic computer programs—EVAL, POSTPRO, SELECT—and an auxiliary program, PREPRO. The modular structure of the HIAP system is shown in Figure 4, and each of these programs is briefly discussed below.

PREPRO converts needs study data to a format suitable for use in the HIAP analysis program (EVAL). This includes editing and supplying highway and traffic data where necessary to standardize and augment the needs study data.

EVAL performs all highway section analysis, i.e., calculation of travel times, vehicle operating costs, accidents, noise levels, and pollutant emissions. It assembles these impact measures into package economic (changes in consumer surplus) and effectiveness (accident and emission totals and maximum noise impact) measures. If desired, great detail can be reported, including impacts by vehicle type on each section.

POSTPRO produces evaluation measures for staged improvements, creates summary reports, and prepares the final input to the investment programming routine. Summary economic measures are calculated based on the impacts estimated in EVAL, analyst-supplied values of time and accidents, and a discount rate. Environmental acceptability of each package is determined by comparing nonuser impact levels to threshold values. The evaluation parameters (unit values, discount rate, and thresholds) are introduced in POSTPRO to facilitate sensitivity testing by enabling the user to change these parameters and develop new evaluation measures without repeating the impact analysis (EVAL).

SELECT is designed to produce multiperiod highway investment programs that satisfy various budgetary and legislative constraints and maximize a specified evaluation (i.e., economic or effectiveness) measure. Although SELECT does not guarantee a globally optimal solution to complex investment programming problems, it produces very efficient solutions that satisfy all constraints, providing a first cut at a program and a starting point for further discussion. SELECT can be used to quickly analyze the implications of various investment policies on the composition and benefits of investment programs.

INTERPRETATION OF RESULTS

The results from any analytic capital budgeting procedure must be correctly interpreted. By their very nature, such techniques cannot incorporate all relevant considerations (especially the subjective ones) that must be made in developing an organization's investment programs. For instance, HIAP assumes that values of costs and benefits are in constant dollars. This does not mean that inflation is totally ignored, only that the relative values of the components remain constant over the planning horizon. The analyst should remember that HIAP is designed not to produce absolute values of the quality of each investment but to provide a consistent and logical method of comparing investments and selecting a set for implementation.

The results of HIAP can best be described as an efficient tentative investment program, a starting point for discussion of issues that cannot be incorporated into the initial (analytic) selection process. Although a state may choose a single evaluation measure as most relevant to its needs, development of alternative programs using other measures may often be instructive. In addition, alternative programs could be developed that reflect different parameter values, such as the discount rate and a highway user's value of time. By comparing these programs, the decision maker can identify those improvement packages that are likely to produce the most beneficial overall program.

CONCLUSIONS

HIAP represents a major step forward in highway investment analysis and programming models. It expands on the detailed highway user analyses of its predecessor (the highway user investment study) by adding a more flexible time framework of investment periods and allowing the analysis of alternative (including staged) improvements. In addition, it analyzes nonuser impacts, specifically air and noise pollution. HIAP is capable of analyzing complex improvements involving several interrelated highway sections as well as those proposed for a single section.

The analysis component of HIAP can be used both as a design tool to evaluate candidate improvement packages at a given site and as part of an investment programming process to prepare evaluation measures for improvements to several sites.

In developing investment programs, HIAP can be used to select the combination of packages in up to four investment periods that best achieve the analyst's objectives, while meeting a broad range of financial, legislative, and community constraints. The model is unique in its ability to properly consider the change in benefits due to delaying the implementation of a package.

HIAP will be tested in one or more states and revised as necessary before its general release. The model should prove valuable to state, regional, and local organizations in developing, analyzing, and programming highway investments. The HIAP program selection process should be easily adapted to multimodal analysis.

REFERENCES

1. J. E. Gruver. Highway User Investment Study. TRB, Transportation Research Record 490, 1974, pp. 20-30.
2. Highway Investment Analysis Package, Volumes 1 and 2. Multisystems, Inc., March 1976.
3. Special Area Analysis, Final Manual. U.S. Department of Transportation, Aug. 1973.
4. Manual for Evaluating Transportation Investments in Venezuela. ECI Systems, Inc., 1973.
5. R. D. Juster. A Methodology for Statewide Programming of Transportation Investments. MIT, Cambridge, master's thesis, 1974.

Improving the Process of Programming Transportation Investments

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This paper presents a methodology that integrates regional equity, funding constraints, public acceptance, and uncertainty into a technical programming procedure. Developed for the Massachusetts Department of Public Works, it can be used to generate tentative multiple-period investment programs that are reasonably efficient in an economic sense and comply with a variety of funding, legislative, and community constraints. The program generation procedure is a heuristic one, based on marginal analysis. It handles independent and mutually exclusive investments, project benefit interdependencies, multiple funding sources, regional and other expenditure minimums, and functional classification constraints. It uses a measure of benefits, the capital cost, and an estimate of the political acceptability of each proposed investment to determine its suitability over alternative projects. The procedure can be made to handle virtually any number of potential investments and has been programmed for computerized operation. In the overall framework of an iterative and participatory transportation planning process among communities, regional planning authorities, and state agencies, this methodology provides a valuable and efficient tool for (a) combining a great deal of essential data into tentative programs and (b) clarifying the trade-offs between and among programs. The resulting programs can then serve as the basis for further discussion and compromise.

During the last few years, the highway investment decision environment has grown steadily more complex. The traditional process for deciding whether or not to build has been complicated by a number of newly important criteria. For example, investment programs must now frequently be evaluated on the basis of issues such as regional equity, efficient use of available funding assistance, statutory constraints, community and environmental impacts, and even general public acceptability.

These changes have created enormous backlogs of projects, many of which may never be constructed. A more significant and longer term consequence is the introduction of fundamental changes in the transportation planning process at both the state and regional levels.

Past concerns for highway needs, for forecasting demands to determine the sizing, location, and program budgeting of a facility, and for developing master plans have shifted to include an almost endless list of policy-oriented transportation and transport-related objectives. Responding to any one of these issues poses difficult analytic and planning challenges; responding within the short time frame that is typically present is especially difficult for most states, given their limited resources. Therefore, statewide planning and programming capabilities need to be improved immediately so that state and regional transportation agencies can be responsive to the increased demands being placed on them. This includes improvements in the overall process of planning and programming as well as improvements in the techniques used in that process.

In the past, the decision on which projects made up the best overall program was generally a highly centralized one, made either by the state's transportation planning or programming group or by each of the state's regions with review at the state level. Budget and project data were combined to arrive at a list of projects on the basis of needs. In many states, the initial definition of needs was a highly technical one related to a deficiency in level of service, capacity, or structural quality. In others, lists of projects were generated on a more ad hoc basis. Once such lists were generated, however, priorities were juggled significantly in both cases to account for anticipated impacts, community opposition, and environmental effects and for the political realities of building these projects. The final list of chosen projects was then simply made public.

Recently, however, the project selection process has become considerably more open. The public is voicing its opinions much earlier in the process through both hearings and regional organizations with planning and review powers. Typically the state agency still retains responsibility for overall (statewide) system planning, however, and in that capacity must generate and develop the alternative programs for review and evaluation by the public. This includes determining for each project (and collectively for the investment program) the effects of each alternative. This essentially technical role requires that fiscal plans, transportation system plans, project development activities, estimates of

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community and environmental impacts, and expressed or anticipated public sentiments based on participation and interaction with a wide variety of interest groups be integrated.

Individual projects may be evaluated sequentially by investigating each issue separately, collecting the relevant data, and carrying out a detailed analysis. But synthesizing this information for all projects to form a statewide investment program requires essentially simultaneous consideration of a wide range of factors, and there is simply too much information to be handled well by a subjective evaluation procedure. Well-defined analytic procedures to aid in the comparative evaluation of projects and the formulation and evaluation of alternative highway programs are requisite for systematic and successful program development. This need will become even more critical as the competition among alternative multimodal investment programs increases.

CONSTRAINTS OF THE PROGRAMMING PROCESS

The basic programming process is common to all states. It is designed to produce the investment program over time that most efficiently maximizes the overall general welfare of the state while maintaining an equitable balance among both individuals and regions. Although both the process and procedures vary widely by state, most state programming processes address the six elements discussed below.

Multiple and Conflicting Objectives

Although the basic objective of a programming process is to develop an optimal program of investments over time, the definition of optimal will most certainly differ among interest groups, as will the criteria for declaring any particular project good or bad. The existence of interest groups with different objectives severely complicates the problem of choosing among projects and among programs. Conflicts among national, state, regional, and community goals will have to be evaluated and resolved. Two alternative approaches have been favored by various states to resolve this problem. The first is a relatively subjective one that ignores technical measures and deals with nonquantifiable effects in an extremely ad hoc manner (1). The second approach is a highly technical one that assumes everything can be quantified and that weights can be found to reduce incommensurables to a single common measure (1, 2). Both approaches are unacceptable for what should be fairly obvious reasons.

The approach described in this paper lies between these two extremes and consists of two phases: (a) efficient development of a number of good alternative investment programs, each seeking to maximize some quantifiable measure of effectiveness in meeting a particular objective (for example, economic benefits or a decrease in anticipated accidents), and (b) introduction of nonquantifiable factors and the evaluation of the alternative programs with respect to both quantifiable and nonquantifiable factors. The object of the second phase is to resolve differences among competing programs through a negotiable, interactive bargaining process.

Total Budget Constraints

Although there are many possible types of budgeting constraints, a limitation on overall expenditures is undoubtedly the most common. Based on projections of future revenues, needs, and allocation policies, an estimate of overall funds available for programming in each period is usually made, which establishes an upper bound on expenditures. As straightforward as this constraint seems, its implications to programming are paramount. First, it is the justification for the process itself, inasmuch as with unlimited funds we would not need to choose among projects; we would simply build every reasonable project now. Second, and less obvious, it affects how projects should be implemented in terms of timing and scale. All too often, alternative project scales (e.g., the number of lanes of a proposed highway) are initially considered but then dropped before the programming process is begun. However, it is imperative that alternative scales be carried into the programming phase, since the optimal scale cannot be determined prior to programming. As will be demonstrated later, in the presence of an overall budget constraint, the best alternative is not always the one with the highest total benefit-cost ratio.

Geographical Constraints

In appropriating money for highways, state legislatures often establish guidelines controlling its allocation among the various areas in the state by designating minimum (and possibly maximum) expenditures for each area. California, for example, requires a 40 to 60 percent north-south regional split as well as county minimum expenditures that must be met over a 4-year period. These geographical restrictions on expenditures are designed to achieve some kind of equity within the state, on the basis of growth policy, needs, contributions to a fund, or some other measure. Unfortunately, such restrictions can result in the selection of relatively poor investments in some regions, from a benefit-cost perspective. On the other hand, they can prove useful in preventing a highly inequitable allocation of funds.

Special Purpose Allocations

Budget constraints may be imposed by designating funds for specific purposes. For example, states may design their investment programs in a way that maximizes the use of federal-aid funds. Although such a policy can lead to the selection of relatively inefficient projects (on the basis of benefits per dollar invested), the overall effect on a given state may be beneficial.

Network and Project Interrelationships

Another programming difficulty is accounting for the interrelationships among projects. For example, if two alternatives are available for a single location, they are typically mutually exclusive; that is, at most only one can reasonably be programmed.

The opposite of mutual exclusivity is contingency; i.e., a certain project cannot be programmed unless another specific project has already been selected. This is the relationship in staged expansion plans. To a certain extent, every project is contingent on every other project chosen and on the entire existing multimodal transportation system. For example, traffic demand for any particular link, a key factor in determining benefits, is dependent on the links it competes and connects with. Thus, project benefit interdependencies are the result of system demands and flows and are quite difficult to determine. However, in many cases, it may be possible to ignore them for all but the most major projects because the benefit interdependencies among most projects are small enough not to significantly affect programming decisions.

Uncertainty

Perhaps the most difficult factor to consider in programming is uncertainty over demand, funding availability, and community acceptance of specific projects. For example, we cannot accurately predict what the cost of fuel will be 20 (or even 5 or 10) years from now or how much capital will be available for construction. However, to prepare effective long-range programs, we must estimate these variables and address the uncertainty surrounding them.

Construction also faces a new kind of uncertainty: the power of an aroused public to halt indefinitely the construction of specific transportation facilities. This veto power over projects is unlikely to be rescinded in the future, and thus the implementation of projects will continue to rely on a successful bargaining process. The implications of this veto power on programming are significant. First, after a project has been programmed, study on it continues, which consumes both money and personnel. If the project is subsequently dropped, limited planning and programming resources have been wasted. Furthermore, there may not be a suitable alternative to fill its place in the investment program or to satisfy the minimum expenditure constraints of the capital budget. This void can lead to construction of relatively unsuitable projects simply because they are readily implementable or happen to be at the right stage of development at the right time. In a study of an actual case of this kind in Santa Barbara, California, Neumann and Pecknold (3) developed a decision analysis approach to addressing the uncertainty of community acceptability. The second implication of an unanticipated community veto can be even more significant. If the rejected project has strong interrelationships with other programmed improvements, rejection can lead to highly undesirable system flows.

Effect of Constraints

The six factors discussed will become even more significant in an era of scarce resources and an aware and questioning public. To cope with these constraints, many states will place increased emphasis on the development of an improved programming process. In most cases this will result in a complex, iterative, participatory process involving multiple sectors, many regional inputs, and a great deal of subjective judgment. Based on the factors just discussed, how can reasonable alternative programs be developed for further evaluation by both regions and states? This problem of program generation is the subject of the remainder of this paper.

PROPOSED HEURISTIC PROCEDURE

A number of previous studies (4, 5, 6, 7) have attempted to address this complex problem by using procedures such as integer and linear programming, dynamic programming, and decision analysis but without much success. All were extremely limited in the problem size they could handle or in their ability to deal with the large number of constraints that characterize the problem. [Pecknold (7) provides a review of various applicable programming and time staging techniques.]

The procedure chosen for the methodology presented here is a heuristic one based on marginal analysis (8). In a straightforward manner it can handle

1. Overall budget constraints,
2. Category, area, or functional classification minimums,
3. Scale or sizing of projects (i.e., multiple alternative scales or sizes for any project location), and
4. Project benefit interdependencies.

It has also been extended to include a measure of the uncertainty of community acceptability of a project. The procedure has been programmed for computer operation and is capable of solving virtually any size problem quite economically (a significant consideration if sensitivity analysis is to be performed). How the procedure addresses the problem is described below.

Handling Multiple Project Scales Under Budget Constraints

Although the difficulties of project programming are generally understood and effectively described in the literature (9, 10), in many cases total benefit-cost measures are still improperly used for ranking projects. Under the restriction of an overall budget constraint, maximization of total net benefits can be achieved only by maximizing the return or benefit measure received from each successive dollar invested. This requires consideration of each project's marginal contribution to the overall program benefit.

Benefit measures may be any measure of effectiveness for which increasing values signify better situations. Perhaps the most common measure in generating programs is some form of economic benefit or net present value that includes all benefits and disbenefits associated with a project. This should take into account the traditional elements such as travel time savings, operating costs, and safety impacts as well as other benefits and costs such as induced economic activity. Because projects have long economic lives and program decisions are required for multiple periods, the value of each alternative project must be calculated for each possible period of implementation and discounted to the present.

The following example demonstrates the inappropriateness of using a total benefit-cost ratio when there are both mutually exclusive alternatives and a total budget constraint to consider. Two alternative scale investments (labeled A and B) are proposed for project site 1, and a single investment alternative is proposed for site 2. The overall budget for this example is $10 million (Table 1).

The total benefit-cost ratio approach to this problem would be to choose projects in order of decreasing benefit-cost (b/c) ratio until the maximum budget is reached. In this case, sequential selection on the basis of total b/c would result in programming project 1A, followed by project 2, to yield a program benefit-cost ratio of 1.8 (assuming one discards project 1B after choosing the mutually exclusive alternative 1A). Such a procedure is equivalent to prescreening the alternatives for each site and discarding all but the one with the highest benefit-cost ratio. (Unfortunately, this approach will not always select the best projects, since the proper alternative for each site depends on the availability of funds and the benefits of all the other alternatives under consideration.) However, the best program for this example is obviously project 1B, with a total benefit-cost ratio of 2.3; thus ranking by simple benefit-cost ratios fails to yield the best program.

To make the correct choice, the algorithm must either determine the best choice directly or it must iteratively test and consider the desirability of all mutually exclusive alternatives throughout the selection process. For a sequential algorithm, the former approach is infeasible because project 1A is actually the best choice for the first $5 million; the availability of additional funds ultimately makes project 1A suboptimal in the example. The solution to the dilemma lies in the latter approach. Whenever a project is chosen, a calculation must be performed for each project with which it is mutually exclusive. This calculation determines the marginal benefit-cost ratio of discarding the newly chosen project and replacing it with the mutually exclusive alternative. (If this marginal benefit measure or cost is less than or equal to zero, the alternative may be eliminated from further consideration.) The algorithm then calls for sequentially selecting the project with the highest total or marginal b/c whose (total or marginal) cost is less than or equal to the remaining total budget. When no such projects with positive benefit-cost ratios remain, the process is completed.

For the example above, the marginal benefit of project 1B, given the prior choice of project 1A, is $8 million (i.e., 23 15) and the marginal cost is $5 million (i.e., 10 - 5). Thus its marginal b/c is 8/5 = 1.6. After choosing project 1A, the algorithm would next choose project 1B with the remaining funds (implying elimination of project 1A) because its marginal benefit-cost ratio is greater than that of the only other remaining project (project 2). Total program benefits would now be $23 million (i.e., the sum of the marginal benefits) for project 1B plus the total cumulative benefits of investing in all prior choices, i.e., project 1A, and total program cost would be $10 million (again the sum of the marginal value for project 1B and the cumulative cost of all preceding selections). Thus the new algorithm properly solves the problem of dealing with multiple alternatives under a budget constraint. Figure 1 shows this process.

Table 1. Example with $10 million budget constraint.

Project Site Alternative	Total Cost ($)	Total Net Benefits ($)	Net Benefit-Cost Ratio
1A	5 000 000	15 000 000	3.0
1B	10 000 000	23 000 000	2.3
2	5 000 000	3 000 000	0.6

Figure 1. Cost-effectiveness curve.

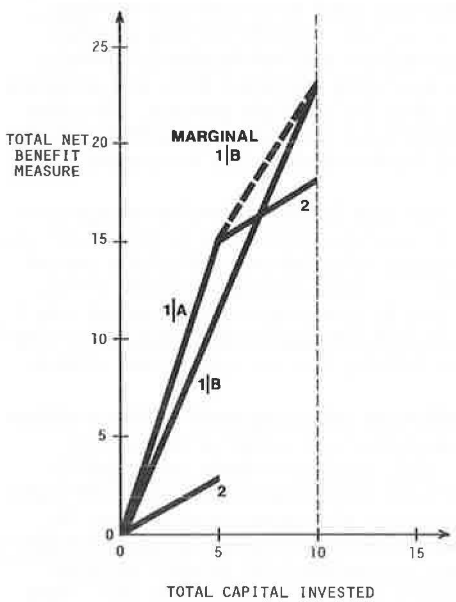
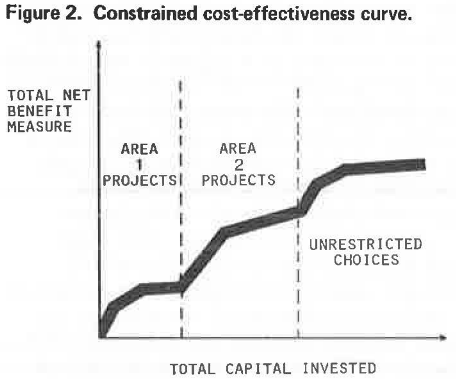


Figure 2. Constrained cost-effectiveness curve.



Satisfaction of Minimum Constraints

Unfortunately there is no guarantee that the marginal b/c selection rule will lead to satisfaction of any minimum budgetary constraints that have been established. For instance, the most efficient projects may all be in urbanized areas so that rural functional class minimums will not be met. Therefore, the selection rule must be modified to ensure satisfaction of such minimum expenditure constraints.

One way this can generally be accomplished is by successively restricting the list of available projects (i.e., those not already chosen or eliminated from further consideration) to those in a particular area, functional class, or other category whose minimum expenditure constraint is unsatisfied. [Development of this aspect of the algorithm and a large-scale computer package capable of handling thousands of alternative projects is currently in progress (11).] For example, projects could be chosen first from among those in area 1; after that minimum was met, selections would be made only from those in area 2 and so on until all minimum constraints were satisfied. The remaining funds (if any) could then be expended on the most worthwhile projects remaining (i.e., still available), regardless of area, class, or category.

In certain circumstances, the algorithm may initially fail to satisfy all minimum constraints before budgeted funds are exhausted. In such cases, doubly restricting the choices may prove effective. For example, if one is making selections to satisfy a particular area minimum and some functional class minimums have not yet been met, the choice would be further restricted to projects in these functional classes.

A typical cost-effectiveness curve illustrating this procedure (for the simple case with two area minimum constraints only) is shown in Figure 2. The existence of minimum constraints restricts the ability of the procedure to sequentially choose the best project until all the minimums have been satisfied; until then, choices are always made from a subset of the proposed projects, which may not contain the best one available.

The order in which the minimum constraints are satisfied may affect the results of this process, particularly if the sum of the minimum constraints of any given type (e.g., areas) approaches the overall budget maximum for the period. Unfortunately no one particular order will universally yield the best results; hence, constraint processing should be tried in various orders to determine the one that produces the best investment program for the problem under study. Because the algorithm handles mutually exclusive projects by a process that includes replacing an already chosen project by another project, it is possible that replacement might alter the status of a previously satisfied constraint. To prevent this, each set of mutually exclusive alternative projects should share the same values of all constrained characteristics (e.g., they should be in the same geographical area or functional class); if this cannot be achieved, satisfaction of all constraints cannot be guaranteed. An example application of this algorithm can be found in Juster (8).

Incorporating Other Constraints Into the Programming Process

At least two remaining constraints should be incorporated into the programming algorithm: uncertainty and project interdependencies. They are the most difficult to handle because they are the hardest to define and measure, conceptually and in practice. Although the techniques presented for dealing with these two factors are clearly the weakest elements of the proposed methodology, they represent an initial attempt at solving a difficult problem. It is hoped that their presentation will stimulate discussion and lead to further efforts to effectively deal with these important aspects of the programming problem.

Uncertainty

Uncertainty in investment programming is commonly dealt with through decision analysis (3, 7, 12). Unfortunately this technique has severe limitations when it is applied to a statewide programming process involving a large number of constraints.

The method suggested here is a heuristic approach for incorporating a measure of the probability of each project's political acceptability (3) into the basic programming process. (Officials in both Massachusetts and California indicate that they can generally estimate this probability, and, in California, such estimates are already being used in evaluating programs.) This is accomplished by simply multiplying the project's benefit measure by a factor between 0.0 and 1.0, which serves to indicate the utility (i.e., the value to the decision makers) of the uncertain benefits to be derived from including the project in the investment program. (The product of the calculated benefit measure and the factor is called the adjusted benefit measure.) The relationship between each project's probability of acceptance and the factor used to adjust its benefit measure is a matter of choice, inasmuch as it defines exactly how one chooses among projects that have different (unadjusted) benefits and probabilities of acceptance. A wide variety of functional relationships are reasonable, but only two are considered here: expected value and risk averse factors.

1. Expected value factors—The expected benefit from programming a project is simply the product of its probability of acceptance and its benefit measure. Hence, the expected value factor is equal to the probability of acceptance.
2. Risk averse factors—Researchers have noted (12) that people often have a measurable aversion to risky situations; that is, a person may prefer a less risky, smaller return to a very risky, larger return (e.g., a 90 percent probability of receiving $100 rather than a 10 percent probability of gaining $1000) even though the latter may have a higher expected value. A benefit adjustment factor that is less than the corresponding probability of acceptance indicates risk aversion.

For the benefit measure in item 1, the assumption is made that the benefit resulting from rejection of a project after it is programmed is zero. The actual benefit obtained is typically nonzero since the budgeted funds are available for use on alternative projects, but its value is not generally available a priori, so an assumption is required.

Project Interdependencies

Under certain circumstances, the benefits of building two separate projects may considerably exceed the sum of the benefits from each if it alone were constructed. This type of interdependency of benefits may be incorporated into the basic proposed methodology by the use of a construct called a joint project. As an example, a new joint project C (construction of both projects A and B) would be given a cost equal to the sum of the costs of the two original projects (A and B); its benefit measure would be that gained if both A and B are built. If projects A, B, and C are then treated as mutually exclusive alternatives (i.e., considered by the procedure to be located at the same site), the programming procedure will automatically select the best investment.

This is true except that the interdependency benefits are most easily incorporated if both projects (A and B in this case) are programmed into the same period. Actually, because the algorithm proceeds sequentially (and therefore never goes back to alter a period already programmed), the procedure can be adapted to handle these interrelationships between projects programmed in different periods. This is best accomplished by stopping at the end of each period and modifying the benefits of still unchosen projects to reflect the effect of those previously programmed.

It is important to realize that the interdependency benefits (i.e., the amount by which the benefits of C exceed the sum of those for A and B) will be realized only if both A and B are constructed. Hence, the political uncertainty associated with these benefits is extremely important to consider. The adjusted benefit measure of joint project C equals the sum of the adjusted benefit measures of each of the component projects, plus the calculated interdependency benefit measure times a factor representing its probability of being realized. For example, if expected values were being used and projects A and B were considered to have independent probabilities of success, the interdependency benefit measure would be multiplied by the product of the probabilities for projects A and B.

Multiperiod Programming

Thus far we have concentrated on selecting projects for a single investment period; however, the extension of the algorithm to multiple periods is reasonably straightforward. (However, it does not account for the differential effects of delayed inplementation on project benefits.) The key lies in the development of the list of projects available for investment in each succeeding period. Each list will typically include both new projects (which could not have been constructed in an earlier period) and projects available earlier but not chosen. Except for staged investment projects (11), however, the list must exclude any projects at sites where improvements have previously been programmed. It should be noted that benefit and cost data for all available projects should be updated before each new period is processed to reflect the effects of delayed implementation. Otherwise, the multiperiod algorithm is identical to the single-period procedure presented earlier.

After a reasonable multiperiod program has been produced and any necessary sensitivity testing has been completed, the entire process should be repeated by using other benefit measures to produce investment programs designed to meet other alternative objectives.

Ultimately, the programming process requires the development (through participation with the various interest groups) of a reasonably efficient and equitable overall investment program. The programs produced by the algorithm for each of the alternative objectives serve as input to this process and provide a measure of the maximum attainable levels of each of the objectives and of the trade-offs involved in substituting one objective for another. An advantage of the programming algorithm presented here is the ease with which many different programs meeting the various constraints can be generated. As a technical tool, the algorithm can increase consistency and reduce thousands of potential investment programs to a relatively few good prospects.

SUMMARY AND CONCLUSIONS

The investment decisions facing state and regional transportation agencies today are enormous. Agencies have been forced to expand their role and deal with much more complex problems, often in an environment of public hostility. In many cases, they have had to improve their decision-making process with essentially the same resources as before. Further research is required to help them continue to refine this role, to provide not only an improved programming process but also improved programming techniques.

This paper has presented a set of techniques developed to assist in improving an evolving programming process. Essentially, this methodology deals with the integration of budget constraints and project data to form reasonably good investment programs for further evaluation and modification. It handles

1. Multiple periods, each with an overall expenditure limit,
2. Legislative minimums on amounts that must be invested in counties or regions,
3. Functional classification constraints, and
4. Interdependencies among projects.

In addition, the procedure has been extended to incorporate estimates of acceptability as one way of handling the uncertainty surrounding a community's response to investment decisions.

The procedures presented here are not intended to replace the technical function of the state's programming groups, but rather to extend their existing tools and to aid in formulating alternative programs to serve as a starting point for discussion, compromise, and review. In addition, the methodology should prove useful for evaluating any proposed programs or changes to programs that may be of public interest and for analyzing some of the impacts of uncertain budget constraints and other aspects of program sensitivity. The ability to evaluate changes to publicly proposed programs is essential, since the overall programming process is an iterative one in which citizen groups seek modifications and the technical team determines the impacts of each proposal. Only through such an open process, supported by sound technical analysis, can essential agreement on a course of action lead to approval and implementation of the best possible investment plans.

ACKNOWLEDGMENTS

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A number of people in state government as well deserve our appreciation for their helpfulness in providing information and their willingness to discuss and try out new ideas. Tom Humphrey and Tom Richardson in the Massachusetts department and Larry Wieman and Bob Adams in the California department deserve special mention.

REFERENCES

1. Objective Priority Programming Procedures. General Analytics, Inc., and Comsis Corp., Final Rept., March 1973.
2. Evalution Criteria and Comparison Methods. Barton-Aschman Associates, Progress Rept. 2, March 1972.
3. L. A. Neumann and W. M. Pecknold. Application of the Time-Staged Strategic Approach to System Planning. HRB, Highway Research Record 435, 1973, pp. 20-31.
4. F. Ochoa-Rosso. Application of Discrete Optimization Techniques to Capital Investment and Network Synthesis Problems. Department of Civil Engineering, MIT, Cambridge, Research Rept. R-68-42, 1968.
5. G. Bergendahl. Models for Investment in a Road Network. National Road Administration, Stockholm, Nov. 1968.
6. Y. Mori. A Highway Investment Planning Model: An Application of Dynamic Programming. MIT, Cambridge, SM thesis, 1968.
7. W. M. Pecknold. The Evolution of Transport Systems: An Analysis of Time-Staged Investment Strategies under Uncertainty. MIT, Cambridge, PhD thesis, Sept. 1970.
8. R. D. Juster. A Methodology for Statewide Programming of Transportation Investments. MIT, Cambridge, SM thesis, Jan. 1974.
9. M. Wohl and B. V. Martin. Traffic System Analysis for Engineers and Planners. McGraw-Hill, New York, 1967.
10. R. Winfrey. Economic Analysis for Highways. International Textbook Co., Scranton, Penn., 1969.
11. R. D. Juster and J. H. Batchelder. Guide to the Highway Investment Analysis Package. Multisystems, Inc., in preparation.
12. H. Raiffa. Decision Analysis—Introductory Lectures on Choices Under Uncertainty. Addison-Wesley, Reading, Mass., 1968.

Gasoline Consumption in Urban Traffic

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A linear relation between fuel consumption per unit distance ϕ and trip time per unit distance $\bar{t}$, $\phi = k_1 + k_2\bar{t}$, has been shown to adequately explain fuel consumption for different drivers driving normally in urban traffic. In the present study, the applicability of this relation to a wider range of drivers, traffic, driver motivations, ambient temperatures, and vehicles is experimentally investigated. The effect of different driver instructions is studied. For example, drivers instructed to minimize trip time experienced higher fuel consumption than predicted by the linear relation, while those who drove slower than the traffic generally consumed less fuel. The parameters k_1 and k_2 obtained for different vehicles are approximately proportional to vehicle mass and idle fuel flow rate respectively; therefore, fuel consumption in urban traffic can be predicted from easily measurable vehicle characteristics. The excess fuel consumed because of cold starts is determined as a function of trip length for different ambient temperatures. These data are combined with data on the dependence of commuting trip speed on trip length to show that the fuel consumed in commuting trips increases substantially less rapidly than trip distance.

Recent investigations (1, 2,) and a number of earlier studies (3, 4, 5) show that the gasoline consumed per unit distance in urban driving at speeds less than ~60 km/h can be expressed as a linear function of the average trip time per unit distance:

$$\phi = k_1 + k_2\bar{t} \quad \bar{v} < \sim 60 \tag{1}$$

where

ϕ = fuel consumed per unit distance,
$\bar{t}$ = average trip time per unit distance (i.e., the reciprocal of the average speed $\bar{v}$), and
k_1 and k_2 = constants.

It is surprising that a process as complex as fuel consumption in urban driving, which depends on many factors such as speed changes, braking, and stopped delays, can nevertheless be described by so simple an expression. Part of the explanation is that the other relevant traffic variables are themselves correlated with the reciprocal of the average speed. Equation 1 organizes a large quantity of complex data. This paper investigates the adequacy of this equation in describing fuel consumption in urban driving in which a wider range of drivers, traffic, driver motivations, ambient temperature, and vehicles are considered than in the previous study (1, 2).

As a consequence of equation 1, the total fuel consumed, F, in a trip of distance D and duration T is given simply by

$$F = k_1 D + k_2 T \tag{2}$$

After equation 2 has been calibrated for a particular vehicle in urban traffic, fuel consumption for particular trips can be estimated by merely noting the distance and duration of the trip, for which a watch and odometer are sufficient instrumentation. In the present study, equation 2 is applied to trips made by a number of different drivers in a variety of traffic situations to further test its generality.

Fuel consumption studies conducted in Britain showed differences between different drivers driving normally (3). Still larger differences were observed when drivers were instructed to drive economically or as if in a hurry (4). Our investigations (2) did not reveal differences among four drivers driving normally with the traffic. This study further investigates the effect of different drivers and of instructions to drive differently from normal. In particular, data for drivers attempting to conserve fuel or save time are analyzed.

The quantities k_1 and k_2 have been interpreted in terms of a model of the engine-vehicle system that relates them to easily measurable vehicle characteristics. Values of k_1 and k_2 have been obtained for different vehicles to investigate this interpretation.

The discussion so far has presumed a fully warmed vehicle. However, about one-third of all distance driven is for trips to and from work (6). In such commuting trips the vehicle starts cold and may not be fully warmed up even when it arrives at its destination.

Analyses of the excess fuel consumed in cold starts have generally been based on observations of fuel con-

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sumption over prescribed driving cycles (7, 8). In the present study, observations of fuel consumption in actual traffic are used to obtain quantitative estimates of modifications that must be made to equations 1 and 2 in the case of a cold start. Estimates of fuel consumed in commuting trips are also given as a function of the distance of the commuting trip, taking into account that the average speed of a commuting trip tends to be a function of the distance of the trip (9, 10). The effect of ambient temperature is also considered.

EXPERIMENTAL DETAILS

Equipment

Fuel consumption was measured by using a model 74 fuel meter developed by General Motors. The transducer of this instrument generates an electronic pulse for each 1.0 ml of gasoline delivered to the vehicle carburetor. A digital display mounted in the passenger compartment shows the accumulated number of ml of fuel, elapsed time to 0.1-s resolution, and fuel temperature to 1°C.

Distance was measured by reading the vehicle's odometer, which was calibrated. By interpolating between the 0.16-km digits, odometer measurements with a standard deviation of 0.014 km were obtained. Inasmuch as distances involve differences between consecutive odometer readings, the standard deviation of a distance measurement is accordingly 0.020 km.

A 1974 standard-sized passenger car with a 6600-cm^3 displacement V-8 engine, two-barrel carburetor, and three-speed automatic transmission was the primary test car and was used for all experiments except calibration of equation 1 for different cars. Its mass, including test equipment and a typical driver, was 2259 kg. Details of the other vehicles used are given later.

All fuel measurements were reduced to standard conditions of ambient temperature and fuel temperature in accordance with the recommended practice of the Society of Automotive Engineers (11). A small correction was also made to account for additional weight for trips with more than one occupant.

Method

The basic approach was to measure the fuel consumed, distance traveled, and time taken for each of a number of small sections of travel that together composed a trip. These data could then be interpreted in terms of equation 1. It has been shown (2) that the results of such analyses are relatively unaffected by the choice of any one of four methods of dividing the trip data into smaller sections. Consequently, the most convenient of these sampling methods was adopted, namely recording data at each stop. A section of travel between consecutive stops is called a microtrip. A normal trip starting and terminating at a specific location is called a macrotrip.

Using microtrips as data elements has a number of advantages. The net acceleration in a portion of a trip has a significant effect on its fuel consumption (2). The net acceleration of all microtrips is zero, so that the effect due to this variable does not contribute any additional variance to the results. An observer can more reliably read synchronous values of fuel consumed, distance traveled, and elapsed time with the vehicle stopped.

Much of the data were collected by unassisted drivers who orally recorded the cumulative fuel consumed, distance traveled, and elapsed time on a portable tape recorder. In some cases, such as when the effect of different driving patterns was investigated, an accompanying observer recorded the data.

For warm start trips, the vehicle was driven around for about 20 min before data collection began. For cold starts, the vehicle was parked outdoors for at least 8 h prior to data collection and was idled for 30 s before it was moved, as recommended by the manufacturer. In practice, some departures from this procedure occurred. The vehicle's fuel tank was normally maintained at above three-quarters full.

All data were collected on essentially level roads within 40 km of General Motors Technical Center, Warren, Michigan, from November 1974 to July 1975. Nine male General Motors employees, including the authors, served as drivers.

RESULTS

Relation Between ϕ and $\bar{t}$

For an appropriate data base to calibrate equation 1, two long trips were made over a route designed to include a wide variety of traffic conditions. The roadways are major urban arterials, business streets in the Detroit CBD, and local streets in Mount Clemens, a town of 21 000 population situated 34 km from Detroit. The values of ϕ and $\bar{t}$ for the 206 microtrips making up the long trip are shown in Figure 1. The straight line is a fit to the data for 65 s/km < $\bar{t}$ < 365 s/km. The curves represent constant-speed fuel consumption per unit distance.

Differences in the character of the traffic on the three types of roadway are apparent from the distributions of average trip time per unit distance for the corresponding microtrips. However, all three groups of microtrips lie close to the same regression line, indicating that equation 1 can be applied to varied roadway situations.

To avoid large percentage errors in distance measurement due to the 0.020-km distance measuring resolution, microtrips shorter than 0.2 km are consolidated with the preceding microtrip. Microtrips with $\bar{t}$ < 65 s/km ($\bar{v}$ > 55 km/h) are not included in the analysis inasmuch as equation 1 is not expected to apply to such high speeds (fuel consumption increases with speed). The remaining points are not evenly distributed over the range of $\bar{t}$ but instead are concentrated at lower values of $\bar{t}$. To avoid giving undue weight to the data in this range, we adopted Everall's procedure (4). The data were grouped into intervals of 10 s/km in $\bar{t}$, and the regression was based on the average values of ϕ and $\bar{t}$ in each interval in the range 65 s/km < $\bar{t}$ < 365 s/km. The upper limit is the largest value of $\bar{t}$ for which a useful number of data were available.

The resulting linear regression obtained for the primary test car is

$$\phi = 112 + 1.05\bar{t} \qquad (3)$$

where ϕ is in ml/km and $\bar{t}$ in s/km. This line is shown in Figure 1. Also shown in Figure 1 is the constant-speed fuel consumption in different transmission gears. The data plotted were made available to us by General Motors engineering staff and were computed by their GPSIM procedure (12). Our test track measurements of constant-speed fuel consumption are in good agreement with these data.

Prediction of Fuel Consumption for Macrotrips

Although equation 3 was derived by analyzing microtrips, it can be converted, as was discussed earlier, into an equation for the total fuel consumed, F, in a trip of arbitrary distance D completed in time T to give

$$F = 112D + 1.05T \quad (4)$$

where T is in seconds, D in kilometers, and F in milliliters.

A total of 26 macrotrips with distances ranging from 8 to 36 km were driven by nine drivers instructed to drive normally and to keep up with the traffic. Many of these macrotrips were obtained in connection with other parts of the study.

The actual fuel consumed in the macrotrips was compared with that predicted by equation 4. The predicted differed from the observed by -6.3 to 9.3 percent, with a root mean square value of 3.8 percent. This result indicates that most of the variability in fuel consumption per unit distance depends on the average trip time per unit distance, irrespective of the individual driver. This is in agreement with our findings (2) but contrasts with Roth's results (3), in which the fuel consumption of five different drivers driving at the same average trip speed varied about 20 percent. This difference may be attributable to the fact that the vehicles used in Roth's research (3) had manual transmissions, and the vehicles used here and in an earlier study (1, 2) had automatic transmissions.

Our results indicate that equation 4 provides acceptable predictions of fuel consumed on a trip of distance D and time T, relatively independent of roadway type, traffic conditions, or driver.

Physical Interpretation of Parameters k_1 and k_2

It has been pointed out (1, 2) that the linear relation between ϕ and $\bar{t}$ can be interpreted in terms of a model of the engine-vehicle system developed by Amann, Haverdink, and Young (13). The parameter k_1 is the fuel consumed per unit distance to overcome rolling resistance. Because the rolling resistance is approximately proportional to the mass of the vehicle for similar types of vehicles, we would expect k_1 to be approximately proportional to vehicle mass.

The parameter k_2 is the fuel consumed per unit time to overcome various mechanical losses. This fuel does not directly produce tractive power and may be considered to be approximately represented by the idle fuel flow rate. In the limit of zero speed, k_2 is the idle fuel flow rate (2). We would accordingly expect k_2 to be approximately proportional to the idle fuel flow rate.

To test these physical interpretations of the parameters k_1 and k_2, equation 1 has been calibrated for a number of different cars. The resulting linear equations for all the vehicles tested, including one from earlier research (2), are shown in Figure 2. In all cases, the percentage of variance explained by the linear relation was similar. The values of the parameters k_1 and k_2 for the curves in Figure 2, as well as other characteristics of the cars, are given in Table 1. Data given in (or computed from) other sources (3, 4, 5) are also presented in this table.

Figure 3 shows k_1 plotted versus the vehicle mass, and Figure 4 shows k_2 plotted versus the directly measured idle fuel flow rate for all available data. These figures show that k_1 is approximately proportional to vehicle mass and k_2 is approximately proportional to idle fuel flow rate.

For large values of $\bar{t}$, the slope of the line for fuel consumption per unit distance versus trip time per unit distance becomes identical to the idle fuel flow rate when stationary (1). However, the constant of proportionality between k_2 and the idle fuel flow rate is 1.21 for our data (Figure 4). Hence, for sufficiently large values of $\bar{t}$, the slopes of curves such as those in Figure 2 will approach values lower than the plotted slopes, which were determined from actual urban traffic data in the range $65 < \bar{t} < 365$ s/km.

From the vehicle mass and idle fuel flow rate, an approximate expression in the form of equation 1 can be derived for fuel consumption in urban traffic by using the relations in Figures 3 and 4.

Different Driver Instructions

The fuel consumption of different drivers driving normally with the traffic is well explained by equations 3 and 4. Deviations from this formula might be expected when drivers alter their normal behavior to save time or to conserve fuel (4). To study this aspect of fuel consumption, 34 test runs were made by nine drivers following various driving instructions over a fixed route of 27 km in suburban Detroit.

The choice of drivers and the set of instructions were designed to produce a relatively wide range of fuel consumption. The nine drivers included one with considerable experience in driving to minimize fuel consumption. The results obtained were not expected to be typical of any group of drivers but should be useful in indicating the extremes of fuel consumption and trip time that might be found on this route. Some sets of instructions involved the use of a vacuum gauge fuel economy meter with a dial divided into three color regions: green for good fuel economy and orange and red for high power with correspondingly reduced fuel economy. Seven instructions were given:

1. Drive normally with the traffic,
2. Minimize trip time,
3. Use vigorous acceleration and deceleration,
4. Minimize fuel consumption,
5. Maintain fuel economy meter in green region,
6. Maintain fuel economy meter in green or orange region, and
7. Drive like a hypothetical very cautious driver.

For instruction 2, drivers generally used vigorous acceleration up to an appropriate speed for the route, changed lanes freely, and adjusted their speed so as to pass through traffic lights when possible. For instruction 3, drivers attempted to maintain the maximum appropriate speed whenever possible. They did not use foresight to anticipate situations in which a temporary speed reduction might lead to a reduced total trip time, as under instruction 2. The driver responses to instruction 4 can be classified into two groups: those who responded mainly by reducing acceleration and speed and those who reduced the number of stops through appropriate speed adjustments, by using rather high accelerations in some instances. The instruction to maintain the economy meter in the green could only be achieved by limiting accelerations to values much lower than those that ordinarily occur in traffic. Keeping the meter in the orange also required rather low accelerations, but they did not seem outside the range of those normally used in traffic. For instruction 7, drivers used low acceleration and speed and avoided lane changes.

The average values and standard deviations of the fuel consumption and trip times for the different instructions are given in Table 2; the average values are shown in Figure 5. These points do not fit the regression line (equation 3) obtained from the microtrips. In fact, a line fit to these points, except for instruction 5, would be approximately orthogonal to the regression line. These results illustrate the contrast between speed changes due to traffic conditions and speed changes due to altered driving patterns in a given traffic situation.

Drivers driving with the traffic experience better fuel economy when their mean speed increases because of an increase in the speed of the traffic stream. However, drivers who increase their speed above that of the traffic stream save time but experience poorer fuel economy. Drivers who reduce their mean speed below that of the traffic stream may save fuel, although the very low accelerations required by instruction 5 resulted in increased fuel consumption as well as increased trip time. Drivers generally achieved better fuel economy under instruction 4, when they were permitted to adjust their speed to avoid stops, than under instructions 5, 6, and 7, when they reduced accelerations but did not generally adjust their speeds to avoid stops. Indeed, the average trip time under instruction 4 for drivers who reduced the number of stops was lower than for most normal runs. This is easy to understand when we consider the fuel penalty imposed by a stop at a red light. Measurements for our primary test car, which are consistent with Claffey's results (14), show that a driver who stops, idles for 30 s while waiting for the light to change, and accelerates to resume a speed of 60 km/h uses about 70 ml more fuel than a driver who passes through the signal at a constant speed of 60 km/h. Our test route included 56 traffic signals.

It is thus possible for drivers to reduce their fuel consumption in urban traffic by adopting effective driving patterns. However, most of these data were for drivers

Figure 1. Average fuel consumption per unit distance versus average trip time per unit distance. The curves represent constant speed fuel consumption per unit distance.

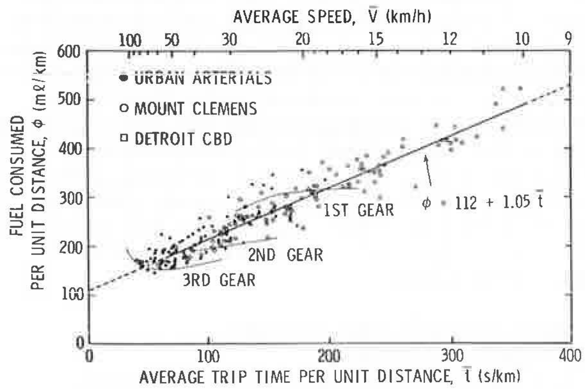


Figure 2. Linear relation $\phi = k_1 + k_2 \bar{t}$ for six vehicles in this study and one vehicle from previous research (2).

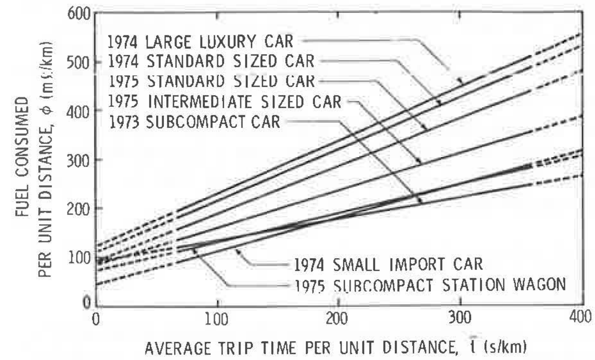


Figure 3. k_1 versus vehicle mass.

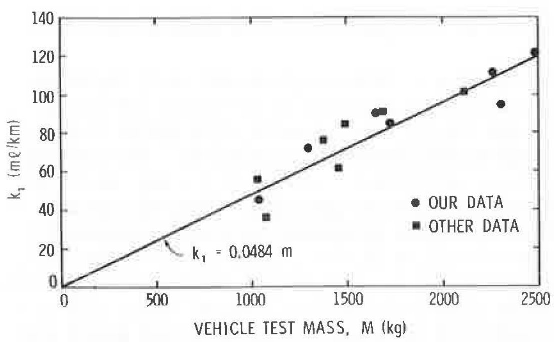


Figure 4. k_2 versus directly measured idle fuel flow rate.

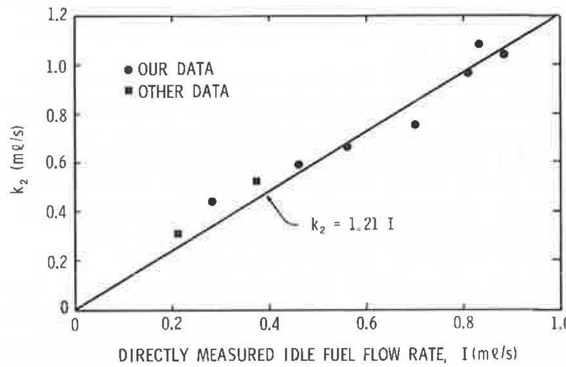


Table 1. Characteristics of vehicles in the present study and earlier research.

Reference	Vehicle	Model Year	Test Mass, M (kg)	k_1 (ml/km)	k_1/M [(ml/km)/kg]	k_2 (ml/s)	Measured Idle Fuel Flow Rate, I (ml/s)	k_2/I
Present study	Standard-sized car	1974	2259	111.59	0.0494	1.045	0.88	1.187
	Standard-sized car	1975	2291	94.64	0.0413	0.964	0.805	1.198
	Small imported car	1974	1033	45.54	0.0441	0.664	0.56	1.186
	Intermediate size car	1975	1720	85.12	0.0495	0.756	0.70	1.080
	Large luxury car	1974	2483	121.80	0.0491	1.084	0.83	1.306
	Subcompact station wagon	1975	1285	72.19	0.0562	0.590	0.46	1.283
2	Subcompact car	1973	1642	90.30	0.0550	0.440	0.28	1.571
3	Small van	1956	1067	35.93	0.0337	0.313	0.21	1.490
3	British car	1955	1372	76.83	0.0560	0.523	0.37	1.414
4	Minibus, empty	1965	1686	91.26	0.0541	0.349		
4	Minibus, loaded	1965	2083	100.91	0.0484	0.400		
4	Small British car	1965	1021	56.45	0.0553	0.322		
4	British car	1964	1478	84.91	0.0574	0.532		
5	Australian station wagon	1965	1451	62.10	0.0428	0.595		

Table 2. Effect of driving instructions on fuel consumption for macrotrips.

Instruction	ϕ Mean	ϕ S.D.	$\bar{t}$ Mean	$\bar{t}$ S.D.	Number of Runs
1	202	6	89.1	7.1	11
2	222	15	77.0	4.7	6
3	237	16	79.6	6.0	3
4	181	13	89.6	8	
5	206		118		1
6	191	5	90.4	5.9	2
7	188	9	96.0	10.6	3

Figure 5. Average fuel consumption per unit distance versus average trip time per unit distance for trips under various driver instructions.

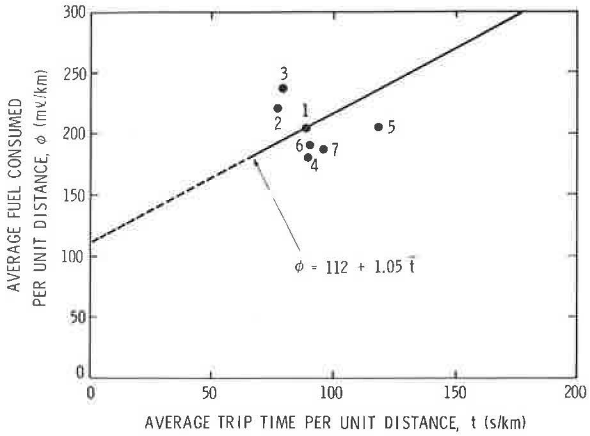


Figure 6. Average excess fuel consumed because of cold start versus distance traveled.

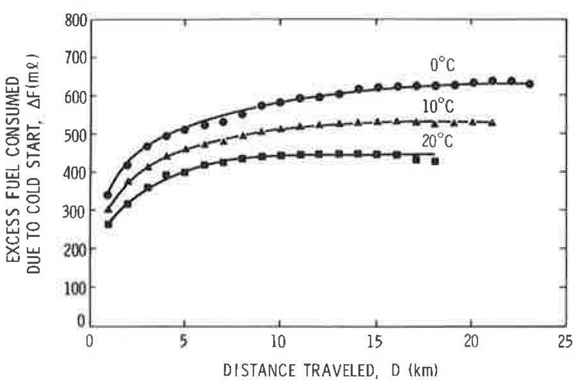
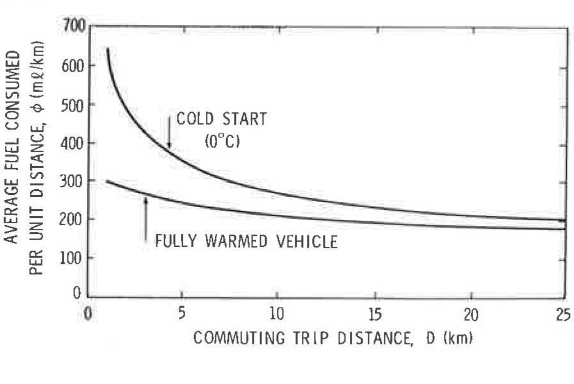


Figure 7. Estimated cumulative average fuel consumed per unit distance versus commuting trip distance for cold start and warm start.



who are more knowledgeable about fuel consumption than the general public, and their performance may not be indicative of the results that would be obtained by typical drivers. It is also important to investigate the effect on the overall traffic system of any alteration in driving patterns on the part of a large number of drivers. Drivers attempting to minimize fuel consumption might cause an increase in the fuel consumption of the total traffic system.

Fuel Consumed in Commuting Trips

Because about one-third of all distance driven is for trips to and from work (6), the question of how the fuel consumed on such commuting trips depends on the trip distance is of obvious interest. Two factors that affect the fuel consumed in commuting trips in urban traffic are discussed. First, a commuting trip normally starts with the vehicle cold. Second, the average speed of a commuting trip is an increasing function of distance (9, 10).

More fuel is consumed on cold start trips than is predicted by equation 2, which presumes a fully warmed vehicle. Let F_c be the measured total fuel consumed in a cold start trip of distance D and trip time T. The excess fuel consumed because of the cold start, ΔF, over the predicted fuel consumed with warm start can be estimated by

$$\Delta F = F_c - F \qquad (5)$$

where F is given by equation 2. Equation 5 gives the excess fuel consumed because of a cold start for test runs conducted in real traffic or in commuting trips without the need to replicate the trip with a fully warmed up vehicle as is usually done in cold start fuel consumption studies (7, 8).

Forty-one cold start trips, including commuting trips, were made with ambient temperature ranging from -17 to 30°C. For each trip, the excess fuel ΔF was estimated at each kilometer increment of distance. For a given trip distance D, ΔF decreased with increasing ambient temperature θ. A linear regression of ΔF on θ at each value of D gave typical correlation coefficients of about -0.66. The estimated excess fuel consumed because of the cold start versus the distance traveled for 0, 10, and 20°C ambient temperatures is shown in Figure 6.

The second factor that affects fuel consumed in commuting is the dependence of average commuting trip speed on distance (9, 10). Published data for trips to and from the General Motors Technical Center, Warren, Michigan (9), were used to estimate the average speed of a commuting trip of distance D. By combining this result with the information in Figure 6 we deduce the excess fuel consumed on a cold start commuting trip. The estimated total fuel consumed in the cold start commuting trip, F_c, is then given by

$$F_c = \Delta F + k_1 D + k_2 T \qquad (6)$$

where $T = D/\bar{v}$. Figure 7 shows ϕ (i.e., F_c/D) plotted versus D for cold start commuting trips at 0°C ambient temperature and for warm start commuting trips. If $\bar{v}$ were independent of trip distance, the warm start curve would be a horizontal line. Some illustrative examples derived from Figure 7 are given below:

Distance	Distance Ratio	Fuel Consumption Ratio: Warm	Fuel Consumption Ratio: Cold
10 km versus 5 km	2	1.75	1.56
15 km versus 5 km	3	2.43	2.06

For example, a 10-km commuting trip requires only 56 percent more fuel than a 5-km commuting trip for cold starts and not 100 percent more as the simple distance ratio would suggest.

This large effect is of importance in estimating commuting fuel consumption associated with different residential and work location patterns.

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REFERENCES

1. L. Evans, R. Herman, and T. Lam. Multivariate Analysis of Traffic Factors Related to Fuel Consumption in Urban Driving. Transportation Science, in preparation.
2. L. Evans, R. Herman, and T. Lam. Gasoline Consumption in Urban Traffic. Society of Automotive Engineers, SAE Paper 760048, 1976.
3. G. J. Roth. The Economic Benefits to Be Obtained by Road Improvements, With Special Reference to Vehicle Operating Costs, Department of Scientific and Industrial Research. U.K. Road Research Laboratory, Harmondsworth, England, Research Note RN/3426/GJR, 1959.
4. P. F. Everall. The Effect of Road and Traffic Conditions on Fuel Consumption. U.K. Road Research Laboratory, Crowthorne, Berkshire, England, RRL Rept. LR 226, 1968.
5. E. Pelensky, W. R. Blunden, and R. D. Munro. Operating Costs of Cars in Urban Areas. Proc., Fourth Conference of the Australian Road Research Board, Vol. 4, Part 1, 1968, pp. 475-504.
6. 1975 Automobile Facts and Figures. Motor Vehicle Manufacturers Association, 1975, p. 41.
7. P. F. Everall and J. Northrop. The Excess Fuel Consumed by Cars When Starting From Cold. U.K. Road Research Laboratory, Crowthorne, Berkshire, England, RRL Rept. LR 315, 1970.
8. C. E. Scheffler and G. W. Niepoth. Customer Fuel Economy Estimated From Engineering Tests. Society of Automotive Engineers, SAE Trans., Vol. 74, Rept. 65-861, 1966, pp. 880-889.
9. R. Herman and T. N. Lam. Trip Time Characteristics of Journeys to and From Work. Proc., Sixth International Symposium on Transportation and Traffic Theory (D. J. Buckley, ed.), A. H. and A. W. Reed, Publishers, Sydney, 1974, pp. 57-85.
10. P. V. Svercl and R. H. Asin. Nationwide Personal Transportation Study: Report 8, Home-to-Work Trips and Travel. U.S. Department of Transportation, Aug. 1973.
11. SAE Recommended Practice, Fuel Economy Measurement—Road Test Procedure. Society of Automotive Engineers, SAE J1082, April 1974.
12. W. C. Waters. General Purpose Automotive Vehicle Performance and Economy Simulator. Society of Automotive Engineers, SAE Paper 720043, Jan. 1972.
13. C. A. Amann, W. H. Haverdink, and M. B. Young. Fuel Consumption in the Passenger Car System. General Motors Corp., Research Publ. GMR-1632, 1975.
14. P. J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP, Rept. 111, 1971.

Energy Analysis for Urban Transportation Systems: A Preliminary Assessment

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This paper discusses and evaluates the capability of conventional urban transportation planning system (UTPS) procedures in dealing with energy issues. Central energy-related issues for planning are identified as (a) reevaluation of long-range plans, (b) modal alternatives, (c) investment needs, and (d) funding flow. The UTPS process is capable of dealing quite well with certain energy policies (e.g., speed reductions, increased vehicle efficiency) but generally is a weak tool for addressing other policies (e.g., rationing, Sunday driving bans, urban activity redistributions). Generally the sensitivity analysis capability of UTPS appears stronger than its ability to predict actual impacts. Specific information on gasoline price elasticity of travel by trip purpose, as well as trip priorities, would greatly increase the predictive power of the system.

One of the immediate effects of the energy crisis of the winter of 1974 was its impact on urban and intercity travel. As the energy crisis evolved through early 1974, certain travel patterns changed markedly while others changed only slightly. Most individuals and households appeared to have taken some steps to conserve energy and fuel in travel (1, 2, 3), but travel gradually returned to 1973 levels after the critical period was over.

In addition, shifts in travel behavior were not entirely as anticipated. Although transit ridership increased sharply in early 1974, some of this gain declined as the crisis subsided; thus urban transit appears not to have benefited substantially from the energy crisis. Rather, evidence suggests that people took more multiple-stop trips and perhaps patronized larger storage closer to home, particularly in nonwork travel. Car pooling was considerably less effective than had been anticipated. However, the sequence and ordering of these and other steps appear to be somewhat different for different income levels. Generally shifts in travel behavior appeared to have involved personal actions taken by individuals and their immediate households, rather than actions involving the social contact of individuals with other families.

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The 1974 crisis also reoriented the process of transportation planning and investment decisions. For example, the distinct possibility (perhaps inevitability) of reduced fuel availability and significantly higher fuel prices in the future has raised basic questions concerning the relationship of future travel to energy constraints. This brings into question the appropriateness of large investments in new transportation facilities that may never be used to capacity and further highlights the importance of including energy considerations in a formal and quantitative manner in long-range transportation planning.

Short-range planning has also been affected, inasmuch as the immediate impact of a reduction in travel during a crisis would be a sharp reduction in revenues from fuel taxes and tolls. Because reductions in transportation program funds would become real if an energy crisis were to occur again and continue for more than a few years, the entire issue of appropriate funding sources for transportation investments is brought into question. Because many state transportation funding agencies, as well as the federal government, use fuel taxes as a revenue source, reduced availability of these funds would greatly increase the competition among possible improvements and would probably hamper the completion of needed transportation projects. If state funds were to fall, significant losses of federal funds might also ensue, with the result that difficult decisions concerning the priorities of transportation investment proposals would have to be made.

That the transportation planning profession was generally not well prepared to deal with these issues is well evidenced by the inability of the profession to address revelent issues during the 1973-1974 energy crisis and issues ensuing from it. While most professionals were generally able to surmise the impact of alternative policies on travel, they had very little hard information available on which to make accurate predictions of policy effects. In a particularly important area, the priority and sequencing placed on trips by households, projected energy-related actions did not occur according to conventional theory; unexpected travel shifts were observed.

This may have been anticipated to some extent, since transportation planning techniques evolved during the 1950s and 1960s, when the possibility of fuel shortages

Table 1. Energy policy testing with UTPS.

			Short-Term Forecasts		
Policy	Key UTPS Stages	Other Essentials Elements	Sensitivity	Estimate	Current Testing Capability
Speed reductions	Distribution (nonwork), modal split	—	H	L	Good
Increased vehicle efficiency	Assignment, evaluation	Gasoline use calculator	H	—	Good
Transit fare reductions	Distribution, modal split	—	H	M	Good
Car pooling	Automobile occupancy	—	H	L	Medium
Increased parking charges	Distribution, modal split	—	H	L	Medium
Tax on gasoline	Generation, distribution, modal split	Gas price elasticity	M	L	Medium
Staggered work hours, 4-day workweek	Generation, modal split	—	M	L	Medium
Transit use increase due to gas price increase	Modal split	Gas price forecast, elasticity	M	L	Medium
Automobile-free zones	Distribution, modal split	Redistribution activities	M	M	Fair
Gas price increase (general)	Generation, distribution, modal split	Gas elasticity by trip purpose, disposable income reallocation	M	—	Poor
Gas price in relation to consumption	Generation, distribution, modal split	Selective trip priorities and frequencies	M	L	Poor
Fixed ration ceiling	Location, generation, distribution, modal split	Trip priorities	M	L	Poor
Sunday driving ban	—	Weekend travel patterns and behavior	L	L	Poor
Urban activity redistribution	Land use activity	Long-term elasticity, redistribution of activities	L	L	Poor

Note: L = weak test is possible, M = some elements possible, and H = test can be done.

or price increases that would influence travel demand, and subsequently the need for transportation investments, was to most professionals remote at best. Only a handful of long-range transportation plans prepared in the 1960s gave more than lip service to the possibility of energy constraints in the future. And analysis of travel forecasting and evaluation techniques shows generally a paucity of procedures that are sensitive in any real sense to energy policies, particularly reduced fuel availability. The logical conclusion, then, is that, generally speaking, transportation planning and the projections made therefrom are not energy sensitive.

Fortunately, this situation is not irreversible. Transportation planning processes in most metropolitan areas are entering the continuing phase, in which, during the next 10 years, plans developed earlier will be reevaluated and perhaps rescaled, based on monitoring and surveillance of key travel parameters. This next round of plans should give considerably more emphasis to energy issues than did the previous round.

ENERGY ISSUES FOR TRANSPORTATION PLANNING

Energy issues that are likely to require consideration in the continuing transportation planning phase fall into three general areas:

1. Modal evaluations,
2. Systems plan reevaluation, and
3. Investment needs and funding.

The role of more energy-efficient modes, particularly urban bus transit, needs to be more carefully considered. Although urban transit is seldom justifiable from a benefit-cost viewpoint, the inclusion of energy considerations in an evaluation of modes may greatly change the picture.

Systems plans developed earlier must be reevaluated in light of energy constraints, and projections revised to account for probable energy-constraint futures.

If travel projections are rescaled downward, many questions about investment needs and funding must be answered: How will investment requirements be affected? What are the most reasonable investment needs under energy constraints in the future? What is the role of gasoline availability and price in influencing investment policies? Are project priority-setting methods capable of filtering out those projects that are most valuable under energy constraints.

POLICY OPTIONS

The ability of long-range transportation planning to address energy issues must be evaluated against the policies likely to be studied in the next few years. The following is a partial list:

1. Encouraging better and wiser use of existing vehicle fleets—These policies include actions such as car pooling that result from priority analysis by households of their travel requirements, gas taxes, rationing policies, and driving bans such as the Sunday driving ban. In all of these policies the objective is to encourage the driving public to use existing vehicles in a more efficient manner.
2. Improving the gas consumption efficiency of vehicles—Examples are speed reduction policies and improvements in vehicle engines.
3. Shifting travel demand in time so that peak loads are spread out, congestion is eased, and operating efficiency is improved—Increased parking charges by time of day, staggered work hours, 4-day workweeks, and differential transit fares could effect such shifts.
4. Inducing modal shifts—These policies include transit fare reductions and service improvements, increased parking charges, taxes on gasoline, gasoline price increases, and gas rationing.
5. Redistributing urban activities—Such policies include automobile bans, redistributions of urban activity locations, particularly work, and more efficient settlement patterns.

CAPABILITY OF PRESENT URBAN TRANSPORTATION PLANNING SYSTEM TECHNIQUES

Which policies can reasonably be evaluated with currently available long-range transportation planning procedures? Before this question can be answered, a distinction must be made between estimating the actual impact of a given policy and measuring the sensitivity of travel to assumed levels of a given policy. For instance, if a policy on car pooling were implemented, it would be difficult, if not impossible, to forecast exactly how much of the traveling market would form car pools (i.e., how much automobile occupancy would change for work trips). But it would be relatively easy to test the sensitivity of gasoline consumption to changes in automobile occupancy. For many of the policies listed, it is possible to determine the sensitivity of energy consumption to an assumed change in travel, but it is quite another matter to estimate the change in travel that would occur if such policies were actually implemented.

Generally, the present conventional urban transportation planning system (UTPS) process more adequately addresses questions concerning sensitivity than questions concerning estimates. Data given in Table 1 show how short-term (1 to 5 years) travel forecasts for specific energy-related policies can be made through the UTPS process. An analysis of the table leads to the following general conclusions.

1. Certain policies can be tested adequately with the present process. These include policies on speed reductions and increased vehicle efficiency.

2. Policies concerning transit fares, car pooling, increased parking taxes, and taxes on gasoline can be tested with reasonable confidence. Information concerning gasoline price elasticity would greatly increase predictive skills in these areas. Although evidence is slowly accumulating that gasoline elasticity over the short term is very low (on the order of -0.1), we need to know considerably more about this phenomenon in order to make headway in the transportation analysis area.

3. Policies concerning general price increases or rationing schemes, as well as Sunday driving bans and urban activity distributions, appear to be beyond the capability of UTPS at this time. The primary reason for this is that there is a paucity of data on the probable impacts of such policies on household redistribution and its effect on trip sequencing and frequency. A parallel problem involves knowledge about the flexibility of disposable household incomes to pay more for available gasoline.

Table 2. Parameters affected by the energy crisis and their input to the simulation system.

Policy	Parameter and Direction of Effect	Input to Transportation Simulation Model
1. Speed change	Lowered speeds	Change speed limits on selected links
2. Car pooling	Increased automobile occupancy	Lower number of trip ends for selected purposes
3. Diversion to transit	Decreased automobile trips	Lower number of trip ends for selected purposes
4. Priority ranking of work and shopping trips	Decrease in either category relative to other	Lower number of trip ends for selected purposes
5. Trip length	Shorter trips	Adjust trip time values downward for shopping trips

Note: Item 1 is the expected effect of lowering the speed limit; items 2 through 5 are the expected effects if either the price of fuel rises dramatically (tax or free market price or both) or gasoline is rationed.

SENSITIVITY ANALYSIS

Table 2 gives a number of key parameters in the UTPS process and the way in which they might be input into a conventional UTPS model to determine energy impacts. Several tests have been made by the New York State Department of Transportation: (a) an 80-km/h (50-mph) speed limit, (b) a 15 percent reduction in work trips, and (c) a 30 percent reduction in work trips.

Results of these tests are given in Table 3. They demonstrate, as expected, that an 80-km/h speed limit (Rochester, New York, test area) would not decrease vehicle-kilometers of travel very much but would save approximately 2 percent in energy over a typical day.

Table 3. Sensitivity analysis of urban area energy policies.

Policy	Test Parameter	Comparison Base	Item	Percentage of Change
80-km/h speed limit	80-km/h maximum speed, redistribution of nonwork trips	1973 speed limit	Total cost/km of travel	+2.2
			Operation cost/km of travel	-3.1
			Accident cost/km of travel	+4.3
			Total	+3.8
			Vehicle-km of travel	-1.6
			Vehicle-h of travel	+2.0
			Speed	-3.7
			NO_x	-3.6
			HC	-0.2
			CO	+1.2
			PM	-1.6
			Fuel use	
			Liters	-2.1
			km/liter	+0.5
Car pooling, diversion to transit	15 percent reduction in work trips	80-km/h test	Total cost/km of travel	-2.5
			Vehicle-km of travel	-6.0
			Vehicle-h of travel	-9.0
			Speed	+3.5
			NO_x	-6
			HC	-7
			CO	-7
			PM	-6
			Fuel use	
			Liters	-6.3
			km/liter	+0.3
Car pooling, diversion to transit	30 percent reduction in work trips	80-km/h test	Total cost/km of travel	-4.5
			Vehicle-km of travel	-13.2
			Vehicle-h of travel	-18.2
			Speed	+6.2
			NO_x	-13
			HC	-14
			CO	-15
			PM	-13
			Fuel use	
			Liters	-13.3
			km/liter	-0.2

Note: 1 km/h = 0.62 mph; 1 liter = 0.26 gal; 1 km/liter = 2.35 miles/gal.

Travel would (in theory) be shifted from expressways to the local street system. On the other hand, a 15 percent reduction in work trips would result in about a 6 percent reduction in vehicle-kilometers of travel and approximately the same reduction in total energy consumption. The results further suggest that decreases in gas consumption are approximately linearly related to decreases in work trips.

These three tests demonstrate the utility of sensitivity analysis for long-range planning. Many proposed policies can be translated into UTPS parameters for testing purposes.

NEEDED IMPROVEMENTS

This overview suggests that, while the conventional UTPS process is capable of addressing certain long-range energy questions with reasonable ease, it falls short in making reasonable predictions in a number of key areas, particularly rationing. Some elements that appear to be essential to increasing the ability to plan for long-range energy impacts are discussed below.

Travel Behavior

We need to know considerably more about the ways in which individuals and households will reorganize travel patterns and priorities under energy constraints. Without this information, predicting the sequence and magnitude of responses to a variety of energy constraints would be impossible.

Elasticity of Fuel Supply and Price

Although a considerable number of studies have been done on the question of gasoline price elasticity, data on the relationship of this information to the travel sequencing and priority are particularly scarce.

Location Decisions

We must know a great deal more about the ways in which households and firms make location decisions. In particular, we need to know the influence of energy constraints on such decisions.

Demand Forecasting Procedures

Models are needed that relate travel demand (generation and distribution as well as modal split) to both gasoline price and availability and socioeconomic factors. This may involve the careful structuring of longitudinal studies to obtain sequential information from a panel of households during periods of gasoline price increases.

PROPOSED RESEARCH

Some of these questions can be answered only after (a) appropriate procedures for analyzing energy price and availability in long-range transportation planning have been developed and (b) methods for including energy and fuel factors in transportation programming and budgeting have been developed. The product of the research ought to be a set of procedures fully integrated with existing methods to assist state and local transportation planning groups in preparing, updating, and revising realistic energy-oriented transportation plans. The research should include the following elements.

1. Land use and transportation effects—Procedures for studying the impacts of the fuel shortage on regional transportation demands and land uses should be researched. Based on estimates of travel behavior, demands on existing and planned transportation systems could then be defined. Procedures for studying existing capacities of transportation modes should also be developed to determine the availability of alternate transportation services.
2. Travel behavior—Research should concentrate on procedures for describing travel behavior under energy constraints, particularly with respect to (a) the sensitivity of travel to energy constraints, (b) the sequencing of household actions as a basis for determining the effects of further tightening or loosening of energy constraints, and (c) household priorities placed on travel needs.
3. Demand forecasting procedures—Virtually none of the current demand forecasting procedures available today can handle energy constraints realistically, let alone provide estimates quickly or base such estimates on sound theory. Research is badly needed to develop special procedures for fast-turn-around travel estimates in response to a variety of energy-related policies.
4. Alternatives—The range of alternatives typically considered in long-range planning should be expanded to include energy-reduced options. Methods to identify and describe such options should be developed.
5. Financial data—The effects of gasoline consumption on transportation finance and fund allocations should be determined. Based on current financial sources, an evaluation of funding levels likely for the states under conditions of a fuel shortage should be made. New sources of revenue should be explored that will be equitable to society and that will promote efficient uses of fuel. Advantages and disadvantages (administrative, political, and economic) should be defined for each taxation strategy.
6. Project evaluation and scheduling—Procedures need to be developed for setting priorities and scheduling project proposals. Such procedures should take into account the impact of proposed projects on energy consumption and impact of energy on availability and cost of construction materials.

CONCLUSION

The efficient use of resources for transportation purposes is critical. Until very recently transportation planning and investment operated under the basic assumption of plentiful, almost unlimited, and cheap fuel supplies; fuel conservation played an extremely minor role in planning. Now that the era of cheap energy is over, it is important that these assumptions be revised. This paper has highlighted the use of sensitivity analysis with conventional UTPS tools to address some of these shortcomings. But many basic questions cannot be easily addressed; research is suggested to improve the overall capability of the profession to deal with energy issues.

REFERENCES

1. D. T. Hartgen. Individual Traveler Behavior Under Energy Constraints. Paper presented at Conference on Transportation and Energy, Union College, Aug. 1975.
2. R. L. Peskin et al. Immediate Impact of Gasoline Shortage on Urban Travel Demand. U.S. Department of Transportation, April 1975.
3. M. D. Stearns. The Behavioral Aspects of the Energy Shortage: Shifts in Trip-Making Characteristics. TRB, Transportation Research Record 592, 1976.

Use of Disaggregate Travel Demand Models to Analyze Car Pooling Policy Incentives

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Increased emphasis is being placed on short-range transportation options as a means of reducing energy consumption, air pollution, and traffic congestion. The research presented evaluates potential car pooling incentives and analyzes the direct and indirect effects of such policies. The travel analysis is based on three disaggregate travel demand models that predict mode choice for the work trip (including drive alone, transit, and the car pool alternative); frequency, destination, and mode choice for the nonwork trip; and household automobile ownership level. The analysis is conducted in a case study framework by using data from Washington, D.C. For each of many randomly selected households, the travel response to a candidate policy is simulated probabilistically by sequentially proceeding through the three models. By predicting the results at the level of each individual household, the models can stratify areawide travel impacts by any socioeconomic or geographic characteristic, e.g., income groupings. Results indicate that most policies result in modest reductions in travel for the work trip but that this may be partially offset by increased nonwork trip making induced by the increased number of automobiles left at home. When a policy influences both work and nonwork trips (gasoline price increases, for example), nonwork travel decreases significantly more than work trip travel, which confirms the more discretionary nature of nonwork travel.

Significant changes in both the scope and the emphasis of transportation planning have occurred in recent years. Where the former forcus was almost exclusively on long-range (1990 or 2000) forecasts of travel demand for use in major facility planning, now more and more transportation policy making is being directed at current problems of air quality, traffic congestion, energy consumption, noise pollution, and social equity. The objective is to develop solutions to these problems that can be implemented immediately, i.e., to make more effective and desirable use of existing facilities.

In this context, the Federal Energy Administration is examining various transportation policy incentives and disincentives that could be used to encourage car pooling with the general objective of reducing overall fuel consumption. To fully evaluate car pooling policies, though, one must go beyond the indirect effects, i.e., the shift to car pooling as the mode used for the work trip. For example, to what extent will the increase in trip circuity and vehicle weight associated with car pooling influence overall fuel consumption? What will happen with the increased number of automobiles left at home as a result of increased car pooling for work trips? Will this increase in automobile availability result in a corresponding increase in the number and length of nonwork trips such that the reduction in fuel consumption achieved by car pooling will be partially offset? Will the policy itself, for example, gasoline price increases, also directly affect nonwork trip making? Will a particular car pooling policy affect all segments of the population, or will certain groups be affected significantly more than others?

RESPONSE OF TRAVEL DEMAND TO CAR POOL INCENTIVES

Traditional aggregate models of travel demand have proved inadequate for this kind of short-range policy planning. Such aggregate models, based on existing relationships between zonal averages, tend to be correlative in nature rather than causal or behavioral and often are completely insensitive to proposed changes in transportation policy. Also by dealing in zonal averages, zonal totals, and zone centroids, aggregate models lose or blur much of the individual household information that sets one household apart from another in terms of travel behavior. Clearly, such models are inappropriate for analyzing the complex and often subtle interrelationship of variables that influence an individual's decision to car pool and are incapable of dealing with the appropriate issues.

Two basic requirements must be satisfied to properly analyze the effectiveness of various policy options related to car pooling (4). First, the models must be sensitive to changes in attributes of transportation alternatives that would result from the policies being analyzed (i.e., the models must be policy sensitive). Second and equally important, the models must be structured in such a way that they accurately reflect the choice process of an individual traveler deciding between travel alter-

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natives based on the attributes of each (i.e., the models must be behavioral). If a model does not meet these two conditions, it cannot be expected to predict with any degree of accuracy the effects on travel behavior of implementing a given policy.

Recently developed disaggregate models are calibrated at the household level by using observations of individual travel behavior, and they have several distinct advantages over aggregate models, including the following.

1. Because disaggregate models are not tied to any particular zonal system, they can be used at any geographical level; i.e., they can be aggregated to any level and are applicable for both areawide and subregional planning.
2. Because disaggregate models are behavioral or explanatory rather than correlative, they are more easily transferred from one situation or area to another. Geographic and temporal transferability of disaggregate models has been substantiated (2).
3. Disaggregate models make more efficient use of available data. A large portion of the variation in any data set is intrazonal rather than interzonal (5). Disaggregate models do not group data but preserve information about each individual household, and hence actually use intrazonal variation in a data set to estimate model parameters. Each individual becomes an observation rather than a zonal total being an observation unit.

INTERRELATIONSHIP OF AUTOMOBILE OWNERSHIP AND WORK AND NONWORK TRAVEL

From the viewpoint of an individual household, three groups of travel-related decisions can be distinguished (Figure 1). First are the long-range or major land use and locational decisions. These include choice of work place location for primary workers in the household and choices of residential location and housing type. These long-run decisions are assumed to be fixed for purposes of short-run policy analysis. Second are the medium-range decisions, which include automobile ownership and usual choice of mode to work decisions. The decisions on automobile ownership and work mode choice, it can be argued, are not typically independent of one another, at least not for the primary worker trips, and should be modeled simultaneously. A change in one would require a reconsideration of the other. A change in automobile ownership may require 1 to 3 years to actually take place, however. The third group of household travel decisions is short-range or nonwork trip decisions. These trips tend to be more discretionary and not to be planned very far in advance. Moreover, one does not decide to make a nonwork trip (shopping, for example), then decide where to make the trip, and then decide by what mode to make the trip in three sequential, independent steps as traditional aggregate models usually suggest; the frequency, destination choice, and mode choice decisions for nonwork trips should be considered simultaneously as alternative travel possibilities available to the household.

Given this basic travel behavior philosophy, three separate disaggregate travel demand models were integrated into a single model system:

1. A joint automobile ownership-work mode choice (for the head of household only) model (3),
2. A work trip mode choice model for all workers (3), and
3. A simultaneous frequency, destination, and mode choice model for nonwork trips (1).

Each of these models is of the multinomial logit form and was calibrated on observed travel decisions of individuals by maximum likelihood estimation. Logit is a specific mathematical form that has properties that match actual travel behavior, both empirically and theoretically, and is tractable computationally; maximum likelihood estimation is a technique for curve fitting or calibration, like least squares or regression but more sophisticated and compatible with the nonlinear logit form.

Each of the models is hypothesized as the probability of an individual or household choosing one of a set of alternative choices; for example, the work mode choice model is the probability of choosing each of three alternative modes—driving alone, sharing a ride, or riding transit—although a given individual may not necessarily have all three alternatives available to him or her. In the automobile ownership model, the choices are 0, 1, or 2+ automobiles owned; and in the nonwork model, the choice is a particular combination of destination and mode plus the option of no trip at all.

In each of the models, an alternative choice is described by its utility, or attractiveness, to the individual decision maker. This utility is an appropriately weighted combination of level-of-service attributes of the alternative, socioeconomic characteristics of the individual or household, and locational attributes such as employment density (which affect the probability of shared ride) given in Table 1. The appropriate weights are the relative weights a homogeneous group of individuals or households would assign to each of these attributes in making trade-offs among them; the weights or coefficients of each of the utility function terms are determined by the calibration or estimation process (maximum likelihood estimation, in this case) based on observed behavior and observed values of each of the variables or attributes of the alternative. (SI units are not given for the variables in these models inasmuch as their operation requires that values be in U.S. customary units.)

The variables represent known characteristics of travel demand. For work trips (Table 2), we know for instance that (a) as the ratio of available automobiles to licensed drivers increases, the probability of a drive alone trip increases; (b) the primary worker, or person of highest personal income, generally is given preference in use of an available automobile; and (c) the existence of more than one worker within a household creates the opportunity for family car pooling.

Locational variables are used in the work model to help define the probability of choosing the shared ride travel mode. For example, employment density at the work zone (employees per commercial acre) is multiplied by the one-way trip distance (miles); as this product increases, the probability of shared ride mode also increases. That is, the greater the density is at the destination zone, the higher the probability will be of finding someone to carpool with, and the longer the trip is, the more incentive there is to join a car pool or the greater the attractiveness of the shared ride mode will be.

Fundamental changes in the level of service of a transportation system, such as in cost, travel time, or modal availability, will lead to changes in automobile ownership over time. These changes may involve, for example,

1. Purchasing or selling a vehicle (frequently a second or third vehicle);
2. Postponing the sale or purchase of a new vehicle to a later time; or
3. Changing to a smaller, more fuel-efficient vehicle.

Figure 1. Travel choice hierarchy.

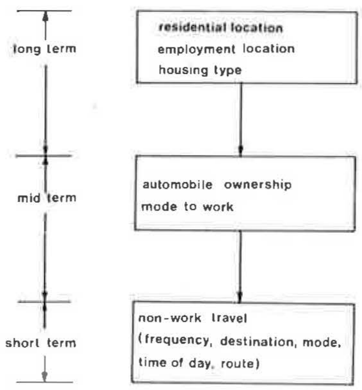
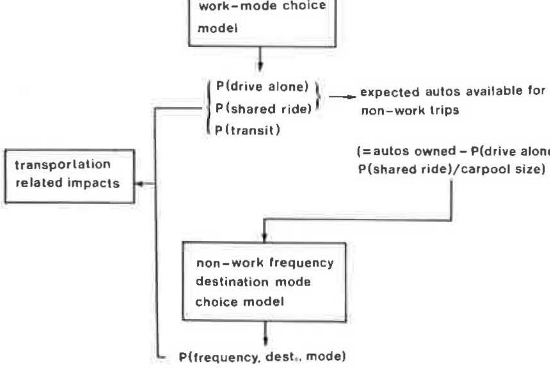


Table 1. Variables included in utility function of disaggregate travel demand models.

Variable	Automobile Ownership	Work Mode	Nonwork Frequency Destination and Mode
Socioeconomic			
Income	X	X	X
Automobile availability	X	DA, SR	X
Primary worker		DA	
Number of workers	X	SR	
Household size	X		X
Number of licensed drivers	X		
Residence type	X		
Level of service			
In-vehicle travel time	X	X	X
Out-of-vehicle travel time	X	X	X
Out-of-pocket travel cost	X	X	X
Locational			
Distance	X	X	X
CBD	X	DA, SR	X
Employment density	X	SR	
Employment type	X	SR	
Retail employment			X

Note: DA = drive alone mode (only), SR = shared ride mode (only), and X = all alternatives.

Figure 2. Model linkage.



The automobile ownership model includes transport level-of-service characteristics for both peak and off-peak travel, socioeconomic attributes of a household, and other locational factors that may influence automobile ownership and mode choice. The model actually is a joint model of automobile ownership and work mode choice, where each combination of automobile ownership level and mode to work is represented by a single alternative. The model, therefore, resolves the interdependency of automobile ownership and usual choice of mode to work by assuming the two decisions are made simultaneously.

FORECASTING CHANGES IN TRAVEL BEHAVIOR

The linkage of the three behavioral travel demand models into a single system is shown in Figure 2, which illustrates the sequence of calculations for a single household. In this way, the required information, such as automobile availability, is passed from model to model, and each model is conditional on any previous calculations for a given household. The computations follow the hierarchy of decisions shown in Figure 1, starting with automobile ownership and proceeding to work and nonwork trips. For predictions of only immediate or short-run impacts, the automobile ownership estimate is bypassed and the process starts with the work mode choice model for each of the household's workers. Only effects on daily travel activity are examined in this case, assuming automobile ownership remains constant. Running all three models, however, is more representative of an intermediate (1 to 3-year) impact time frame.

The model system also includes a variety of intermediate computations or submodels that are not shown in Figure 2, including shared ride automobile occupancy, automobile operating cost, and fuel consumption. These are performed, by household, on a trip-by-trip basis. For example, the probable size of a car pool is estimated as part of the work trip model and is based on the relevant socioeconomic, level-of-service, and locational variables. Fuel consumption is estimated as a function of trip length and vehicle weight, such that the effects of cold starts and increased automobile occupancy are taken into account.

MODEL REPRESENTATION OF POLICIES

Estimates of areawide impacts are projected from individual household impacts by repeating the model calculations for a suitable number of randomly selected households. This approach, called the random sample enumeration method, is free from any aggregation bias and, because the basic household level home interview survey data are used as a representative sample of areawide households, all the household-specific locational, level-of-service, and socioeconomic information can be preserved. The random sample of households needs to be large enough to be representative of the distribution of areawide households, to an acceptable level of accuracy. For Washington, D.C., a sample size of 800 households was found to be statistically sufficient for drawing areawide conclusions.

When a particular car pool incentive is analyzed, the household variables that would be directly affected by the incentive (e.g., work trip parking cost) are altered to reflect superimposition of the new incentive (Table 3). Then the models are used to simulate the travel choice probabilities of individual households, initially in the absence of a candidate incentive to provide a base case and then under the assumption that the incentive is in place. Areawide total changes are predicted by an

Table 2. Washington work trip mode choice model.

Variable	Car	Shared Ride	Transit	Standard Error	t-Statistic
Drive alone constant	-3.24			0.473	-6.86
Shared-ride constant		-2.24		0.401	-5.60
Out-of-pocket travel cost divided by income	-28.8	-28.8	-28.8	12.7	-2.26
In-vehicle travel time	-0.015 4	-0.015 4	-0.015 4	0.005 7	-2.67
Out-of-vehicle travel time divided by distance	-0.160	-0.160	-0.160	0.039	-4.08
Automobile availability (drive alone only)	3.99			0.395	10.08
Automobile availability (shared ride only)		1.62		0.305	5.31
Primary worker (drive alone only)	0.890			0.186	4.79
Government worker (shared ride only)		0.287		0.161	1.78
CBD work place (drive alone only)	-0.854			0.311	-2.75
CBD work place (shared ride only)		-0.404		0.298	-1.36
Disposable income (drive alone and shared ride only)	0.000 071	0.000 071		0.000 02	3.46
Number of workers (shared ride only)		0.098 3		0.095	1.03
Employment density (shared ride only)		0.000 65		0.000 49	1.34

Table 3. Examples of car pooling incentives and their representation.

Policy	How Represented in Model System
Car pool matching and promotion	Based on empirical data, modify government worker (car pool incentive) dummy variable to indicate matching assistance
Van pools	Extend alternative set to include this option with the appropriate travel times and costs
Preferential traffic control	Decrease car pool and increase drive alone travel times by appropriate amount, iterate for congestion effects
Area restrictions	Eliminate alternatives that require parking in that area or increase car out-of-vehicle time if have to park farther away
Gasoline rationing	Add shadow price to car travel cost, iterate for convergence
One-day/week driving ban	Decrease automobile ownership for each household by one for selected day per week
Preferential parking	Decrease car pool and increase drive alone excess time
Car pool parking subsidies	Decrease car pool travel cost
Parking tax surcharges	Increase car travel cost
Area of facility tolls	Increase car travel cost for selected trips
Gasoline tax	Increase car travel cost
Vehicle purchase or registration taxes	Increase ownership costs in automobile ownership model

Table 4. Example results of car pool policies for Washington, D.C.

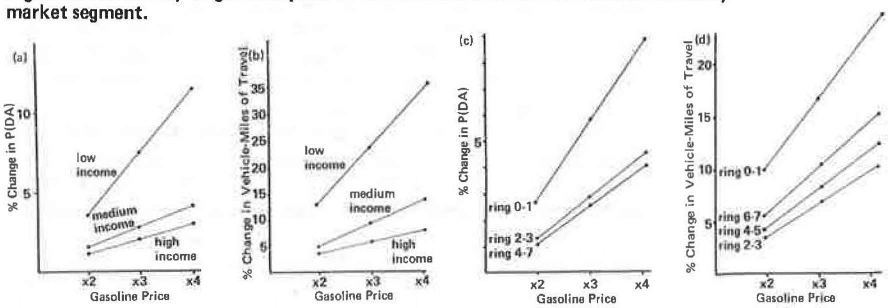
Policy	Percentage Change in Work Trip Mode Shares			Percentage Change in Vehicle-Miles Traveled			Percentage Change in Fuel Consumption
	Drive Alone	Car Pool	Transit	Work	Nonwork	Total	
Base value	52.9	25.4	14.5				
Parking incentives	-10.7	22.1	0.4	3.4	1.0	-0.6	-0.6
Parking incentives and parking costs	-22.3	43.8	4.6	-9.8	2.5	-2.2	-1.8
Base parking cost + $1 (areawide)	-5.1	4.6	10.6	-3.3	0.7	-0.8	-0.7
Base parking cost + $3 (areawide)	-15.6	13.9	32.6	-10.2	2.3	-2.5	-2.1
Base parking cost + $1 (CBD only)	-2.2	1.0	6.3	-1.4	0.3	-0.3	-0.3
Employer incentives	-3.9	16.7	-5.0	-1.8	0.5	-0.4	-0.2
200 percent gasoline price increase	-1.4	1.6	2.4	-1.4	-6.6	-5.12	-4.7
300 percent gasoline price increase	-2.9	3.2	4.9	-2.6	-12.4	-9.7	-9.0
Gasoline rationing	-9.3	8.2	12.6	-9.1	-22.4	-19.1	-17.4

Table 5. Base values against which data in Table 4 are compared.

Base Value	Vehicle-Miles Traveled			Fuel Consumption (gal/day)
	Work	Nonwork	Total	
Excluding weekend travel	10.4	16.7	27.1	2.58
Including weekend travel	10.4	27.6	38.0	3.68

Notes: 1 vehicle-mile = 1.6 vehicle-km; 1 gal/day = 3.8 liters/day.

Figure 3. Sensitivity to gasoline price of mode choice and vehicle-miles of travel by market segment.



appropriate summation of the individual household results; the households analyzed are grouped by homogeneous classes or market segments to examine differential impacts or to determine inequities that would result if the incentive were implemented. For each of the car pool strategies analyzed, the following specific market segments were examined:

1. Income (low, middle, and high),
2. Distance from central business district (three rings), and
3. Automobile ownership (0, 1, or 2+).

Several resource constraint policies impose a limitation on available supply (e.g., parking spaces or gasoline rationing) or result in significantly altered congestion effects, and require a calculation of supply-demand equilibrium; for example, if a gasoline rationing policy is to be implemented as a household-specific limitation (i.e., based on the number of licensed drivers, persons over 16, or full-time workers), the first iteration for a particular household would determine the amount of fuel consumed by that household under no resource constraint. If that figure is greater than the amount that would be available to the household, a shadow price or penalty for using a constrained resource would be estimated and added to the per gallon price of gasoline for that household. This resulting new fuel price would then be used in a second iteration to predict adjusted travel behavior of the household. This iterative process would continue one household at a time until the amount of fuel consumed by each household is in equilibrium with the amount of fuel allocated. The final value of the shadow price represents the price that each household would be willing to pay for one more unit of fuel. For a reduction in the supply of parking, the same basic logic would apply except that the iteration would proceed to equilibrium over the entire sample rather than for each household individually.

RESULTS OF POLICY ANALYSES

The results for nine of the policies analyzed are given in Table 4. The average household base values with and without weekend travel are given in Table 5. (The values in Tables 4 and 5 and Figure 3 are not given in SI units because operation of the model requires that they be in U.S. customary units.) The shifts in mode choice probabilities for work trips; work, nonwork, and total vehicle-miles traveled; and fuel consumed resulting from these policies are tabulated as percentage changes from the base values. Several findings are apparent from these data.

Existing levels of private ride sharing for work trips are already fairly high, 25.4 percent in Washington, based on total person work trips. The use of car pool pool incentives, therefore, reflects an effort to increase the use of ride sharing, not the introduction of an entirely new mode.

The positive impact (i.e., reduced fuel consumption) of a policy affecting only the work trip may be offset by increased nonwork travel resulting from increased automobile availability. For example, increasing the areawide base parking cost by $1/day decreases work travel by 3.3 percent; however, nonwork travel increases by 0.7 percent. When both work and nonwork changes are expressed as a percentage of total vehicle-miles traveled (-1.2 and +0.4 percent respectively), the resulting change in total travel (-0.8 percent) is 65 percent of the expected reduction based on work trips alone; i.e., 35 percent of the potential reduction is lost because of increased nonwork trip activity. This increase in nonwork travel is induced by a 2.4 percent increase in the number of automobiles available for such trips. Almost all (90 percent) of the increase results from increased trip frequency or destination shifts; only 10 percent is due to a shift in mode from transit to automobile.

When a particular policy affects both work and nonwork trips (e.g., gasoline rationing and price increases), the reduction in nonwork travel is even greater than that predicted for work trips despite the increased automobile availability for nonwork trips. This is in agreement with other findings that nonwork trips, because they are more discretionary in nature, are more sensitive or elastic to changes in level of service (6). For example, tripling the base gasoline price decreases work trip travel 2.6 percent, but decreases nonwork travel 12.4 percent. This decrease occurs despite a 1.8 percent increase in automobile availability for these trips. Here again, changes in mode shares have little impact on the decrease in nonwork travel, which is brought about by a 5 percent decrease in average trip length, a 7.2 percent decrease in trip frequency, and only a 0.6 percent shift in mode from automobile to transit. These results emphasize the importance of considering all aspects of nonwork travel.

In cities having well-developed transit services, such as Washington, there is a potential for policies that act as car pool incentives to divert riders from transit as well as from the drive alone mode. For example, a comprehensive program of employer incentives applied to all firms increases car pooling by 16.7 percent, but at the expense of a 5.0 percent decrease in transit use. This implies that a program should be carefully designed to encourage transit ridership as well as car pooling and van pooling; for example, perhaps it should avoid offering car pool incentives to persons who are well served by transit.

Allowing for longer run changes in both automobile ownership levels and shifts to more fuel-efficient vehicles results in fuel savings that are considerably larger than the immediate short-run conservation effects given in Table 4. Doubling the price of fuel without accounting for changes in automobile ownership results in a 4.7 percent decline in fuel consumption. Considering both changes in the number of vehicles owned and the shift to more fuel-efficient cars shows a decline in automobile ownership of 0.06 percent but three times the fuel savings, 15.1 percent versus 4.7 percent. The increase in the shared ride mode, however, declines from +1.6 percent to +1.1 percent when changes in automobile ownership and vehicle type are taken into consideration.

The strategies examined, which can be characterized as being disincentives, have potential inequities in the distribution of their effects; in each case, low- and middle-income households are affected more than higher income households, and one-car households are impacted more severely than households with two or more cars. Figure 3 shows the effects of gasoline price increases by income and geographic market segments.

Although the analysis results focus on the travel and energy effects of various actions examined independently of one another, it is much more likely that a combination of individual actions would be implemented as a well-designed, coordinated program. As one would expect, the effects of such programs on fuel conservation are likely to be greater (and more equitable) than those of individual strategies implemented in isolation, although not necessarily in a linear additive manner. For example, the combination of preferential traffic treatment and an employer-based program consisting of promotion, van pooling, and preferential parking results in regionwide reduction in daily travel of 1.7 percent. If these incentives are then combined with fairly strong pricing and automobile restrictions, a travel reduction of more than 8 percent can be achieved.

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REFERENCES

1. T. Adler and M. E. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. TRB, Transportation Research Record 569, 1976, pp. 136-150.
2. T. J. Atherton and M. E. Ben-Akiva. Transferability and Updating of Disaggregate Travel Demand Models. TRB, Transportation Research Record 610, 1977.
3. A Behavioral Model of Automobile Ownership and Mode of Travel. Cambridge Systematics, Inc., 1975.
4. Car pool Incentives: Analysis of Transportation and Energy Impacts. Cambridge Systematics, Inc., 1976.
5. C. R. Fleet and S. R. Robertson. Trip Generation in the Transportation Planning Process. HRB, Highway Research Record 240, 1968, pp. 11-31.
6. R. L. Peskin and others. The Immediate Impact of Gasoline Shortages on Urban Travel Behavior. Federal Highway Administration, U.S. Department of Transportation, 1975.

New Technique for Evaluating Urban Traffic Energy Consumption and Emissions

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This paper describes the development of a computerized tool designed to provide accurate, location-specific estimates of fuel consumption and vehicle emissions, stratified by vehicle type. This tool is an extension of the UTCS-1 microscopic traffic simulation program developed previously for the Federal Highway Administration. Data bases representing fuel consumption and emission rates are provided by other models developed for the Transportation Systems Center and the Environmental Protection Agency respectively. These data bases and the models that produced them are described. Results obtained by applying the extended UTCS-1 model to networks representing a portion of the CBD in Washington, D.C., are presented. First, the effects of allowing right turns on red on traffic operations and on fuel consumption and vehicle emissions are assessed. Then a comparison is made of two signal timing patterns. These results indicate that right turns on red can improve fuel consumption by approximately 4 percent and reduce emissions by 6 percent. Improving signal timing patterns for the cases studied can produce a 25 percent improvement in fuel consumption and vehicle emissions.

Traffic engineers concerned with improving traffic operations in urban areas generally base their evaluation on measures such as accident reduction, volume, vehicle delay, vehicle stops, and mean speed. Environmental engineers have conducted impact studies addressing the effect of vehicle emissions by basing their calculations on average vehicle speeds and volume.

Recent events have provided the impetus for traffic engineers to consider energy consumption and vehicle emissions in their assessments of traffic operations. Similarly, environmentalists must become more familiar with the details of traffic operations to improve the precision of vehicle emissions estimates. While some recent studies have reflected the need for synthesizing traffic operations and environmental considerations, the use of simplifying assumptions, which can compromise results, is still a prevalent practice.

This paper describes the development of a computerized tool designed to provide accurate, location-specific estimates of fuel consumption and vehicle emissions, stratified by vehicle type—automobile, truck, bus. This tool is an extension of the UTCS-1 microscopic traffic simulation model developed for the Federal Highway Administration (5). Data bases representing fuel consumption and emission rates are provided by other models developed for the Transportation Systems Center (TSC) and the Environmental Protection Agency (EPA) respectively. Results obtained by applying this extended UTCS-1 model to a network representing a portion of the CBD in Washington, D.C., are presented. The effects of right turns on red (RTOR) and two signal timing patterns are assessed. A further comparison is made with results obtained by using values derived from average speed estimates.

BASIC CONSIDERATIONS

Vehicle fuel consumption rates and emission rates depend on many factors including vehicle type, size, and age; propulsion and transmission system; engine temperature; antipollution devices; optional features; and operating characteristics. During the last several years, research activities conducted for EPA and TSC have led to the development of two valuable models:

1. An automobile exhaust emission modal analysis model (1, 2) based on a voluminous data base (3) and
2. A computer program that simulates the performance of a vehicle engine to estimate fuel consumption rates (4).

Each of these models will provide a data base for specified vehicles of sufficient detail to construct a response surface of emission rates or fuel consumption rates in the speed-acceleration plane (Figure 1).

As described later, such response surfaces were derived for a representative (composite) automobile, truck, and bus. Figures 2 through 5 show curves representing sections through these response surfaces along lines of constant acceleration for the composite automobile. The units shown are those of the tables used to define the response surfaces. The following comments are based on examination of these curves.

1. The effect of vehicle acceleration on energy con-

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sumption rates and on all emission rates considered is most pronounced.

2. At a given acceleration, the rate of fuel consumption is relatively insensitive to speed over a broad range of speeds.

3. Deceleration causes an increase in emission rates of carbon monoxide (CO) and hydrocarbon (HC) pollutants relative to those at zero acceleration. Deceleration has a negligible effect on energy consumption and a beneficial one on emission of oxides of nitrogen (NO_x).

4. The rates of CO and HC emissions are insensitive to speed at zero acceleration; the sensitivity of emission rates increases with speed.

The data bases permit accurate determination of energy consumption and pollutant emissions for specified fleets of vehicles if their trajectories are known. As indicated, the resolution of these trajectories must be sufficiently microscopic to provide the necessary resolution of speed and acceleration, inasmuch as all measures are extremely sensitive to small differences in acceleration.

With these factors in mind, FHWA decided to extend the scope of the existing UTCS-1 traffic simulation program. UTCS-1 is a validated microscopic traffic simulation model in which each vehicle is identified and processed as a discrete entity. The program produces the necessary vehicle trajectories and provides values of speed and acceleration at 1-s time intervals. As many as 10 vehicle types may be identified. Buses and trucks are identified and processed as such. For full details, see Worrall and Lieberman (6).

In this paper, values are expressed in customary units to be compatible with model design.

DEVELOPMENT OF THE MODEL

The UTCS-1 traffic simulation model (5, 6) traces the trajectory of each vehicle traversing the network, with a resolution of 0.1 s. At the conclusion of each 1-s time step, the status of each vehicle is determined and all relevant data items are packed within a single vehicle-trajectory word. These items include

1. Location—network link and longitudinal position to ±8ft;
2. Vehicle type—automobile, truck, or bus;
3. Acceleration or deceleration—to nearest integer in feet per second squared; and
4. Speed—to nearest integer in feet per second.

The simulation model was refined and extended to produce, for each second of simulated time, a record of data on a peripheral device. This record consists of a vector of vehicle-trajectory words, each word representing one vehicle on the network. At the conclusion of a specified interval of simulated time (say, 15 min) a new module named FUEL is called by the UTCS-1 executive routine to process these records of trajectory words. A table look-up procedure locates the fuel consumed and emissions corresponding to the data included within each vehicle-trajectory word. The structure of UTCS-1 is shown in Figure 6.

For each vehicle type, the following measures of effectiveness are computed and printed, in addition to the traffic operations data:

1. Gallons of gasoline consumed,
2. Fuel consumption rate in miles per gallon, and
3. CO, HC, and NO_x emissions in grams per vehicle-mile.

This information is presented for each network link and is also aggregated over the network.

GENERATING THE DATA BASE

The TSC model (4) simulates the operation of a motor vehicle as it executes a speed-acceleration trajectory (also known as a driving schedule). This is accomplished by computing the load that is placed on the engine at every point on the trajectory. The model then computes the amount of fuel the engine must consume to output sufficient energy to overcome the loading requirement.

The load on the engine can be split into several parts:

1. The forces to be overcome at the rear wheels;
2. The rotational inertia at the rear wheels due to the rotating parts such as the wheel, universal components, and drive shaft;
3. Losses in the universal and the transmission gears;
4. Losses in the automatic transmission torque converter;
5. Accessory loads (i.e., air conditioning, fan, power steering); and
6. Rotational inertia of the front end rotating components (including the engine).

The forces to be overcome at the rear wheels consist of tire rolling resistance, aerodynamic drag, acceleration inertia, and grade climbing. In this application grade effects were ignored because the main contributor to fuel consumption in urban environments is stop-and-go driving caused by control devices.

The fuel requirements of the engine thus can be obtained from the engine map, which yields the brake-specific fuel consumption as a function of engine revolutions per minute and brake mean effective pressure.

Karl Hergenrother, who developed the TSC model, calibrated it for FHWA to generate tables of instantaneous fuel consumption rates related to vehicle speed and acceleration.

These data represent a weighted composite of 1971 vehicles based on 11 automobiles and 9 engines. This weighting reflects the proportion of each automobile class in the total automobile population. These classes of automobiles were selected to be consistent with the composite used to obtain the emissions data, discussed later. The TSC model was also calibrated to generate tables for a city diesel bus (with a two-speed automatic transmission) and a heavy gasoline-powered truck (with a five-speed manual transmission) commonly used in urban areas.

The tables of emission rates for this study were generated by using the results obtained from a program of dynamometer tests of 1020 passenger cars chosen at random in which HC, CO, and NO_x emissions were measured (3). All vehicles were tested over the surveillance driving schedule, which consists of five steady-state (constant speed) modes and 32 acceleration-deceleration modes. Here, a mode consists of a monotonic segment of a driving schedule. The 1020 vehicles were aggregated into 11 classes, depending on test conditions. An analytical study (1, 2) processed the emissions data for each mode and developed a regression relation. The regression relation had 12 coefficients and included some cubic and quartic terms in the product of acceleration and speed. A total of 33 regression expressions are available, one for each of three emittants and 11 classes of automobiles.

It was assumed that these regression relations were valid for the instantaneous emissions rates. In this study, the available 1971 group of vehicles was considered to be most representative of the present vehicle fleet. The associated regressions were used to generate three

Figure 1. Response surface of emission rates and fuel consumption rates in the speed-acceleration plane.

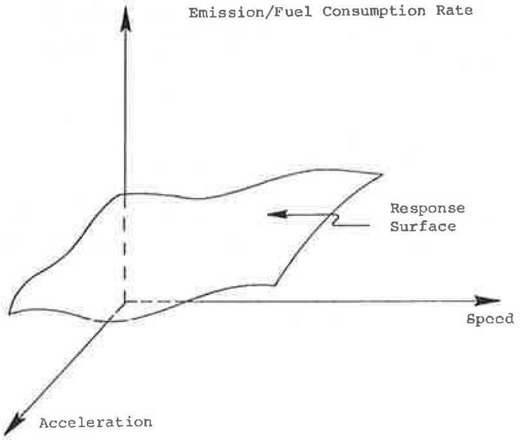


Figure 2. Automobile fuel consumption versus speed for several acceleration rates.

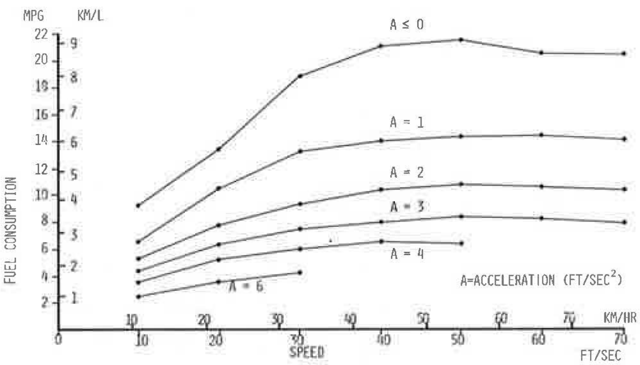


Figure 3. Automobile CO emissions versus speed for several acceleration rates.

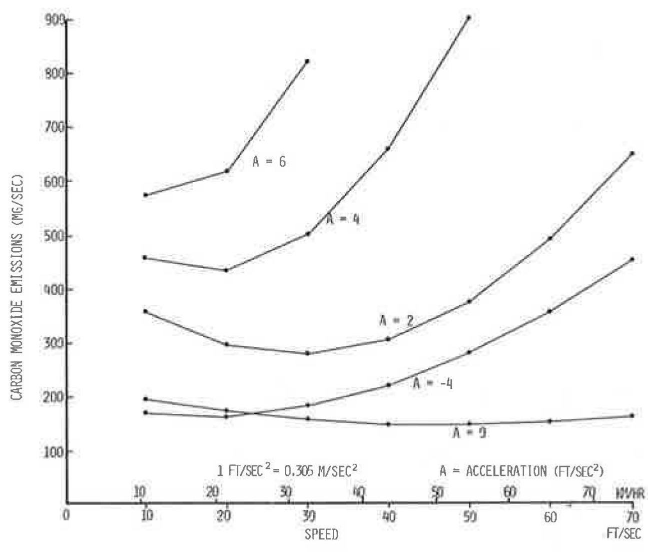


Figure 4. Automobile HC emissions versus speed for several acceleration rates.

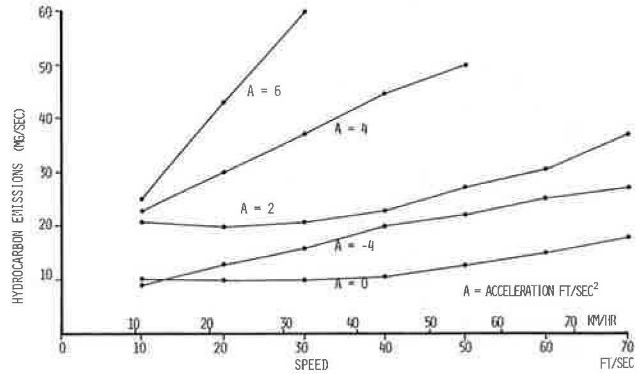


Figure 5. Automobile NO_x emissions versus speed for several acceleration rates.

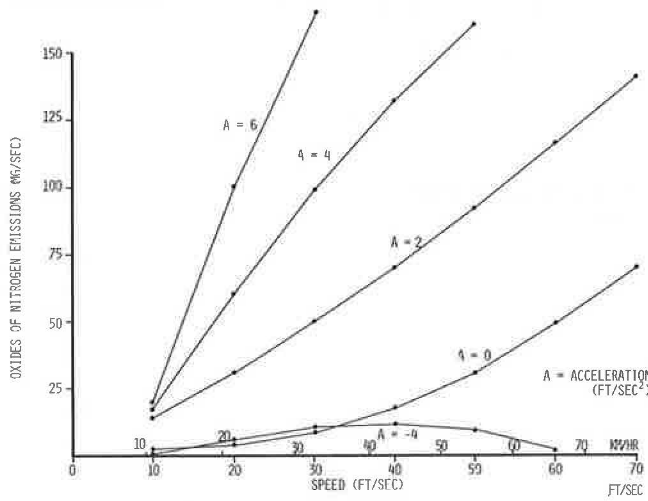
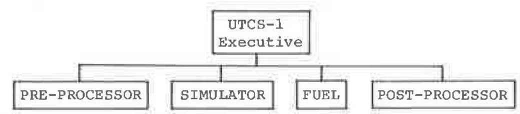


Figure 6. Structure of the UTCS-1 model.

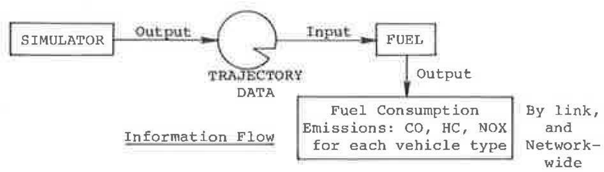


PRE-PROCESSOR: Reads and stores all inputs, performs a wide range of diagnostic tests, and primes storage

SIMULATOR: Performs the microscopic simulation of urban traffic flow, aggregating and storing MOE statistics in the process

FUEL: Reads and processes the vehicle trajectory data and prints the fuel consumption and emission results

POST-PROCESSOR: Performs an evaluation by statistically comparing the results of two separate sets of MOE describing traffic operations (optional)



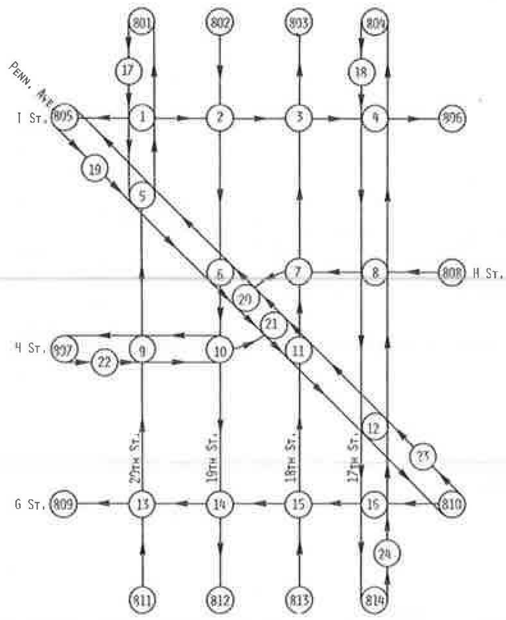


Figure 7. CBD network in Washington, D.C.

emissions tables over the same speed and acceleration ranges used for the fuel consumption data. Because of the cubic and quartic terms in the regression expressions, the tabulated values tended to oscillate rapidly and some values of emission rates were negative. When this occurred, the values were set to zero. The authors were unable to locate any emissions data of sufficient detail for trucks and buses.

The accuracy of these tables was tested by using them to compute the fuel consumption and emissions for the composite passenger car traversing the federal short cycle driving sequence (3, pp. 2-51). The results were as follows:

Item	Value
Fuel consumption, km/liter	7.14
HC, g/km	1.36
CO, g/km	19.0
NO_x, g/km	2.44

These results are within 2 percent of those experimentally devised values given in the literature (3).

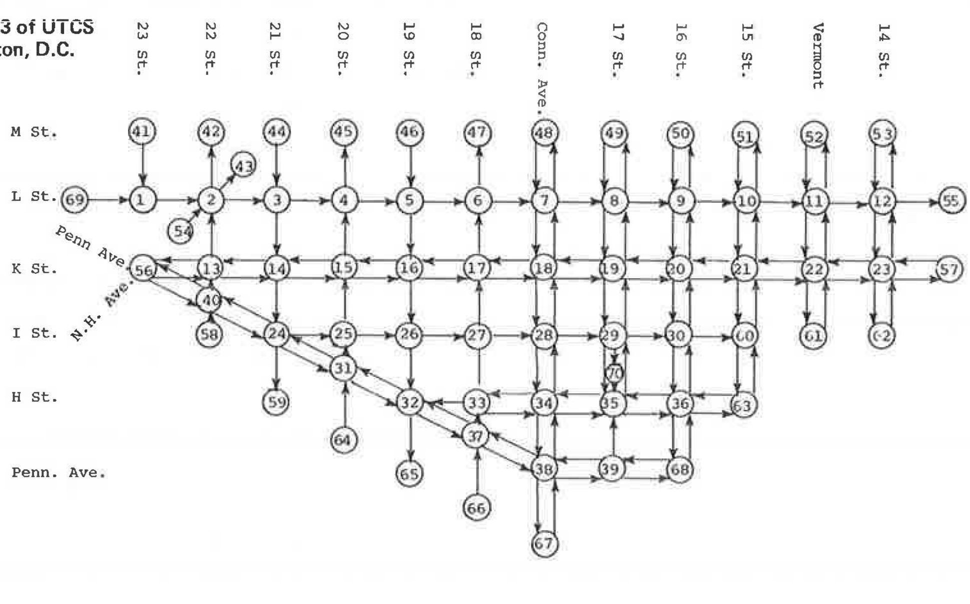
Table 1. Results of RTOR evaluation.

Control	Vehicle-km	Mean Speed (km/h)	Stops per Vehicle	Total Fuel (liters)	Gas Consumption (km/liter): From Model	Gas Consumption (km/liter): Based on Average Speed	Emissions (g/km): HC	Emissions (g/km): CO	Emissions (g/km): NO_x
No RTOR	1246	17.65	1.60	323.5	3.62	4.53	3.06	54.61	4.14
	1531	16.29	1.71	423.5	3.44	4.45	3.25	58.80	4.18
	1744	11.62	1.88	605.7	2.78	4.06	4.17	79.62	4.52
With RTOR	1247	18.91	1.53	312.1	3.76	5.50	2.91	51.27	4.07
	1529	17.72	1.62	402.8	3.61	4.59	3.06	54.65	4.11
	1759	13.47	1.73	558.4	3.02	4.08	3.77	70.44	4.41

Table 2. Results of signal timing evaluation on urban network.

Signal Timing	Vehicle-km	Mean Speed (km/h)	Stops per Vehicle	Total Fuel (liters)	Gas Consumption (km/liter)	Emissions (g/km): HC	Emissions (g/km): CO	Emissions (g/km): NO_x
SIGOP	3761	14.06	2.46	1175.2	3.22	3.62	66.2	4.24
TRANSYT	3616	17.86	1.92	952.3	3.78	3.03	52.9	4.02

Figure 8. Section 3 of UTCS network, Washington, D.C.



APPLICATIONS

The modified UTCS-1 model has been applied extensively since it was completed in mid-1974. Among the first applications was a study to explore the effects of the right-turn-on-red (RTOR) control feature on traffic operations, fuel consumption, and emissions over a range of traffic volumes. A portion of the CBD network in Washington, D.C., was studied with the model (Figure 7). The existing traffic volumes in the a.m. peak hour were studied, as was the impact of increasing or decreasing these volumes by 20 percent. The results of this study are given in Table 1.

It is instructive to compare the results for fuel consumption, obtained from the TSC data base by applying the value of mean speed at zero acceleration, and the data generated by the model. As indicated in Table 1, basing estimates of fuel consumption on a measure of average speed leads to an optimistic view of fuel consumption, by as much as 46 percent. This error reflects the sensitivity of fuel consumption to acceleration, as noted earlier. Hence, using only an (accurate) estimate of average speed ignores the turbulent characteristic of urban traffic flow, which contributes so strongly to fuel consumption. All of these comments apply equally to determining vehicle emissions.

Another study was designed to assess the relative impact of two signal timing patterns, generated with different algorithms (7, 8). The results generated by the model are given in Table 2 for the study network shown in Figure 8.

Examination of Tables 1 and 2 reveals that the RTOR provision can provide approximately a 4 percent reduction in fuel consumption and 6 percent reduction in vehicle emissions. An improved signal timing pattern can yield substantially greater benefits. In the study conducted, these benefits, expressed as reductions in fuel consumption and vehicle emissions, can range as high as 25 percent.

CONCLUSIONS

As demonstrated, variations in traffic control policies can influence fuel consumption and vehicle emissions, in addition to the traffic operational characteristics. It is now incumbent upon the practicing traffic engineer and the urban planner to consider these factors in defining policies that influence the design and implementation of surface transportation systems.

Available data relating rates of fuel consumption and emissions to vehicle operations indicate that these rates are extremely sensitive to vehicle acceleration and, to a lesser degree, to vehicle speed. To obtain accurate estimates of energy consumption and vehicle emissions requires that both operational measures be considered. The extended UTCS-1 model, because of its microscopic approach, is a valuable tool for obtaining these estimates for urban traffic. In the application presented, it was found that the RTOR policy provided both operational benefits and reductions in energy consumption and emissions, over a wide range of traffic volumes, for a representative urban network.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of Karl Hergenrother of TSC who provided much insight into this model along with the fuel consumption data base, and of Nancy Rosenfield of KLD who programmed a significant portion of the FUEL module. This effort was accomplished under subcontract to Alan M. Voorhees and Associates, Inc., in support of a study sponsored by the Federal Highway Administration. Hugh McGee is the principal investigator for the study. Justin True of the Traffic Systems Division is contract manager.

REFERENCES

1. P. Kunselman et al. Automobile Exhaust Emission Modal Analysis Model. Environmental Protection Agency, EPA-460/3-74-005, 1974.
2. H. T. McAdams. Automobile Exhaust Emission Modal Analysis Model Extension and Refinement. Environmental Protection Agency, EPA-460/3-74-24, 1974.
3. A Study of Emissions From Light Duty Vehicles in Six Cities. Automotive Environmental Systems, Inc., 1973.
4. Analysis of 1973 Automobiles and Integration of Automobile Components Relative to Fuel Consumption. Transportation Systems Center, Sept. 1974.
5. E. B. Lieberman, R. D. Worrall, and J. M. Bruggeman. Logical Design and Demonstration of UTCS-1 Network Simulation Model. HRB, Highway Research Record 409, 1972, pp. 46-56.
6. R. D. Worrall and E. B. Lieberman. Network Flow Simulation for Urban Traffic Control System, Phase II, Vols. 1-5. NTIS, Springfield, Va., PB 230 760, 230 761, 230 762, 230 763, 230 764, March 1973.
7. SIGOP: Traffic Signal Optimization Program. Traffic Research Corp., Sept. 1966.
8. D. I. Robertson. TRANSYT: A Traffic Network Study Tool. Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 253, 1969.

Energy Conservation Potential of Urban Public Transit

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Trends in urban passenger travel show a steady decline in transit ridership after World War II; currently bus and rail systems carry only 2.5 percent of the urban passenger traffic. However, since 1972 public transit ridership has been increasing in absolute, if not relative, terms. Although transit carries only a small fraction of urban traffic, existing bus and rail systems are two to three times more energy efficient than automobiles. Thus transit offers the hope of vastly reduced energy consumption for urban transportation. The energy implications of a number of recent transit improvements are discussed. Unfortunately, the energy impacts are slight, in part because transit now carries so few people relative to the total and in part because the increased ridership only slightly reduces automobile traffic. Thus the short-term energy saving potential of improved and expanded transit service is small relative to the savings possible through measures that directly affect the automobile and its use. However, in the long run (beyond 1985) the energy conservation potential of public transit may be significant.

The future role of urban public transit in the United States is an important but uncertain issue today. The period from 1945 to 1972 saw a steady decline in the importance of transit relative to the private automobile: Bus and rail transit ridership fell in both absolute and relative terms. However, since 1972, a number of forces have combined to halt and perhaps even reverse the downward trend.

These forces include the oil embargo and subsequent higher prices for gasoline. After nearly 2 decades of falling real prices, the price of gasoline increased 26 percent between 1972 and 1974; since then prices have risen even higher. Because of higher gasoline prices, the percentage of personal consumption expenditures devoted to gasoline increased 23 percent between 1972 and 1974 (to $36 billion in 1974).

In addition, public support of transit is growing. The National Mass Transportation Assistance Act of 1974 authorizes the expenditure of nearly $12 billion during the period 1975 to 1980. Unlike previous federal programs for public transit, the 1974 legislation authorizes operating, as well as capital, grants for transit systems.

This paper examines the period 1950 to 1973 with respect to urban travel and its energy use, discusses the relative energy efficiencies of different automobile and transit services, evaluates several recent experiments with improved transit service, and estimates possible future energy impacts of expanded and improved transit. The paper concludes that the short-term energy conservation potential of increased transit service is slight. In the long-run, however, improved transit offers the hope of large energy savings and other benefits such as improved mobility, reduced urban congestion, and less urban air pollution.

HISTORICAL TRENDS IN URBAN TRAVEL AND ENERGY USE

Total transportation fuel use grew from 9.4 EJ (8.9 quadrillion Btu) to 19.3 EJ (18.3 quadrillion Btu) in 1974 (1, 2) with an average annual growth rate of 3.0 percent. Between the mid-1960s and 1972, the growth rate increased to 4.7 percent a year. However, transportation fuel use increased only 3.3 percent between 1972 and 1973 and actually declined 3.2 percent between 1973 and 1974 (1). The 1974 decline was due to a combination of sharply higher fuel prices, spot shortages during the summer, the oil embargo during the winter, and a 2 percent decline in GNP between 1973 and 1974.

Figure 1 shows actual transportation fuel use from 1965 through 1974 and projections to 1985 from three different sources. The Department of the Interior (DOI) projection was prepared in 1972 (3), long before the recent oil price increases. The other two sets of forecasts, by Jack Faucett Associates (JFA) (4) and the Federal Energy Administration (FEA) (2), were prepared during the summer of 1974 as part of the Project Independence effort. These forecasts used crude oil prices (in 1973 dollars) of $43 and $69/m^3 ($7 and $11/bbl). The variation among the forecasts is considerable. The DOI forecast is much higher than the others, presumably because it assumes the low oil prices of the 1960s; its growth is equal to the long-run growth rate over the last 2 decades. The other four forecasts show growth rates far below the historical trend. If these latter forecasts prove correct, considerable fuel savings will be achieved in the trans-

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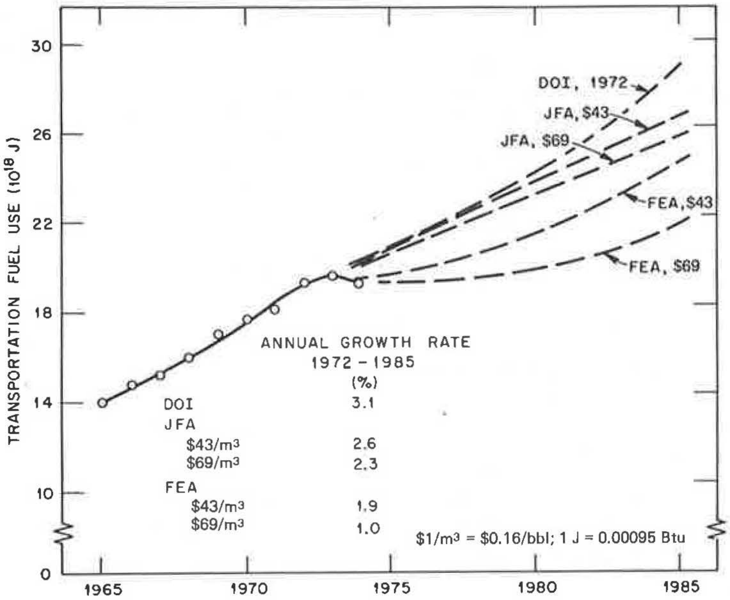


Figure 1. Total transportation fuel use and forecasts.

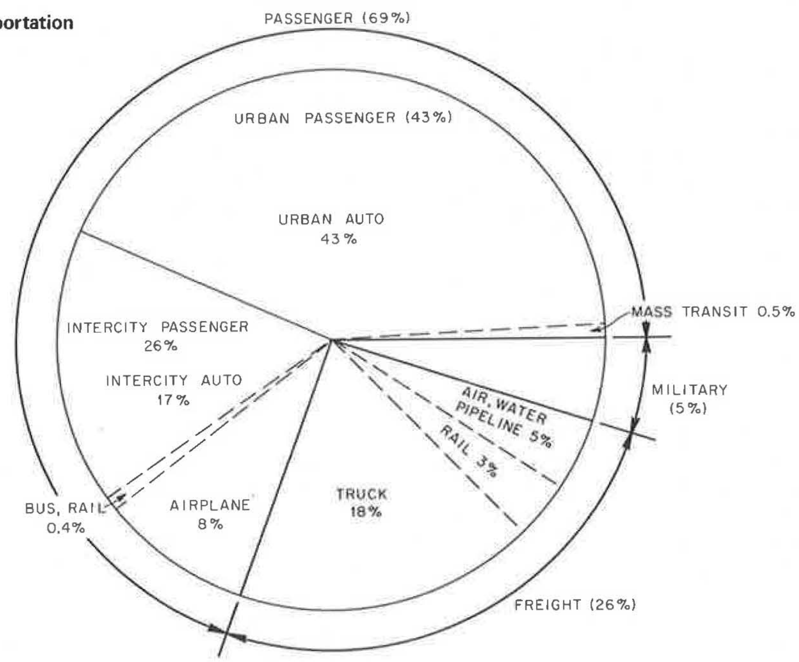
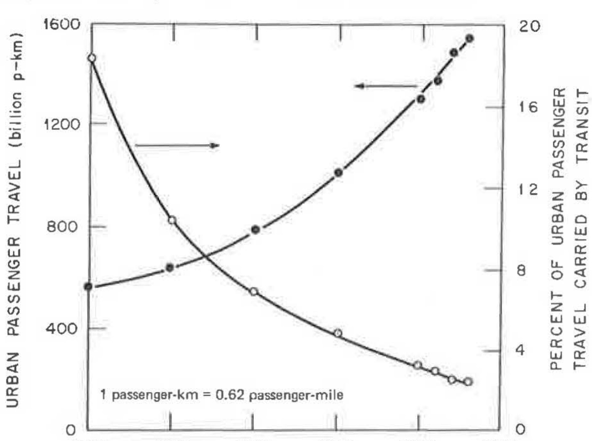


Figure 2. Distribution of transportation fuel use in 1972.

Figure 3. Urban passenger travel from 1950 to 1973.



portation sector because of fuel price increases alone.

Figure 2 shows the distribution of transportation fuel by mode, market, and purpose for 1972 (4). Passenger travel dominates the fuel use budget, accounting for more than two-thirds of the total. The automobile [defined to include cars, motorcycles, and personal use of trucks (4)] uses 60 percent of the fuel. Urban transit, for reasons discussed later, accounts for only 0.5 percent of the fuel use. Intercity bus and rail passenger service also use less than 1 percent of the fuel.

Trucks are the second most important energy-using mode. However, trucks represent a much more heterogeneous mode than do automobiles. The 18 percent figure shown for trucks is for both local and intercity truck freight traffic; the figure does not include use of trucks as passenger vehicles. The third most important energy-using mode is the airplane, accounting for 8 percent of the fuel. Nontruck freight modes use 8 percent, and the military uses another 5 percent of the transportation fuel budget.

Between 1950 and 1973, total urban passenger travel grew by a factor of almost three, as shown in Figure 3 (5, 6, 7). Although total traffic grew at an average annual rate of 4.5 percent, public transit travel declined in both absolute and relative terms from nearly 20 percent of the total in 1950 to only 2.5 percent in 1973. However, during the last few years the long-term decline in the absolute value of transit ridership has been halted. Nevertheless, transit still accounts for only a tiny fraction of urban passenger travel.

This long-term trend in urban travel away from transit was due to a combination of declining real fuel prices, declining real prices for new automobiles, rising transit fares, rising personal incomes, changing urban and suburban development patterns, federal support for highway construction, and the consequent drop in transit revenues and service. Although it is too soon to know, transit may, in the future, capture an increasing share of the urban travel market because of recent (and likely future) changes in a number of these forces. In particular, gasoline prices during the last few years have skyrocketed.

The three major urban travel modes, automobiles, buses, and rail systems, all show long-term increases in energy intensiveness (EI, measured in megajoules per passenger-kilometer) during the 23-year period shown in Figure 4 (5, 6, 7). Buses are half as energy intensive as are cars. Rail systems (trolleys, subways) are roughly one-third as energy intensive as are cars.

There is considerable uncertainty over the precise values of EI for each of these modes. Estimates differ because of different definitions of urban and automobile and because of differences in data and assumptions on average trip length and vehicle occupancy (load factor). The data shown in Figure 4 assume constant occupancy for automobiles at 1.6 passenger-km/vehicle-km (the units in terms of passenger-miles/vehicle-mile are identical) and constant trip lengths for bus (6.0 km or 3.7 miles) and rail (10.6 km or 6.6 miles) systems for the entire 23-year period (7). In spite of the uncertainty about the values of EI for the different urban passenger modes, there is little doubt that bus and rail systems are considerably more energy efficient than automobiles.

Total fuel use for urban passenger travel grew from 1.9 EJ (1.8 quadrillion Btu) in 1950 to 7.0 EJ (6.6 quadrillion Btu) in 1973, with an average annual growth rate of 5.5 percent (Figure 5). This growth rate is higher than that for traffic (4.5 percent a year growth in urban passenger-kilometers from Figure 3) because of the shift from transit to automobiles and increases in EI for all urban modes (Figure 4).

During this 23-year period, urban passenger travel accounted for a steadily increasing share of the total transportation fuel use budget (2): up from 22 percent in 1950 to 35 percent in 1973. This increase was due to increasing urbanization, the shift from transit to automobiles, and increasing automobile EI (changes in vehicle design and increased congestion).

AUTOMOBILE AND TRANSIT ENERGY INTENSIVENESS

The curves of urban passenger EI in Figure 4 show national averages only. However, variations in EI among and within modes are completely masked by use of national average figures.

Variations in EI among automobile services depend strongly on the vehicle itself and its occupancy. Table 1 gives the national average EI and reasonable upper and lower limits on urban automobile EI—twice as energy intensive and one-third as energy intensive as the national average (5, 7). Thus, a subcompact with three occupants (admittedly a rarity) is more efficient than the average transit system. Van pools (i.e., the use of 12-passenger vans as subscription buses for commuting to and from work) are also potentially more efficient than the average transit system.

Recent experience with dial-a-ride systems (8), on the other hand, shows disappointingly high energy consumption, primarily because of very low average occupancies.

Variations in automobile EI due to differences in occupancy related to trip purpose (5, 7, 9) are as follows:

Purpose	Occupancy	Energy Intensiveness
Work	1.2	6.0
Shop	1.7	4.3
Social-recreational	2.1	3.5
Average	1.6	4.5

Occupancies for urban automobile commuting are considerably lower than the urban average, and this yields an EI one-third higher than the average. Social-recreational trips, on the other hand, are relatively energy efficient because of their high occupancy. These figures do not include differential impacts on EI of cold start, congestion, vehicle type, or trip length. For example, EI for social-recreational trips is even lower than indicated because such trips are nearly 50 percent longer than the average automobile trip and are generally conducted during off-peak hours (10).

Urban transit EI varies considerably from city to city (8, 11, 12, 13, 14). The data given in Table 2 suggest that bus system efficiency improves with increasing city size, probably because of variations in population density. The EI (in megajoules per passenger-kilometer) of the bus system of some sample cities (8) follows:

City	EI	City	EI
Chicago	1.3	San Diego	1.6
Baltimore	1.4	Albuquerque	3.1

Presumably EI declines with increasing city size because of higher bus occupancies in the larger cities.

The Lindenwold (12) and BART (13) commuter rail services have very nearly equal EIs. In both cases, the EI given in Table 2 is that required to propel trains; heat, air-condition, and light trains; and operate stations. Chicago's (8, 14) urban rail systems are considerably more efficient than the BART and Lindenwold lines because the Chicago systems serve a more compact and dense area, are slower, and offer fewer amenities than either BART or Lindenwold.

The data below illustrate temporal and route variations in EI for a particular bus system (8).

Peak and Direction	EI as Percentage of Overall Average
a.m. peak	
Inbound	80
Outbound	77
Circumferential (with flow)	157
Circumferential (counter)	328
p.m. peak	
Inbound	88
Outbound	84
Circumferential (with flow)	176
Circumferential (counter)	260
Off-peak	
Radial	91
Circumferential	290

The average is 1.6 MJ/passenger-km (0.0024 Btu/passenger-mile). Efficiencies are highest during the morn-

Figure 4. Energy intensiveness of urban travel modes for 1950 to 1973.

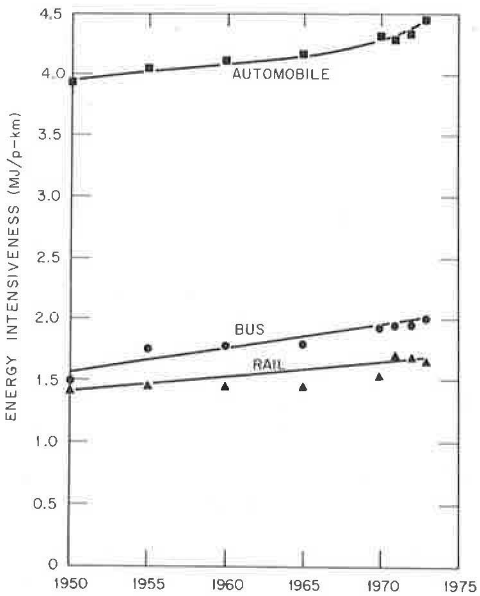


Figure 5. Urban travel energy use, 1950 to 1973.

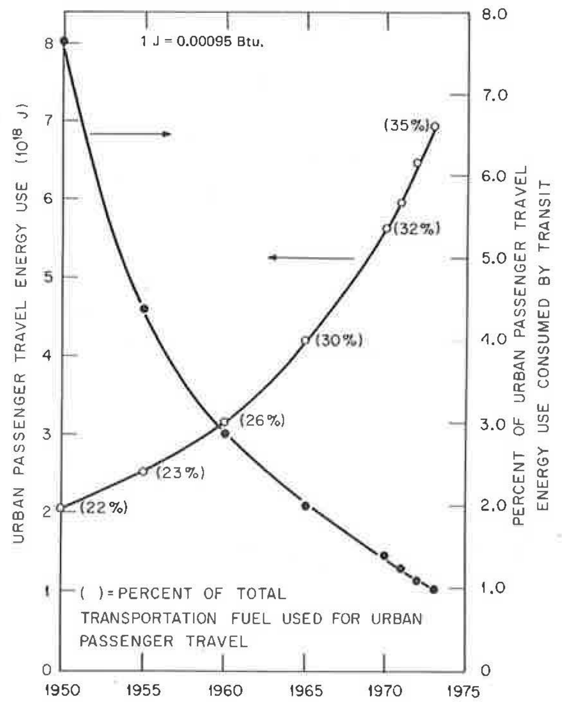


Table 1. Energy intensiveness of urban travel modes in 1973.

Mode	Passenger-Kilometers per Vehicle-Kilometer	Gasoline Consumption (km/m³)	Energy Intensiveness: Megajoules per Passenger-Kilometer	Energy Intensiveness: As Percentage of Automobile National Average
Automobile				
National average	1.6	4800	4.5	100
Gas hog	1	3800	9.1	200
Gas miser	3	8500	1.4	30
Public transit				
Bus	11.5	1600	2.0	45
Rail	24.5	1000	1.5	33
Dial-a-ride			4.9+	110+
Van pool	8	4300	1.0	23

Note: 1 km/m³ = 0.00235 mile/gal; 1 J/passenger-km = 0.0015 Btu/passenger-mile.

Table 2. Energy intensiveness of urban transit in 1974.

Transportation System	Population (millions)	Energy Intensiveness (MJ/passenger-km)
Chicago	7.09	
Bus		1.3
Elevated and subway		1.5
Illinois Central		1.3
Chicago and North Western		1.5
Philadelphia, Lindenwold	4.88	2.4
San Francisco, BART	3.13	2.2
Baltimore, bus	2.13	1.4
San Diego, bus	1.44	1.6
Albuquerque, bus	0.36	3.1

Note: 1 J/passenger-km = 0.00152 Btu/passenger-mile.

ing and evening peaks, especially for buses that operate with the prevailing traffic flows. Surprisingly, the base day (off-peak) radial bus routes are also relatively energy efficient. The least efficient are circumferential, counterflow routes; they show an EI four times higher than that for peak-period radial routes. These variations in EI differ sharply from those for automobile travel. Although peak-period bus service is relatively efficient, automobile commutation is quite inefficient.

The figures in Table 3 do not include variations in bus fuel economy due to differences among routes in congestion, stopping frequencies, and average speed. These figures include only variations in bus load factor.

ENERGY CONSERVATION THROUGH IMPROVED TRANSIT

Although transit is considerably more energy efficient than automobiles are, at present transit carries such a small fraction of total urban passenger travel that its short-term potential contribution to energy conservation is slight. The data given in Table 3 from three recent transit demonstrations (12, 15) suggest that the energy impacts of transit fare reductions and service improvements (expanded area coverage, reduced headways) are almost negligible.

There are several reasons for the slight energy effects shown here. First, transit accounts for a tiny fraction of urban travel and an even smaller fraction of the urban travel energy budget. Thus sizable increases in transit traffic will have only slight impacts on total urban traffic and energy use. Second, although reduced fares and improved service will increase ridership, the experience cited above suggests that less than half the

Table 3. Energy conservation impacts of transit improvements.

City and System	Other Data	Estimated Savings as Percentage of Regional Transportation Fuel Use
Atlanta, regional bus	Fare reduction from 40 cents to 15 cents; 28 percent increase in ridership; 31 to 35 million bus-km/year	0.5
Washington, D.C., bus corridor service	18-km busway in median of Shirley Highway; 1900 to 11 500 passengers/day in 5 years; 40 percent of riders were automobile drivers; 30 percent access bus by automobile	0.1
Philadelphia, rail corridor service	Lindenwold Line; 30 000 riders/day; 28 percent were automobile drivers; 90 percent access line by automobile	0

Note: 1 km = 0.62 mile.

Table 4. Energy impacts of transportation conservation measures.

Measure	Estimated 1980 Energy Savings (EJ)
Increase new-car fuel economy by 40 percent between 1974 and 1980	1.49
Increase automobile occupancy for commutation by 33 percent in 1980 (car pooling)	0.95
Double fraction of urban travel carried by public transit from 2.5 percent in 1973 to 5.0 percent in 1980	0.12

Note: 1 J = 0.000948 Btu.

increase comes from former automobile drivers. The remainder are automobile passengers, walkers, users of other transit systems, and people who formerly stayed home. Only shifts from automobile driver to transit reduce overall energy use. Third, expanded route coverage and reduced headways lower system load factors; this increases EI and energy use. Fourth, automobiles are often used (kiss-and-ride, park-and-ride) to gain access to transit systems; this automobile energy use must be subtracted from the energy savings due to the shift from automobile to transit.

The major conclusion from Table 3 is that transit improvements alone offer little hope of large energy savings. Improving public transit (time, costs, service characteristics) can save energy only if the increased transit ridership comes primarily from automobile drivers. Increasing transit patronage by attracting people from nonautomobile modes (other transit systems, walking, bicycling, previously foregone travel) will probably increase urban passenger energy use.

Thus, saving energy by increasing transit use requires both the carrot and the stick. The carrot is used to induce people to travel via transit, and the stick is used to force people out of their cars. The following policies provide transit incentives and automobile disincentives to shift travel from automobiles to transit:

Transit Incentives	Automobile Disincentives
Time and service	Time
Exclusive bus lanes	Automobile-free zones
Priority traffic signals	Reduced freeway lanes
Improved scheduling	
Reduced headways	
Improved routing	
Paratransit	
Park and ride	
Costs	Costs
Reduced fares	Gasoline taxes
Revised fare structure	Parking taxes
Employer-subsidized fares	Highway tolls

Even if transit improvements and automobile disincentives are effective, transit is unlikely to provide substantial energy savings during the next decade (Table 4). [The data given in Table 4 were calculated relative to a base of 1.9 trillion vehicle-km (1.1 trillion vehicle-miles) of automobile travel in 1980, 6000 km/m^3 (14 miles/gal) fuel economy, 1.6 passenger-km/vehicle-km urban vehicle occupancy, 1.2 passenger-km/vehicle-km commutation occupancy, urban travel of 55 percent of total automobile travel, and commutation of 34 percent of total automobile travel.] The potential energy savings are limited by the small size of the present transit plant and the small fraction of urban travel moved by transit. Doubling the fraction of urban travelers carried by transit from 2.5 percent in 1973 to 5.0 percent in 1980 would require 100 000 new buses during this 7-year period, compared with the 1973 fleet of 46 000 buses (6).

If we assume that funds can be found to finance the purchase of these new buses; that drivers, mechanics, and managers can be trained during this period; that ridership will increase; and that the new riders will have been automobile drivers, the energy savings for 1980 will be about 0.12 EJ (0.11 quadrillion Btu) (5, 6, 7). Although this is hardly a trivial amount of oil, it is much less than could be saved with other measures.

For example, increasing new-car fuel economy by 40 percent between 1974 and 1980 would save about 1.49 EJ (1.41 quadrillion Btu), more than 10 times as much as transit improvements might save. Similarly, increasing car pooling sufficiently to raise urban automobile commuting load factors from 1.2 to 1.6 passenger-km/vehicle-km would save 0.95 EJ (0.90 quadrillion Btu) in 1980 (9, 10), seven times as much as transit improvements might save. Thus transit does not offer large energy saving opportunities in the short term. However, the long-term potential may be substantial because of the high energy efficiency of transit.

Although the short-term energy conservation potential of increased public transit use is slight, this does not mean that transit improvement programs should be abandoned. Changes in urban travel patterns are likely to require at least a decade because of long lags associated with changes in land use patterns, automobile ownership, and individual attitudes toward public transportation. Thus, unless transit improvement projects are undertaken now, the long-term potential benefits of transit will never be realized. Also, transit offers other benefits besides reduced energy use such as less congestion during peak periods, fewer traffic fatalities, and increased mobility for those with limited access to automobiles. Finally, combining transit improvements with automobile disincentives provides a transportation alternative to those dislodged from their automobiles.

CONCLUSIONS

The future of urban public transit in the United States is uncertain because of major changes in several of the underlying forces that determine urban passenger travel patterns: fuel prices, automobile purchase costs, automotive emissions and safety requirements, federal support for transit and for urban highway construction, and changing attitudes toward automobiles and energy conservation. The net impacts of these forces on urban travel, urban energy use, and transit ridership are unclear.

However, it is clear that transit cannot contribute substantially to the reduction of petroleum imports during the next 5 (and probably not even the next 10) years. This is so because of the extremely low base from which transit operates today: less than 3 percent of urban passenger travel. Even in the long term (beyond 1985), transit improvements can save significant quantities of petroleum only if they are coupled with automobile disincentives.

REFERENCES

1. U.S. Energy Use Down in 1974 After Two Decades of Increases. Bureau of Mines, U.S. Department of the Interior, news release, April 3, 1975.
2. Project Independence Report. Federal Energy Administration, Nov. 1974.
3. W. G. Dupree, Jr., and J. A. West. United States Energy Through the Year 2000. U.S. Department of the Interior, Dec. 1972.
4. Jack Faucett Associates. Project Independence and Energy Conservation: Transportation Sectors. Federal Energy Administration, Project Independence Blueprint Final Task Force Rept., Nov. 1974.
5. 1973 Highway Statistics. Federal Highway Administration, U.S. Department of Transportation, 1974.
6. 1974-1975 Transit Fact Book. American Public Transit Association, March 1975.
7. 1974 National Transportation Report. U.S. Department of Transportation, Dec. 1974.
8. The Potential for Transit as an Energy Saving Option. R. H. Pratt Associates, draft final rept., Nov. 1975.
9. Nationwide Personal Transportation Study—Report 1: Automobile Occupancy. Federal Highway Administration, U.S. Department of Transportation, April 1972.
10. Nationwide Personal Transportation Study—Report 7: Household Travel in the United States. Federal Highway Administration, U.S. Department of Transportation, Dec. 1972.
11. Statistical Abstract of the United States: 1974. Bureau of the Census, U.S. Department of Commerce, July 1974.
12. D. Boyce et al. Impact of Rapid Transit on Fuel Consumption and Cost for the Journey to Work. Univ. of Pennsylvania, Philadelphia, draft final rept., June 1975.
13. T. J. Healy. Energy Requirements of the BART System. Univ. of Santa Clara, Calif., Nov. 1973.
14. E. W. Walbridge. Energy Consumption and Costs for Suburban Commuter Diesel Trains. Univ. of Illinois at Chicago Circle, Aug. 1974.
15. J. P. Curry. Case Studies of Transit Energy and Air Pollution Impacts. De Leuw, Cather and Co., May 1976.

Relationships Between Transportation Energy Consumption and Urban Structure: Results of Simulation Studies

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If the urban transportation planning process is to deal with the problem of providing transportation in a future characterized by fuel shortages, a long-term perspective is needed. The study described documents the relationships between energy consumption in urban passenger travel and the spatial structure of cities, which is an important determinant of travel demand. Experiments were conducted with 37 hypothetical cities in which combinations of urban form, transport network, and resulting travel patterns were varied in order to identify structural characteristics contributing to increased energy consumption. Preliminary findings suggest that structural changes in transportation and land use patterns can produce significant reductions in energy consumption for urban passenger travel.

The 1974 petroleum crisis illustrated the possible future of energy in the United States: reduced fuel availability and increased fuel price. Among responses considered by urban travelers, the private sector, and government were reductions in trip making, increased use of public transport, car pooling, increased preferences for smaller, more economical automobiles, fuel price increases, and gasoline rationing. Some of these were implemented at the peak of the gasoline shortage. Yet, such responses represent only marginal improvements in the energy efficiency of urban transportation (1).

High prices and restrictions in fuel supplies may be common in the future. Thus, it is appropriate to explore alternative strategies for increasing energy efficiency of travel in urban areas.

Fuel shortages strongly impacted urban passenger transportation because, in many cities and for many types of trips, there is no alternative to the automobile. The spatial structure of cities and their transportation networks has shifted from a strong transit orientation to a strong automobile orientation and is characterized by extensive land use patterns and freeway networks. Transit has declined, as much as for any other reason, because it is not economically feasible to serve such patterns with public modes.

To respond to a long-run problem with a long-run solution depends on an understanding of the fundamental relationships among urban structure, transportation networks, and energy consumption in passenger travel. The policy options considered during the recent fuel shortage were short term. At present, with gasoline readily available, little public concern is expressed about options considered in 1974. Research and development have, to a large extent, focused on technology rather than on changes in policies and the spatial structure of activities.

Solutions entailing intervention in the land market received little interest because of the implications of such options for a free-enterprise land economy. Yet, part of the disinterest in the relationships between land use and energy consumption in transportation stems from the fact that little is known about these phenomena; and without such knowledge, it is unlikely that such policy options will receive appropriate consideration.

The structure of urban land use and transportation networks may have a significant effect on energy consumption in urban passenger travel. Understanding the magnitude and direction of these effects may provide guidance for future long-term policy development. The availability of such information may also provide a basis for adopting policies that now run counter to public preferences but that may provide future benefits.

APPROACH

Several investigations (2, 3, 4) have significantly increased our understanding of the connections between urban travel and spatial structure; however, little guidance for formulating planning policies oriented toward energy-related issues has emerged. Two strategies for conducting a policy-oriented investigation are considered here. One is to gather data on land use patterns and travel behavior from current metropolitan transportation planning studies; however, this demands great expenditures of time and effort to collect and manipulate such data sets.

Another possibility is to approach the problem abstractly by using normative models to allocate persons to homesites and worksites to optimize a travel-related objective. Such approaches characterize the works of

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Dantzig and Saaty (5) and Hemmens (6), which are based on the assumption of aggregate optimizing behavior. Yet, it is unlikely that persons behave in such a manner as to achieve a social optimum.

Difficulties inherent in the empirical approach and uncertainties of the normative approach suggest a compromise: Data from an existing city are used along with mathematical models to simulate travel behavior in a series of hypothetical cities. Such an approach may be more robust than the others in that many elements in the urban spatial structure can be varied to determine the effects on energy consumption.

Several previous efforts (7, 8, 9) used similar approaches to the problem of relating spatial patterns to travel patterns; each centered on the exogenous specification of residential and employment sites and then applied a gravity trip distribution model to distribute work trips over the network.

Although those studies were useful in investigating the travel requirements of various urban structures, each contains one troubling aspect: Preselecting activity sites (residential, retail, and employment centers) before the travel modeling process is initiated can create biased results. Exogenous allocation of activities to sites can portray an unrealistic location behavior of residents and workers of each city. It would be desirable to lessen the possibility of introducing bias by reducing the number of exogenous attributes.

Can the interaction between land use and transportation in a hypothetical city be adequately described without prejudicing the study results by overspecifying the behavior of its residents? It is this question that this study addresses.

This study (a) chooses a representative city in which aggregate travel behavior has been observed and documented; (b) resettles the residents of that city into different patterns and analyzes the travel and accessibility characteristics and the transportation energy requirements arising from changing the spatial variables (shape, form, density patterns); and (c) identifies those factors that most strongly affect transport energy requirements and activity accessibility.

In the experimental design, values of the activity variables (population, employment, and so on) must be consistent across all designs so that the travel required to connect activities within each design can be compared and the effects of changing the media (such as the highway network) through which these activities interact can be assessed. Activity variables, therefore, are fixed in quantity but not by location for all designs; interaction variables can differ across the designs.

Fixed city attributes were taken from an existing city to ensure that the results would be well grounded. These attributes include population, employment by category, labor force participation rate, interzonal impedance (friction) factors by trip type, and trip rates per capita by trip type. Impedance factors represent the propensity to make trips of various lengths and vary between cities. Therefore, these factors belong to the set of spatial variables and should not be fixed across different spatial patterns. The same is true of trip rates per capita by trip type, which also depend on the spatial arrangement of activities and the transport system (10). However, there is no theory that can be used to account for the variation; thus, a single set of factors was applied for each trip purpose across all urban designs. Similarly, trip generation was assumed to depend solely on distance from the city center, a surrogate reflecting the effects of automobile ownership, income, and family size.

Construction of land use designs for alternative cities was accomplished with a Lowry type of land use model (11), which applies the attributes to interaction variables specified in the context of a given hypothetical city. The model was used to ensure that the design of the hypothetical cities was realistic. The interaction variables included urban form (density patterns and shape), network characteristics (highway speeds, transit routes), transport technologies (automobile, automobile-transit, transit), and modal split by trip type. A modal-choice model was not used; transit share was prespecified for each design because including a modal-choice model in the simulation package would have greatly increased computational requirements.

Given the location of basic (usually manufacturing) employment and the nature of the transportation network, the Lowry type of model allocates residential and retail activities to specific locations subject to constraints on available land, residential densities, and the minimum feasible size of retail employment centers (11). in the process, 24-h home-based trip types are generated and distributed (change-mode, serve-passenger, and social trips do not involve employment at the attraction end). The simulation of social and non-home-based trip making is accomplished by simple trip generation and gravity models (12). Change-mode trips are not considered; nor are through trips, external trips, or truck trips. Trips are allocated a priori to modes and assigned via a free-assignment method.

The Lowry model simultaneously estimates service trips and the allocation of workers serving such trips to the service sites. Service trips were separated into long and short trips by observing that, in the data set used (13), personal business, recreational, school, and durable-goods shopping trips on the average exceeded 6 min in length, whereas convenience shopping trips averaged about 5 min. This is because location behavior of service establishments to which the former trip types are made is less dependent on nearness to the clientele than that of establishments to which convenience shopping trips are made. Therefore, home-based service trips were categorized either as type S (shop location behavior sensitive to location of clientele) or type N (shop location behavior not sensitive to location of clientele). There are then five trip purposes: home-based work, service (type N or S), social, and non-home-based.

Trip tables for each purpose are computed either internal to the model (for the first three types) or through postprocessing by using gravity models (for social and non-home-based). Model calibration is obviated by using a given set of friction factors for each trip purpose. Successive iteration of the Lowry model gives rise to the allocation of the activities of interest (residential population and service employment for each service category). Products include total population and employment (by category) per zone, work and nonwork trip tables, and vehicle flows on the network.

Modal energy requirements are assessed by using data on automobile and bus fuel consumption as a function of traffic conditions (14) and Davis' formulas for frictional resistances of electric transit vehicles as a function of vehicle type and speed (15).

EXPERIMENTAL DESIGN

Three basic urban shapes were adopted as paradigms out of which emerged the hypothetical cities studied; comparisons were made between the cities to discover factors determining the relative amounts of transportation energy consumed and accessibility to activities. Experiments were conducted sequentially so that information from preceding experiments could influence the selection of subsequent experiments.

The three basic shapes selected for study are shown in Figure 1. The concentric-ring shape (7) has a total land area (381.4 km^2 or 147.25 $mile^2$) approximately equal to that of the study area from which much of the data for this research were collected (13). The linear shape (8) represents city forms having low transportation capital costs, good proximity to activities, and a compact land use pattern (25.2 km^2 or 9.75 $mile^2$). The polynucleated shape is attractive from the point of view of accessible open space but incorporates nuclei of fairly high density (a total developed area of only 15.8 km^2 or 6.1 $mile^2$) and neighborhood and community facilities within walking distance. Thirty-five experiments were conducted by using these three shapes. Two additional experiments were conducted by using a pure cruciform design that combines the best features of the linear and polynucleated shapes: physical separation of neighborhoods from commercial and industrial areas yet compact land use (26.5 km^2 or 10.25 $mile^2$ of developed land) spread out to provide good accessibility to open space.

Zone size in each urban shape was determined by (a) the need to capture as much interzonal vehicle traffic as possible and (b) the need to minimize the total number of zones, inasmuch as computation time increases geometrically with the number of zones. Except in the concentric ring shape, where intrazonal traffic in zones 26 to 100 traveled by automobile, all intrazonal transactions are assumed to be on foot.

Automobile, conventional bus, and rail rapid transit were selected for study, and specific combinations of the modes used in each experiment are given in Table 1.

Except in the polynucleated shape, automobiles and buses traveled on a grid network of links connecting zone centroids. In experiments using the polynucleated shape, the streets were coincident with the interzonal radial routes shown in Figure 1. In those experiments using the ring shape, a freeway network was provided. Rapid transit routes are shown for each of the remaining city types in Figure 1 and, with the exception of six experiments (28, 32, 33, 34, 35, 37), they were assumed to be fixed-rail systems (12). In the remaining experiments, a bus rapid system was assumed to operate on separate guideways.

RESULTS

Transportation energy and regional accessibility to population for each experiment are shown in Figure 2. Total energy refers to that energy required for daily person travel from home to work, to service type N, to service type S, for social purposes, and one-half of the total daily non-home-based travel. The total energy required for all person travel (except serve-passenger and change-mode trips) can be estimated by doubling the amounts shown in Figure 2. Zonal accessibility is measured by using the denominator of the gravity trip distribution equation. Because the original study (12) showed that accessibility measures based on different activities were highly correlated, accessibility to population was selected as the representative measure.

Figure 2 shows wide variation in energy requirements for differing urban structures. Structures with sprawling land use patterns have larger energy requirements than relatively compact structures. For example, the first five experiments have energy requirements 9 to 10 times that of the least energy-intensive structure (experiment 20). Those five structures have the greatest dispersion of population and employment—measured by the second moments of population and employment—of all cities examined; experiment 20 is a more compact pattern.

Cities with compact land use patterns occupy energy-efficient locations in the space of feasible structures. For example, the linear forms (experiments 24 to 29), the cruciforms (experiments 30 and 31), and the polynucleated forms (experiments 32 to 37) occupy the lower left portion of the trade-off space and represent cities with low energy costs but concomitant low levels of regional accessibility to population.

Cities using only the automobile have much larger energy requirements than cities using transit. For example, experiments 1 to 13, 22 to 25, and 36 have only the automobile. Only one city (experiment 14) having an automobile-transit network exceeds the energy value of 2110 GJ (2 000 000 000 Btu), and only one city (experiment 25) having the automobile as its sole means of transport has a lower energy requirement. Hence, 2110 GJ is, in these experiments, the threshold above which nearly all of the automobile-oriented energy costs lie and below which almost all of the energy requirements of automobile-transit cities are found.

Structures with the same shape have varying energy requirements and accessibility based on their density patterns and the relative importance of the automobile. For example, experiments 1 to 5 and 9 to 13 represent cities with large land requirements (381.4 km^2 or 147.25 $mile^2$), but the first five are sprawled patterns, and experiments 1 to 5 and 9 to 13 represent cities having more concentrated activities. Experiments 1 to 5 and 9 to 13 might be visualized as lying on a line from upper left to lower right in which movement downward and to the right is accompanied by increasing concentrations of activities. When transit is introduced, the energy requirements fall, but accessibility is decreased as well. For example, experiments 14 to 21 represent the same city as experiment 13 but with differing levels of transit service and modal splits. For the same relative transit service (ubiquitous service and a frequency of 10 buses per hour), an increase in transit share brings about a drop in both energy required for accomplishing that travel and accessibility. The latter is the result of longer travel time by transit than by automobile.

Several structural components affect energy requirements and accessibility patterns, explaining most of the variation in Figure 2. These are urban form, transportation level of service, and role of transit in the transportation system. Four distinct dimensions of urban form are apparent contributing factors: shape, geographic extent, population concentration about the centroid, and employment concentration about the centroid.

The concentric ring is the most energy-intensive city type; it also provides the highest levels of accessibility to population and employment. Of 18 automobile-only experiments (Figure 2), 13 are associated with the group to the upper right (numbers 1 to 13) and have the basic concentric ring shape. Experiments 24 and 25, linear forms, appear more nearly central in the space. Experiment 36 is highly energy-intensive in spite of its low level of accessibility. Thus, it appears that, where automobiles are used exclusively, the concentric-ring city provides best accessibility, followed by the linear structures; the cruciform and polynucleated shapes offer low accessibility to population, though within-nuclei accessibility may be good.

Expansiveness of land use was measured by developed land area in square kilometers. This variable seems to have a clear, though imprecise, effect on energy consumption. When total energy is related to developed land area (Figure 3), a clear upward trend in energy is detected as the amount of land area in the city increases. This suggests that expansive land use patterns characterized by low density consume larger amounts of transportation energy than do compact urban structures. However, developed area does not by itself determine the absolute level of energy consumption. Indeed, among the most land-intensive cities, experiment 22 exhibits a level of energy consumption not greatly different from that of experiment 14, which is far less land intensive.

Table 1. Specification of experiments.

	Urban Form							
Experiment	Shape	Area (km²)	Location of Basic Employment	Population Distribution	Service Employment Distribution	Mode	Transit (%)	Network Level of Service (km/h)
1	Sprawled concentric ring	381.4	Central 25 zones of ring	Sprawled, peaks around freeway, not in zones of basic employment	Sprawled, peaks around freeway	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
2	Sprawled concentric ring	381.4	Central 25 zones of ring	Sprawled, peaks around freeway, not in zones of basic employment	Sprawled, peaks around freeway	Automobile only	0	38.6 on arterials, 72.4 on freeway
3	Sprawled concentric ring	381.4	Central 25 zones of ring	Sprawled, peaks around freeway, includes zones of basic employment	Sprawled, peaks around freeway	Automobile only	0	38.6 on arterials, 72.4 on freeway
4	Sprawled concentric ring	381.4	Two antipodal zones adjacent to central 25 zones	Sprawled, peaks around freeway, not in zones of basic employment	Sprawled, peaks around freeway	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
5	Sprawled concentric ring	381.4	Uniform through first and second suburban rings	Sprawled, peaks around freeway, includes zones of basic employment	Sprawled, peaks around freeway	Automobile only	0	38.6 on arterials, 72.4 on freeway
6	Compact spread concentric ring	52.4	Uniform through all zones	Uniform through all zones	Uniform through all zones	Automobile only	0	38.6 on arterials, no freeway
7	Extensive spread concentric ring	233.7	Uniform through all zones	Uniform through all zones	Uniform through all zones	Automobile only	0	38.6 on arterials, no freeway
8	Extensive spread concentric ring	233.7	Uniform through all zones	Uniform through all zones	Uniform through all zones	Automobile only	0	38.6 on arterials, 72.4 on freeway
9	Extensive concentrated concentric ring	381.4	Uniform through first and second suburban rings	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
10	Extensive concentrated concentric ring	381.4	Uniform through first suburban ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
11	Extensive concentrated concentric ring	381.4	Central 25 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile only	0	38.6 on arterials, 72.4 on freeway
12	Extensive concentrated concentric ring	381.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
13	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile only	0	19.6 in central area, 38.6 on other arterials, 72.4 on freeway
14	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	10	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
15	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	10[a]	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
16	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peak in central zones	Automobile, conventional bus	36	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
17	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	33	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
18	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	43	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
19	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	38	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
20	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	66	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in central area, 24 elsewhere
21	Compact concentrated concentric ring	109.4	Central 9 zones of ring	Concentrated with peak in central zones	Concentrated with sharp peaks in central zones	Automobile, conventional bus	62	Automobile: 19.6 in central area, 38.6 on other arterials, 72.4 on freeway Bus: 19.6 in contral area, 24 elsewhere
22	Quasi-cruciform	381.4	Cruciform in central zones	Concentrated with peaks adjacent to basic employment zones	Concentrated with peaks adjacent to basic employment zones	Automobile only	0	38.6 on arterials, 72.4 on freeway
23	Quasi-linear	233.7	Four corner zones of circumferential freeway	Uniform through two rings adjacent to circumferential freeway	Within and adjacent to freeway corridor, not in basic employment zones	Automobile only	0	38.6 on arterials, 72.4 on freeway
24	Pure linear	25.3	Two zones, each end of spine	Uniform through zones parallel and adjacent to spine	All zones, peaks in spinal zones	Automobile only	0	38.6 at the spine, 19.6 elsewhere
25	Pure linear	25.3	Two zones, each end of spine	Uniform through zones parallel and adjacent to spine	All zones, peaks in spinal zones	Automobile only	0	38.6 at the spine, 28.5 elsewhere

Table 1. (continued).

Experiment	Urban Form: Shape	Urban Form: Area (km^2)	Location of Basic Employment	Population Distribution	Service Employment Distribution	Mode	Transit (%)	Network Level of Service (km/h)
26	Pure linear	25.3	Two zones, each end of spine	Uniform through zones parallel and adjacent to spine	All zones, peaks in spinal zones	Automobile, conventional bus, rail rapid transit	50	Automobile: 38.6 at the spine, 19.6 elsewhere Bus: 19.6 Rail: 36.2
27	Pure linear	25.3	Two zones, each end of spine	Uniform through zones parallel and adjacent to spine	All zones, peaks in spinal zones	Automobile, conventional bus, rail rapid transit	50	Automobile: 38.6 at the spine, 19.6 elsewhere Bus: 19.6 Rail: 36.2
28	Pure linear	25.3	Two zones, each end of spine	Uniform through zones parallel and adjacent to spine	All zones, peaks in spinal zones	Automobile, conventional bus, rail rapid transit	50	Automobile: 38.6 at the spine, 19.6 elsewhere Bus: 19.6 Rail: 36.2
29	Pure linear	25.3	4 nonadjacent zones along spine	Uniform in parallel zones, plus high-density zones on spine	All zones, peaks in spinal zones	Automobile, conventional bus, rail rapid transit	50	Automobile: 38.6 at the spine, 19.6 elsewhere Bus: 19.6 Rail: 36.2
30	Pure cruciform	26.5	Central 5 zones	Outlying zones	All zones except central 5 zones	Automobile, conventional bus, rail rapid transit	90	Automobile: 19.6 at the spine, 38.6 elsewhere Bus: 19.6 Rail: 80.5 top speed
31	Pure cruciform	26.5	Central 5 zones	Outlying zones	All zones except central 5 zones	Automobile, conventional bus, rail rapid transit	50	Automobile: 19.6 at the spine, 38.6 elsewhere Bus: 19.6 Rail: 80.5 top speed
32	Polynucleated	11.7	Central and 4 outlying zones	Uniform in all except central and 4 outlying zones	All zones except 4 outlying basic employment zones	Automobile, conventional bus	50	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed
33	Polynucleated	11.7	Central and 4 adjacent zones	Uniform in all except central and 4 adjacent zones	All zones except 4 outlying basic employment zones	Automobile, conventional bus	50	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed
34	Polynucleated	11.7	Central zone	Uniform in all except central and 4 adjacent zones	All zones except central zone	Automobile, conventional bus	50	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed
35	Polynucleated	11.7	Central zone	Uniform in all except central and 4 adjacent zones	All zones except central zone	Automobile, conventional bus	50	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed
36	Polynucleated	11.7	Central zone	Uniform in all except central and 4 adjacent zones	All zones except central zone	Automobile only	0	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed
37	Polynucleated	11.7	Central zone	Uniform in all except central zone	All zones	Automobile, conventional bus	50	Automobile: 19.6 in central area, 38.6 elsewhere except 56.3 at circumferential beltway Bus: 72.4 top speed

Note: 1 km^2 = 0.38 $mile^2$; 1 km/h = 0.62 mph.
[a]Automobile occupancy increased by 50 percent for each trip purpose.

This is because population and service employment are concentrated around the cruciform distribution of basic employment in experiment 22, and trip lengths to work and to shop are relatively short.

The automobile-only experiments in Figure 2 (numbers 1 to 5, 8 to 13, 22) that have common urban form exhibit a strong negative correlation between regional accessibility to population and total energy consumption. This correlation (-0.918), the strong positive correlation (0.985) between the second moment of population and total energy, and the strong negative correlation (-0.905) between the second moment of population and accessibility suggest that trade-offs between the 12 points can be accounted for by the extent to which population is concentrated about the city centroid.

The effects of increasing population concentration is shown in Figure 4, where vectors represent direction and magnitude of change. Experiments 2 and 3 represent the same city, except that residences are absent from the central 25 zones of experiment 2, whereas in experiment 3 residences are in all zones except number 1. Experiment 11 assumed the same city as in number 3, except for a more intense concentration of residences about the central 25 zones. Experiments 5 and 9 differ in that 5 is a sprawled configuration, and activities in 9 are confined to the central 41 zones. Experiment 13 differs from 12 solely in that the developed area is smaller (109.4 km^2 or 42.25 $mile^2$ versus 381.4 km^2 or 147.25 $mile^2$).

The elasticities of energy and accessibility with respect to population concentration (measured by the second moment) are less than one, suggesting that a large change in the concentration of residential activities is required to bring about a change in either dimension.

Figure 5 shows that concentration of employment (measured by the second moment of employment) has an important effect on energy consumed in travel. In experiment 5, basic employment is located in two suburban

Figure 1. Urban shapes: (a) concentric, (b) pure linear, (c) polynucleated, and (d) pure cruciform.

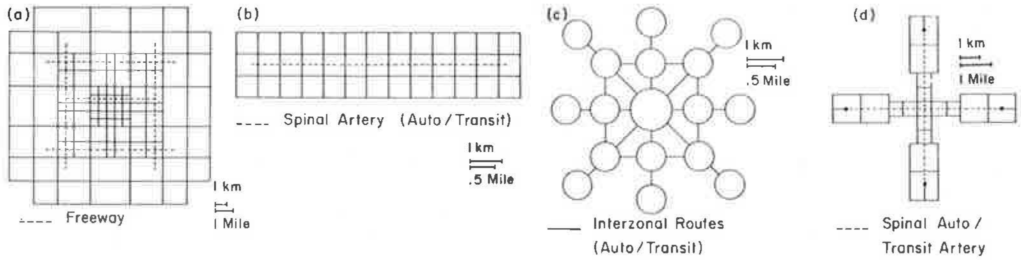


Figure 2. Total energy and regional accessibility to population for each experiment.

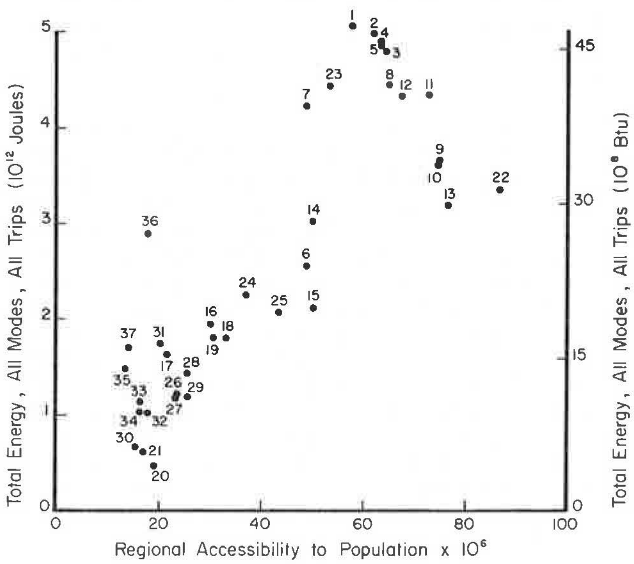


Figure 3. Total energy for all modes and all trips as a function of geographic extent.

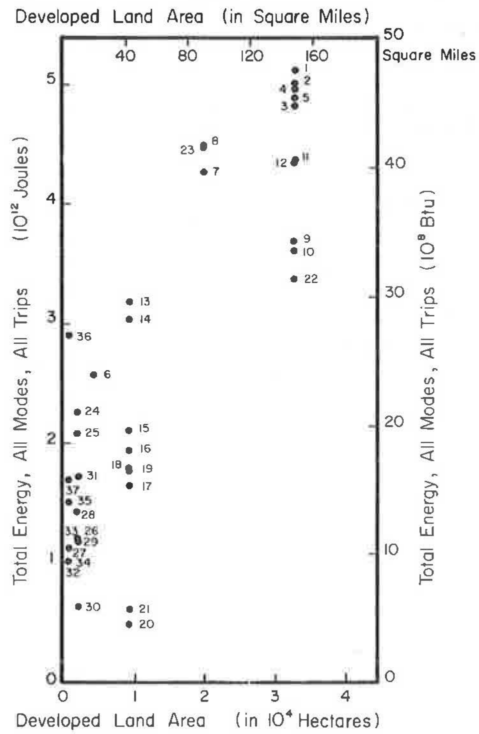


Figure 4. Effect of increasing population concentration on energy and accessibility in seven automobile-only experiments.

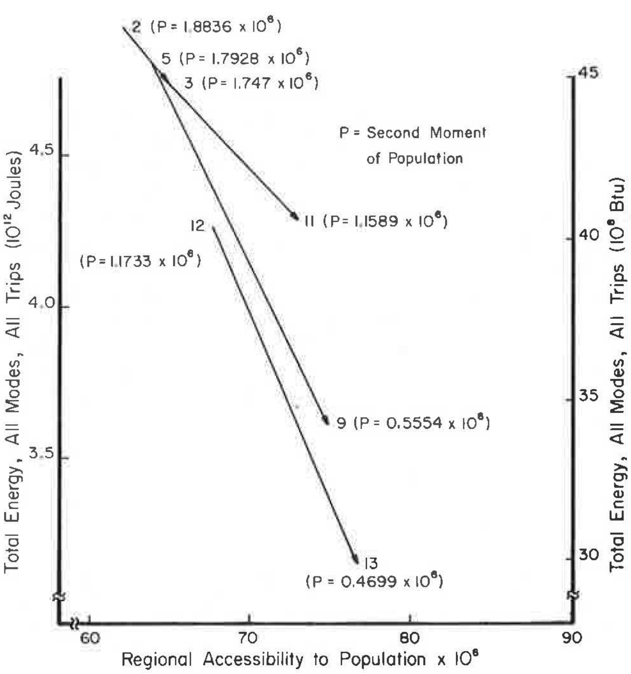
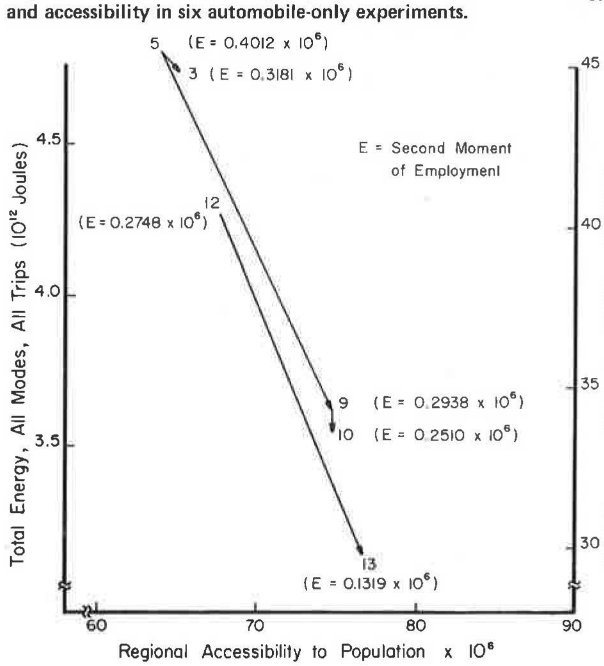


Figure 5. Effects of increasing employment concentration on energy and accessibility in six automobile-only experiments.

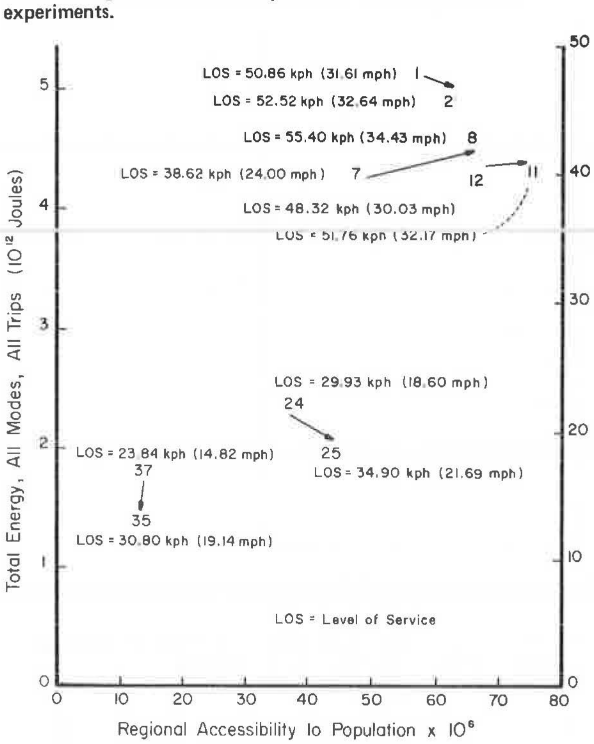


rings whereas in experiment 3 employment is in the central 25 zones. Basic employment distribution in experiment 9 is the same as that in number 5, but service employment is concentrated about the most central zone. Basic employment is tightened about the central zones in experiment 10 (located in one ring instead of two), but location of service employment remains largely unchanged. Because experiment 13 is a compact version of experiment 12, employment distribution is more compact as well.

The elasticities of energy and accessibility with respect to concentration of employment are not great. For the experiments examined, energy efficiency might be better served by concentrating population, with less concern for centralization of employment.

Network level of service, measured by average trip speed, affects both energy consumption and accessibility to population. Figure 6 shows the results of 10 experiments wherein, in all but one case, an increase in level of service effects an increase in the level of regional accessibility. This is not the case in experiments 35 and 37, both polynucleated; employment is concentrated in the central zone in 37, and population is tightly concentrated about that zone. This means congestion on routes to the central zone; hence, level of service suffers, but accessibility is heightened by the concentration.

Figure 6. Effects on energy and accessibility of increasing levels of service in eight automobile-only and two automobile-transit experiments.

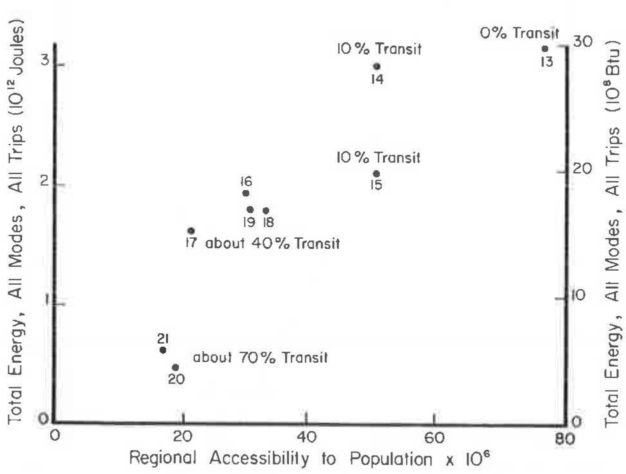


The effect of increasing level of service depends on degree of congestion in the central area; the service improvements that alleviate congestion decrease the energy consumed as in 24 and 25 or 1 and 2; an increase in level of service where there is little congestion can mean higher energy consumption. The U-shaped automobile-energy versus speed function (14) explains what is observed.

A shift in modal share to transit results in energy savings because of the lower joules per passenger-kilometer consumption of transit vehicles with high load factors, compared with that for automobiles. Figure 7 shows energy savings and accessibility values at differing levels of transit use. Each experiment represents a concentric-ring city with basic employment in the central nine zones and service employment concentrated about them. Experiment 13 is an automobile-only city, while, in experiment 14, 10 percent of all trips are by transit. Experiment 15 was identical to 14, except for increased levels of automobile occupancy. Modal split levels for experiments 16 to 19 are around 40 percent transit, and the differences between them arise from differences in bus routing schemes and operating frequencies. Experiments 20 and 21 use transit to a greater extent (70 percent of all interzonal trips), and the difference between them is due to frequency of service (10 buses/h in 21 versus 6 buses/h in 20).

Tremendous energy savings accrue from greater transit patronage. However, and perhaps equally important, accessibility decreases as well because of time penalties paid by transit travelers.

Figure 7. Energy and accessibility as functions of different levels of preference for transit modes in nine concentric-ring cities.



CONCLUSION

This research suggests the desirability of controlling the spread of cities and of channeling development into higher density, nucleated forms. Whereas this is an objective for existing cities and a design principle for new towns, it may also serve in the short term as a policy on rezoning requests and building permits and as a criterion for construction of increments to urban infrastructure.

There is a need to improve traffic operations to reduce the congestion, yet this should be done without building new high-speed facilities, which are likely to be self-defeating (because they encourage horizontal spread of cities) unless strict land use controls are applied.

Moving more people by transit is a promising energy-minimizing strategy; but, because transit solutions reduce accessibility, better ways of providing service must be found if people are to use transit by choice.

Finally, there is a need to explore the behavioral assumptions inherent in both the models used in this study and the urban forms that have been analyzed. If the assumptions are wrong, predicted futures may not be so desirable as expected. More likely, however, if the behavior required to bring about one of the desired urban forms is significantly different from that that would occur otherwise, society will not permit that policy option to be implemented.

REFERENCES

1. J. L. Schofer and R. L. Peskin. Immediate Impact of Gasoline Shortages on Urban Travel Behavior. Northwestern Univ., Evanston, Ill., Nov. 1974.
2. M. Schneider. Access and Urban Development. HRB, Special Rept. 97, 1968, pp. 164-177.
3. L. Wingo, Jr. Transportation and Urban Land. Resources for the Future, Washington, D.C., 1961.
4. W. Alonso. Location and Land Use. Harvard Univ. Press, Cambridge, Mass., 1964.
5. G. Dantzig and T. Saaty. Compact City. W. H. Freeman and Co., San Francisco, 1973.
6. G. Hemmens. Experiments in Urban Form and Structure. HRB, Highway Research Record 207, 1967, pp. 32-41.
7. H. Levinson and K. Roberts. System Configurations in Urban Transportation Planning. HRB, Highway Research Record 64, 1965, pp. 71-83.
8. G. Jamieson, W. Mackay, and J. Latchford. Transportation and Land Use Structures. Urban Studies, Vol. 4, No. 3, Nov. 1967, pp. 201-217.
9. J. Schneider and J. Beck. Reducing the Travel Requirements of the American City—An Investigation of Alternative Urban Spatial Structures. U.S. Department of Transportation, Research Rept. 73-1, Aug. 1973.
10. J. Jordan. Distribution Patterns of Automobile Travel in the New York Metropolitan Area. HRB, Highway Research Record 392, 1972, pp. 159-160.
11. I. S. Lowry. A Model of Metropolis. Rand Corp., Santa Monica, Calif., RM-4035-RC, 1964.
12. J. Edwards. Relationships Between Transportation Energy Consumption and Urban Spatial Structure. Civil Engineering Department, Northwestern Univ., Evanston, Ill., PhD dissertation, June 1975.
13. Sioux Falls Metropolitan Area Transportation Study. Wilbur Smith and Associates, Columbia, S.C., 1965.
14. P. J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP, Rept. 111, 1971.
15. R. G. Hennes and M. Ekse. Fundamentals of Transportation Engineering. McGraw-Hill, New York, 1969, p. 370.

Urban Transportation Planning System: Philosophy and Function

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This paper describes the philosophy and functional requirements of a computer-based system for urban transportation planning. It begins with a view of the current transportation problem and the resulting demands on the planner. After outlining a planning framework composed of three analytical activities—long-range planning, short-range planning, and system surveillance—the paper describes the functions of a software system that would effectively support today's transportation planner. Such a system is currently under development at the Urban Mass Transportation Administration.

In the 1950s, transportation planners dealt in unimodal terms, undisturbed by social and environmental nightmares and unaware of energy crises.

In the 1970s, some planners began to perceive the apparent ineptitude of their perspective. During those 20 years, Americans invested trillions of dollars in automobiles, roads, parking facilities, traffic signals, police officers, traffic courts, hospitals, insurance companies, tire factories, oil industries, drive-ins, and billboards—all in deference to the private automobile-highway system. Yet, in spite of this enormous capital expenditure, congestion still paralyzes the cities, which smell awful and look worse than they did 20 years ago.

In their own defense, planners can argue that they should not be faulted for the current state of affairs. They had been misguided in their ignorance of the issues. Only those supporting the popular demand for more cars and more roads had urged them to consider costs and benefits. They had lacked both the technical and fiscal wherewithal to plan for, much less build for, anything but the automobile-dominated existence supported at enormous national expense.

It was not until the 1960s that federal legislators admitted that urban residents could not move by car alone and looked to transit for help. Like an aged football player abruptly recalled from retirement to substitute for the limping superstar, public transportation was dusted off, given an aspirin, and sent into the dying seconds of the game. Renamed mass transportation, it was expected to reduce congestion so that automobiles could go faster. Transit was given less than 1 percent of the capital budget spent on the automobile-highway system and was asked to solve the problems that the automobile had caused. And to make matters worse, transit operations were not federally subsidized.

Since the 1950s, planning procedures have changed little. The technical expertise needed to solve problems (problems unknown in the fifties) has increased by an order of magnitude. But new methods are needed to deal with the transportation issues of the seventies, such as priority lanes, congestion pricing, dial-a-ride, personal rapid transit, environmental impact statements, energy conservation, quality of life, and UMTA capital grant. The problems are new, and the ground rules for their solutions have changed. UMTA's current concerns and goals are described below.

LESSONS LEARNED

Examination of transportation planning during the last 20 years teaches four lessons that must be learned if transportation planning in the future is to be successful and if urban transportation systems are to be saved from inexorable decay.

The first lesson is that the transportation problem can be solved only at the local level. It is apparent that the problem was made worse by a federal tilt toward highways during the last 20 years, and federal policy that earmarks dollars for specific modes, regardless of local needs and desires, aggravates rather than ameliorates the situation. Any effective solution will likely require a better use of the automobile coupled with vastly improved public transportation.

The second lesson is that we must make better use of existing transportation resources and not automatically assume, in response to a problem, that what we need is more. Our superb highway system is 50 percent underused about 90 percent of the time. Too often roads are conceived of as providing for the movement of cars and trucks, not of people and goods, while in fact at certain times it is advantageous to ban cars and trucks

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from some segments of the road system. Public transit riders, pedestrians, and cyclists should receive much higher priority in the planner's mind and on the city's streets.

The third lesson is that urban transportation planning, implementation, and operation must be coordinated without an artificial administrative and jurisdictional partitioning of functions and responsibilities. Planners must guide builders. Operators must trust planners. Planners must be informed by builders and operators. In the past, these people scarcely knew one another. Today they must work together.

The fourth lesson is that planners must consider a much larger set of options and issues. They must look for more and better transportation alternatives. The evaluations of these alternatives will, in large measure, be based on nontransportation issues. Not only is today's problem more acute, but also the constraints on feasible solutions are tighter. More technical expertise is required.

Today, planners must plan a system, not merely design appendages to growing freeways. They now must justify their recommendations through lengthy analyses of alternatives and examination of vastly different and sometimes radical proposals. They must describe and defend the numerous potential impacts of a proposed plan to impatient politicians, a vociferous press, and a suspicious public, whose questions are selfish, diverse, and microscopic. A decision to build will never again be based on a simplistic travel time measure. Many other criteria, often conflicting, must be addressed.

NEEDED: IMPROVED PLANNING TOOLS

Despite the staggering problems of this new era of transportation planning, a clear view of the stunning differences between the fifties and the seventies can help us decide what kinds of tools are needed.

Traditional planning techniques now in common use are slow and costly: slow because they use a hunt-and-peck system to find a good plan and costly because of long turnaround times and high data costs. Their most serious weakness is the inability to evaluate multimodal planning alternatives accurately and responsively. At best, they plan effectively for one mode, the private automobile.

Local planners are keenly aware of these shortcomings. They must respond quickly to local policy questions. Despite inadequate resources, they must go ahead and plan with what they have. Piecemeal efforts of local planning agencies to improve tools often cost more than their marginal success is worth. The federal government's research and development of improved planning techniques will be especially valuable and welcome at the local level.

RESPONSES OF THE URBAN MASS TRANSPORTATION ADMINISTRATION

For as many years as large computers have been available, state and local agencies have used them to plan. UMTA research and development best helps local planners by packaging the best products in computer software. In this way UMTA provides technical and fiscal support necessary to improve local planning.

In 1972, the UMTA Office of Research and Development began a program to

1. Research and develop improved planning techniques,
2. Implement these techniques in generalized computer software,
3. Pilot test software in urban areas to ensure its appropriateness and demonstrate its utility,
4. Distribute the software to local planners, and
5. Provide technical backup by training users and responding to queries from the field.

The result of this program is the urban transportation planning system (UTPS). UTPS is a package of computer programs for site-specific planning of multimodal transportation systems. The package is evolutionary in that it is constantly enlarged and updated. Its ultimate goal is a streamlined, easy-to-use set of modular tools applicable to several planning activities.

UTPS PLANNING PHILOSOPHY

Two considerations affect the design of UTPS. First, variations in local issues and resources bring about many different planning situations, and no one model fits them all. Second, to be easy to use and yet adequately sophisticated, the technical complexity of UTPS must in large measure be invisible to the user, like that of a telephone.

To accommodate the variety of planning situations, UTPS distinguishes three overlapping, sequential, and iterative planning activities: long-range planning, short-range planning, and system surveillance (Figure 1). The first provides a context for the second; the second precedes implementation; and the third monitors performance to feed information back to the first two. Each is discussed below.

Long-Range Planning

There are two types of long-range planning. One searches for a strategy, and the other articulates in some detail a design within a selected strategy. We call these strategic (or sketch) planning and tactical planning (Figure 2). Both involve both manual and computerized processes. When computerized, each entails the design, coding (for computer consumption), evaluation, debugging, and improvement of a transportation system concept (Figure 3).

Sketch planning in long-range planning is the preliminary screening of possible multimodal configurations or concepts under varying assumptions regarding alternative futures. It is an aggregate, multivariate system evaluator and comparer. Especially needed in long-range regional planning (10 to 20 years), sketch planning, at minimum data costs, yields preliminary estimates of capital and operating costs, patronage, wide corridor traffic flows (by mode), service levels, and land development implications for a multimodal network. It also estimates factors such as energy consumption and air pollution. It compares all these data with those available for other networks and provides the information needed for broad policy decisions.

The demands on such a strategic model for long-range planning are challenging. First it must be very easy and quick to evaluate credibly an alternative strategy. Future options are limitless. Scores of them must be considered, and thus each must be done quickly. Second, the model must have capabilities for simulating the performance of modes that are as yet unspecified. Third, it must deal explicitly with uncertainty. Two of the most annoying uncertainties are those associated with socioeconomic and land developments and those associated with the costs and performance of new transportation technologies.

Sketch planning input is characterized by a small (less than 800 nodes) but rich abstraction of a multimodal network. By using highly aggregated measures, it compares a large number of proposed policies in analytical detail just sufficient to support strategic decisions. Trip generation, distribution, modal split, and assignment—traditionally four different technical steps—are handled in a single step. Supply-demand equilibriums are explicitly considered. Outputs relate directly to the issues. It evaluates a single system alternative at less than 10 percent of the cost of existing long-range planning techniques.

The planner remains in the sketch planning mode until possible comparisons are made or a strategic plan worthy of consideration at the tactical level is found.

Tactical planning treats the kind of detail appropriate to midrange (5 to 10 years) planning and identifies the best configuration within a given strategic concept uncovered in the sketch planning phase. The input and analytical techniques are close to those of today's state-of-the-art regional and corridor planning studies. Input includes the location of principal highway facilities and delineated transit routes. These feed a network model that addresses any automobile-transit vehicle interaction. Disaggregate demand forecasting techniques are applicable here.

In contrast to sketch planning, tactical planning can provide disaggregated cost and benefit measures that relate more accurately to the citizens and resources affected. At this level of analysis the outputs are estimates of transit fleet size and operating requirements for specific service areas, refined cost and patronage forecasts, level-of-service measures for specific geographical areas, and where necessary a program for staged implementation. Household displacements, noise, localized pollution, and aesthetic factors can also be evaluated.

The cost of examining an alternative in midrange planning is 10 to 20 times its cost in sketch planning, although default models, which assume away certain data requirements, might be run for a relatively inexpensive first look. Apparently promising plans can be analyzed in further detail, and problems uncovered at this stage may suggest a return to sketch planning to accommodate new restraints.

Short-Range Planning

As in long-range planning, there are two distinct types of activities in short-range planning. One is a quick evaluation of broad, areawide transportation strategies, and the other is detailed delineation of an optimal system design reflecting a given strategy. In the former, the difference between long and short-range strategic planning is that the short-range case requires more accurate cost-benefit estimates. Fortunately, greatly improved accuracy is obtainable. Also, the feasible transportation options in the short term are very limited, and the costs and capabilities of individual system components are accurately known. Additionally, in the short term, human behavior and demand for transportation are less difficult to forecast. Thus, a much more precise evaluation is possible. Some examples of the kinds of policies a short-range strategic model can address are

1. Areawide dial-a-ride service;
2. Widespread designation of automobile-free zones;
3. Road user tax or increased gas tax;
4. Order of magnitude increase in transit fleet size or exclusive guideway (lanes); and
5. Broad changes in parking policy.

Detailed delineation of the plan and the system's expected costs and benefits is required before the final decision is made to implement. The outputs of long-range tactical planning models and short-range strategic models are usually too abstract for engineering design purposes, but as the time to implement projects draws near (5 days to 5 years) detailed simulations can be made to refine design parameters. Some examples of activities at this stage are

1. Detailed evaluation of the extension, rescheduling, or repricing of existing bus service;
2. Simulation of bus priority lanes or signal systems;
3. Analysis of passenger and vehicle flows through a transportation terminal or activity center; and
4. Comparison of possible routing and shuttling strategies for a demand-activated system.

Analysis at this detailed level can be prohibitively expensive except for subsystems whose implementation is very likely and for cases in which such design refinements bring substantial increases in service or significant reductions in cost or uncertainty. Analysis at this level is effective only when the large number of exogenous variables can be accurately observed or estimated.

Surveillance

Besides enabling continual scrutiny and evaluation of transportation services, performance, costs, and use, the data from a good surveillance program support near-term planning to eliminate problems such as overloaded links, inadequate transportation opportunity, and the underutilization of existing resources. Knowledge of the current state of affairs is a prerequisite to any planning. It is essential that existing highway and transit systems and their users and environment be monitored to determine the service provided, to whom, and at what cost. Such data are needed for supply and demand model verification and calibration as well as for system evaluation. In addition to the traditional traffic counting, user-oriented surveys of things such as convenience and travel time must also be maintained. Information on citizens' travel patterns and socioeconomic attributes is also needed.

The development of good short-range planning and surveillance tools brings the greatest return for the model development dollar. This is especially true because the strong tradition of pure highway planning, preoccupied with long-range, capital-intensive programs, is of little help in the evaluation of immediate-action programs. Short-range planning provides the tools and analytical techniques badly needed to evaluate and optimize the use of a city's existing transportation resources. The development of these tools has high priority at UMTA.

UTPS FUNCTIONAL CHARACTERISTICS

To support the planner in the four stages identified above, UTPS acts as a highly interactive system, using time-shared computers with on-line graphics terminals, which is vastly different from the present slow-motion, error-prone batch operation. Interactive browsing through network and land use data, both digital and graphic, speeds up the planner's evaluations. Maps, charts, and graphs replace the millions of numbers that now overwhelm the planner (Figure 4). Graphic input via an electronic tablet speeds the data entry and run setup. An interactive network design model allows the planner to specify or to modify a plan virtually instantaneously. Many analytical processes are run while the planner waits at the cathode ray tube (CRT), giving him or her instant turnaround. Successful execution of the system is ensured by performing an interactive dry run

Figure 1. The planning process.

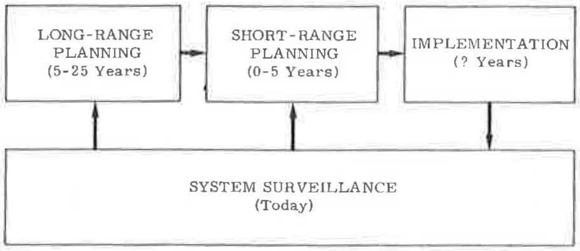


Figure 2. Planning types.

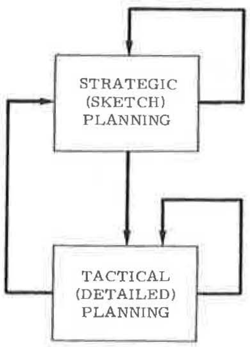


Figure 3. Computer-aided design.

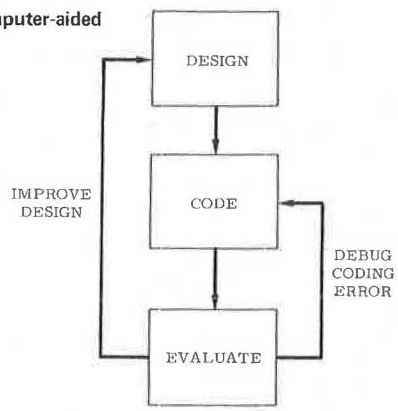
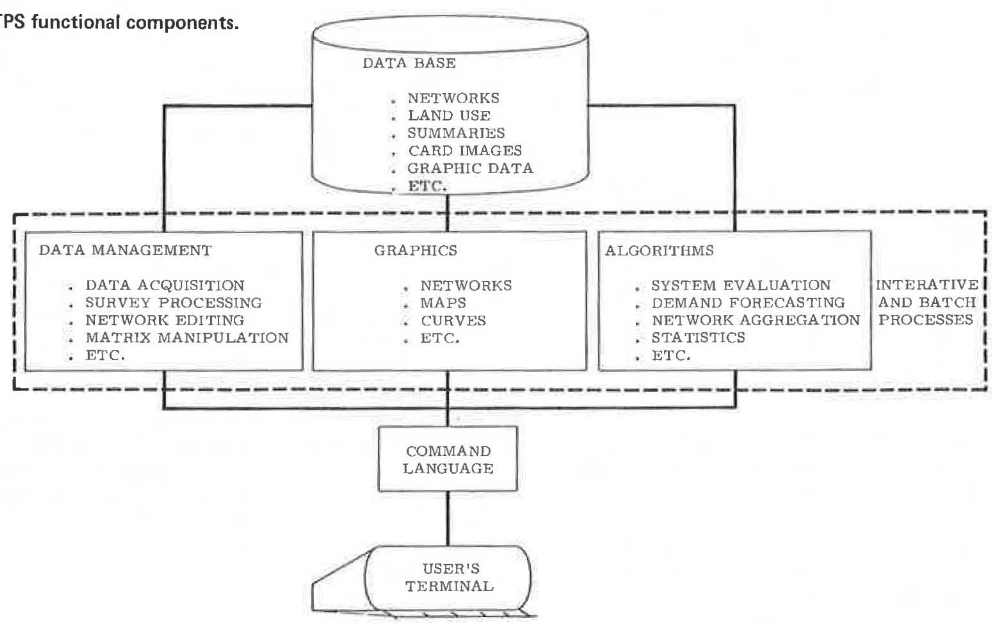


Figure 4. UTPS functional components.



of longer analyses that require batch processing. Later the planner interactively browses through the outputs of the batch process.

The UTPS program library includes data management routines, graphics routines, and algorithms for statistical and mathematical programming packages, and specific planning models, the software need to examine transportation supply and demand at each of the three planning levels described. UTPS modules meet uniform software design standards, and adherence to those standards allows UTPS to add new software and provide improved analytical techniques as they become available.

Among the most important modules are those for system evaluation, demand estimation, network aggregation, data acquisition, and data management.

System Evaluation

The system evaluation tool is an open-ended set of analytical reports and graphics, selected for the use of local planners, who may also add their own processes and reports on local issues. UMTA adds new reports as national issues arise. Local planners can compare significantly different network conceptions and make detailed analyses of the minor perturbations of a given network. They can evaluate present and proposed systems according to current and future demands. The other modules described below directly support system evaluation.

Demand Estimation

Planners making demand estimates may choose from three kinds of models: off-the-shelf default models for local use without site-specific parameter estimates, default models with locally calibrated parameters, and user-made models that can be integrated with an existing module with little programming effort.

Algorithms for establishing supply-demand equilibriums provide the capacity to determine route and mode selection equilibrium, origin-destination demand equilibrium, and land development-transportation equilibrium. The software supports the development, calibration, and application of both aggregate and disaggregate models.

Network Aggregation Models

Among the improved tools under research are the network aggregation models, which are useful at all levels of planning. The automatic reduction in size of the coded network description speeds up the computing process by providing the most efficient data base for an analysis. There are three network aggregation techniques: subarea windowing, regionwide abstraction, and subarea focusing.

Subarea windowing is the most straightforward technique. The software physically extracts a subarea of the network and collapses external demand to within the subarea's periphery. It can be used for detailed analysis and short-range planning when external demands are assumed to be fixed.

Regionwide abstraction is technically more difficult. The computer reduces detailed networks to a specified level of abstraction by aggregating links, nodes, and zonal data to yield a network amenable to sketch planning. This permits movement from the short-range stage back to the sketch planning stage and thus allows rapid macroscopic evaluations of detailed networks.

Subarea focusing is the most difficult technique because it combines windowing and abstraction. A subarea of interest is windowed; the links outside the window are not deleted but are abstracted, so any modification of the subarea's internal network can have the appropriate effect on external demand. This is accomplished by increasing network abstraction as distance from the window increases. Subarea focusing greatly improves the effectiveness of traditional long-range (tactical) planning and reduces its cost and increases its accuracy.

Data Acquisition

Although data collection is essential to planning in general and system surveillance in particular, the notoriously large sums of money spent on data acquisition should be channeled into more productive analyses. To do this, planners need more efficient data gathering techniques. UTPS must couple modern sampling techniques with the capabilities of an on-line, time-shared computer and modern data entry hardware to speed the collection, editing, and correcting of survey data and to reduce the cost. Also, a disaggregate travel demand data base is available to researchers to eliminate the need for more data in certain cases. Detailed network coding manuals show the planner the quickest way to input transportation system characteristics.

Data Management

The data management system is used to specify network and land use configurations, edit data, and evaluate systems. A good data management system must allow the planner to execute programs and interact with the data base without detailed knowledge of the data base's design. It should also be possible to provide a common source of data for all UTPS modules, allow efficient modification of the data base, avoid a proliferation of data files, and furnish a repository for output from computational modules.

Besides the many computational similarities (e.g., matrix manipulation), there are also many common data requirements among the three levels of planning analysis, such as network descriptions, land use data, and graphic data. Therefore, data preparation time and user training time are reduced, and the software is fully exploited. At any time the user can modify the basic network or land use data by using the interactive network design program. The modifications can be additions, deletions, or the updating of any or all elements; but the basic integrity of the original design and its predecessors is preserved in a tree-like file structure. At any time, the planner may analyze any version of the network. In UPTS a single data base might contain scores of networks, all quickly available for analysis.

The planner can design a network while graphically describing it to the computer. He or she sits at a CRT and, using a stylus or lightpen, draws the network, either by explicitly entering nodes, links, transit lines, and the like or by circumscribing parametrically geographical areas of homogeneous service (e.g., street spacing, number of bus stops).

The UTPS package can generate maps, charts, or graphs. When the software processes a request for graphics, it saves the results in the graphics file of the data base. The file contains the points, lines, and annotations that constitute the graphic in a standard format. The planner may browse through the available graphics at any time, recalling, combining, modifying, or displaying those needed, without the expense of regeneration. Attribute or land use data can be overlaid on network plots and the graphic directed to a display tube or hard-copy plotter.

CONCLUSION

All components and capabilities described above are among the objectives of the UTPS development. All are currently in a research or development stage. A few products have already been released to the planning community. Most are scheduled for future delivery.

In its present skeletal state, UTPS is 13 software modules and attendant documentation that form a fairly powerful suite of programs that run in the batch mode on the IBM 360/370 series of computers. Basically comprising a traditional transportation model, UTPS best supports long-range tactical planning but can provide limited service for the strategic or short-range planner. It includes highway and transit network analysis models, demand forecasting models, màtrix manipulation, and limited graphics capabilities. It installs easily at the user's computer facility and is being continually improved as new developments arise.

It is hoped that, within 3 years, UTPS will evolve to include all the capabilities discussed above. It will be in a form that allows it to be fairly readily installed on non-IBM computers and will exploit mini-computer and nationwide computer network technologies. The result will be a ubiquitously available software system that will aid federal, state, and local planners who search for effective solutions to today's complex and vexing transportation problems.

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Abridgment

New Approach to Economic Evaluation of Labor-Intensive Transportation Systems

Michael Everett and Jack Dorman, University of Southern Mississippi

Simple point estimates of easily measured costs and benefits may have provided sufficient information to stem grossly inefficient pork-barrel projects and to guide, at least crudely, capital- and energy-intensive transportation investments. With the increased concern for environment, quality of life, and energy conservation, however, planners now must incorporate these more difficult-to-measure variables in their analyses. The managerial economics literature has provided easy-to-use tools for decision making under uncertainty for more than a decade (1). Recently social planners have begun adopting some of these concepts.

Applying these tools for decision making and planning under uncertainty to a proposed bicycle-pedestrian transportation system on a medium-sized university campus generated important low-cost, easy-to-use information. Both benefits and costs contained a number of difficult-to-measure social and environmental variables such as loss of consumer surplus to restricted drivers and increased exercise and recreation for pedestrians and bicyclists. After the data were ranged from expected low to high values, a computer simulation model generated a distribution of costs and benefits with an expected benefit-cost ratio of 1.7:1 and probability of failure between 2.6 and 26 percent. Failure of the bicycle-pedestrian system (restricting parking and driving and developing other forms of transportation) would entail a low financial cost—$346,000 of fixed investment—and would be easily reversible. A hand-calculated example of the technique is presented by Everett (2).

REFERENCES

1. D. B. Hertz. Risk Analysis in Capital Investment. Harvard Business Review, Jan.-Feb. 1964, pp. 79-95.
2. M. D. Everett. Benefit-Cost Analysis for Labor Intensive Transportation Systems. Univ. of Southern Mississippi, in press.

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Abridgment

Measuring the Economic Value of Exercise in Labor-Intensive Urban Transportation Systems

Michael Everett, College of Business Administration, University of Southern Mississippi

Recent studies show that labor-intensive transportation modes such as bicycling and walking play an essential role in providing needed exercise in an otherwise sedentary society. Transportation planners have not incorporated the value of exercise in benefit-cost analyses partly because of the measurement difficulties. The present analysis attacks these problems by

1. Ranging the value of the health benefits of threshold exercise by a 0 to 80 percent reduction in premature coronary heart disease (CHD), mortality, and morbidity (1); and
2. Ranging the economic benefits of reducing CHD based on the following methods: (a) the present value per 1-h exercise session of $0 to $2.30 [about 14 cents/km (23 cents/mile) for bicycling] and (b) the consumer surplus value of bicycling exercise, which ranged from 35 to 78 cents/km (56 cents to $1.25/mile) for a sample of university students.

These data show that the exercise benefits compose one of the major sources of benefits for bicycle and pedestrian systems. Computer simulated techniques for decision making (or benefit-cost analysis) under uncertainty can compare these (plus other) ranges of benefits with ranges of costs for bicycling facilities to generate distributions of probable benefit-cost ratios (2).

REFERENCES

1. M. Everett. The Economics of Exercise, Physical Fitness, and Health. Encyclopedia of Physical Education Fitness and Sports, in press.
2. M. Everett. Benefit Cost Analysis for Labor Intensive Transportation Systems. Univ. of Southern Mississippi, in press.

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