NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 210

MARKET OPPORTUNITY ANALYSIS FOR SHORT-RANGE PUBLIC TRANSPORTATION PLANNING

ECONOMIC, ENERGY, AND ENVIRONMENTAL IMPACTS

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NOTICE

This report is one of a series of five emanating from NCHRP Project 8-16, "Guidelines for Public Transportation Levels of Service and Evaluation," as follows:

NCHRP Report 208, "Market Opportunity Analysis for Short-Range Public Transportation Planning — Procedures for Evaluating Alternative Service Concepts."

NCHRP Report 209, "Market Opportunity Analysis for Short-Range Public Transportation Planning — Transportation Services for the Transportation Disadvantaged."

NCHRP Report 210, "Market Opportunity Analysis for Short-Range Public Transportation Planning — Economic, Energy, and Environmental Impacts."

NCHRP Report 211, "Market Opportunity Analysis for Short-Range Public Transportation Planning — Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements."

NCHRP Report 212, "Market Opportunity Analysis for Short-Range Public Planning — Method and Demonstration."

A full picture of the results of the project research requires all five reports. How they complement each other is shown in the diagram below and also is explained more fully in the Foreword of each report.

Please note that the current mailing (October 1979) includes only the first four of these reports. Production and mailing of the fifth will be delayed until Spring of 1980. As a member of TRB in 1979 you will automatically receive Report 212 at the time it is published without further action on your part.

We regret this inconvenience caused by circumstances beyond our control.

Policy	Marketing	Engineering
NCHRP Rpt. 211 Short-Range Transportation Goals and Policy Development for Urban Communities Institutional Issues Facing Public Transportation Organization of a Public Transportation Market-Oriented Approach	NCHRP Rpt. 209 Transportation Services for the Transportation Disadvantaged NCHRP Rpt. 212 A Market Opportunity Analysis Approach to Short-Range Public Transportation Planning Methodology and Demonstration of a Market Opportunity Analysis for Short-Range Public Transportation Planning	NCHRP Rpt. 208 Procedures for Local Selection and Cost Evaluation of Alternative Public Transportation Service Concepts NCHRP Rpt. 210 Economic, Energy, and Environmental Impacts of Public Transportation

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 210

MARKET OPPORTUNITY ANALYSIS FOR SHORT-RANGE PUBLIC TRANSPORTATION PLANNING

ECONOMIC, ENERGY, AND ENVIRONMENTAL IMPACTS

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WASHINGTON, D.C. OCTOBER 1979

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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FOREWORD

By Staff
Transportation
Research Board

Environmental assessments of alternative public transportation proposals are required by federal regulations developed in response to the 1969 National Environmental Protection Act. Therefore, impact analysts will be specially interested in this report. Transit marketers, planners, and engineers, at state and local levels, will also find how impact analysis interrelates with policy, marketing, and engineering—the three primary activities of short-range public transportation planning. The report is oriented mainly to small- and medium-sized urban areas.

Public transportation traditionally has been provided by fixed-route service financially supported through revenues from passengers. Reduced patronage, resulting primarily from increased use of the automobile plus higher operating costs, has caused growing deficits. Public concern about energy, environment, auto dependency, congestion, and the quality of urban living in general has obliged governments to underwrite these deficits in most urban areas. The rising amounts of required public monies plus the successful operation of a wide range of services directed at more specialized market segments have posed questions concerning how much financial support is appropriate, what services are required, and how these services should be provided. Public officials need this information in order to establish appropriate public policies.

Project 8-16 was initiated in order to develop a method to provide public officials with the desired information and direction for local public transportation actions. The initial 12-month period of the project was spent conducting an in-depth analysis of present procedures and practices of the urban mass transit industry. Included in this effort were research team visits to 18 urban areas within the United States. From this research process, a model (Fig. I) was developed depicting the necessary information and procedural steps required for the application of market opportunity analysis to the planning of short-range public transportation. As depicted in the model, the application of market opportunity analysis requires both direction from policy decision areas and data from an engineering data base. A full explanation of this model, its application, and potential value is presented in *NCHRP Report 212,* "Market Opportunity Analysis for Short-Range Public Transportation Planning—Method and Demonstration." Four companion reports are concerned with the application of a market-oriented public transportation planning approach. These constitute a group of reports that bear the main title "Market Opportunity Analysis for Short-Range Public Transportation Planning," and are subtitled as follows: *NCHRP Report 208,* "Procedures for Evaluating Alternative Service Concepts"; *NCHRP Report 209,* "Transportation Services for the Transportation Disadvantaged"; *NCHRP Report 210,* "Economic, Energy, and Environmental Impacts"; and *NCHRP Report 211,* "Goals and Policy Development, Institutional Constraints, and Alternative Organizational Arrangements." Obviously, all elements of the comprehensive planning model could not be addressed in one report. Thus, each report is aimed at one specific segment of the over-all model as shown in Fig. II for this report. Together, the reports provide

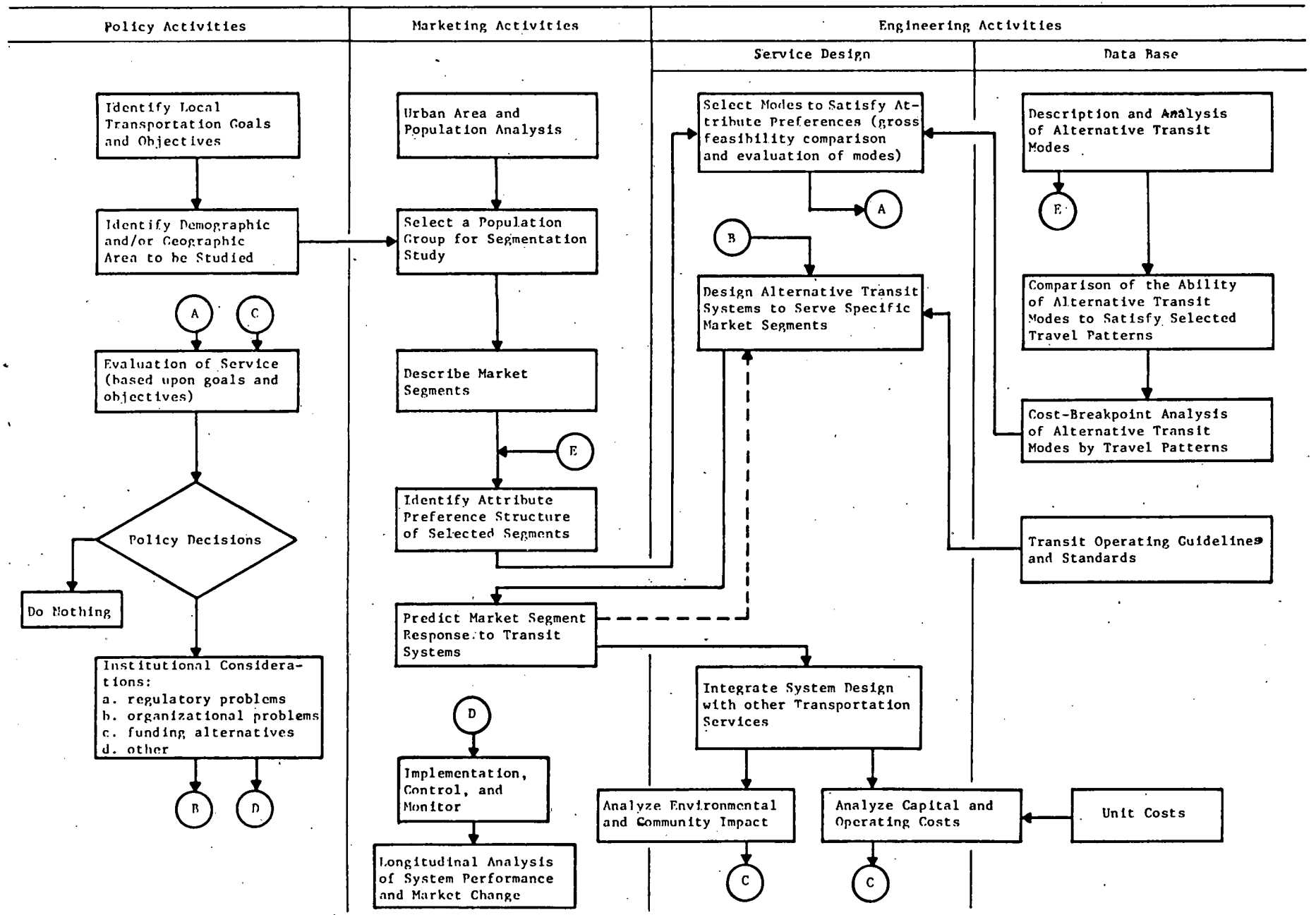

Figure I. NCHRP Project 8-16 model—a market opportunity analysis approach to short-range public transportation planning.

comprehensive guidelines for public transportation officials covering the three primary activities described in the model—policy, marketing, and engineering (Fig. III).

The present report, "Market Opportunity Analysis for Short-Range Public Transportation Planning—Economic, Energy, and Environmental Impacts," recommends that analyses be based on expected market utilization instead of theoretical system capacities. Information is provided for both the Engineering Data Base and the Service Design sections of the model.

The findings described in the report will assist the analyst in structuring information to permit an analysis of various public transportation service alternatives in meeting specified objectives, even though objectives may be conflicting.

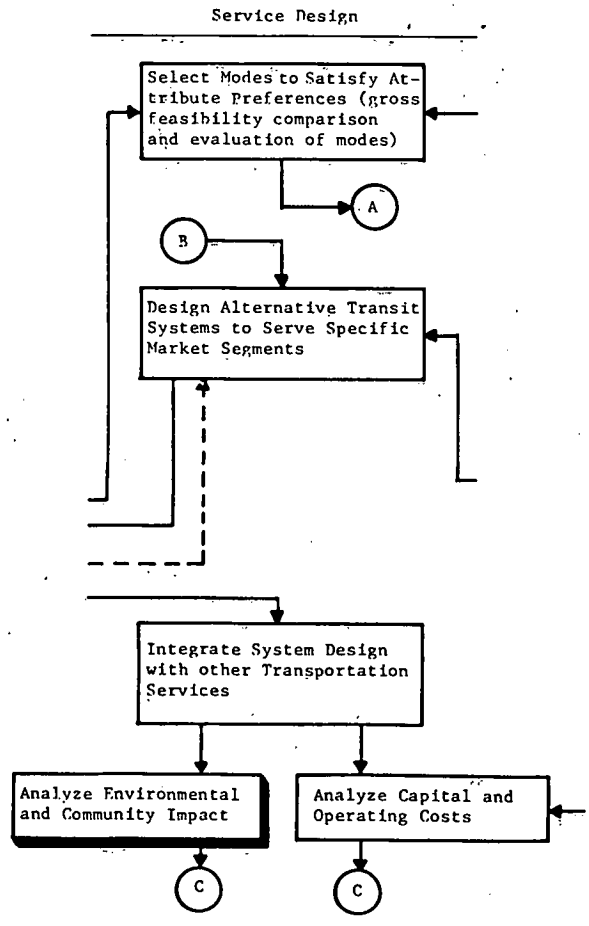

Figure II. Relationship of report to project model.

Policy	Marketing	Engineering
NCHRP Rpt. 211 Short-Range Transportation Goals and Policy Development for Urban Communities Institutional Issues Facing Public Transportation Organization of a Public Transportation Market-Oriented Approach	NCHRP Rpt. 209 Transportation Services for the Transportation Disadvantaged NCHRP Rpt. 212 A Market Opportunity Analysis Approach to Short-Range Public Transportation Planning Methodology and Demonstration of a Market Opportunity Analysis for Short-Range Public Transportation Planning	NCHRP Rpt. 208 Procedures for Local Selection and Cost Evaluation of Alternative Public Transportation Service Concepts NCHRP Rpt. 210 Economic, Energy, and Environmental Impacts of Public Transportation

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The research reported herein was performed under NCHRP Project 8-16 by The University of Tennessee Transportation Center. Drs. Ray A. Mundy and Kenneth W. Heathington were the principal investigators. The authors of this report are Dr. Frederick J. Wegmann, Professor, Department of Civil Engineering; Mr. Carlos R. Bonilla, Research Assistant, Transportation Center; Dr. Thomas L. Bell, Associate Professor, Department of Geography; Dr. Dudley Dewhirst, Professor, Department of Industrial Management; Ms. Carol A. Sovchen, Research Assistant, Transportation Center; and Dr. Kenneth W. Heathington, Director, Transportation Center.

During the course of this research project many public and private transportation individuals, too numerous to mention, were interviewed concerning their transportation services. Their assistance and cooperation in providing this information are greatly appreciated.

MARKET OPPORTUNITY ANALYSIS FOR SHORT-RANGE PUBLIC TRANSPORTATION PLANNING

ECONOMIC, ENERGY, AND ENVIRONMENTAL IMPACTS

SUMMARY

This report is a part of NCHRP Project 8-16, "Guidelines for Public Transportation Levels of Service and Evaluation," which is directed toward the development of improved methodology for short-range public transportation programs in small-to-medium sized urban areas (50,000 to 500,000 population range). The material presented supports the general concept adopted by this project that there is a broad range of public transportation service concepts available to a community. The planner should attempt to relate the inherent operational attributes of the proposed services to the travel needs defined by various market segments. Any community contribution as significant as transit requires that a broad viewpoint be taken, thereby identifying the benefits and costs associated with the service.

Also, planners must be objective in assessing the contribution of public transportation. The desired attribute of transit should not be accepted a priori. The extent and nature of benefits will vary with the type of transit service provided and the manner of deployment.

As a result of research pertaining to the economic development, energy, and air pollution consequences of proposed alternative actions, and to the evaluation of transportation services once in place, a number of conclusions were drawn. These are offered in the interest of encouraging planners and decision-makers to scrutinize the detailed attributes of the service being considered. It should be noted that, in some cases, the conclusions are based on limited observations transferred from other cities. In all cases, the planner is encouraged to undertake a localized analysis.

Economic Development

- A temporary loss of public transportation service will have an adverse impact on certain portions of the community and on certain of its citizens. Travel in general, will become more expensive and less convenient, particularly for captive riders.
- During the temporary loss of public transportation service, captive riders will reduce their trip-making. However, the captive group is generally able to find alternative travel arrangements for essential travel. Discretionary trips previously made by public transportation are canceled in many cases.
- Semicaptive and choice riders of public transportation systems are generally able to rely on a range of substitute modes and are not as adversely affected by a temporary loss of public transportation services.
- The economic impact from a temporary loss of public transportation service is directly related to the number of captive riders in the system.

- Businesses that are most affected by a temporary loss of public transportation service are those that cater to captive riders. Other businesses, whose clientele are more automobile- or commuter-oriented, tend to have a minimal loss of business activity.
- To say that a small-to-medium-sized city cannot survive without conventional public transportation service provided by the public sector is misleading. Mainly because of the small number of riders, public transportation, by itself, is neither a necessary nor a sufficient condition for economic vitality in a small-to-medium-sized city.

Energy Efficiency

- Bus transit services are not necessarily more energy efficient in fuel consumption than some energy-efficient private autos. The energy efficiency of bus services for an urban area relative to the private automobile will be directly related to the utilization rates of bus transit services.
- Transit efficiency is associated with urban area population. Passenger-miles per vehicle-mile goes down as population decreases. Estimates based on national averages of bus usage probably overestimate the efficiency of bus transit in communities below 500,000 population.
- Some forms of paratransit, on the average, are as efficient as conventional transit. However, taxis and dial-a-ride services are not particularly energy efficient.
- One promising policy to reduce petroleum consumption is to directly increase the efficiency of the various vehicles used in urban transportation. This may have more impact than policies that would try to increase the utilization rate of public transportation services.
- Increasing the utilization rate of transit services will not necessarily reduce the amount of energy consumed in an urban area. The energy consumption will be directly related to the utilization of automobiles left at home while a given trip is being made by public transportation. New trips made as a result of the availability of the automobile could increase the total amount of energy consumed in an urban area.
- When determining the total energy required by a given mode, one must include in the analysis the amount of access energy required. Access energy is that energy required to gain access to the mode serving the long-haul portion of the trip. Sometimes, the amount of access energy can be quite large.

Air Quality

- Because of the operating requirements of some modes (e.g., deadheading, slow speeds, empty-schedule runs, etc.), they are not necessarily less polluting than a private auto on a per passenger-mile basis. Therefore, care should be exercised not to underestimate pollutant emissions with these modes.
- Slower average speeds increase emissions of CO and HC in all modes, and of NOX in vehicles using diesel fuel.
- Commuter buses are lower emitters of all three pollutants, but access modes need to be accounted for to provide a full disclosure of all emissions.
- Taxis, dial-a-ride vehicles, and autos are the principal emitters of CO per passenger-mile for intraurban services. Conventional transit and jitneys are lower emitters of CO and constitute a better alternative to providing services at locations suffering from high concentration of that pollutant.
- A given public transportation alternative that will satisfy the objectives

in one area (such as energy) will not necessarily meet the objectives in another area (like air quality control). The transportation planner must be aware of the characteristics of each public transportation alternative relative to land use development, economics, energy, and air quality. It is through a complete analysis of the contribution in each area that a given public transportation alternative can be selected that will make improvements of long standing.

Evaluation of Implemented Transportation Services

- In spite of on-going periodic evaluation of transportation services being necessary to assure the maximum service at minimum costs, the state of the art is not well advanced and most transportation services are not subject to meaningful periodic evaluation.
- The evaluation process is made more difficult because of the major problems of measuring social costs and benefits of a particular function (i.e., public transportation) in a complex environment. Research done in the program evaluation field (the evaluation of social action programs) provides some guidance in formulating principles to guide the evaluation effort.
- The potential for effective evaluation (that is, one whose results will be used to improve service and/or reduce costs) is enhanced by high quality transportation planning, the use of multiple criteria to evaluate the transportation system, and the participation and cooperation of the operator with local government agencies and officials.
- Individual system evaluation should be tailored to the unique characteristics of the system being evaluated. Some guidelines for operations evaluation are proposed but should be supplemented by other evaluative methods specifically tailored to individual needs.
- Because no single agency possesses all the characteristics desired to facilitate effective evaluation, in most instances evaluation should be a joint activity of several institutions or agencies.

CHAPTER ONE

INTRODUCTION

Public transportation provides users and the community with many benefits. In recent years the expansion of transit systems has become associated with achieving energy conservation and reductions in undesirable levels of atmospheric pollution. Today, transit is an indispensable public service vital to the economic and social well-being of the community and its citizens.

Traditionally, transportation planning attempted to identify quantitative benefis and costs resulting from the provision of transit services. With the use of transportation system demand models which traditionally have been used, it is possible to identify user savings resulting from the improvement of transit service and to equate the savings to facility and operating costs. Any community contribution as significant as transit, however, requires a broad viewpoint and necessitates identifying the benefits and costs incurred by nonusers, special sections of the community, and the community at large. Clearly, these costs and benefits defy expression in simple monetary terms. At best, they can be expressed only as qualitative statements. Table 1 provides a comprehensive categorization (categorizations are approximate; depending on the particular issue and item, some reclassification might be expected) of benefits accruing from improved transit for a medium-sized city (*1*). Benefits are stratified into three groups:

TABLE 1

CATEGORIZATION OF ALLEGED BENEFITS ACCRUING FROM IMPROVED TRANSIT SYSTEMS

CATEGORIES	BENEFITS TO TRANSPORTATION SECTOR (Travelers)	BENEFITS TO SPECIAL GROUPS	BENEFITS TO THE COMMUNITY AT LARGE
Direct Economic Benefits (dollar values can be assigned)	• Savings in travel time • Savings in travel costs (parking, auto purchase, license fees, insurance, depreciation, etc.) • Savings in reduced congestion • Savings in highway safety	• Savings in parking construction requirements for merchants and employers • Increased land values (permits upward growth and denser development of office, & residential uses)	• Increase in taxes (sales & property) from areas of higher density development • Savings in highway & bridge construction costs in heavily travelled corridors • Taxes from land not taken off tax rolls for public highway & parking construction • Some savings in school district busing cost
Other Quantifiable Benefits	• Increased flexibility in travel arrangements • Choices available for trips to work, airport, etc. • Improved accessibility to other areas • Improved mobility for non-drivers	• Widened retail market areas by improved accessibility (e.g. CBD, shopping centers) • Widened employment market for major employers	• Reductions in unemployment • Reductions in highway noise in some corridors • Reductions in vehicle-crankcase emissions (smog) • Improved civil defense capability • Energy conservation
Nonquantifiable Benefits	• Increased pleasure and comfort of travel	• New life-style available to elderly, young, handicapped • Job, educational, service, cultural, recreational opportunities - social impacts	• Community development opportunities • Environmental and aesthetic benefits • Greater community efficiency

Source: Wilbur Smith and Associates, Inc., Community Benefits Resulting from an Improved Transit Program in the Sacramento Region, prepared for the Sacramento Regional Area Planning Commission, Sacramento, California, March 1971.

1. *User benefits.* Include those, already using the system, that receive greater mobility, reduced travel costs, etc.

2. *Special group benefits.* Include groups or institutions that receive special treatment, such as large employment concentrations, downtown retail and office interests, and property owners located in close proximity to the transit stations. These benefits also include the increased mobility provided to certain segments of the community that depend on transit.

3. *Community-at-large benefits.* Include benefits received by the whole community from higher taxes resulting from increased property values, reduced rush-hour congestion, a decreased need for road construction, reduced energy consumption, and improved levels of atmospheric pollution.

Table 1 shows that some benefits can be translated into direct economic benefits, that others can be translated into quantitative benefits, and that some nonquantifiable benefits must rely on subjective statements. The benefits actually received will vary from community to community and will depend on the nature of transit investment and how the investment ultimately affects travel behavior. For example, it can be argued that fixed-facility transit investment will provide a strong focus on land-use decisions, thereby stimulating high density development around transit stations. In contrast, bus routes are flexible and adaptive and thereby affect development to a lesser extent.

Although the desirable attributes of public transportation cannot be denied, it is important for planners to be objective in assessing the contributions of public transportation. The desirable attributes of transit cannot be accepted a priori. The extent and nature of benefits will vary with the type of transit service provided and the manner of deployment.

As discussed in Ref. (2), there exists a range of alternative transportation service concepts. It is the responsibility of the planner to match alternative service concepts with the travel needs dictated by a market segment and the community's expectations for transit as reflected in statements of public transportation goals. The evaluation process requires an analysis of market needs, the cost of providing the service, and the benefits to be achieved. Since a discussion of cost was covered in another document, this report is structured around the benefits: energy conservation, reduced atmospheric pollution, economic enrichment, and metropolitan development.

The intent of this report is to: (1) provide factual data on the effectiveness of alternative transit service concepts, (2) compare the performance of alternative services, and (3) provide an awareness of the factors involved in selecting alternative services to ensure that the complexities of the problem are appreciated. In many applications a detailed evaluation, employing a precise analysis based on

the detailed structure of the service provided, will be required. It is not the intent of this report to replace such an analysis. Rather, this report provides "first cut" approximations to assist in narrowing the range of alternatives. The report identifies the complexities that might underlie conventional assumptions. Material is presented in the interest of encouraging planners and decision-makers to scrutinize the attributes of the service being considered and not rely on generalizations. An attempt has been made to cite cases or conditions that conflict with conventional wisdom in order to encourage thoughtful analyses. Also, a chapter has been devoted to a discussion of evaluation as a continuing activity in managing a transit system. Although this report is structured by considering each element or benefit separately, trade-offs between benefits and costs will need to be considered.

CHAPTER TWO

ECONOMIC BENEFITS OF PUBLIC TRANSPORTATION

Mass transit has been credited with the ability to produce economic enrichment. Traditionally, it has been assumed that large segments of American industry and commerce received direct benefits from transit service, primarily through increased access to their activities. In conjunction, individual members of society profit from these services. Transit patrons, especially low-income individuals, can realize improved access to employment and social opportunities.

The economic benefits of mass transit generally have been acknowledged by transportation planners and the patrons of the service. Yet, with declining patronage and rising labor and operating costs for a transit system, it can be questioned if these economic benefits are equal to the necessary costs of achieving them. With the loss of private transit systems and the increase in mass transit subsidizations, it is necessary to evaluate the extent to which mass transit provides its alleged benefits for society (*3*).

This section reviews the effects of decreased mass transit upon its economic environment. Major emphasis is placed on patronage, employment, and business development. Transit patronage is segmented according to user market segments. The effects on each transit segment are further evaluated in terms of employment and business opportunities. It might be expected that increased transit use would achieve the opposite results from those discussed. Because it is difficult to segregate the impacts resulting from increased transit use in the complex socioeconomic activities of a city, emphasis is placed on the more controlled situation of describing the impacts resulting from the temporary removal of transit services.

Although over 100 communities have lost transit service since 1955 (see Table 2), and some communities have initiated totally new service, the economic benefits actually resulting from transit improvements or termination in small- and medium-sized cities have not been documented. Some studies have been conducted on the impact of supplementing an existing transit system with a high quality facility, such as the Bay Area Rapid Transit System (BART) in San Francisco. Also, numerous demonstration projects identifying the impact of incremental changes to an existing transit service have been documented (*4*).

TABLE 2
URBAN TRANSIT SYSTEMS DISCONTINUING SERVICE (1955-1969)

Size of City	Systems Discontinuing Service
Less than 25,000	51
25,000 - 50,000	40
50,000 - 80,000	9
Greater than 80,000	0
Total	100

Source: Brachman, Mitchell E., Sinha, Kumares C., and Pustay, Michael W., The Effects of Labor Strikes on Bus Transit Use, Purdue University, West Lafayette, Indiana, 1976.

Another approach to evaluating transit benefits is to describe the impacts resulting from a temporary transit interruption. Although transit strikes are not permanent situations, they do highlight changes in travel behavior and economic losses. The results of a transit strike can help

assess to what extent the alleged economic benefits of transit are real. It is realized that taking away transit does not provide a comprehensive examination of transportation and economic development but is only one issue that can provide some insight into these issues.

The transit strikes reviewed lasted from 12 to 120 days and were distributed between medium-sized and major metropolitan areas. In addition, case studies are cited in which increased public transit was terminated because of unfulfilled expectations and economic loss. Transit in this section is defined in the context of fixed-route, fixed-schedule bus or rail service.

There are several limitations associated with this approach. A major difficulty encountered was the lack of research and uniform analysis within the field. The population size and the availability of transit alternatives varied in each strike community. In addition, each transit system resumed service immediately after the strike; thus, all impacts were of a temporary nature, presenting only a basis for short-term reasoning. Yet, the extent to which transit achieves its alleged benefits can be revealed in the magnitude of economic dislocations resulting from a strike.

EFFECTS ON TRANSIT PATRONS

The mass transit market can be broken down into three basic user market segments:

1. *Transit dependent riders.* Individuals are dependent on mass transit for their transportation. These include the elderly, the young, the handicapped, and the low-income families.
2. *Semidependent riders.* Individuals use the transit system, but are able to travel by another mode. These typically include members of a one-car family in which there are two or more drivers.
3. *Independent riders.* Patronage from these individuals is sought by the transit systems; these are choice riders who have a car (or alternative mode) immediately available for use.

Each strike reviewed resulted in increased traffic congestion and longer travel time as most transit patrons temporarily pursued another form of transportation. However, some suppression of travel resulted and is an applied measure of patronage effect. In this situation, individuals were unable to adjust their transportation methods, resulting in trip suppression. As shown in Figure 1, the shifting of modes and extent of travel suppression stimulate the economic impact; the scope of these activities determines the dimensions of impact.

Figure 1 represents the effects of eliminating services on both dependent and independent transit patrons. These effects are traced into potential socioeconomic impacts. In addition, the transit operator likewise would be affected by loss of employment.

It is evident that all groups will realize a loss of flexibility and convenience, but the greatest impact will be felt by the transit dependent, the individual without a viable mobility option. An investigation into a number of transit strikes revealed that after service is restored choice and marginally captive patrons return to the system at a much slower rate than transit dependent or captives. This is because the captives cannot locate an attractive alternative travel mode, while independent riders may have found such an option at their disposal (*5*).

The economic impacts resulting from a temporary suspension of transit service will vary from system to system. In order to trace the economic impacts, it is necessary to acknowledge the number of individuals falling under the definitions of captive, choice riders, etc. Also, it must be determined what alternative transportation services are available. The impacts are determined on the basis of how individuals make adjustments: Do users suppress travel or find an alternative mode? Do users suppress travel differently for discretionary vs. nondiscretionary trips? What alternative modes are selected as a substitute for public transportation? Are transportation-efficient means selected such as walking, or carpooling vs. driving alone? Is there a broad geographic impact on altered business activities, or is it geographically localized? Are there long-range effects on business settlement patterns?

Although it is difficult to provide generalizations, a review of strike studies revealed the following observations.

SUPPRESSION OF TRAVEL

The data in Figure 2 show that for the 1974 Alameda-Contra Costa (Calif.) transit strike, there was a trip suppression rate of 50 to 60 percent for the elderly and the young, almost twice the average trip suppression rates for all transit users. Twenty-five percent of San Bernardino's dependent riders ceased their travel during the 1974 Southern California Rapid Transit strike, in contrast to only 4 percent of the semidependent patrons (*6*). During the 1966 New York City transit strike, 60 percent of the dependent riders remained home for the entire strike, compared to 15 percent of the semidependent (*7*). In Knoxville, Tenn., it was found that elderly captive riders had to suppress their travel at twice the rate of the elderly noncaptive riders (31.1 percent vs. 14.4 percent). The impact of the strike was felt most dramatically by the elderly living in senior citizen complexes (34 percent of normal trips were suppressed). The trips most frequently suppressed were for religious purposes, visiting friends and relatives, leisure and recreational trips, and personal business. In spite of the loss in transit service, nondiscretionary travel continued to be made for shopping, medical appointments, and work trips. Apparently, the dependent rider segment is greatly affected by a reduction of transit service. In contrast, a relatively small percentage of the semidependent rider segment was required to eliminate travel (*8*).

Effects of Travel Suppression on Employment

A socioeconomic benefit associated with mass transit is the increased job opportunities for lower income residents because of expanded mobility. The transit dependent rider, which includes low-income individuals, is most likely to suffer from a transit interruption. Because a large percentage of dependent riders remained at home during the

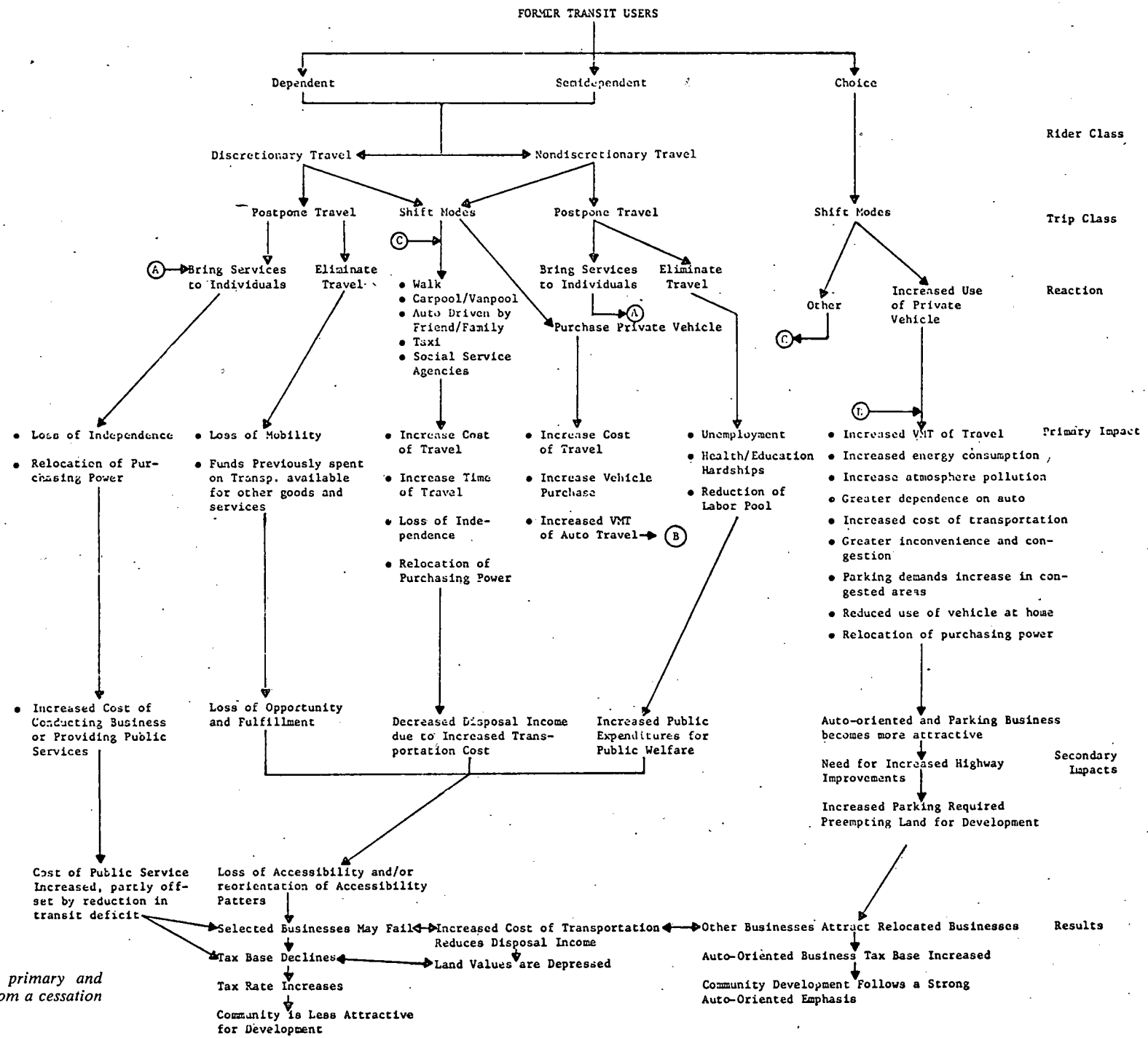


Figure 1. Potential primary and secondary impacts from a cessation of transit services.

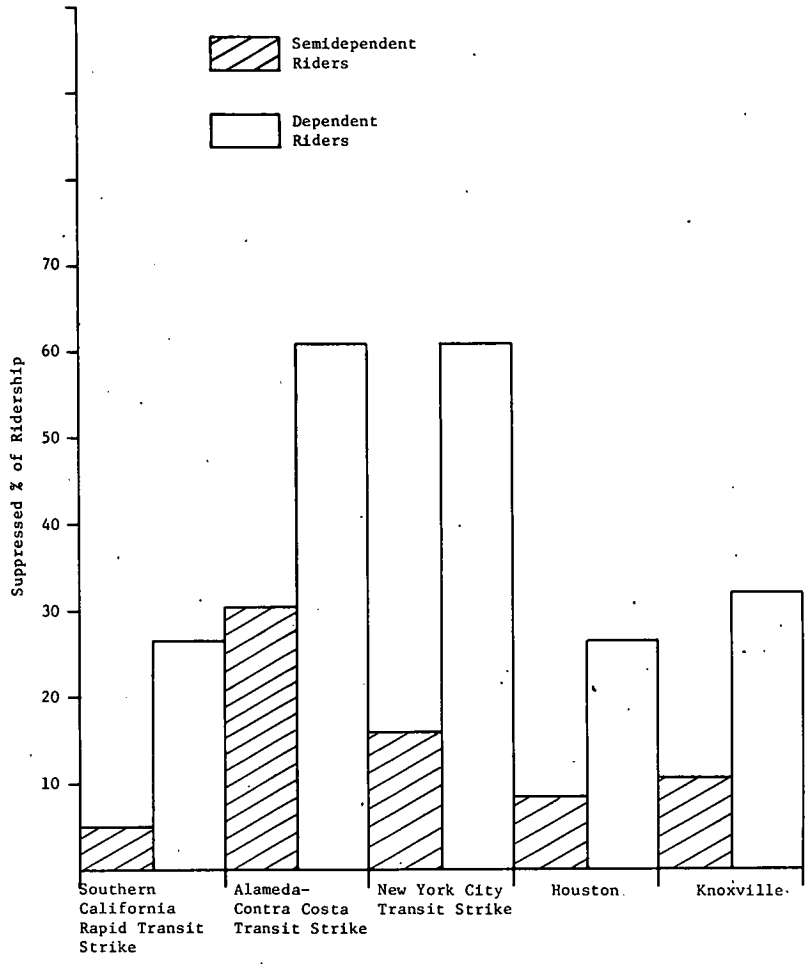


Figure 2. Suppression of travel due to transit strikes.

strike, a reduction in their employment level would be presumed. However, strike statistics did not show this to be the case.

From August 12 to October 18, 1974, the Los Angeles area's public transportation system was operationally shut down because of a labor strike (*6*); the Southern California Rapid Transit District system served about one million daily riders. The over-all impact showed many unaffected people; a large number was slightly inconvenienced (traffic tie-ups, etc.); and only a small number was hurt directly because of missed medical trips, inability to pick up employment checks, and lost jobs. However, of 316 interviewees, only 4 percent stated that they lost their jobs because of transportation. In November, the comparative statistics of new unemployment applications for Los Angeles County and the state recorded no statistical evidence that unemployment occurred because of lack of transportation.

For a 121-day period in the late fall and winter 1972-73, three major Connecticut cities went without bus service (*9*). Hartford, New Haven, and Stamford traditionally have relied heavily on buses for transportation. Yet, the cities did not undergo any serious dislocations in economic or social activities because of lack of service. Similarly, in Knoxville, no noticeable increase in community unemployment could be identified because of a 6-week strike. Major industrial firms and employment centers, excluding downtown retail merchants, all reported no difficulty in having employees reach work sites.

The New York City transit strike lasted from January 1 to January 13, 1966, and was conducted by two public agencies and five private agencies. The strike affected 16 million residents. Forty percent of the semidependent workers who normally used the subway or bus to go to work lost one or more work days during the strike, while 15 percent did not go to work at all. Among transit dependents, the corresponding figures were 60 percent losing some time and 30 percent not working at all. However, 79 percent of the 85 percent working employees attempted only one alternative mode and then remained at home. The car was the most frequent mode selected, serving over half of the workers who traveled during the strike (*7*). Apparently, the strike's brief duration did not cause elaborate travel adjustments of its patrons. Also, New York City's reliance on mass transit is not indicative of the majority of other U.S. cities.

The previous case studies have shown the effects of a temporary transit interruption upon employment levels. Over-all, a certain percentage of unemployment developed after a strike's initiation, as seen in New York City. How-

ever, this percentage decreased with the prolongation of the strike. Apparently, people learn to adjust to the restricted travel environment and find alternative transit modes. This general observation has been seen in the large metropolitan areas of Los Angeles and Houston, Tex., and in the smaller cities such as Hartford, New Haven, and Stamford. The effects of these transit strikes (from 12 to 121 days) are not evident within the counties' statistical unemployment records. Of course, some jobs were lost, but the number was so low that it was not detectable within the over-all statistics.

However, job opportunities and social mobility are major sociological objectives for the mass transit industry. About 40 percent of the Urban Mass Transportation Administration's (UMTA) service development and improvement funds have been used to improve transportation facilities for urban residents of low income, in most cases by increasing lateral or outward mobility (*4*). Accordingly, the transit systems have attempted to provide reverse communication trips from an urban center to a job located in the suburbs. The purpose of this service is twofold: to increase job opportunities among urban residents of low income and to expand the labor pool for employers.

However, whether improved mass transit fulfilled these social and business objectives is questionable. For example, in the 1950s and 1960s, a pattern of firm proliferation occurred along Route 128, the circumferential highway around Boston, Mass. (*5*). In May 1968, it was estimated that 3,894 jobs were available to innercity, unemployed persons in the area; about 60 percent of the jobs were located one-half mile off Route 128. From May to November 1969, with an UMTA grant, the Massachusetts Bay Transportation Authority operated a direct bus service from Roxbury, a low-income community, to points on Route 128. The service was accompanied by a campaign publicizing low-skill job opportunities for Roxbury residents.

The service's results were poor. Only 42 riders responded to a questionnaire (of which 25 reported a secured income due to the service), and only 12 stated that they would have to find another job if the service was terminated. In this case, the service proved highly unprofitable and was terminated at the demonstration's end.

In another case, the sponsor of a St. Louis, Mo., demonstration reported that many who used the bus to find jobs bought automobiles quickly and discontinued using the bus. It was assessed that the over-all effect of the bus service on unemployment in the area was minimal.

Another project providing an interesting insight on employment opportunities occurred in April 1968 in St. Louis. A bus service known as Transportation, Employment and Manpower Provides Opportunities (TEMPO) was established to link the central city ghetto with the Hazelwood area of St. Louis County, about 20 miles northwest of the city (*4*). Evaluations were made of the impact of the TEMPO buses on both ghetto residents and employers in the Hazelwood area in terms of the ability of the line to provide jobs and the value of the service in meeting existing manpower needs. Employers were interviewed to find out how many hires had resulted from TEMPO, how personnel managers evaluated the new workers, and whether an extended program would be welcomed. The results showed that most firms already had access to an adequate, even abundant, labor supply. In all, an estimated 106 workers were hired by 92 different firms in Hazelwood. Thirty-two firms accounted for the employment of 96 central city workers who found their jobs through TEMPO. Of the 96 employees, 84 quit the first year. Of the 92 firms, only two employers stated that they would favor the subsidization of TEMPO. The employers' over-all conclusion was that the bus line was only a minimum benefit for many new employees. Similar results have been obtained in Chicago, Ill., and in Los Angeles and Sacramento, Calif. Of the 15 cities that undertook outward mobility movement projects with UMTA, 12 reported an economic loss (*4*).

It must be questioned if mass transit is vital for individuals to reach job markets. Although this is evident to some extent in New York City, findings for other studies cannot replicate their conclusions. For many small-to-medium-sized cities, it would be questioned if a loss of transit service will result in big layoffs. It appears from the limited data available that in many cases individuals will endure hardships to continue making "vital" trips. The suppression of travel is associated mainly with trips that might be classified as "discretionary." The impacts realized are related partially to the mode shift that occurs when transit is no longer available.

Mode Shifts as a Result of Travel Suppression

What alternative transportation services are utilized when transit is discontinued? The primary concern of all transit patrons is how to get to work. Table 3 gives the principal alternative modes used by general transit patrons during a transit interruption in order to commute to and from work.

In Los Angeles over 650,000 daily transit riders needed an alternative means of transportation during the 1974 Southern California Rapid Transit District strike. To identify consumer behavior due to the strike, Bigelow-Crain Associates conducted a survey for Caltrans of 270 regular transit riders. Approximately 45 percent of the patrons rode with friends and coworkers, whereas 15 percent drove their own cars. Thus, the automobile met the transportation needs of 60 percent of the usual transit patronage. Los Angeles taxi business increased throughout the strike. Yellow Cab Company reported an over-all 26 percent increase in revenues. Yet, many of those required to use cabs reduced trip-making because of the cost of this service. Los Angeles' adjacent transit systems felt a definite increase in ridership. Revenues in Montebello increased by 33 percent, and in Gardena by 32 percent during the strike. But other systems lost riders who usually transferred to or from the Rapid Transit District System. An interesting result is that the systems experiencing increased patronage appeared to hold some of these riders even after the strike's conclusion (*6*).

During the 1972 Trenton, N. J. strike, the competing bus companies were able to accommodate the transit market left unattended by Transport of New Jersey (TNJ).

TABLE 3

EXAMPLE OF ALTERNATIVE MODES USED DURING A TRANSIT STRIKE FOR WORKERS

	Los Angeles*	Trenton	New York*	Knoxville*
Drove Own Car	15%	22%	38%	37%
Automobile Passenger	45	9	33	46
Bus	--	43	8	--
Taxi	3	--	12	7
Walked	15	--	6	9
Other	--	10	29	--
Stayed Home	16	**	***	***
Railroad	9	27	7	****

* Travelers could choose more than one alternative mode.

** Small percentage, less than 1%.

*** Not included, statistics are for workers traveling during the strike.

**** Service not available in the community.

Other bus companies received 43 percent of TNJ's regular riders. In direct contrast with Los Angeles, the automobile was the least favored alternative. Only 9 percent commuted as car passengers. The railroads received 27 percent of the commuters, and 22 percent drove their own cars. However, if the automobile trips were added together, 31 percent of the commuters chose the automobile as their means to commute to and from work. In general, strike-inflicted modal choices proved to be unpredictbale as the number of alternative modes of transit available and their respective levels of service increased. The commuters that had chosen the rail mode during the strike showed a greater tendency to stay permanently with their new mode than any other forced to change. Only two of the 981 individuals surveyed remained at home because of the transit strike (*10*).

The consulting firm of Barrington and Company evaluated the impact of the New York City strike from January 1 to January 13, 1966. The automobile was the main alternative mode of transportation selected with 33 percent of the general transit patrons becoming automobile passengers and 38 percent driving their own cars. However, a variety of substitute travel modes was used by workers during the strike. Eighty percent of the individuals used one mode of travel only, 20 percent used two modes or more, and a very small proportion (about 4 percent) used three or more alternatives (*7*).

Table 3 shows the number of travel alternatives attempted by 85 percent of the New York workers who worked at some time during the strike. Buses (mainly employer-arranged), taxis, railroads, and walking—each provided a solution for 6 to 12 percent of the workers. Miscellaneous means included boat and helicopter and, combined with staying away overnight, amounted to 29 percent of the cases. However, staying away overnight was not a popular solution. One percent adopted it immediately, although by the end of the strike, 7 percent of all workers had stayed away overnight at least once to avoid traveling. With the exception of the Queensboro Bridge Bus, all buses were arranged by employers. The Queensboro Bridge Bus served only a little more than 1 percent of the workers. Twelve percent of all workers walked to work. Over-all, only 14 percent walked to work at any time during the strike. Eleven percent immediately used a taxi, and before the strike was over 14 percent of the workers had used this mode at least once. The railroads, mainly the Long Island and the New York Central, provided transportation for 8 percent of the workers at first; before the strike was over about 10 percent had tried this means. In addition, shoppers who did not return to using mass transit reverted to walking in more than half the cases (*7*).

In Knoxville, over 7,000 daily Knoxville Transit Corporation riders had to find alternative modes of travel. However, the private bus companies did not have an increase in demand, with the exception of providing additional buses for the transportation of students for The University of Tennessee. Twelve cab companies recorded no significant increase in the number of calls received during the first week of the strike. In a survey conducted after the strike, almost all of the taxi operators contacted expressed surprise that the strike had not brought increased patronage. Interviews with private social service paratransit operators revealed some increased demand for service resulting from the transit strike. However, in many cases this demand was not as great as first expected. As with the other strike sites, a substantial portion of the community transportation needs had been met with private arrangements maintained between co-workers, friends, and relatives.

In addition, an analysis of Tennessee Valley Authority

employees in Knoxville (of whom 95 percent are choice riders) indicated that when the publicly operated express bus service was discontinued for six weeks, 35 percent formed carpools of three or more riders, 28 percent drove with one individual, 29 percent drove alone, and 5 percent shifted to one of the private bus lines operating during the strike. Of 600 autos that potentially could have been added to the roadways during the peak hours, less than 300 actually were added (*8*).

Mode shifts resulting from an interruption of transit service are an important element in determining the impact resulting from a transit strike. The strike studies revealed that transit patrons, even choice riders, will not necessarily respond by driving their own vehicles. Instead, efficient alternatives are selected such as walking, carpooling, and utilization of nonstriking transit lines. Captive transit riders who are without the benefits of a private vehicle will rely on social service operators, friends, and family members who are able to provide rides.

Effects of Travel Suppression on Retail Business

Redefined travel patterns can have impacts on retail trade. A large variation exists concerning the estimated sales loss during a transit strike within each business structure, such as department stores, supermarkets, discount houses, shopping centers, and franchises. One would anticipate the highest sales reduction within central city businesses because, traditionally, the central business district (CBD) is a major center of retail trade located at the hub of transit activities.

For evaluation purposes, the businesses are classified by the transit market segments which they primarily serve. As expected, the retail structures within a downtown setting reported the highest percentage of suppressed sales. *The Houston Chronicle,* on December 1, 1976, reported:

> The hardest hit are the less advantaged and those businesses that draw many of their customers from this group. Business along the north end of Main Street, where many bus riders shop, have been particularly hard hit.

Figure 3 shows that the suppressed sales for Houston were 10 to 65 percent below their 1975 sales levels. Most stores averaged 50 to 60 percent sales reductions. Negative effects on suburban stores were negligible. An interesting point is that the president of Houston's Downtown Merchant's Association (DMA) claimed that the bus strike had only "slight" impact on sales at the 40 mainly small, downtown retail stores represented by DMA (*11*).

In Los Angeles, a 10 to 50 percent sales reduction was experienced by retail structures. The average suppression rate was between 10 and 30 percent. Suburban stores were affected with a 5 to 10 percent sales drop; major department stores within the downtown area were severely affected with 20 to 50 percent drops in weekly sales. The recession and the lost transit patrons accounted for this reduction in department store sales (*12*).

In Knoxville, retail stores experienced 10 to 80 percent reductions in sales from the previous year. The average suppression rates were between 50 and 80 percent. The lack of access of transit dependents to downtown Knoxville by public transportation definitely affected businesses selling smaller and lower priced items more adversely than larger, more exclusive stores. Knoxville's specialty shops (clothing and shoe stores, restaurants, and food/drug/variety stores), being more dependent on pedestrian access and a less affluent clientele, were the hardest hit. Knoxville's suburban businesses were affected only slightly. In contrast with Los Angeles, the lack of transit service did not significantly affect large department stores that are served by five out of eight transit routes. However, Los Angeles' older Broadway shopping area (primarily Black and Mexican-American customers) experienced critical situations. Small independent stores were hit hard, and some were forced to close.

Apparently, retail stores and small specialty shops are the types of businesses that receive the most adverse impact from a transit strike. Primarily, these businesses serve the dependent and semidependent transit riders. Results of the New York City strike of 1966 indicated that only 64 percent of the population continued their shopping patterns normally done via transit. Only 14 percent of these shoppers continued purchasing in their usual places, while the remaining shoppers purchased at new locations on the basis of convenience (*7*).

It can be seen that the loss of transit service will have a major impact on retail trade. In Knoxville, the downtown merchants reported that 15 employees were laid off because of business losses. Undoubtedly much of this business was redirected to other retail establishments in the community.

SUMMARY

This chapter has attempted to trace the impacts for temporary curtailments of transit service on transit riders and the community. Although the studies cited were distributed between medium-sized and major metropolitan areas and strikes lasted 12 to 120 days, they do provide some insight into the major dislocations that result from the loss of transit service. This is not meant to imply that taking away transit will provide a comprehensive examination of the relationship between transportation and economic development.

The studies show that a temporary loss of transit service will have an adverse impact on the community and its citizens. Travel, in general, will become more expensive and less convenient for many.

As expected, the strike most decidedly affected those segments of the population that directly rely on public transportation as the principal means of mobility. For captive transit riders, this loss of mobility resulted in a reduction in trip-making and a forced shift in travel modes and destinations. To a large extent, the captive group is able to find alternative travel arrangements for essential travel. However, discretionary trips previously made by transit (religious trips, visits to friends and relatives, leisure/recreational, and personal business trips) were cancelled in many cases. Most shopping, work, school, and medical trips continued to be made. Major economic dislocations because of transit captive riders being unable to find a means of gaining access to the work site were not reported.

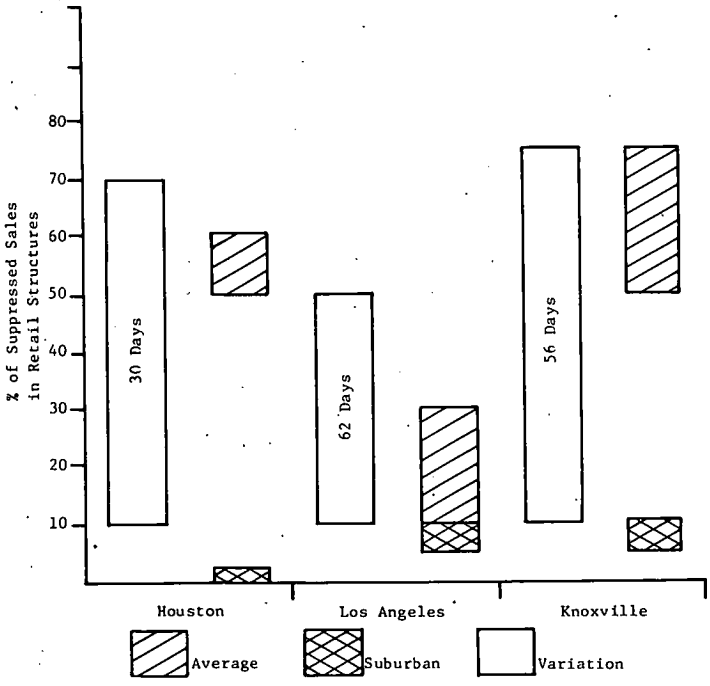


Figure 3. Suppression of sales due to transit strikes.

Semicaptive and choice riders relied on a range of substitute modes. In many cases relatively efficient modes, such as carpools and walking, helped integrate the adverse impacts of having a large number of private automobiles added to the street system.

With a shift in the travel pattern of the transit users because of the strike, downtown merchants, particularly those catering to transit dependents, lost substantial amounts of business. In Knoxville, a number of firms reported drops in sales of 50 to 80 percent, forcing reduced operating hours and the layoffs of sales personnel. The downtown business establishments that were affected most seriously were specialty shops, clothing and shoe stores, restaurants, and fast food/drug/variety stores. Interviews with store managers, however, revealed that sales returned to normal levels within two months after the strike was settled. Interestingly, many CBD merchants felt only minor repercussions ranging from no loss to 5 to 10 percent declines in sales during the strike. In the case of many of these merchants, the patrons were automobile-oriented or commuters.

The strike studies showed that transit is a significant element of the public services provided by the community. Since most captives and choice riders returned to transit, this suggests that transit was judged to be superior in terms of cost and convenience to the alternative modes utilized during the strikes.

It is difficult to provide a general assessment on the economic variability of conventional transit service for small- and medium-sized cities. Realization of the alleged benefits will depend on the number of transit riders; the number of riders classified as captive, semicaptive, and choice; the options available in terms of substitute public and private transportation services; the level of social opportunities afforded the citizens; and commitment to the economic vitality of the downtown area.

To say that a small-to-medium-sized city cannot survive without transit is a misnomer. Transit services provide certain benefits that should be measured against the associated cash and commitment to certain segments of the business community and population. Also, the benefits from transit must be assessed against alternative public and private options to provide needed mobility. On the basis of the available evidence, it is concluded that public transit by itself is neither a necessary nor a sufficient condition for economic vitality in a small-to-medium-sized city.

CHAPTER THREE

EFFECT OF PUBLIC TRANSPORTATION ON ENERGY CONSERVATION

In recent years the availability and cost of energy have become major domestic issues. Although all forms of energy are in limited supply—coal, natural gas, nuclear material, and petroleum—and all have accelerated in cost, particular concern is devoted to petroleum because it is being consumed at a far faster rate than it can be domestically produced. Continued dependence on large amounts of imported petroleum to bridge the gap between supply and demand threatens to erode the U.S.'s financial and political independence.

Since 1950, transportation's consumption of all domestic energy sources has remained constant (about 25 percent of total supply). However, transportation consumes slightly over 50 percent of all petroleum resources. From 1950 to 1974 the domestic consumption of petroleum for transportation increased by 160 percent to 3,248 million barrels (*13*). During that period the average automobile fuel economy dropped from 14.95 to 13.10 miles per gallon (*13*).

It is estimated that 55 percent of all auto vehicle-miles traveled (VMT) in the United States occurs in urban areas (*14*) and that fuel consumption per mile of urban driving is much higher than fuel consumed in rural driving because of cold starts, lower speeds, and stop and go operations (*15, 16*). Inasmuch as auto travel alone consumes 25 percent of all petroleum used in the United States, it can be concluded that urban automobile travel must be responsible for over 15 percent of domestic petroleum consumption. Further, energy efficiency of gasoline-powered vehicles is relatively low (20 to 30 percent); this suggests ample room for improvement. Over the long term, various policies can be pursued to reduce petroleum consumption through improved fuel economy, introduction of new nonpetroleum-based vehicular propulsion systems, reduction of urban travel demand, long-term changes of land-use patterns, and restrictions on vehicular use.

However, of immediate concern to planners are short-range actions that can be taken to increase the occupancy levels of private autos and transit vehicles. Yet, planners cannot pursue energy efficient actions as the sole objective. It generally is recognized that the movement of people and goods is a basic part of the economic infrastructure—the lifeline to progress and to a higher quality of life. Planners must be able to evaluate the effectiveness and implications of alternative energy efficient actions on a comprehensive basis. By measuring energy expenditures both before and after new services are provided, recent studies, such as BART in San Francisco, have shown that the introduction of energy efficient services is not always as effective as might be expected (*17*).

The objective of this chapter is to present guidelines that urban transportation planners may use to approximate the energy consumption of urban transportation modes and to discuss the potential that specified policies may have in conserving petroleum resources. Urban transportation modes are defined by the combination of vehicular technology and the service concept under which they operate. There are several ways of grouping urban transportation services, but two trip categories satisfy most user needs while demanding substantially different functions from the vehicles used. These trip categories are intraurban service—where all trips are made within the confines of an urbanized area; and commuter service—where trips are made exclusively for work, generally exceeding 10 miles in length and with few intermediate stops. Vehicular technologies are grouped into three service classes: private auto; conventional fixed-route, fixed-schedule transit; and paratransit.

In this report energy efficiency is defined as the energy consumed per vehicle-mile and per passenger-mile. *NCHRP Synthesis of Highway Practice 43* (*18*) introduces these efficiency measures. It does not attempt to compare efficiencies between urban transportation modes, but instead references the rates obtained by others under different assumptions. The present report develops a methodology to obtain comparable rates for different service concepts.

Local conditions, such as average service speed, trip distance, load factors, etc., will affect energy efficiencies of urban transportation modes. Some of those factors have been found to vary significantly with population size of an urbanized area. Various factors affecting modal energy consumption rates in urban areas with population under 500,000 have been identified. The proposed guidelines are intended *only* for preliminary planning and are *not* a replacement for more detailed analysis at an advanced planning level or pre-implementation stage.

FUEL CONSUMPTION RATES

To provide a comparison of the energy efficiency of various urban transportation service concepts, fuel consumption rates need to be presented on an equivalent energy rate basis. In this report, British thermal units (BTU) were adopted because of data availability and general acceptance. By using British thermal units, the energy expenditures of vehicles become comparable whose direct source for propulsion is electricity, diesel fuel, or gasoline. Other energy expenditures, such as those required to build vehicles, guideways, and transfer facilities, may be considered; but, because these expenditures are frequently related to other social and economic objectives, they will be

disregarded. All operating energy, however, including that required by garages, stations, and maintenance, should be accounted for to the extent possible.

The energy required to operate vehicles varies by system technology and service provided. General information will be provided, but a planner should rely on local data whenever possible. For a private auto, it is mainly the amount of gasoline consumed in transporting people from one point to another. For conventional bus systems, it includes fuel used in transporting passengers, deadheading miles, and idling at end of the run; it may also include other specific energy requirements for terminal and transfer facilities. For an electrified system like heavy rail transit, stations are major users of energy and must be considered together with vehicular propulsion energy. For all systems, operating energy varies by factors like load, trip length, cruising speed, distance between stops, and other characteristics specific to each type of service. However, average energy consumption rates can be used for gross comparisons of different vehicles and services—independent of urbanized area characteristics. Table 4 contains energy consumption rates for several transportation modes.

The detailed assumptions and data sources used in deriving this table are noted in the footnotes at the bottom of the table. Column 3 of Table 4 presents mileage rates in terms of vehicle-miles traveled per unit of energy. Of

TABLE 4

MODAL ENERGY REQUIREMENTS PER VEHICLE-MILE

(1) Mode	(2) Energy Source[a]	(3) Vehicle Mileage (miles/gal. or /KWH)	(4) BTUs/vehicle mile
Intraurban			
Private Auto	gas	11.9[b] (9.0-24.0)[c]	10,924 (5,417-14,444)
Conventional Transit			
Minibus	diesel	10.0[d]	14,500
Full-size Bus	diesel	4.1	35,366
Heavy Rail	KWH	5.2	52,000
Light Rail	KWH	4.5 [e]	45,000
Trolley Coach	KWH	6.5	65,000
Paratransit			
Dial-a-Bus (small)	diesel	12.0[f]	12,083
Dial-a-Van	gas	9.0[g]	14,444
Taxi	gas	11.0[h]	11,818
Jitney	gas	9.0[i]	14,444
Commuter			
Private Auto	gas	14.0[b]	9,286
Carpool	gas	14.0[b]	9,286
Vanpool	gas	10.0[j]	13,000
Bus	diesel	6.6[k]	21,970

a. 1 gallon of gasoline = 130,000 BTUs, 1 gallon of diesel = 145,000 BTUs, 1 kilowatt-hour can be generated by 10,000 BTUs (19).

b. From energy consumption rate of 11,400 BTUs per vehicle mile by 1971 average auto in urban driving; miles per gallon obtained using conversion factor of 136,000 BTUs per gallon, pregiously assumed by Hirst (22).

c. From Energy Statistics, U.S. DOT, 1975, p. 137.

d. Mercedes Benz, 19 passenger minibus; from "Ultra-Personalized Service in Morgantown, West Virginia," Metropolitan, November/December 1974.

e. Calculated from Transit Facts by APTA (27).

f. Estimated from various agencies using Mercedes Benz minibuses.

g. Data from CUTS handbook (19).

h. From Wells, J.D., and Selover, F., "Characteristics of the Urban Taxicab's Transit Industry," Economic Characteristics of the Urban Public Transportation Industry, Institute for Defense Analysis, for U.S. DOT, February 1972, p. 8-26.

i. Estimate for Atlantic City jitneys from Kirby, R.F., et al, Para-Transit: Neglected Options for Urban Mobility, The Urban Institute, for UMTA and FHWA, 1974, p. 175.

j. Knoxville Commuter Pool data.

k. Estimated fuel consumption for the Reston community commuter bus (19).

vehicles using gasoline for propulsion, the private auto travels about 11.9 miles per gallon (mpg), a taxi about 11.0 mpg, a jitney about 9.0 mpg, and a van used for dial-a-ride service about 9.0 mpg. A minibus and a regular transit bus travel, respectively, about 10.0 miles and 4.1 miles, on a gallon of diesel fuel; heavy rail and light rail cars run for about 5.2 miles and 4.5 miles per kilowatt-hour (KWH), respectively. These are average rates for vehicles used in intraurban travel; if the same vehicles were used for commuting, their mileage rates would increase. For example, when placed in commuter service without frequent starts and stops, an average auto can achieve 14.0 mpg, a van 10.0 mpg, and a full-size commuter bus 6.6 mpg. These rates are specified by vehicle size and type of service rather than the customary classification by vehicle type only.

To compare modal consumption regardless of fuel type or energy source, BTU per vehicle-mile is used as a common energy measure, as shown in column 4 of Table 4. By using a conversion factor of 130,000 BTU per gallon of gasoline, 145,000 BTU per gallon of diesel, and 10,000 BTU per KWH (*19*), energy intensiveness of various modes can be expressed in terms of BTU per vehicle-mile. Energy intensiveness is highly related to the weight of the vehicle and to the speed at which it travels. Large, electrically powered transit vehicles show the highest energy consumption rates, while the subcompact private auto seems to be the most energy efficient per vehicle-mile.

Obviously, comparison of average energy consumption rates of various transportation modes described in terms of BTU consumed per vehicle-mile is not meaningful as the sole differentiation between modes. For preliminary planning and for providing an understanding of how one mode compares with another, average energy consumption rates at some level of personal mobility should be used.

Fuel Consumption Rates per Vehicle Capacity

For a critical comparison of the energy efficiency of alternative modes, energy consumption must be based on some measure of BTU consumed per unit of mobility. Many relevant measures of mobility can be devised, and the first comparison noted in Table 5 is based on seat-miles. As noted in Table 4, the BTU consumed per vehicle for a luxury private auto and a minibus is almost equivalent; yet, the efficiency of the two vehicles is quite different because the luxury vehicle has a seating capacity of six passengers, whereas the minibus has a 19-seat capacity.

Columns 2 and 3 of Table 5 identify seating capacity and its associated energy consumption per passenger-mile —the latter on the premise that all seats are occupied. The average private auto in intraurban service becomes an efficient mode of conveyance at 2,012 BTU per passenger-mile, ranging from 1,354 to 2,407 BTU per passenger-mile. Conventional transit ranges from a low of 707 BTU per passenger-mile for a full-size bus (excluding electrically powered systems) to 763 BTU per passenger-mile for a minibus. Paratransit services range from a low of 755 BTU per passenger-mile for a dial-a-ride diesel minibus to 1,970 BTU per passenger-mile for a taxi. Commuter services range from a low of 431 BTU per passenger-mile (excluding buspools with parking at destination) to a high of 1,710 BTU per passenger-mile for private commuter autos and carpools.

This is a hypothetical and rather gross comparison. Conventional transit cannot operate fully loaded in all directions because of reversed directionality of passenger trips during off-peak periods. Unlike private autos and vehicle pools, both transit and urban paratransit vehicles are generally garaged at places other than the origin or destination of users, thereby, requiring empty moves. Thus, fuel consumption rates per passenger-mile account for operating conditions of specific modes. Still, seating configurations of similar vehicles are not considered, like a transit bus with forward-facing seats to maximize seated passengers versus the same vehicle with aisle-facing seats to maximize standees. Autos, vans, minibuses, and full-size buses come in various sizes and seat arrangements, and averages are an attempt to select typical usage.

Transit vehicles show a major advantage over other vehicles in their capability to handle large peaks of passenger trips by the use of standing areas. In general, maximum vehicle capacity is a classification pertaining to conventional transit only, as other transportation modes can be said to have a maximum capacity equal to their number of seats. At maximum capacity, a full-size transit bus consumes 472 BTU per passenger-mile and a minibus 630 BTU per passenger-mile. Heavy and light rail cars show even greater efficiencies, because their design allows a much greater proportion of standees than of buses. Transit efficiencies under maximum capacity represent a potential resource for reducing energy consumption where demand is high enough, or can be encouraged to be high enough, to achieve such loadings.

Fuel Consumption Rates for Average Occupancy

The maximum capacity measure is based on the assumption that vehicles operate with a full load of seated and standing passengers, where standees are feasible or allowed, at all times. In contrast, average occupancy is a field measure of passenger-miles traveled to vehicle-miles operated as reported by transportation agencies throughout the United States. However, transit services do not operate at capacity, and average occupancy is more reliable in attempting to estimate energy consumption rates for providing transit services than the assumpion of capacity. For example, autos typically are occupied at only 28 percent of their maximum capacity, while transit buses operate at 16 percent of their maximum capacity. Taxis typically are loaded to 11 percent of their capacity, while dial-a-ride vans are occupied to 12 percent and jitneys to 36 percent of their respective maximum capacities. (These percentages are derived from the ratio of passenger-miles traveled to capacity-miles.)

For purposes of this analysis, generalized values of vehicle occupancies based on nationwide averages are presented. Whenever a mode comparison is being made for a community where vehicle occupancy by type of service is known, the energy consumption rates given in Table 5 should be modified. This is particularly important for conventional transit services in small-to-medium-sized urban

TABLE 5

MODAL ENERGY REQUIREMENTS PER PASSENGER MILE

(1) Mode	(2) Seating Capacity	(3) BTU/ Pass. mile	(4) Maximum Capacity	(5) BTU/ Pass. mile	(6) Average Occupancy	(7) BTU/ Pass. mile
Intraurban						
Private Auto	5.43[a]	2012(1354-2407)	5.43[a]	2012(1354-2407)	1.53[b]	7140(3541-9441)
Conventional Transit						
Minibus	19[c]	736	23	630	4.32[d]	3356
Full-size bus	50	707	75	472	11.83[b]	2990
Heavy rail	72	715	200	260	24.51[b]	2101
Light rail	68	662	151	298	20.5	2195
Trolley Coach	50	1300	75	867	14.00[e]	4643
Paratransit						
Dial-a-Bus	16[c]	755	20	604	1.36[f]	8885
Dail-a-Van	11	1313	11	1313	1.36[g]	10621
Taxi	6	1870	6	1970	0.68[h]	17379
Jitney(van)	11	1313	11	1313	4.0[i]	3611
Commuter						
Private Auto	5.43	1710	5.43	1710	1.4[j]	6633
Carpool	5.43	1710	5.43	1710	3.3[j]	2814
Vanpool	12	1083	12	1083	9.85[k]	1320
Bus	51	431	51	431	16.55[l]	1327

[a]Determined from estimated distribution of economy, compact and standard size cars by FHWA for 1975, with 4, 5, 6, seats, respectively for each type of car; from Highway Travel Forecast, FHWA, Nov. 1974, p. 34.

[b]See Table 6.

[c]Mercedes Benz minibus used with 19-seat configuration for transit and with 16-seat configuration for dial-a-ride.

[d]Calculated for Evansville, Indiana based on estimated transit trip length of 3.2 miles (See Table III-4) and reported passengers per vehicle mile of 1.35. From Misner, J. Small City Transit - Evansville, Indiana, service report to UMTA (UMTA-MA-06-0049-76-9), Reprint by UMTA, May 1976.

[e]Estimated as slightly higher than full-size transit bus, since it generally is available along higher density corridors.

[f]Estimated the same as dial-a-van.

[g]Calculated from reported passenger average trip time of 13 minutes and passengers per vehicle hour of 6.3. From Michener, W. and Waksman, R., Small City Transit - Ann Arbor, Michigan, Pilot Dial-a-Ride Project report for UMTA, March 1976.

[h]From Wells, J.D. and Selover, F., "Characteristics of Urban Taxicab's Transit Industry," Economic Characteristics of the Urban Public Transportation Industry, Institute for Defense Analysis, for U.S. Department of Transportation, February 1972, p. 8-26.

[i]Estimated average occupancy from Kirby, R.F., et al, Para-Transit: Neglected Options for Urban Mobility, The Urban Institute for UMTA and FHWA, 1974, p. 269.

[j]Trips to work from Nationwide Personal Transportation Study - Automobile Occupancy Report No. 1, U.S. Federal Highway Administration, April 1972.

[k]Unweighted average of actual occupancy for five systems (3-M, Aerospace, CONOCO, Cenex, Knoxville) using 12-passenger vans in commuter trips, under the assumption that all mileage is conducted at average occupancy. Data from Knoxville Commuter Pool and from Economic Feasibility of Independent Vanpool Operations, office of Energy Conservation and Environment, FEA, September 1976.

areas where bus occupancy can be considerably lower than the national average. The national average of bus occupancy is 11.83 passenger-miles per vehicle-mile, whereas the rates vary from about 6 to 14 passenger-miles per vehicle-mile from small-to-large urban areas (see Tables 6 and 7). When average occupancy of bus transit is not known for a given community, an occupancy rate obtained from Table 7 may be used as a default value to modify the energy consumption rate given in Table 5.

For the same vehicle technology, intraurban services re-

TABLE 6

AVERAGE VEHICLE OCCUPANCY

Mode	Weekday	Per Hour
Bus Transit	11.83	16.65
Automobile	1.53	1.28
Heavy Rail	24.51	34.17

Source: 1974 National Transportation Report. U.S. Department of Transportation, Washington, D.C. 1975.

TABLE 7

MEDIAN VALUES OF AVERAGE VEHICLE OCCUPANCY BY POPULATION CLASS FOR 1972

Bus Transit	Passenger Miles Per Vehicle Mile
Population Class (Thousands)	
2,000 and over	13.8
1,000 and under 2,000	11.8
500 and under 1,000	9.3
250 and under 500	5.6
100 and under 250	6.5
50 and under 100	6.2

Source: 1974 National Transportation Report: Urban Data Supplement, Wells Research Co. and Control Data Corp. for U.S. Department of Transportation, May 1976.

flect a lower occupancy than commuter trips for vans and buses because of the nature of services provided. Commuter pools are generally prearranged for most trips to have an approximate common origin and destination, while services like dial-a-ride with several origins or destinations incur extensive deadheading and waiting time. Transit buses operate through peak and off-peak periods, whereas commuter buses operate only during peak hours with close to full loads. For energy comparison, it is important to differentiate service characteristics provided by the vehicle. From column 7 of Table 5, vehicles that provide service on demand, such as the average private auto, consume 7,140 BTU per passenger-mile and taxis 17,379 BTU per passenger-mile. Jitneys, which are intermediate between demand-responsive and headway service, consume about 3,611 BTU per passenger-mile and are very close in efficiency to subcompact autos. The conventional transit bus uses 2,990 BTU per passenger-mile and is the lowest in energy consumption of noncommuter services, excluding electrically powered vehicles. In summary, of intraurban transportation modes only buses and jitneys are more efficient than the average auto, while dial-a-ride services and taxis expend considerably more energy.

Commuter services can be rendered by using the private auto, carpools, vanpools, express or commuter buses, and, in selected cities, jitney services. Unfortunately, little information is available to fully evaluate jitney service. A commuting private auto consumes about 6,633 BTU per passenger-mile, a carpool consumes about 2,814 BTU per passenger-mile, and a 12-seat van averages 1,320 BTU per passenger-mile and a commuter bus about 1,327 BTU per passenger-mile—all based on average occupancy levels.

In general, with average occupancy loadings and in intraurban usage a transit bus is 58 percent more efficient than an average private auto; but a more careful analysis is needed for urban areas with population under 500,000. For these urban areas, the average occupancy of buses can deviate substantially from the average figures quoted in Table 6. Nevertheless, the transit bus is only 16 percent more efficient than a subcompact auto, and some new subcompacts that can run 30 to 40 miles on a gallon of gas are more efficient than regular transit buses. Heavy rail, where available or feasible, on the average is much more efficient than any other mode, and additionally its energy can be obtained from nonpetroleum sources. It is a long-range alternative, however, and will not be discussed here.

Paratransit efficiency depends on the specific service provided. Taxi and dial-a-ride services, respectively, are 143 percent and 49 percent more energy consuming than the private auto; a jitney is 49 percent more efficient than the average private auto. On the other hand, the private auto used in commuter service is more energy consuming than paratransit commuting modes. In other words, carpools and commuter buses are 58 percent and 80 percent more efficient, respectively, than the private commuter auto.

As suggested by the occupancy comparisons, energy efficiencies can be improved to the extent that vehicle occupancies can be increased, disregarding any traffic generated because of a reduction of road congestion. This is particularly relevant for the private auto, since the urban auto is used for only 28 percent of its seated capacity. Perhaps more importantly, autos come in different sizes, from luxury to subcompact, ranging in average urban fuel economy from 9.0 to 24.0 mpg, respectively (*13*). Increased use of subcompact autos or increased fuel economy of all types of cars will decrease gasoline consumption in proportion to the change made.

All operating energy required to provide a service should be accounted for as a necessary expense incurred by all passengers. In addition to propulsion, maintenance, and station energy, some modes should consider access energy, or the energy to get to and from the service. For example, the use of private autos to get to a commuter bus stop should be regarded as an energy expenditure of the commuter bus service.

The use of energy consumption rates for the comparison of alternative services will be demonstrated through the scenarios presented in Appendix A.

OTHER FACTORS TO BE CONSIDERED

The energy consumption rates for different modes have been based on generalized conditions representing a typical or average community. More precise information can be obtained by considering the service provided and certain factors or characteristics of a given community.

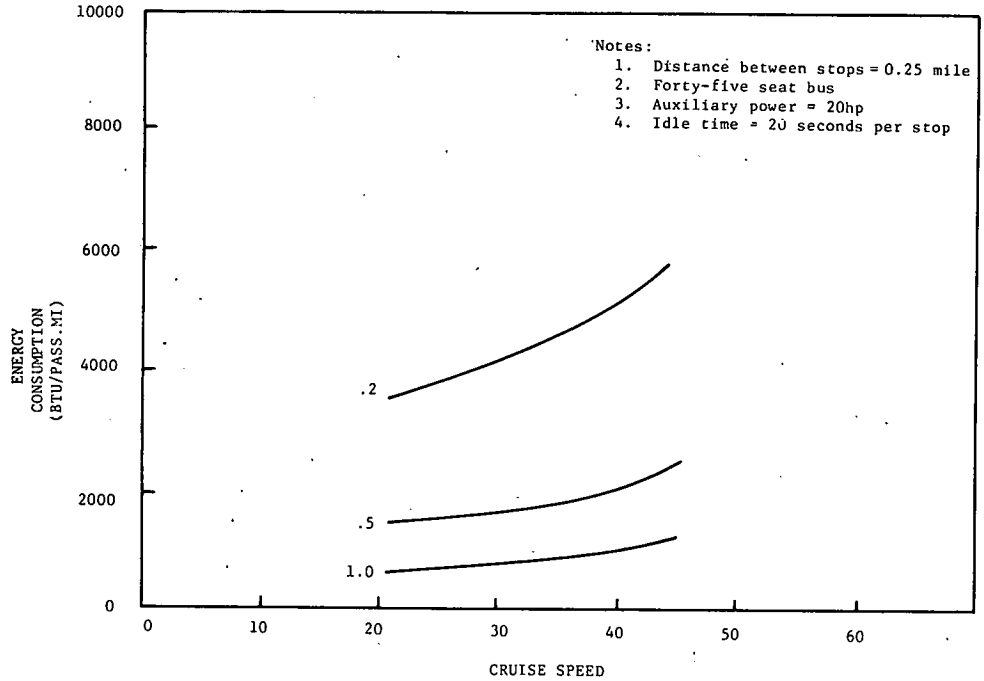
Effects of Speed, Trip Distance, and Load Factors on Energy Consumption Rates

A direct comparison of energy consumption for a specific service requires identification of those operating characteristics that influence each mode's intensiveness of energy consumption; for example, an express bus will have lower energy consumption rates than a local bus with frequent stops for the same length trip. Smylie (*20*) reports on a study performed in support of the Denver Rapid Transit District that cruise speed, distance between stops, and load factors are highly significant in determining the vehicular energy efficiency of mass transportation systems. In a comparison of six alternative transportation systems providing about the same type of service, conventional heavy rail transit was found to be significantly lower in vehicular energy consumption than automated guideway systems—but only about 25 percent lower than an extended bus system. The findings apply to Denver conditions only, but the means used to estimate operating energy is illustrative of the effects of operating conditions on energy consumption rates.

As prepared for the Denver study, Figure 4 shows energy consumption rates of regular transit buses for different cruising speeds at selected load factors (load factor is the proportion of passengers to seats). Figure 5 shows the effect of distance between stops at selected load factors for regular transit buses, which, also, affects the over-all speed of the transit service. Energy consumption for the bus concept ranges from 700 to 6,000 BTU per passenger-mile, depending on mode of operation (*20*). In general, energy consumption was found to be linear with respect to speeds up to about 45 miles per hour (mph). It is also linear with respect to distances between stops down to about ¾ of a mile, below which results become nonlinear because of the energy consumed by the idling engine and use of auxiliary power while stopped. The additional energy consumed during the acceleration phase then becomes a larger percent of the total. However, for longer separation between stops, energy consumption approximates the rate at cruise speed. Similar figures were prepared for heavy rail, for light rail, and for automated scheduled vehicles. They all support the principle that speed, as controlled by distance between stops and load factor, greatly affects vehicular energy consumption rates on a per passenger-mile basis.

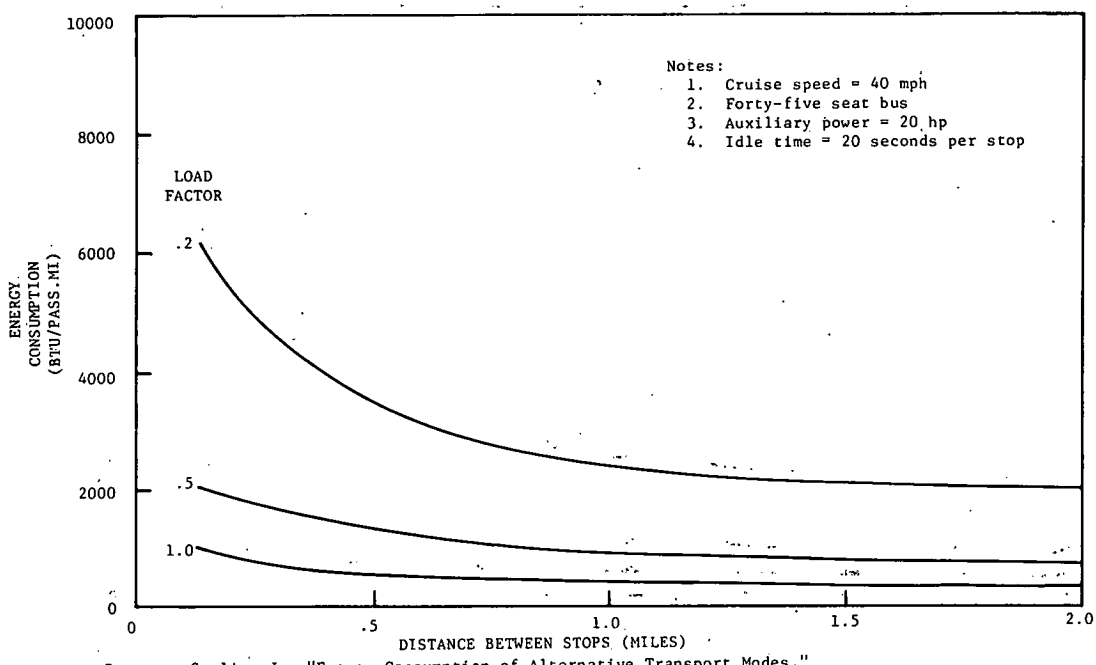
At a given level of demand, speed and equipment requirements introduce an additional trade-off problem. For example, an express run serving a 30-mile round trip may be provided with two bases operating at an average speed of 30 mpg and 30-minute headways. Yet, if those vehicles are able to operate at only 20 mph, because of factors such as street configuration, three vehicles would be required to maintain headways. Three vehicles consume more energy than two running at higher speeds. Figure 4 shows that energy consumption between 20 and 30 mph increases only marginally. Introducing a third vehicle increases energy consumption by close to 50 percent.

Smylie's curves do not address load factor as a continuous independent variable; load factor is used to deter-



Source: Smylie, J., "Energy Consumption of Alternative Transport Modes," Energy Conservation in Transportation and Construction, report on conference sponsored by the American Road Builders Association, Clemson University, Georgia Institute of Technology, and the National Highway Institute (FWHA), Atlanta, Georgia, December 1975.

Figure 4. Effect of cruise speed on energy consumption for buses.



Source: Smylie, J., "Energy Consumption of Alternative Transport Modes," Energy Conservation in Transportation and Construction, report on conference sponsored by the American Road Builders Association, Clemson University, Georgia Institute of Technology, and the National Highway Institute (FHWA), Atlanta, Georgia, December 1975.

Figure 5. Effect of distance between stops on energy consumption for buses.

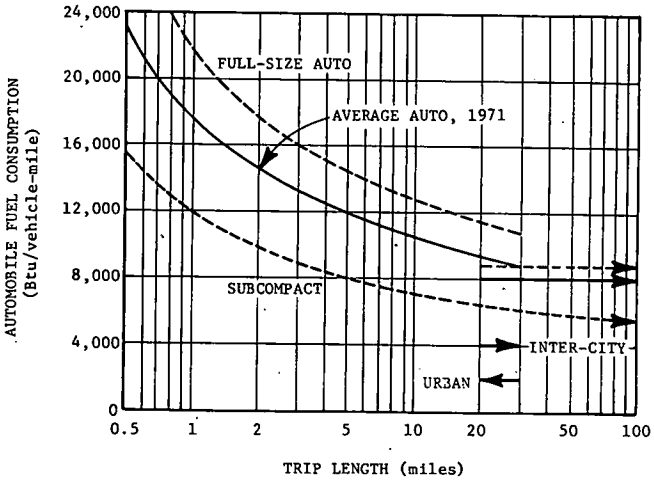
mine energy consumption rates based on cruising speed and distance between stops. Appendix A (under the heading "Scenario Three") shows this more clearly. The potential effect that loading levels may have on energy consumption rates may be confirmed from Environmental Protection Administration (EPA) data, which indicate that a 50 percent increase in the weight of an auto will increase fuel consumption by 33 percent, when operating under urban driving conditions (*21*). Some modern heavy rail vehicles approach a 45 percent increase in total weight at maximum capacity loading (not crush capacity) over the weight at average occupancy levels; the total weight of a conventional transit bus increases over 43 percent under similar conditions. A standard auto total weight would increase by less than 16 percent based on similar assumptions (heavy rail car weight used is 55,000 pounds, conventional bus weight used is 20,000 pounds, and a standard auto weight used is 4,000 pounds), and fuel consumption would not increase substantially. Further, unlike transit vehicles, the average auto generally has more power than it needs to operate under normal driving conditions and a full load requires very little additional energy.

Hirst (*22*) has analyzed energy consumption rates on automobiles, based on trip length, and has observed how fuel consumption is affected by speed changes, stop and go cycles, and cold start operations. Tests were conducted to determine 1971 fuel consumption rates for a full-size auto, an average auto, and a subcompact based on trip length. Urban congestion plus the fact that many autos do not fully warm up in trips below 10 miles in length (*22*) result in curves resembling those obtained for transit, as shown by Figure 6. Thus, the longer the trip, the less energy is consumed per vehicle-mile up to the point where a vehicle fully warms up. Table 8 shows trip length as it varies by population of an urbanized area.

It should be kept in mind that methods which consider speed, trip distance, and load factors require extensive use of computers for comparing entire systems. These factors severely affect energy consumption rates, and proper adjustments of previously presented average rates should be made to compare alternative services.

Peaking Characteristics

Peak-to-off-peak hour variation in occupancy levels will affect energy consumption rates, depending on type of service. Some transit trunk lines observe a dramatic increase in passenger loadings during the peak hours and probably operate at close to seating capacity. Such a condition would more than quadruple the average occupancy of a bus system operating through the whole day. However, route frequencies tend to be substantially increased during the peak hours and occupancy increases are less than expected. Nationwide, bus transit occupancy goes from 11.83 passenger-miles per vehicle-mile as a weekday average to 16.65 passenger-miles per vehicle-mile during peak hours—or about 41 percent (see Table 6). Yet, because of congestion, more frequent stops, and longer dwell times, the average speed of conventional bus service during peak hours is considerably less than off-peak hour speeds. Various bus speeds studies suggest a range of 23 to 27 percent peak-hour speed reduction for arterial streets and 17 to 29 percent for collector streets (*19*). On the basis of vehicle dynamics simulation studies conducted by Gen-



Source: Hirst, E., "Automobile Energy Requirements," Transportation Engineering Journal, American Society of Civil Engineers, November 1974.

Figure 6. Automobile fuel use per passenger mile as function of trip length, 1971.

eral Motors, decreasing the speed of a full-size bus from 15 to 10 mph increases energy consumption measured in gallons per mile by 30 percent, and a further decrease to 5 mph increases fuel consumption by an additional 78 percent (*19*). Assuming an over-all reduction in speed of 25 percent, from 12.5 to 10 mph, average fuel consumption should increase by at least 15 percent. In addition, maintenance of a larger bus fleet required to provide only peak-period service plus auxiliary facilities makes peak to off-peak variations in fuel consumption fairly small and probably negligible.

Data for heavy and light rail are not necessarily comparable to bus or auto data because of peaking characteristics of these modes. Rail system loading peaks tend to be much higher than those of highway-oriented ones. For example, BART service has been found to be over five times more efficient than the average auto during peak hours in the peak direction in the San Francisco to Oakland corridor. However, along the same corridor it is only about three times as efficient as autos during all hours of the day because of the much lower utilization during off-peak hours. As a statement of caution, BART energy savings that resulted from attracting auto users to a more energy efficient mode were offset by induced auto traffic due to reduced highway congestion, making total energy saving negligible (*17*).

Indirect Energy Uses

Over-all energy consumption comparisons may consider other indirect energy uses including construction of vehicles, guideways, and complementary facilities necessary for operation. Maintenance and operation of facilities for electrically powered systems have already been included in Tables 4 and 5, but construction of the system and of the vehicles is not included. Attempts to qualify indirect energy uses of autos and rail rapid transit have been made by various authors. Hirst (*23*) implies that auto manufacturing and highway construction account for about 23 percent as much energy expenditure as direct gasoline consumption by the auto. Curry (*24*), summarizing estimates made on BART rail transit, shows that construction energy may add from 50 to 100 percent as much direct energy as that required for vehicle propulsion, accessories, and live storage over a period of 50 years. (Other estimates for maintenance station energy, guideway construction, and vehicle manufacturing energy are available in *Urban Transportation and Energy: The Potential Savings of Different Modes,* Tables A-3 through A-5 (*25*).)

Indirect energy uses are highly related to other social and economic activities of the community. Accounting for manufacturing and construction energy as a transportation expenditure may be misleading at the community level, because many energy inputs come from outside the region and from various nonpetroleum sources. Transportation construction projects are generally multipurpose (e.g., for pedestrian movement and recreation; for allow-

TABLE 8

MEDIAN VALUES OF AVERAGE PERSON TRIP DISTANCE BY URBANIZED AREA POPULATION

Population (Thousands)	Average Trip Distance (Miles)			
	Automobile	Bus Transit	Rail Transit	Commuter Rail
2,000 and over	6.4	3.9	6.0	18.1
1,000 and under 2,000	6.5	4.6		
500 and under 1,000	6.0	4.0		
250 and under 500	5.4	3.1		
100 and under 250	4.8	3.2		
50 and under 100	3.5	3.0		

Source: Smylie, J., "Energy Consumption of Alternative Transport Modes, "Energy: Conservation in Transportation and Construction, report on conference sponsored by the American Road Builders Association, Clemson University, Georgia Institute of Technology and the National Highway Institute (FHWA), Atlanta, Goergia, December 1975.

ing handicapped access to activities; for the movement of goods and people to and from residential, business, and institutional areas). Different modes achieve these objectives to varying degrees. At the state and federal levels, construction and manufacturing energy is accounted for separately, and adding nonoperational transportation energy may result in double counting. Vehicle manufacturing is performed mainly by national industries whose activities have an impact on the national economy, depend highly on nonpetroleum energy sources, and continuously change their products and markets.

ENERGY CONSERVATION POLICIES

With the interest in achieving energy independence, various energy conservation strategies have been explored. A key area of emphasis has been to increase the demand for public transportation services by improving alternatives to private auto travel and restricting urban auto use.

The INTERPLAN report (*26*) prepared for UMTA, EPA, and Federal Energy Administration (FEA) has gone into great detail to analyze the results of specific actions required to implement energy conservation policies. The report ranks the impact of various policies at the national level based on average conditions and findings of U.S. cities and on the judgment of the consultant's team. It is difficult to evaluate alternative community policies because the results achieved will depend on the level at which a policy is implemented. The following are areas of interest and probable impacts.

Increase Regular Route Transit Capacity

This policy has low significance at the national and community levels. Increasing transit capacity means increasing vehicle-miles of transit service, but transit ridership increases at a lower rate than vehicle-miles. For example, nationwide transit service remained fairly stable in capacity during the 1965-75 decade, but until 1973 ridership kept going into a steady decline. During that decade operating costs increased from a break-even balance to an annual deficit exceeding over a billion dollars per year (*27*). It is through continuous capital and operating subsidies and/or through local government ownership that conventional transit companies have been able to survive and maintain services at previous levels. For smaller urban areas it must be questioned whether increasing system capacity will divert large numbers of travelers from their private auto and whether these communities can absorb the costs of increasing system capacities.

Attract Transit Ridership

Actions to increase transit ridership also have limited ability to conserve energy. This was the conclusion reached by INTERPLAN, even after using the assumption of a dramatic mode shift from auto to public transportation. INTERPLAN assumed that all projected auto travel between 1974 and 1990 would be redirected to transit and paratransit modes. However, the 1972 National Transportation Report (*28*) foresees only a 50 percent increase in transit ridership during the same period or about one-tenth as much as INTERPLAN's assumptions. Specific actions to increase transit ridership include expanding existing transit services and improving their quality through better accessibility, provision of transfer facilities, increased reliability schedules, provision of more and better information centers, reduced fares, active marketing of transit, improved integration with other modes, improvement in passenger security, and others.

There is little statistical evidence relating ridership increases with specific service improvements, and the information available for specific cities undergoing general upgrading of transit services is disappointing. San Diego increased annual bus vehicle-miles by 28 percent and ridership increased 19 percent for a demand elasticity of +0.7 to +0.8 (*29*). From July 1972 to July 1975, Atlanta increased annual bus vehicle-miles by 40.3 percent, while ridership increased only by 24.6 percent (*30*). In Atlanta's case, transit fares were lowered from $0.40 to $0.15, the transfer charge of $0.05 was eliminated, and extensive service improvements were introduced.

Even less is known about the true impact of attracting ridership to transit as a measure to conserve energy. San Francisco's BART experience supports this contention. Even though the system is considerably more efficient than the automobile on a per seat-mile basis and there exists considerable potential for energy savings on a per passenger-mile basis, the net energy savings are very small and almost negligible when considering the many new auto trips induced by BART (*17*). It is possible, however, that in smaller urbanized areas with a potentially lower latent demand for travel, the ability to attract auto riders to transit may bring different results.

Increase Paratransit Capacity

INTERPLAN (*26*) assumed that paratransit would serve 10 percent of total 1990 urban passenger-miles traveled. Yet, it was concluded that, even at this usage, the ability to conserve energy resources would not be very promising. Also, any attempt to increase paratransit capacity would require elimination or revision of regulatory and labor restrictions and the provision of capital and operating subsidies.

Paratransit energy efficiency depends on the vehicle and type of service provided. Commuter services appear to have the greatest potential for energy savings, including buses, vanpools, and carpools (see Table 5). Even with very efficient commuting pools, energy savings occur only if the vehicle left at home is not used extensively for other purposes. If the vehicle left at home is used for a few short trips, such as taking children to and from school and going to the grocery store, gas savings are considerably reduced because of the high rates of fuel consumption associated with short trips from a cold start. Also, a vehicle left behind incurs evaporative losses and still requires oil changes and other maintenance that consume energy. Energy used to access commuter pools by private autos should not be overlooked in establishing consumption.

Reduce Urban Auto Use

In general, this objective interacts with that to improve alternatives to private auto travel and has low significance in conserving energy resources. Policies to achieve a reduction in urban auto use are those to increase auto occupancy, increase the cost of auto use, and restrict zonal access. The major drawback to conserving energy by increasing occupancy is that as occupancy increases congestion decreases, and this induces new trips that previously were not made. However, this alternative has advantages in that it can provide door-to-door service with a fairly high degree of reliability and implementation costs are low. Besides, even the limited reduction in vehicle-miles traveled compares favorably with those obtained from other policies (*26*).

The policy to increase cost of auto use and, thus, decrease auto trips made relies on three actions: the implementation of road pricing techniques, the manipulation of parking costs, and the increase of fuel costs. This policy may have some significance in conserving energy resources at the national level and can have low to medium significance at the community level. By increasing the cost of auto travel to discourage its use, the policy attempts to encourage substitution of less expensive, higher occupancy, more energy efficient modes. Vehicle-miles traveled can be reduced almost proportionately to the extent that substitution occurs, but the negative impact on urban mobility caused by loss of freedom in the selection of alternate transportation services must be considered.

Increasing auto travel costs to reduce unnecessary auto travel can be achieved through concerted community actions. Exacting a toll from auto users going through congested sectors or bridges may be easy to physically implement at a community level, but may meet opposition from private and commercial interests. High parking charges may discourage auto travel to congested areas, but this is limited to lots that charge parkers and accounts for only a small portion of all parking space in urban areas. Eighty-five percent of all urban area employees and about 50 percent of all auto shopping trips utilize free or subsidized parking (*31*). Increasing fuel cost may be effective on a regional basis, but fuel prices have to be greatly increased or fuel rationed to be effective (*30*). Most importantly, all pricing increases need to be complemented by increasing the supply of alternative transportation services. Overall, there is limited information about net reduction in gasoline consumption because of road pricing techniques.

The restriction of access by private auto to specific zones is also estimated to have very low significance. Such a policy may be more effective in reducing air pollution in downtown areas than in reducing energy consumption. Zonal access can be restricted only in areas where alternate transportation services are available to provide substitution mobility. The effectiveness of this policy in reducing energy consumption is low and should be considered supplementary to other policies, such as those to increase transit and paratransit use, rather than as a primary measure to reduce energy consumption.

Reduce Vehicular Petroleum Consumption and Urban Travel Demand

These two separate objectives are grouped because policies to implement them are generally beyond direct community control, but their significance in energy consumption is so high that they warrant discussion.

Reduction of urban travel has important applications in the long run, but it has very low significance with short-term actions at community, state, and national levels. The approaches of this policy are the substitution of communications for travel and the encouragement of decentralized land-use patterns. Both are complementary, because the decentralization of land-use patterns would depend on the extent to which communications substitute for travel.

Reduction of vehicular petroleum consumption has very high significance from the national viewpoint. As found by INTERPLAN, it is probable that these policies to implement this objective most effectively will reduce energy consumption. However, specific actions to implement its policies are beyond most communities' control and will be primarily in the hands of federal and state governments. The most promising short-term policy is to improve vehicular fuel economy through the reduction of vehicle size and weight. As noted in Table 5, an average subcompact car yielding 24 mpg consumes only about half as much energy as the average auto, and about 18 percent more than a full-size transit bus. Yet, there are subcompact cars already on the market that are more fuel efficient than a bus, and this may represent a viable means for short-term reduction of petroleum consumption.

SUMMARY

Various policies have been proposed and are being implemented to promote more intensive use of transit and paratransit modes. Those policies attempt to satisfy community goals of reducing petroleum consumption, increasing urban mobility, and lowering transit operating costs.

Careful examination of proposed changes should be exercised at the community level to determine energy savings accrued by shifting auto travelers to transit and paratransit. The planner should consider economic levels and population demographics. Also, because of the operating requirements of conventional bus transit (e.g., deadheading and varying occupancy levels across the day), this mode is not necessarily more efficient in fuel consumption than some energy efficient private autos. Transit efficiency is related to urban area population; that is, passengers per bus-mile goes down as population decreases. Estimates based on national averages of bus usage probably overestimate the efficiency of bus transit in communities below 500,000 population.

Excluding taxi and dial-a-ride, paratransit on the average is as efficient as conventional transit, and its potential for satisfying community mobility seems higher than for transit. Nevertheless, like transit, savings in energy consumption depend on how much latent demand exists in a given urban area, and what is done with any private auto left

behind when transit or paratransit is used as the primary mode. The more promising policy to reduce petroleum consumption is to directly increase the mechanical efficiency of the various vehicles used in urban transportation. Yet, actions required to implement this policy are generally beyond the control of individual communities.

Average energy consumption rates can be used for preliminary comparison of modes when policies to encourage the change from the private auto to transit and paratransit are being proposed. As indicated by Table 5, BTU per passenger-mile is the measure that allows for direct efficiency comparison between modes. Occupancy levels different from those given in Table 5 can be locally obtained or, in the case of conventional transit, approximated from Table 7. Average auto occupancy does not vary significantly by population size but does depend on the particular community. Paratransit operators can adjust their services to match demand much faster than transit agencies and, excepting dial-a-ride, loadings remain fairly stable. Paratransit service occupancies can be assumed as given in Table 5, or for dial-a-ride can be approximated from similar services in other communities regardless of population size.

Community and specific system characteristics should be considered after preliminary screening of alternatives to analyze the effects of shifting to a specific mode. For example, the effects on energy consumption of shifting the private auto commuter to some other mode, such as peak-period express buses, should be analyzed considering factors, such as geographic location of corridors, periods of service, seating capacity of vehicles considered, etc. All these factors allow for a detailed comparison of modes serving a given market.

Over-all, any comparison in average energy consumption between alternative modes should consider the external effects of modal shifts, such as attraction of new trips. The additional energy expenditures required to operate the system plus effects on urban mobility, cost of providing public transportation, air pollution, and socioeconomic impacts should not be overlooked. A careful assessment of local conditions should be made to ascertain the applicability of generalizations to a given community.

CHAPTER FOUR

EFFECT OF PUBLIC TRANSPORTATION ON AIR QUALITY

Transportation's contribution to urban air pollution was first recognized as a major problem in the 1950s. In the 1960s, evidence showed that, under certain conditions of concentration and exposure, air pollutants can affect human health adversely and can damage or deteriorate vegetation and materials.

Congress became concerned and created legislation to control environmental pollution under the 1963 Clean Air Act. This act, with subsequent amendments, is of vital concern to transportation planners because it calls for federal interventions including the restriction of funds and the possibility of fines for noncompliance. Public transportation is a key control strategy for local planners to decrease automobile vehicle use and thereby reduce automobile emissions. In recent years, court cases have helped define the requirements of the act.

Air pollutants are emitted by mobile and stationary sources. Autos are the primary mobile source of these pollutants—while industry, housing, commerce, and power generation are stationary sources. Sixty percent of the air pollution of major metropolitan areas in the United States comes from transportation related emissions. The private auto accounts for 90 to 95 percent of transportation related pollution, or about one-half of all air pollution in major metropolitan areas (*32*).

Transit has been viewed as a potential solution for regionwide pollution problems, but its greatest contribution may come from reducing pollution in localized sectors where air pollutant levels exceed regionwide concentrations. Regionwide impacts are those affecting an urbanized area, sometimes extending beyond the urban boundaries. Localized impacts include those affecting an activity center, a transportation corridor or any sector that, because of topographic or man-made conditions, is subjected to higher levels of pollutant concentrations than regionwide averages. The same pollutants affect small sectors as well as urbanized areas, but vehicular emissions tend to create more severe problems of localized pollution than stationary sources. This chapter is concerned with pollutant emission rates by urban transportation vehicles and does not reflect regionwide effects that need to consider dispersion of emissions plus background concentration produced by other sources.

Several vehicular emissions have been identified as air pollutants; the five most important are carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulate matter. Carbon monoxide and hydrocarbons are emitted through the exhaust pipe and result from the incomplete combustion of fuel during the operation of internal combustion engines. Hydrocarbons are produced from the evaporation of fuel from the gas tank and car-

buretor. Nitrogen oxides are produced when the oxygen and nitrogen in the air combine under heat and pressure of the internal combustion engine. Sulfur oxides are formed from sulfur that remains in fuel after the refining process. Particulate matter, including lead from gasoline, is emitted through the exhaust system.

This analysis will consider only carbon monoxide, hydrocarbons, and nitrogen oxides because they are the principal components of auto emissions. Planners may be interested in all three pollutants or in any particular one that presents more serious hazards at a given location. It is important to realize that some vehicular emissions tend to create severe problems of localized pollution, while others might constitute a significant contribution to regionwide pollution. Carbon monoxide creates serious conditions, mainly around transportation corridors and at activity centers. Emissions of nitrogen oxides and some of the hydrocarbons combine after they are discharged into the atmosphere and are exposed to sunlight. This reaction results in photochemical smog composed of particulate matter, ozone, other oxidants, and complex organic compounds (*33*).

The generation of air pollutants by surface vehicles is a very complex process affected by such factors as hot to cold cycles, ambient temperature, stop and go operations, speed, and vehicle maintenance. However, the Environmental Protection Agency has developed procedures for determining expected emission rates from various vehicle types under several operating conditions (*34*). EPA methods require an understanding of their detailed procedures and very careful and extensive manipulation of tables to determine emission rates for any one mode. It is recommended that for detailed analyses the EPA procedure be consulted.

This chapter presents pollutant emission rates for various vehicular technologies operating in different kinds of services. This allows an examination of emissions between alternate urban transportation modes during the planning process. Intraurban services, such as conventional transit, are treated separately from commuter services because they represent different services to the user and emission rates vary substantially between them.

POLLUTANT EMISSION RATES

To be useful during the planning process, preliminary comparison of pollutant emissions between various urban transportation modes should be made as simple as possible. The heterogeneous mix of vehicles of different years of manufacture and average speeds of vehicles in a given type of service are important factors determining emissions. Emission rates for any year model are related to engine design and emission devices required by manufacturers to comply with EPA regulations. Average speed is related to engine efficiency and to the number of stop and go cycles that have been found to affect vehicular emissions. Considering these factors, emission rates for various urban transportation modes have been calculated using EPA methodology. Operating emission rates are presented for the private auto, nonelectirc transit, and paratransit vehicles. (Electrically powered modes have been excluded because they do not present a localized area pollution problem and, in general, constitute a long-range alternative.)

Table 9 gives emission rates by vehicle type stratified by service-urban area or commuter. The values shown have been computed following procedures outlined in *Supplement No. 5 to AP-42,* published by the Environmental Protection Agency (*34*). Carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOX) are all expressed in grams per vehicle-mile (gpm). Private auto, transit bus, and various paratransit emissions are quantified under different assumptions of vehicle mix and speed. All rates were calculated for 1978, and other estimates may vary depending on model mix and projection year.

The private auto, both urban and commuter, was assumed to follow EPA vehicle age distributions. Average speed of the private auto in urban operations is assumed as 19.6 mph, the base value used by EPA. The commuter private auto is assumed to travel at an average speed of 40 mph, including time lost in casual errands completed while traveling to and from work as noted in Table 9.

For conventional transit, only minibus and full-size bus transit are considered. Minibuses are assumed to be equally distributed among the most recent 6 years of production, and are assumed to travel at an average speed of 15 mph. Full-size buses are assumed to be distributed over a longer time period including buses manufactured prior to 1968, and are assumed to travel at an average speed of 13 mph (*35*). Paratransit includes both intraurban services, where all trips are made within the confines of an urbanized area; and commuter service, where trips are made exclusively for work, generally exceeding 10 miles in length and with few intermediate stops. A careful assessment of model mix and average speed has been made to correspond to average field conditions found in most U.S. cities. However, under different conditions of model mix and speed, somewhat different results may be obtained.

In urban traffic the average private auto emits 35.1 gpm of CO, 5.4 gpm of HC, and 3.5 gpm of NOX. Full-size transit buses emit 29.5 gpm of CO, 5.0 gpm of HC, and 22.2 gpm of NOX, while minibuses can be estimated at 50 percent as much for each pollutant. Note that full-size buses emit about the same level of CO and HC as autos, but that NOX emissions are several times higher than auto rates. Paratransit alternatives emit amounts close to those of autos for all three pollutants per vehicle-mile.

In commuter traffic the private auto emits 16.7 gpm of CO, 4.0 gpm of HC, and 4.0 gpm of NOX. For commuter traffic, CO and HC emissions are 52 percent and 26 percent lower, respectively, than those of the urban auto; and NOX emissions are 14 percent higher because of the difference in average operating speed. Of the paratransit alternatives, carpool and vanpool vehicles produce roughly the same amounts of CO and HC as the private auto in commuter service, but vans emit about 43 percent more NOX than the private auto because this pollutant is not currently controlled for large vans. Commuter buses produce 38 percent less CO and 30 percent less HC, but 48 percent more NOX, than private autos engaged in commuter service.

Nevertheless, emissions per vehicle-mile are not a very

TABLE 9

VEHICULAR EMISSION RATES

Service Type & Vehicle (1)	Model Mix (2)	Speed (mph) (3)	Emissions (grams/mile) CO (4)	HC (5)	NOX (6)
Private Auto					
Urban	All Yrs.	19.6	35.1	5.4	3.5
Commuter	All Yrs.	40	16.7	4.0	4.0
Conventional Transit					
Minibus (0.5 full-size estimates)	6 Yrs.	15	14.8	2.5	11.1
Full-size	All Yrs.	13	29.5	5.0	22.2
Paratransit					
Urban:					
Dial-a-Ride	4	15	37.8	5.7	4.5
Taxi	8	19.6	31.8	5.0	3.5
Jitney	6	19.6	37.1	5.8	4.9
Commuter:					
Carpool	All Yrs.	40	16.7	4.0	4.0
Vanpool	6	40	16.8	4.2	5.7
Bus	12	40	10.4	2.8	5.9

meaningful procedure to differentiate between modes. Emission rates at some level of personal mobility, such as passenger-miles, may provide a better measure for evaluating over-all emissions at a given location or area.

Emission Rates per Passenger-Mile

Rates obtained on a per vehicle-mile basis may provide a distorted view of over-all emissions. As noted in Table 9, CO emissions for an urban private auto are not much different from those for jitneys (less than 6 percent); yet, a full-size auto has a maximum seated capacity of 6 passengers, whereas a jitney accommodates 11 or more seated passengers, depending on design.

Table 10 presents emissions per passenger-mile. Comparisons between modes can be made on the basis of emission rates alone or on the basis of total emissions for any specific service of interest. Yet, to determine total emissions, additional information about trip makers and vehicle trips may be needed. Column 1 identifies the various modes considered, categorized under urban or commuter. Columns 2 and 6 specify vehicle loading assumptions for maximum capacity and average occupancy levels, respectively.

Columns 3, 4, and 5 of Table 10 present computed emission rates for CO, HC, and NOX based on maximum load capacity, expressed in grams per passenger mile (gppm). The average private auto in intraurban service produces 6.5 gppm of CO, 1.0 gppm of HC, and 0.6 gppm of NOX. In contrast, both large and small diesel buses emit below one-tenth as much as the private auto of each of the three pollutants under the maximum capacity assumption. All gasoline-powered paratransit vehicles emit at least 50 percent as much as the private auto; the taxi is the worst of this group, emitting about 80 percent as much pollutants as the private auto. (Note that in these comparisons all model emissions are expressed as a percent of the private auto emissions.)

Of commuter vehicles, the private auto emits 3.1 gppm of CO, 0.7 gppm of HC, and 0.7 gppm of NOX. Compared to the private auto used in urban trips, the commuter auto produces less than 50 percent of the amount of CO, 70 percent of HC, but slightly more NOX, provided all seats are occupied. Vanpools emit about 45 percent as much CO, and below 70 percent as much HC and NOX as the commuter auto. Full-size commuter buses produce below 7 percent as much CO and HC and below 15 percent as much NOX as the private commuter auto under the maximum capacity criteria. Under these criteria the private auto seems to be the worst polluter for both categories, while buses rate the best.

All of the foregoing comparisons are made under ideal conditions where vehicles are always loaded to maximum capacity. This represents only a gross comparison of maximum potential for improvement, because vehicles generally do not operate fully loaded in all directions. Average

TABLE 10

EMISSION RATES PER PASSENGER-MILE

Mode (1)	Maximum Capacity (2)	CO grams per passenger mile (3)	HC grams per passenger mile (4)	NOX grams per passenger mile (5)	Average Occupancy (6)	CO grams per passenger mile (7)	HC grams per passenger mile (8)	NOX grams per passenger mile (9)
Urban								
Private Auto	5.43	6.5	1.0	0.6	1.53	22.9	3.5	2.3
Conventional Transit:								
Minibus	23	0.6	0.1	0.5	4.32	3.4	0.6	2.6
Full-Size	75	0.4	0.1	0.3	11.83	2.5	0.4	1.9
Paratransit:								
Dial-a-Ride	11	3.4	0.5	0.4	1.36	27.8	4.2	3.3
Taxi	6	5.3	0.8	0.6	0.68	46.8	7.4	5.1
Jitney	11	3.4	0.5	0.4	4.0	9.3	1.5	1.2
Commuter								
Private Auto	5.43	3.1	0.7	0.7	1.4	11.9	2.9	2.9
Carpool	5.43	3.1	0.7	0.7	3.3	5.1	1.2	1.2
Vanpool	12	1.4	0.4	0.5	9.85	1.7	0.4	0.6
Bus	51	0.2	0.05	0.1	16.55	0.6	0.2	0.4

occupancy loadings are more realistic to determine air pollutants emitted into the atmosphere in the provision of a specified service. Variations from average loadings can and do occur, but emission rates can be adjusted accordingly if local operating conditions deviate significantly from the stated averages.

Column 6 of Table 10 shows average occupancy of different modes expressed in terms of passenger-miles per vehicle-mile. Columns 7, 8, and 9 show the computed values of CO, HC, and NOX emissions, respectively, based on average occupancy loading. The average private auto in urban service produces 22.9 gppm of CO, 3.5 gppm of HC, and 2.3 gppm of NOX. Diesel buses and minibuses emit below 15 percent CO and 18 percent HC as much as the private auto; however, NOX emissions are roughly the same.

Paratransit alternatives differ widely under this alternative. Dial-a-ride vehicle emissions are all higher than for the private auto but within a 50 percent range. Taxis have the worst performance, emitting more than twice as much of each pollutant per passenger-mile as the private auto. On the other hand, the jitney produces below 50 percent as much pollution per passenger-mile as the private auto. Compared with diesel buses, the jitney emits more CO and HC but less NOX.

CO and HC emissions per passenger-mile are considerably reduced by the various commuter modes compared to the same vehicle technologies used in urban traffic. Comparing emissions on this basis, the average private auto in commuter service produces about 52 percent as much CO and 83 percent as much HC as the private auto in urban usage. Carpools use the same vehicle technology; yet, they produce less than 43 percent as much CO and HC as the commuter private auto. Vanpools produce less than 14 percent as much CO and HC as the commuter private auto; commuter buses produce even less, or below 7 percent as much as the commuter private auto. NOX emissions per passenger-mile for the private auto in commuter use increase by about 26 percent over those of the urban auto; yet, carpool, vanpool, and commuter bus observe a decline of over 50 percent compared to their respective technology in urban usage. Compared to commuter autos, carpools emit only 41 percent as much NOX, vanpools 21 percent as much NOX, and commuter buses only 14 percent as much NOX on a per passenger-mile basis.

Determining emissions per passenger-mile allows for mode comparisons based on equal service to users. Average occupancy factors reflect actual usage of modes rather than theoretical capacities and allow for more realistic determination of emission rates. Under the average occupancy criteria, it has been demonstrated that diesel buses produce less CO and HC than all other modes per passenger-mile. However, in intraurban service the jitney is lowest in NOX emission rates, and taxis are by far the worst polluters followed by dial-a-ride and private autos. In commuter trips autos are the worst offenders.

Understanding local air quality conditions by specific pollutant is required before proposing the use of any one mode to reduce air pollution problems. Full-size transit buses are not necessarily the least polluting option, particu-

larly in smaller urban areas where average occupancy is much lower than the average for all urbanized areas. (Evaluation of air pollutant emissions by mode is demonstrated in Appendix B through the use of scenarios.)

OTHER FACTORS TO BE CONSIDERED

Vehicular pollutant emission rates have been introduced as represented by typical communitywide conditions. A planner needs to consider particular pollution characteristics of a given city in relation to specific services proposed. This may require a more thorough understanding of services, including specific areas and routes to be served, schedules or periods of service, specific vehicles being considered, average speed along corridors traveled, traffic conditions during periods service will operate, weather, etc. This level of analysis is generally conducted after a preliminary screening of alternatives.

Appendix D of Ref. (34) provides the methodology to calculate projected composite emission factors based on the Federal Test Procedure (FTP). This procedure can be outlined by the formula:

$$\text{Emissions} = (\text{Avg. Emissions})\ (\text{Model Mix Factor})\ (\text{Travel Factor})\ (\text{Speed Factor})\ (\text{Temperature Factor})\ (\text{Hot/Cold Cycle Factor}) \quad (1)$$

where Emissions are in gpm for projected year; Avg. Emissions are tabled values based on the FTP; Model Mix Factor accounts for emission controls available in vehicles manufactured during various years; Travel Factor accounts for vehicle model usage; Speed Factor accounts for variations in road or service speeds; Temperature Factor accounts for a geographic characteristic; and Hot/Cold Cycle Factor accounts for operating characteristics.

Emissions shown in Table 9 result from computations based on FTP emissions adjusted for model mix, travel by mode, and speed variations depending on type of service. Temperature corrections and hot/cold cycle corrections were not included because both depend on average temperature which is a geographic factor. EPA is now in the process of distributing a computer program and a revised manual (*36*) that includes correction factors for air conditioning, vehicle load, humidity, and combinations of the previous factors. (Those interested in preparing a precise analysis of air pollutant emissions considering specific local conditions are encouraged to read *Supplement No. 5 to AP-42* (*34*) and *Mobile Service Emission Factors* (*36*).)

Vehicular emissions are partially related to the operating efficiency of the internal combustion engine. Fuel consumption per vehicle-mile decreases with increasing average speed until it levels off at about 45 mph; beyond that speed fuel consumption increases. Speed correction factors for CO and HC also decrease with increasing average speed, but begin to level off at average speeds beyond 60 mph. For gasoline-powered engines, NOX increases as average speed increases; for diesel-powered engines, NOX decreases with increasing average speed. These relationships between pollutants and average speeds can be seen in Figure 7.

Further, stop and go cycles are closely related to average speed for any roadway type. Emissions, as well as fuel consumption, are lowered by a reduction in the number of acceleration/deceleration cycles or increasing average speeds. Yet, when all acceleration/deceleration cycles are eliminated, average speed is the same as steady state speed. It then occurs, as shown in Figure 7 from actual tests, that emissions of HC at steady state speeds change very little within the range of 20 to 70 mph. Under steady state conditions, CO emissions decrease from 20 to 30 mph; but, for speeds greater than 30 mph, CO emissions continuously increase with increasing speeds. Thus, steady state speeds can significantly alter the previous assumptions and bring about completely different results from estimates based on EPA methodology. Applications for steady state speeds are limited, but the concept should be considered for modes using exclusive rights-of-way.

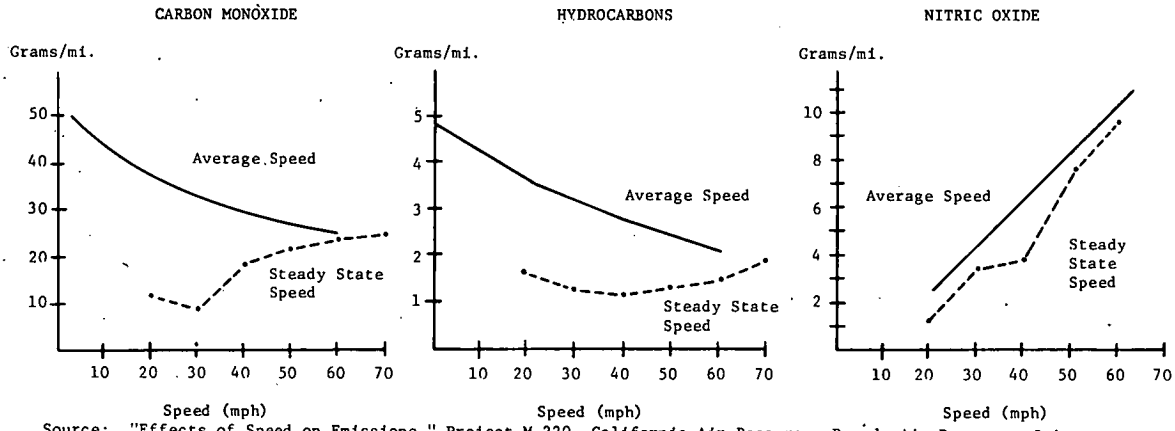
Temperature variations that influence fuel consumption also affect emissions. NOX emissions increase as the temperature goes down. Yet, temperature variations also influence emissions of CO, HC, and NOX through the hot to cold cycles. Trip distance and traffic characteristics, which have also been found to affect fuel consumption (*32*), are indirectly considered by the composite method of EPA in the hot to cold cycle correction factors. The computer model available from EPA considers trip distance and traffic characteristics as well as other variables that reflect specific operating conditions.

Location factors affect pollutant generation and reactions in the atmosphere. Besides pressure and temperature, which influence combustion inside engines, weather conditions affect dispersion and reaction of pollutants in the atmosphere. Emissions of NOX and some hydrocarbons combine after they are discharged into the atmosphere and exposed to sunlight. Results of this reaction are photochemical smog composed of particulate matter, ozone, other oxidants, and organic compounds (*33*). Thereby, air pollution effects in Los Angeles do not follow the same chemical reactions as in New York City, because the effects in the environment are different. It is possible for some cities to suffer from severe carbon monoxide pollution downtown or along major corridors, while the rest of the urbanized area maintains acceptable air quality conditions. Further, the effect of air pollution may be more pronounced for people working outdoors than indoors in areas where buildings are maintained quasiairtight (*38, 39*).

Finally, air pollutants affect people in different ways at given stages of their lives or under various health conditions. Young persons, elderly, people with respiratory problems, or those undergoing strenuous conditions tend to be adversely affected by high levels of air pollution more than healthy middle-aged persons. Factors affecting human health have not been discussed here, but should be kept in mind by those looking for answers to localized air pollution problems that affect a known sector of the population.

AIR POLLUTION CONTROL POLICIES

Vehicular emissions create localized problems of air pollution along corridors and activity centers, and in some urban areas they contribute significantly to regional air pollution. Recent strategies to cope with this problem have been to promote transit and paratransit alternatives, to



Source: "Effects of Speed on Emissions," Project M-220, California Air Resources Board, Air Resources Laboratory, Los Angeles, California, March 1971.

Figure 7. Emissions of CO, HC, and NOX as a function of speed.

discourage use of low occupancy autos, and to reduce emission of vehicular air pollutants.

A recent study undertaken by INTERPLAN (*26*) has approached this problem by looking at joint actions between UMTA, FEA, and EPA under the goals of improving urban mobility, conserving energy, and reducing air pollution. Evaluation of alternative community policies is difficult because implementing actions often produce synergetic effects. No attempt is made here to propose new policies, but rather to rely on those related to transit and paratransit that already have received extensive discussion.

Increase Conventional Transit Capacity

Since the inception of UMTA's capital grant program in 1964, many of those funds have gone to replace aging vehicles and, more recently, to expand service. Increasing bus-miles since 1972 (*40*) clearly establishes this new trend to increase capacity as well as service. Yet, the number of bus-miles has increased about 50 percent faster than the number of bus passengers, which implies declining productivity of bus service. Operating subsidies now exceed one billion dollars. Conventional transit continuously and increasingly depends on capital and operating subsidies to maintain or expand services. In smaller urban areas, the over-all effectiveness of service increases in attracting riders is questioned as well as the ability of those communities to absorb increasing operating deficits. Further, the effectiveness of reducing air pollution along corridors or activity centers may be more dependent on other policies than on increasing transit capacity. These sectors usually are served much better by transit, and additional transit services are intended to increase capacity in less dense areas. This policy was judged to have low significance in reducing urban air pollution problems.

Attract Transit Ridership

Specific actions to increase transit ridership include service improvements through more and better service, reduction of fares, institution of marketing programs, improved transit integration with other modes, and improvement of passenger security. Service improvements and fare reductions are short-range actions that deserve attention. However, there is little statistical evidence relating ridership increases with specific service improvements. Information available for Atlanta and San Diego indicates that the elasticity of ridership to bus-miles ranges from 0.3 to 0.8. These elasticity indices were obtained at the same time that fares were being reduced and service improvements implemented. Demand appears consistently more sensitive to in-vehicle time than to fare changes. Time elasticities have been identified as varying from —0.6 to —1.3 by various studies (*26*). Over-all, transit service improvements seem to produce very little reduction in auto mileage and, consequently, little reduction in air pollution. Combined strategies, however, such as improved transit service plus restricted zonal access, may prove more promising in reducing some air pollution problems.

Increase Paratransit Capacity and Use

Specific actions to increase paratransit services include providing implementation guidance, providing capital and operating subsidies, and eliminating market and labor restrictions. Local agencies can provide or obtain information on organization and implementation guidelines to give both public and private organizations interested in paratransit services a better chance for successful operations. Capital and operating subsidies may be needed to start operations or to improve existing systems. However, the labor protection provisions of the Urban Mass Transportation Act discourage private operators, who can run efficient or effective services like jitneys and taxis, from applying for aid. Those restrictions favor conventional transit operators in providing new services, even though the same service may be provided by a private paratransit operator at lower cost. Paratransit effectiveness in reducing air pollution depends on the vehicle technology, on service provided, and on the extent to which auto vehicle-miles are substituted for paratransit services. Commuter and intraurban paratransit

services, with the exception of dial-a-ride and premium service taxis, are promising alternatives to the private auto in reducing air pollution.

Improve Vehicular Flow

Traffic improvement to increase average speed and reduce stop-and-go operations is a common action taken to reduce congestion and is now viewed as a useful method for reducing pollutant emissions. Once congestion is reduced, traffic control improvements encourage long-term increases in vehicle-miles of travel that may outweigh any short-term improvements in air quality. In a study by the Institute of Public Administration (*41*), actual cases are presented of improvements in which emissions declined for the first two to four years but, afterwards, because of the induced traffic, became higher than if no traffic flow measures had been implemented. It was concluded that "traffic flow improvements should be viewed only as extremely short-term measures for reducing air pollution, unless traffic volumes can be reduced or restricted."

Other Supportive Policies

Increasing the cost of auto use and restricting zonal access are two independent policies that directly restrict mobility. Increasing the cost of using autos seeks to discourage private auto use and to encourage substitution of more efficient, less polluting modes and to reduce travel through congested sectors or sites with air quality problems. The effectiveness of this policy, as suggested by INTERPLAN, to control air pollution in specific sectors seems to be moderate, but the negative impact on urban mobility must also be considered.

Restricting zonal access more directly controls air pollution concurrent with increasing pedestrian mobility and safety. It is less dependent on consumers' choice for its effectiveness but can be implemented in sectors where alternative transportation modes (including walking) can easily be substituted for the excluded autos by creating pedestrian areas or by dividing a sector into a number of zones where traffic can access through only one point. Orski (*42*) comments that excluding vehicles effectively reduces street-level concentration of pollutants, particularly CO, but will contribute little to improving over-all urban air quality that results from thousands of vehicles throughout the metropolian area.

SUMMARY

Despite recent advances in controlling air pollution, there are still many urbanized areas that do not meet national air quality standards because of transportation related emissions. Several policies have been promoted to reduce vehicular emissions and to shift people away from autos into conventional transit and paratransit modes.

Proposed changes to transit and paratransit should be carefully analyzed to determine probable reductions in pollutant emissions before embarking into projects, because some may actually worsen air quality. Because of the operating requirements of some modes (e.g. deadheading, slow speeds, empty scheduled runs), they are not necessarily less polluting than a private auto on a per passenger-mile basis. Slower average speeds increase emissions of CO and HC in all modes, and of NOX in vehicles using diesel fuel. Deadhead mileage and nearly empty runs contribute to emissions, but increase passenger-miles very little. This is typical of most conventional transit and some paratransit modes. Because average occupancy of transit services in medium-to-small-sized urban areas is much lower than the national average, care should be exercised not to underestimate pollutant emissions with these modes.

It is important to understand the relationship between types of pollutants and air pollution problems. CO tends to create problems of localized pollution, whereas HC and NOX contribute more to regional air quality degradation. Of intraurban services, taxis, dial-a-ride, and autos are the largest emitters of CO per passenger-mile. Conventional transit and jitneys are lower emitters of CO and constitute better alternatives to provide services at locations suffering from high concentrations of that pollutant. On the other hand, regional pollution problems need to be viewed as the combination of transportation emissions and emissions from stationary sources. Commuter buses are lower emitters of all three pollutants, but access modes need to be accounted for to provide full disclosure of all emissions.

Emission rates have been presented on the basis of average occupancy levels. Characteristics of the community and of the mode being proposed should be considered after preliminary screening of alternatives. Introducing factors, such as temperature, corridors or areas to be served, periods to be served, loading factors, seating capacity, and the like, will allow for a more precise comparison between alternatives serving specific markets.

In general, any comparison between modes should start by considering the principal objectives of providing a particular transportation service. Community goals, such as urban mobility, reducing energy expenditures, and particular social and economic objectives, should not be overlooked. The effectiveness of particular policies and their implementing actions should be measured against how well they satisfy community goals.

CHAPTER FIVE

EVALUATION OF ONGOING TRANSPORTATION SERVICES

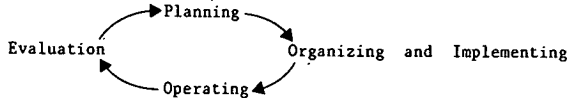
In addition to attempting to identify impacts resulting from the provision of transit service, the planner must be concerned with the services that are being provided. In this chapter, evaluation is concerned with the periodic judgment of ongoing transportation systems. The primary purpose of evaluation in this context is to provide a review of system efficiency and effectiveness. This is only one of several types of evaluation. Evaluation might, for example, have a primary goal of determining if a major transportation system, once built, is a good investment. Alternatively, evaluation can be viewed as the beginning of the planning process in which transportation needs of existing and potential markets are evaluated along with present transportation modes.

Both these types of evaluations are beyond the scope of this chapter. Rather, present analysis begins with the assumption that the comprehensive transportation planning process has been accomplished and that the system resulting from this over-all transportation plan has been in operation long enough to provide data for the evaluation.

EVALUATION AS A CONTINUING MANAGERIAL ACTIVITY

Evaluation has been discussed in the context of selecting a new transit service concept, but, in any organized activity, evaluation is needed to provide information to decision-makers concerning the efficiency and the effectiveness of operations. The feedback from evaluation serves as the basis for reexamination of goals, reformulation of plans, reallocation of resources, and development of new services if necessary.

Thus, evaluation should be viewed as a continuing part of the management process as follows:



Ideally, evaluation is a continuing managerial activity. Because of organizational structure, evaluation frequently gets less attention than is needed. Thus, there is a need in any organization for periodic systematic evaluation. This chapter attempts to facilitate the evaluation process, to improve the quality of evaluations, and to make evaluation more productive in accomplishing its major purpose—that of providing decision-makers with information that will be used to improve the effectiveness and efficiency of public transportation systems.

THE GROWING NEED FOR EVALUATION AND CHANGING SCOPE

The shift of many urban transportation systems from private to public ownership has increased the need for evaluation and dramatically changed its scope. One of the great advantages of private enterprise is that it provides the discipline or incentive for managers to engage in evaluations. Private enterprise managers receive an over-all evaluation of their operations in the form of an income statement, which both reflects the customers' evaluation of the services and provides a measure of organizational efficiency. If services provided are not needed, or if low efficiency increases costs, feedback from the income statement signals that something is wrong and, thereby, provides a strong incentive to private enterprise managers to evaluate organizational activities.

One of the major disadvantages of private enterprise transportation systems, however, is that the criteria for evaluation do not include social costs or social benefits that may accrue from increased population mobility; lower levels of air pollution; or lower demands for energy, highways, and parking facilities that transit systems may provide but for which they do not collect fares. If customers are not willing to pay for service at a price that will cover costs (including return), the classic verdict of private enterprise evaluation is that the service should be eliminated.

This limited nature of private enterprise evaluation has special relevance for the state of the art in evaluation of transportation systems. Because of years of experience and the relatively "hard" nature of evaluation criteria, evaluation from a private enterprise point of view is fairly mature. Certainly, difficulties in measurement, interpretation of data, and the existence of a variety of strategies to meet transportation needs create difficult challenges for the evaluation of transportation from the private enterprise viewpoint. However, when transportation systems become public property, the evaluator's task becomes even more difficult. Because it is generally accepted that transit systems operate at a deficit, the valuable discipline of an income statement is lessened. The evaluator must measure social benefits along with and against more quantifiable elements of revenues and costs. Not only are there more criteria on which to base an evaluation, but the criteria are more difficult to measure and often tend to conflict (i.e., more service and lower cost). To further compound the evaluator's task, the state of the art of evaluation of public transportation is not as well developed as that of private systems.

STATE OF THE ART OF EVALUATION OF PUBLICLY OWNED TRANSPORTATION

The state of the art of evaluation of public transportation systems has not kept up with the growing industry. In fact, typically, an urban system primarily using buses does

not evaluate at all. The more advanced urban areas developed standards of service that considered such variables as route spacing, headways, and frequency of service in relation to population density. For the most part, these standards were based on the underlying assumption that if such services were provided, people would use the services. It was also assumed that the benefits to the community resulting from increased mobility of transit dependents, lower levels of congestion, lower levels of pollution, lower levels of energy consumption, and reduced need for facilities would exceed the cost of the service—heroic assumptions, indeed. As noted previously, these assumptions are subject to analysis, and trade-offs frequently occur. It is patently true that the goals involved make the criteria for evaluation difficult to develop and even more difficult to measure. However, the need for evaluation still exists.

One approach used in the present project was to examine the evaluation of social action programs in fields other than transportation. Because of the growth in number and size of publicly supported social action programs in recent years, demands for evaluation by funding agencies, Congress, and the taxpaying public have resulted in increasing attempts to evaluate such programs. Because such evaluations are concerned with social benefits, this field seemed a likely source of guidance in developing evaluative procedures for urban transportation systems. The following major points emerge (*43*):

1. Accurately predicting outcomes of programs aimed at accomplishing social change and benefits to society at large is different. Results for any particular program may range from nothing to spectacular results far exceeding expectations.
2. Administrators of such programs generally have negative incentives to engage in meaningful evaluations based on results-oriented "hard" criteria.
3. Meaningful evaluations conducted by outsiders are desirable if public funds are to be wisely spent.
4. Because of severe problems in measuring outcomes and in isolating the effects of a particular program from those resulting from other factors in the environment, the only way to properly evaluate programs is to follow basic sound principles of experimental design. That is, one must measure criterion variables on groups in the program and a control group not in the program. Measurements should be taken both before and after the program begins.
5. Perhaps more than anything else, what is needed to accomplish these difficult standards for meaningful evaluation is a philosophy that treats programs as experiments; that is, a philosophy that accepts the fact that many programs, especially innovative ones, will fail. Thus, evaluation is an essential part of any program. Systems and criteria for evaluation need to be built into the program itself. Program planners, managers, and evaluators need to adopt a viewpoint that considers any program as a trial solution.

Not all of the foregoing conclusions drawn from the literature on evaluation of social programs are completely applicable to the evaluation of transportation services. In particular, the suggestion that "programs are experiments" would be largely impossible to apply to many capital intensive, fixed transportation systems such as BART. On the other hand, some of the conclusions reached by evaluators of social action programs are applicable to transportation. These conclusions, combined with conclusions drawn from management literature on evaluation in the private section (*45*), and previous work on evaluation of public transportation (*46*), lead to the following set of general principles for evaluation of transportation services.

EVALUATION PRINCIPLES FOR PUBLIC TRANSPORTATION

Improve Effectiveness and Efficiency of System

The basic purpose of evaluation should be to improve the effectiveness and the efficiency of the transportation system. The evaluation process should be objective and fair. It should not be designed to substitute for a financial audit of operating results or to expose embezzlement or incompetence. On the other hand, evaluation should not be a public relations device to win plaudits for transportation planners, elected officials, and/or transportation operators. The evaluation should concentrate on operating results of the transportation system. In so far as possible, the evaluator should allow the facts to speak for themselves, and assure that resulting interpretation and elaboration have a factual basis.

Practical but Experimental Viewpoint

Effective evaluation should be enhanced by an experimental, pragmatic point of view. Planning is important—so important that it deserves considerably more input, thought, effort, information gathering, and analysis than it usually has received in the past. Although quality planning is necessary, it alone is not sufficient to assure the most effective transportation system for a number of reasons.

First, transportation systems are increasingly complex. The number of variables that logically should be considered, the array of alternative ways to provide transportation, and the trade-offs between levels of service and costs all combine to create a virtually infinite number of solutions to any area's transportation problems. As advanced and sophisticated as transportation planning is or may become, planning alone will not provide the truly optimum solution. Not only are the number of variables high, but they change with time, and many variables are subject to measurement error. For example, surveys of intent to use a new transportation service may or may not predict actual use.

The point of the preceding discussion is not to downplay the importance of planning, but to suggest that any transportation system or any particular element in a transportation system, resulting from any planning process should be viewed as a trial solution. Any transportation system, especially a new one or an innovative addition to an older one, is an experiment; the evaluator's job is to use the data generated by that experiment to improve the solution. The critical test is the pragmatic one—does it work?

Planners often become enamored of their plan. Public officials and system operators often become committed to a plan because it was prepared by experts and cost a lot of money. Furthermore, having campaigned vigorously to "sell" the plan to others, planners, public officials, and system managers tend to see it as "the solution." It is

psychologically difficult for such individuals to view the plan as a trial solution, but evaluation would be much easier if they could. Because this philosophy of judging systems by outcomes (rather than inputs) is so difficult for most parties associated with transportation systems to accept, evaluators must adopt the philosophy as fundamental to their endeavors.

Planning Process Generates Evaluation Criteria

The criteria for evaluation should result from the planning process.

> Each urban community must define its public transportation mission. The crux of the mission/goal task is determining what the role and scope of public transportation is to be in the community. There is no one mission that is best. Rather, each community must decide what public transportation is intended to accomplish in terms of market/service mix (*44*).

It follows from this statement that there can be no standardized set of criteria on which evaluation can be based. Different communities will define the role and scope of their transportation systems differently. Some will emphasize economic criteria, whereas others will emphasize social criteria. It is not possible to maximize service while concurrently minimizing costs. Thus, the lowest cost system is not the best—nor is the system that provides the highest level of service. This creates a dilemma for evaluators, which can be resolved only by reference to the definition of role and scope provided by the transportation planning process. For example, the Tri-County Metropolitan Transportation District of Oregon (TRI-MET) defined the following financial goal in its planning process: "Farebox revenues of the system as a whole must be maintained to cover 40 percent of the operations cost as a minimum" (*44*).

This goal provides the basis for evaluation because it has defined the trade-off between cost and service level. If Portland TRI-MET farebox revenues amount to only 30 percent of operating costs, they clearly have not met their goal. Conversely, if TRI-MET has cut service levels (and thereby not met other goals) so that revenues are 50 percent of operating costs, they clearly have not achieved the desired balance between service and costs. If they have met other goals and collected fares equal to 42 percent (an example only) of operating costs, they have done very well. If they have exceeded their service delivery goals and still managed to collect 40 percent of their operating costs in fares, again they have done well.

Consider the problem of the evaluator when such goals do not exist. How does one evaluate city X, which has not defined the desired trade-off between costs and services? One criterion for evaluation is missing. Although the evaluator might make some judgment on the basis of historical comparison or intuited goals, such criteria are clearly second best; thus, the resulting evaluation is also second best.

Consider Goals Individually as well as Jointly

Because transportation systems have multiple goals and objectives, evaluation should be based on multiple criteria that consider those goals and objectives both individually and jointly. Individual goals need to be considered separately to see the degree to which actual performance exceeded or fell short of the goals. However, this information must be placed in context with the total set of goals. Referring again to the example of TRI-MET, it is helpful to know that they met their goal of providing 40 percent of operating costs from fares. Meeting that goal is much more meaningful and much more of an accomplishment if they have met other possibly conflicting goals at the same time. Other goals might be:

1. To provide a level of service that will induce 36 percent of all travelers to the CBD to use the bus.
2. To increase ridership of citizens over 65 years of age by 10 percent.
3. To increase level of on-schedule arrivals at all points on the fixed-route system to 93 percent.
4. To increase ridership by 15 percent per year.

The transportation system management could meet the financial goal rather easily by reducing levels of services to eliminate high-cost/low-revenue elements. However, if the total set of goals is considered, the task of meeting them becomes much more difficult. The goals of increasing ridership and producing higher levels of service increase the difficulty of meeting the financial goals. Conversely, the financial goal places constraints on expansion of service levels to increase ridership. In addition to considering an array of individual criteria, the evaluation should consider the over-all performance of the transportation system against the total set of evaluation criteria.

Evaluation Must Provide Useful Information

The evaluation should be conducted so as to enhance its actual use in improving the transportation system. Because evaluations are often unwelcome, roadblocks may appear for the evaluator. Required data may be "unobtainable," whereas elaborate explanations of why goals were not accomplished may be all too easy to obtain. Worst of all, the evaluation may be ignored. To maximize cooperation with the transportation operator and acceptance of the results, the evaluation should be conducted so that the operator and the local government participate to the maximum extent possible in the process. There should be no surprises. The criteria for evaluation should be known well in advance. The first people to see the evaluation should be managers and public officials responsible for the system. Disclosures to the media, especially premature disclosures that emphasize negative results, are disastrous for future evaluative efforts. Finally, the evaluator should help develop and encourage implementation of improvements during the evaluation process. Thus, he becomes a source of aid rather than a critic.

EVALUATION PROCESS

The evaluation process should be flexible to best fit the particular transportation system being evaluated. To the degree that each urban transportation system is unique—reflecting the geographic, demographic, and economic characteristics of individual urban areas, as well as the

goals and objectives—evaluations cannot and should not be identical. Nevertheless, some guidelines for evaluation have a degree of general applicability to all systems.

Operations Evaluation

The easiest and most straightforward evaluation is the operations evaluation. As the name suggests, these evaluations of the existing transportation system are based on data derived from the operators' records. They approximate the type of evaluation made in any private enterprise operation. The data would be available in any moderate to large transportation system, especially those with well-developed management information systems. Because the data are usually available, the operating evaluation should be conducted annually.

The criteria for the operations evaluation can be classified into categories as follows:

1. Provision of transportation services.
2. Utilization of transportation services.
3. Cost of transportation services.
4. Revenues derived from transportation services.
5. Efficiency measures.

Specific evaluation criteria for each of the foregoing categories are given in Table 11.

It is suggested that the evaluation measure first be compiled for the total urban system, including all of its segments, although they may differ dramatically (e.g., fixed-route bus and dial-a-ride feeder service). Further, it is suggested that the data compiled include the following for each measure:

1. The basic measure itself (e.g., total vehicle-miles operated).
2. A comparison of the current year's results with those of the preceding year (e.g., percent change in total miles operated).
3. A comparison of current year results with predetermined goals, objectives, budgets, etc.

Once these data are compiled for the total system, the analysis should be repeated for each major component of multifaceted transportation systems (e.g., fixed-route bus system, dial-a-ride feeder service). Not all criteria will be available or appropriate for subsystem analysis. Those measures felt to be appropriate for evaluation of major subsystems are indicated in the right column of Table 11.

Types of Supplemental Evaluations

The operating evaluation has several major limitations. It does not answer several important questions about the quality of service provided by the system. It generally does not measure social benefits or the achievement of certain important goals relating to the effectiveness of the system. Services directed at special market segments, such as the handicapped, may need additional evaluative efforts because of particular data requirements. Once one has conducted the base or operating evaluation, attention should focus on additional evaluation criteria that attempt to provide more insight into the total worth of public transportation. Because such additional evaluations may require considerable effort and expense just to collect data, they should be conducted less frequently. Examples of such supplemental evaluations would be the following.

On-board Surveys

These surveys attempt to measure passenger satisfaction on items such as system convenience; perceived availability of schedule/route information and ease of using system; transit dependency status of passengers (what proportion rides by choice); perceived driver courtesy; perceived equipment cleanliness; perceived system reliability, safety, and on-time arrivals; and trip purpose, trip length, origin and destination points.

Telephone Surveys

These evaluations measure perceived benefits to non-users and infrequent users on such variables as perceived availability of schedule/route information; knowledge of services available; reputation of system for reliability, safety, courtesy, etc.; and unmet transportation needs.

Pollution Analysis

This evaluation measures outputs of major pollutants (NOX, CO, HC) for each vehicle and compares them with similar measures from the average automobile. Contribution to pollution reduction could then be calculated. An additional part of such an evaluation might include periodic measurement of air pollution levels in the CBD to determine progress toward pollution reduction.

Evaluation of Special Market Segments

Special groups, such as low income or handicapped, present particular problems in evaluation. Since both social goals and legal requirements may dictate special service for these market segments, special evaluations are appropriate. Such evaluations would include the gathering of data to determine actual system usage by the special market segment, the evaluation of service adequacy by users and non-users, and the proportion of the target segment that uses the service.

Goal-Directed Evaluation

This evaluation measures particular goals previously established. For example, the Portland TRI-MET goal, that 36 percent of all travelers to the downtown area should use the bus, will require periodic traffic counts to determine if this goal is being met.

Evaluation of New Service and Innovative Transportation Modes

New transportation services, especially those that are innovative, should receive special evaluations. Consistent with the philosophy developed by the evaluators of social action programs, the evaluation should be planned along with the innovation itself. Adequate control groups and

TABLE 11

CRITERIA FOR OPERATIONAL EVALUATION

	Primary Data Year Being Evaluated	Current Year as Percent of Previous Year	Current Year as Percent of Goal/Objective	Appropriate for Subsystems Within Total System
A. Provision of Service				
1. Quantity of service provided				
a. Total vehicle miles operated	X	X	X	X
b. Total seat miles operated	X	X	X	X
c. Vehicle miles per capita	X	X		
d. Seat miles per capita	X	X		
2. Quality of service provided				
a. Safety				
(1) Accidents per 1,000,000 vehicle miles	X	X	X	X
(2) Fatalities per 1,000,000 vehicle miles	X	X	X	X
(3) Disabling injuries per 1,000,000 vehicle miles	X	X	X	X
(4) Property loss, $, per 1,000,000 vehicle miles	X	X	X	X
(5) Total insurance claims, $, per 1,000,000 vehicle miles	X	X	X	X
b. Convenience				
(1) Average speed, mph	X	X	X	X
(2) Average system headways, minutes	X	X	X	X
(3) Percentage on time arrivals	X	X	X	X
(4) Customer complaints	X	X	X	X
(5) Customer information/assistance calls answered	X	X		
(6) Transfers as a percent of total passengers	X	X		
B. Utilization of Service				
1. Ridership				
a. Total	X	X	X	X
b. Senior citizen	X	X	X	X
c. Handicapped	X	X	X	X
d. Student	X	X	X	X
e. Child	X	X	X	X
f. Other	X	X	X	X
2. Utilization factors				
a. Passengers per vehicle mile	X	X	X	X
b. Passengers per seat mile	X	X	X	X
c. Passengers per vehicle operating hour	X	X	X	X
d. Passenger miles per seat mile	X	X	X	X
C. Cost of Service				
1. Total operating costs				
a. Total operating cost	X	X	X	
b. Total operating cost per vehicle mile	X	X	X	
c. Total operating cost per passenger	X	X	X	
d. Total operating cost per passenger mile	X	X	X	
2. Operations and maintenance costs				
a. Total operations and maintenance cost	X	X	X	X
b. Total operator labor costs	X	X	X	X
c. Total maintenance labor cost	X	X	X	X
d. Total fuel/propulsion power cost	X	X	X	X
e. Operations and maintenance cost per vehicle mile	X	X	X	X
f. Operations and maintenance cost per passenger	X	X		X
g. Operator labor costs per vehicle mile	X	X	X	X
h. Operator labor costs per passenger	X	X		X
i. Maintenance cost per vehicle mile	X	X	X	X
j. Maintenance cost per passenger	X	X		X
k. Fuel/propulsion power costs per vehicle mile	X	X	X	X
l. Fuel/propulsion power costs per passenger	X	X		X
3. General administrative costs				
a. Total general administrative cost	X	X	X	
b. General administrative cost per vehicle mile	X	X		
c. General administrative cost per passenger	X	X		

TABLE 11 (continued)

	Primary Data Year Being Evaluated	Current Year as Percent of Previous Year	Current Year as Percent of Goal/Objective	Appropriate for Subsystems Within Total System
D. Revenue				
1. Passenger fares for transit services				
a. Total fare revenue	X	X	X	X
b. Total fare revenue per vehicle mile	X	X	X	X
c. Total fare revenue per passenger	X	X	X	X
d. Total fare revenue per passenger mile	X	X	X	X
e. Total fare revenue/total operating costs	X	X	X	X
f. Total fare revenue/vehicle operating day	X	X	X	X
2. Fare revenue categories				
a. Adult full fares	X	X	X	X
b. Senior citizen fares	X	X		
c. Student fares	X	X		
d. Child fares	X	X		
e. Handicapped rider fares	X	X		
3. Other revenues				
a. Charter revenue	X	X	X	
b. Charter revenues per charter vehicle mile	X	X	X	
c. School service revenue	X	X	X	
d. School service revenue per school service vehicle mile	X	X	X	
e. Advertising revenue	X	X	X	
f. Other revenue	X	X	X	
4. Revenue ratio				
Total revenue/total operating cost	X	X	X	X
E. Efficiency Measures				
1. Vehicle utilization				
a. Vehicle miles/vehicle	X	X	X	X
b. Vehicle operating hours/vehicle	X	X	X	X
c. Average number of vehicles operating/total vehicles	X	X	X	X
d. Revenue operating miles/total vehicle miles	X	X	X	X
e. Vehicle breakdowns/vehicle mile	X	X	X	X
2. Work force utilization				
a. Operator man-hours/vehicle mile	X	X	X	X
b. Operator man-hours/passenger	X	X	X	X
c. Maintenance man-hours/vehicle mile	X	X	X	
d. Total work force man-hours/vehicle mile	X	X	X	
e. Absenteeism, %	X	X	X	
3. Fuel efficiency				
a. Fuel consumption per vehicle mile	X	X	X	X
b. Fuel consumption per passenger mile	X	X	X	X
c. Fuel consumption per passenger	X	X	X	X

experimental groups can be identified before the new service begins, and preinnovation data can be gathered, thus assuring that the best evaluation will be accomplished.

Evaluation of System Segments

Special characteristics of particular systems or special circumstances may dictate the necessity of other evaluations. A major criterion for selecting segments of total systems for special evaluation should be the net cost of that particular segment to the taxpayer. Certainly, transportation systems will continue to tolerate deficit operations and even extraordinary deficits to accomplish important social goals. Nevertheless, the larger the deficit, the larger the obligation of the evaluator to assure that the important social goal is, in fact, being accomplished.

ANALYSIS OF DATA AND INPUT TO PLANNING PROCESS

Once the data have been compiled, the evaluator should analyze the data and attempt to put the information in perspective in order to reach some over-all conclusion with respect to the operation of the system as compared with previous experience and with system goals and objectives. Because each evaluation will have unique aspects, specific statements cannot be made as to how to do this. In general, however, the analysis should focus on those measures that demonstrate the greatest differences with previous results or goals. The analysis should separate those changes or variances that are most subject to managerial control from those that are not. Finally, the evaluator should highlight areas that suggest changes in transportation needs and uses. In some instances, the evaluation will produce questions rather than answers. It is part of the evaluators' role to follow the unanswered questions until they are reasonably sure that they can explain the results.

It should be obvious by now that evaluation is not truly separate from planning. Earlier, it was argued that the best basis for evaluation is goals, objectives, and targets that result from the planning process. It is equally true that a major basis for the planning process is the results of the evaluation process. Thus, the two processes are inextricably interrelated.

INSTITUTIONAL ARRANGEMENTS AND EVALUATION

Just as there is no "one best" mission for all urban transportation systems, there seems to be no obvious "one best" institution or agent to perform the evaluation. Some characteristics to consider for an effective evaluation are as follows:

1. The evaluator should have the necessary staff with the requisite technical skills to perform the evaluations.
2. The evaluator should be objective and unbiased.
3. The evaluator should be independent of pressure from special interest groups.
4. The evaluator should have or develop good understanding of the particular urban area and its particular set of objectives and goals for the transportation system.
5. The evaluator should have or develop good working relationships with the transportation system operator and local officials, both elected and appointed.
6. The evaluator should be reputable and influential to prevent the evaluation from being ignored.

Given the existing set of institutions and agencies in most urban areas, it appears that no single agency will meet all of the desired criteria for the role of evaluator. The most obvious possible parties to do the evaluation are the mayor or city manager's staff, the metropolitan planning organization, the transportation authority, the transportation system operator, the state department of transportation, or an outside consultant. Table 12 presents a brief analysis of favorable and nonfavorable factors for each of these for the role of the evaluator. As can be seen, no single group has all of the desirable characteristics. Although there will be exceptions in some urban areas, it appears that those most appropriate for the evaluative role are the metropolitan planning organization, the state department of transportation, or the outside consultant. The choice of which of these should have primary responsibility for evaluation depends on each particular situation. Whichever group has the primary responsibility, it will probably be desirable to form an ad hoc evaluation committee with members from the operators, the transportation authority, the local MPO, the state DOT, and a representative from the mayor's or city manager's staff. Each of these parties can make a valuable contribution to the evaluation process.

CHAPTER SIX

CONCLUSIONS

The general concept adopted by this project is that there is a broad range of public transportation service concepts available to a community. The planner should attempt to relate the inherent operational attributes of the proposed services to the travel needs defined by various market segments. An important element of market-oriented planning is evaluation. Any community contribution as significant as transit requires that a broad viewpoint be taken, thereby identifying the benefits and costs associated with the service.

TABLE 12

ANALYSIS OF VARIOUS GROUPS IN ROLE AS EVALUATOR

Group	Factors Favoring Group for Role as Evaluator	Factors Not Favoring Group for Role as Evaluator
Mayor or City Manager's Staff	• May be most responsive to public view of mission. • Has best understanding of desirable balance in resource allocation between transportation and other public services.	• May identify too closely with present system to be objective. • May not possess sufficient technical knowledge. • Most likely to be influenced by political pressure of special interest groups.
Metropolitan Planning Organization	• Usually has necessary staff with requisite skill, and knowledge.	• Likely to be major contributor to design of present system. This could reduce objectivity.
Transportation Authority	• Provides most direct link to public transportation users.	• Unlikely to have necessary staff and technical skills. • Usually has little or no incentive to control costs. • Probably has least understanding of balance between transportation and other public service needs.
System Operator	• Has most intimate knowledge of operations, costs, current trouble spots.	• Difficult for operator to objectively evaluate own performance.
Group	Factors Favoring Group for Role as Evaluator	Factors Not Favoring Group for Role as Evaluator
State DOT	• Usually will have necessary staff with requisite technical skills. • Has some knowledge of local systems. • Has enough "distance" to be objective and largely free of local political pressure.	• May be viewed as "outsiders". • May not have adequate understanding of unique urban area mission and objectives. • Could, in some instances, politicize the evaluation process (e.g. along party lines).
Outside Consultants	• Usually have necessary staff with requisite technical skills. • Independent of current system, political influence.	• May be viewed as "outsider". • May not have adequate understanding of unique urban area mission and objectives. • Most easily ignored by decision makers.

Likewise, planners must be objective in assessing the contribution of public transportation. The desired attribute of transit should not be accepted a priori. The extent and nature of benefits will vary with the type of transit service provided and the manner of deployment. The following conclusions pertaining to economic development, energy, air pollution, and evaluation are offered in the interest of encouraging planners and decision-makers to scrutinize the detailed attributes of the service being considered. It should be noted that, in some cases, the conclusions are based on limited observations transferred from other cities. In all cases, the planner is encouraged to undertake a localized analysis.

ECONOMIC DEVELOPMENT

1. A temporary loss of public transportation service will have an adverse impact on certain portions of the community and on certain of its citizens. Travel, in general, will become more expensive and less convenient, particularly for captive riders.

2. During the temporary loss of public transportation

service, captive riders will reduce their trip-making. However, the captive group is generally able to find alternative travel arrangements for essential travel. Discretionary trips previously made by public transportation are canceled in many cases.

3. Semicaptive and choice riders of public transportation systems are generally able to rely on a range of substitute modes and are not as adversely affected by a temporary loss of public transportation services.

4. The economic impact from a temporary loss of public transportation service is directly related to the number of captive riders in the system.

5. Businesses that are most affected by a temporary loss of public transportation service are those that cater to captive riders. Other businesses whose clientele are more automobile- or commuter-oriented tend to have a minimal loss of business activity.

6. To say that a small-to-medium-sized city cannot survive without conventional public transportation service provided by the public sector is misleading. Mainly because of the small number of riders, public transportation, by itself, is neither a necessary nor a sufficient condition for economic vitality in a small-to-medium-sized city.

ENERGY EFFICIENCY

1. Bus transit services are not necessarily more energy efficient in fuel consumption than some energy-efficient private autos. The energy efficiency of bus services for an urban area relative to the private automobile will be directly related to the utilization rates of bus transit services.

2. Transit efficiency is associated with urban area population. Passenger-miles per vehicle-mile goes down as population decreases. Estimates based on national averages of bus usage probably overestimate the efficiency of bus transit in communities below 500,000 population.

3. Some forms of paratransit, on the average, are as efficient as conventional transit. However, taxis and dial-a-ride services are not particularly energy efficient.

4. One promising policy to reduce petroleum consumption is to directly increase the efficiency of the various vehicles used in urban transportation. This may have more impact than policies that would try to increase the utilization rate of public transportation services.

5. Increasing the utilization rate of transit services will not necessarily reduce the amount of energy consumed in an urban area. The energy consumption will be directly related to the utilization of automobiles left at home while a given trip is being made by public transportation. New trips made as a result of the availability of the automobile could increase the total amount of energy consumed in an urban area.

6. When determining the total energy required by a given mode, one must include in the analysis the amount of access energy required. Access energy is that energy required to gain access to the mode serving the long-haul portion of the trip. Sometimes, the amount of access energy can be quite large.

AIR QUALITY

1. Because of the operating requirements of some modes (e.g., deadheading, slow speeds, empty-schedule runs), they are not necessarily less polluting than a private auto on a per passenger-mile basis. Therefore, care should be exercised not to underestimate pollutant emissions with these modes.

2. Slower average speeds increase emissions of CO and HC in all modes and NOX in vehicles using diesel fuel.

3. Commuter buses are lower emitters of all three pollutants, but access modes need to be accounted for to provide a full disclosure of all emissions.

4. Taxis, dial-a-ride vehicles, and autos are the principal emitters of CO per passenger-mile for intraurban services. Conventional transit and jitneys are lower emitters of CO and constitute a better alternative to providing services at locations suffering from high concentration of that pollutant.

5. A given public transportation alternative that will satisfy the objectives in one area, such as energy, will not necessarily meet the objectives in another area like air quality control. The transportation planner must be aware of the characteristics of each public transportation alternative relative to land use development, economics, energy, and air quality. It is through a complete analysis of the contribution in each area that a given public transportation alternative can be selected that will make improvements of long standing.

EVALUATION

1. In spite of on-going periodic evaluation of transportation services being necessary to assure the maximum service at minimum costs, the state of the art is not well advanced and most transportation services are not subject to meaningful periodic evaluation.

2. The evaluation process is made more difficult because of the major problems of measuring social costs and benefits of a particular function (i.e., public transportation) in a complex environment. Research done in the program evaluation field (the evaluation of social action programs) provides some guidance in formulating principles to guide the evaluation effort.

3. The potential for effective evaluation, that is, one whose results will be used to improve service and/or reduce costs, is enhanced by high quality transportation planning, the use of multiple criteria to evaluate the transportation system, and the participation and cooperation of the operator with local government agencies and officials.

4. Individual system evaluation should be tailored to the unique characteristics of the system being evaluated. Some guidelines for operations evaluation are proposed but should be supplemented by other evaluative methods specifically tailored to individual needs.

5. Because no single agency possesses all the characteristics desired to facilitate effective evaluation, in most instances evaluation should be a joint activity of several institutions or agencies.

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APPENDIX A

ENERGY CONSUMPTION SCENARIOS

SCENARIO ONE

Problem Statement

In Jacksonville, Fla. (urban pop. 520,000), the transportation authority is considering the elimination of the north-south beach route because of its low productivity of 1.4 passengers per bus-mile (*A-1*). From another study it has been found that the average passenger trip length is 4.3 miles and the average occupancy is about 6.0 passenger-miles per bus-mile (see Table 8). A substitute service is being sought and dial-a-ride and jitney services seem to be viable alternatives. Dial-a-ride would provide services for 18 hours a day, and jitney service would be available on a reliable basis for only about 12 hours.

Analysis

Energy consumption rates for dial-a-ride and jitney are 10,621 BTU/passenger-mile and 3,611 BTU/passenger-mile, respectively (see Table 5). Both services would use 11-seat vehicles to serve the same general area. For the existing bus service, a consumption rate can be calculated using energy consumption per vehicle-mile (see Table 4). For conventional bus it would be:

35,366 BTU/passenger-mile ÷ 6.0 passenger-miles/vehicle1mile = 5,894 BTU/passenger-mile

Thus, based on energy considerations alone, jitney services are 39 percent more energy efficient than conventional bus service and 66 percent more efficient than dial-a-ride service. In fact, given that jitneys use smaller vehicles, have higher frequency of service, and travel faster than conventional buses, jitney efficiency probably could be higher than shown here because of attraction of new trips if the service were provided.

Summary

It becomes readily apparent that dial-a-ride and conventional bus transit consume more energy per passenger-mile than jitney services. Yet, they are different services operating over different time periods. Dial-a-ride provides higher accessibility, offers a more personalized service, and requires a higher government subsidy than conventional bus transit. On the other hand, jitneys provide higher frequency of service than the dial-a-ride and conventional bus, but at no cost to the government. Jitney fares may be higher than subsidized public transit. Service through the same period as bus transit can be provided with dial-a-ride, but jitney service may need to be supplemented with minimum bus service during nighttime hours. A more detailed analysis is possible at an advanced planning stage.

SCENARIO TWO

Problem Statement

The City of Knoxville, Tenn. (pop. 200,000) is considering the expansion of vanpools to areas now served by express buses. The Metropolitan Planning Commission has been examining this proposal and wants to define energy trade-offs between the two services without getting into a detailed route-by-route analysis.

Ten express routes serving Tennessee Valley Authority employees run a one-way route length of 14 miles, including 1-mile access from the bus barn. The average loading during peak hours is 37 passengers per trip in the peak direction (*A-2*). A study examining TVA's service (*A-3*) shows that for each express bus-mile driven, 2.32 private auto vehicle-miles are required for access to buses. Existing vanpools serving other routes use 12-seat vans and operate with an average occupancy of 10. From the TVA study it is obtained that for every vanpool vehicle-mile, 10.96 private auto vehicle-miles are required for access. Access refers to the use of private autos to drive from home to remote collection points, for dropping off a passenger, or for parking and riding.

Analysis

On the assumption that 37 passengers travel the productive length of the route (14 one-way miles minus one-access mile = 13 miles), the number of passenger-miles produced equals 481. The average occupancy for the line-haul is obtained as follows:

481 passenger-miles ÷ 28 bus-miles = 17.2 passenger-mile/bus-mile

The BTU per vehicle-mile is determined for the commuter bus and divided by average occupancy to obtain line-haul BTU per passenger-mile as follows:

21,970 BTU/bus-mile ÷ 17.2 passenger-mile/bus-mile = 1277 BTU/passenger-mile

For vanpool service, energy intensiveness for the line-haul is 1,300 BTU/passenger-mile (see Table 5).

Access energy (i.e., energy consumed to reach line-haul service) needs to be determined to obtain total energy consumption per line-haul passenger-mile. Using TVA's experience, access energy can be computed on a per passenger-mile basis to be added to the line-haul energy. Private autos consume 10,924 BTU/vehicle-mile (see Table 4). The access energy for each line-haul vehicle-mile is:

	Express Bus	Vanpool
BTU/auto-mile	10,924	10,924
Auto-mile/veh-mi	× 2.32	× 0.96
BTU/veh-mi	25,344	10,487

And access energy per line-haul passenger-mile is:

	Express Bus	Vanpool
BTU/veh-mi	25,344	10,487
Average Occupancy	÷ 17.2	÷ 10
BTU/pass.-mi	1,473	1,487

It then follows that total energy per passenger-mile is the source of the line-haul energy plus the access energy or:

	Express Bus	Vanpool
Line-haul energy	1,277	1,300
Access energy	1,473	1,487
	2,750	2,787 BTU/pass.-mi

Thus vanpools and express bus services consume about the same energy per passenger-mile.

Summary

There is no significant difference to justify one system over another, based only on operating energy concerns. In fact, by using aggregate data, the system-to-system variations may be large enough to hide a clear preference. Other energy-consuming activities, like maintenance and garage, may need to be considered before a decision is made when recommending a system based only on energy consumption. Further, community goals, such as reduction of transit operating subsidies, may have an even greater impact on the decision to recommend one system over another.

SCENARIO THREE

Problem Statement

The Knoxville Transit Corporation operates 45-seat transit buses between downtown Knoxville and West Town Mall. The round-trip distance of this route is approximately 8 miles by either Kingston Pike, a four-lane arterial, or by I-40, an Interstate freeway. Vehicle loadings, average distance between stops, and load factors are known for three different services currently being operated (see Table A-1). It is desired to determine average operating BTU per passenger-mile expended in these services (relationships derived for Denver (Figs. 4 and 5) can be used for a more precise approach).

Analysis

Because variation in operating conditions exists between peak and nonpeak directions for a given service, it is important to determine energy consumption based on both directions. Because the number of passengers also varies by direction, it is necessary to weight energy consumption rates based on passenger loadings. Thus, BTU/passenger-mile for the whole bus trip will be obtained for each service alternative.

Energy consumption rate for a peak-hour bus on an arterial can be determined as follows:

	BTU/pass.-mi
Peak direction CS = 20, LF = 1.0	3,550
Nonpeak direction CS = 40, LF = 0.2	2,400

$$\text{Weighted average} = \left(\frac{3550 \times 1.0 + 2400 \times 0.2}{1.0 + 0.2}\right) = 3{,}358$$

The energy consumption rate for off-peak hour bus is:

TABLE A-1

SERVICE ALTERNATIVES

	Peak-Hour Arterial		Off-Peak Arterial	Peak-Hour Express	
	Peak Direction	Nonpeak Direction	Peak Direction	Nonpeak Direction	
Cruise Speed (CS) in mph	20	40	40	40	40
Distance Between Stops (miles)	0.25	1.0	0.5	0.0 (use max.)	
Load Factor (LF) (pass/seat)	1.0	0.2	0.5	1.0	0.0 (use min.)

Peak and nonpeak directions CS = 40, LF = 0.5 (from Fig. 5) — BTU/pass.-mi: 1,400

And the energy consumption rate for peak-hour express bus is:

Peak direction CS = 40, LF = 1.0 (from Fig. 5) — BTU/pass.-mi: 400

Nonpeak direction CS = 40, LF = 0.0 (from Fig. 5) — 2,000

$$\text{Weighted average} = \left(\frac{400 \times 1.0 + 200 \times 0.2}{1.0 + 0.0}\right) = 800$$

(Note that the 0.2 value used here for load factor is minimum shown in curves to include energy consumption for the nonpeak direction.) As could have been expected, express buses consume much less energy than off-peak hour or peak-hour services while serving the same corridor. However, it should be remembered that this procedure uses relationships derived for Denver, based on fairly refined assumptions. Caution should be exercised in using these relationships to be sure that they approximate local conditions.

SCENARIO FOUR

Problem Statement

The city of Knoxville, Tenn. (pop. 200,000) wishes to evaluate energy savings resulting from Tennessee Valley Authority (TVA) efforts to promote ridesharing. This program has been accomplished through the promotion and subsidization of carpools, vanpools, and express buses since 1974. TVA has surveyed before and after conditions that allow for more precise analysis (*A-3*).

In November 1973, 65 percent of TVA employees working in downtown Knoxville drove alone, 3.5 percent were riding in conventional buses, 30 percent participated in carpools, and 1.5 percent used other means to get to and from work. In contrast, by January 1977, only 18 percent of the employees drove alone, 3 percent were passengers in regular buses, 28 percent switched to express buses, carpool users increased to 41 percent, and newly introduced vanpools transported 7 percent of the employees. During that 3-year period, TVA employment increased by 450 persons to a total of 3,400, and the number of private autos driven to work decreased by 1,147 to 1,048. In addition, 23 full-size buses and 18 vans were added to the fleet of vehicles (see Table A-2).

TABLE A-2

MODAL USAGE PATTERNS OF TVA EMPLOYEES

Mode of Transportation	Percent of Work Force	
	Nov. 1973	Jan. 1977
Drive Along	65.0	18.0
Regular Bus	3.5	3.0
Express Bus	0.0	28.0
Carpool	30.0	41.0
Vanpool	0.0	7.0
Bike, Walk, etc.	1.5	3.0
Total Work Force	2,950	3,400
No. of Express Buses	0	23
No. of Vans	0	18

Source: Davis, F.W., et al, Ridesharing and the Knoxville Commuter, Transportation Center, The University of Tennessee, Knoxville, Tennessee, August 1975.

By using current levels of employment and primary miles of passenger travel, an analysis can be made to compare energy consumption under both modal schemes to determine energy savings. At first glance it may appear that fewer vehicles definitely will produce fewer vehicle-miles of travel and will result in substantial fuel savings. However, to provide effective bus and vanpool services, additional mileage needs to be driven to provide access to those workers now being moved by express buses and vanpools. Also, carpools need to be driven extra mileage to drop and pick up passengers.

It should be noted that the objective here is not to determine how many BTUs are expended per passenger-mile; but rather, by service—or the number of BTUs and gallons of fuel saved by the alternative scheme. This is possible with the use of survey data gathered by TVA.

Analysis

Table A-3 presents passenger-miles and vehicle-miles of travel by primary mode of transportation based on 1973 modal shares. Passenger-miles of travel divided by vehicle-miles of travel can give a more refined index of BTU per passenger-mile, but this is not desired at this time. Instead, total fuel and BTU consumption can be obtained from daily vehicle-miles of travel plus excess mileage as follows:

Total daily auto miles of travel = 50,243
Gallons of gas = 60,243 mi ÷ 14.0 mph = 4,303 gal
BTU consumed = 4,304 gal × 130,000 BTU/gal = 559.4 million BTU

Table A-4 gives passenger-miles and vehicle-miles of travel by 1977 modes. Table A-5 gives excess miles due to access modes plus excess miles of carpools. Thus, total energy consumed by autos in 1977 is:

Primary auto miles (excluding access miles) = 23,056 + 959 = 24,015 mi
Gallons of gas = 24,015 ÷ 14.0 mpg = 1,715 gal
Access auto miles = 2,510 + 797 = 3,307 mi
Gallons of gas = 3,307 ÷ 10.2 mpg = 324 gal
Total auto gallons = 1,715 + 324 = 2,039 gal
Total auto BTU = 2,039 × 130,000 = 265.1 million BTU

Total energy consumed by vans in 1977 is:

Primary van miles = 828 mi
Gallons of gas = 828 ÷ 10.0 = 82.8 gal
Total van BTU = 8,280 × 130,000 = 10.8 million BTU

Total energy consumed by express buses in 1977 is:

Primary bus miles = 1,082 mi
Gallons of diesel = 1,082 ÷ 5.7* = 190 gal
Total bus BTU = 190 × 145,000 = 27.6 million BTU

Thus, total energy consumed for commuting to work by TVA employees in 1977 is:

Total gallons (gas and diesel) = 2,039 + 190 = 2,313 gal
Total BTU = 265.1 + 10.8 + 27.6 = 303.5 million BTU

Summary

The rideshare program has reduced energy consumption of TVA employees commuting to work from 559.4 million BTU per day to 303.5 million BTU per day, or 46 percent. Even if vehicles left at home under the rideshare scheme were used for another trip similar to the access trip (which may be close to actual usage), energy savings per day would still represent 38 percent.

In this particular case, other energy savings have been accrued by allowing for less congestion in the downtown and adjacent areas, but this subject is difficult to quantify. (It has been estimated that traffic flowing through a major freeway segment of I-40 moves 10 mph faster than it could if TVA employees retained their previous modal usage.) Also, other energy has been saved by not building 1,463 parking spaces that would have been required under the old modal scheme.

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* Composite fuel consumption factor for 13 transit buses +10 over the road type buses; transit bus mileage in commuter service estimated at 5 mpg; over the road bus mileage estimated at 6.6 mpg.

TABLE A-3
DAILY VMT BASED ON THE MODAL USAGE PATTERN OF NOV 1973

By Primary Ridesharing Modes:					
Mode of Transportation	Employees	Vehicles	Daily Passenger Miles of Travel	Daily VMT Auto	Van	Bus
Drive Alone	2,210	2,210	51,897	51,897	--	--
Regular Bus	119	--	1,190	--	--	--
Express Bus	0	0	--	--	--	--
Carpool	1,020	319	24,263	7,588	--	--
Vanpool	0	0	--	--	0	--
Bike, Walk, etc.	51	--	306	--	--	--
Total	3,400		77,656	59,484	0	0
For Picking Up Passengers of Car Pool:						
Daily Excess VMT by Auto = 10% of Primary VMT = 10% of 7,588 = 759						
Total Daily VMT (Primary and Excess) by Auto = 59,484 + 759 = 60,243						

Source: Davis, F.W. et al, Ridesharing and the Knoxville Commuter, Transportation Center, The University of Tennessee, Knoxville, Tennessee, August 1975.

TABLE A-4
DAILY VMT BY PRIMARY RIDESHARING MODES BASED ON THE MODAL USAGE PATTERN OF JAN. 1977

Mode of Transportation	Employees	Vehicles	Daily Passenger Miles of Travel	Daily VMT Auto	Van	Bus
Drive Alone	612	612[a]	13,464	13,464	--	--
Regular Bus	102	--	1,020	--	--	--
Express Bus	952	23	20,944	--	--	1,082[b]
Carpool	1,394	436	30,668	9,592	--	--
Vanpool	238	18	10,948	--	828	--
Bike, Walk, etc.	102	--	612	--	--	--
Total	3,400		77,656	23,056	828	1,082
Total VMT by all Primary Modes = 24,966						

[a] Employees traveling on regular buses do not contribute any additional VMT.

[b] Includes deadhead miles.

[c] VMT contributed by motorcycles is insignificant.

Source: Davis, F.W., et al, Ridesharing and the Knoxville Commuter, Transportation Center, The University of Tennessee, Knoxville, Tennessee, August 1975.

TABLE A-5

DAILY EXCESS VMT FOR ACCESS TO PRIMARY MODES BASED ON THE MODAL USAGE PATTERN OF JAN. 1977

For Access to Regular and Express Bus Stops:

Mode of Access	Modal Usage[a]	Employees	Number of Autos	One-Way Trip Length in Miles	Daily VMT By Auto
Car Drop-Off	12%	126	126	2[b]	504
Park-and-Ride:					
(1) Drive Alone	28%	295	295	3	1,770
(2) Carpool	18%	190	59[c]	2	236
Other	42%	443	--	-	--
Total		1,054			2,510

For Access to Vanpool Pickup Points:

Mode of Access	Modal Usage[a]	Employees	Number of Autos	One-Way Trip Length in Miles	Daily VMT By Auto
Car Drop-Off	7%	17	17	5[b]	170
Park-and-Ride	40%	95	95	3.3	627
Other	53%	126	--	--	--
Total		238			797

For Picking Up Passenger of Carpools:

Daily Excess VMT by Auto = 10% of Primary VMT = 0.10 x 9.592 = 959

Total Daily Excess VMT by Auto = 2,510 + 797 + 959 = 4,266

[a]Based on bus and vanpool rider surveys.

[b]In the case of car drop-off, the daily travel of some vehicles involves two round trips from home, while some persons are dropped off by others on their way to other destinations. It is assumed that on the average the daily travel will be two times the one-way trip length.

[c]Average occupancy of carpools is 3.2.

Source: Wegmann, F.J., A. Chatterjee, and S.R. Stokey, "Evaluation of an Employer Based Commuter Rideshare Program," paper presented at the 1978 Annual Meeting of the Transportation Research Board, Washington, D.C., January 1978.

APPENDIX B

POLLUTANT EMISSION SCENARIOS

SCENARIO ONE

Problem Statement

A large employer located in downtown Chattanooga, Tenn. (urban pop. 120,000) is considering following the TVA example in Knoxville to promote vehicle pooling. Yet, for simplicity, it wishes to get involved with only one mode and is considering either vanpools or express buses. For evaluation purposes, the MPC wants this employer to determine the contribution of each mode in reducing air pollution.

A previous study shows the desirability of serving eight express routes with an average two-way route length of 25 miles. A study examining TVA's service in Knoxville shows that for every express bus-mile driven, 2.32 private auto vehicle-miles are required for access to buses (*B-1*). Also, for every vanpool vehicle-mile, 0.96 private auto vehicle-miles are required for vanpool access. The access

refers to use of private auto in driving to remote parking lots for dropping off a passenger or for parking and riding..

Analysis

Carbon monoxide, hydrocarbon, and nitrogen oxide emissions, expressed as grams per passenger mile (gppm), can be obtained (see Table 10) readily for both modes based on average loadings as follows:

	Express Bus Line-Haul (gppm)	Vanpool Line-Haul (gppm)
CO	0.6	1.7
HC	0.2	0.4
NOX	0.4	0.6

Considering TVA's experience, the effects of car access to rideshare modes on a per passenger-mile basis can be prepared. Private auto emission multiplied by rates (2.32 for express bus access and 0.96 for vanpool) estimate pollutants emitted to access each mode by auto:

	Express Bus Access-Haul (gppm)	Vanpool Access-Haul (gppm)
CO	53.1	22.0
HC	8.1	3.4
NOX	5.3	2.2

Over-all effects on express buses and vanpools can be shown by adding both effects:

	Express Bus Line-Haul + Access (gppm)	Vanpool Line-Haul + Access (gppm)
CO	53.7	23.7
HC	8.3	3.8
NOX	5.7	2.8

Summary

It is clear that vanpools emit fewer pollutants within the metropolitan area than express buses. The difference is significant on the basis of over-all emissions; however, the real problem confronting the MPC may be emissions in the downtown area rather than throughout the whole metropolitan area. In the latter case, a more detailed approach to the analysis needs to be taken based on mileage through the downtown area by either mode. Further, a more comprehensive evaluation would consider the over-all effects on patronage and auto usage. Other community goals concerning energy consumption, transit subsidies, and the like should be considered to properly evaluate this case.

SCENARIO TWO

Problem Statement

Jacksonville, Fla. (urban pop. 520,000) is considering eliminating the beach bus route because of its low productivity of 1.4 passengers per bus-mile (*B-2*). It has been found that the average passenger occupancy is about 6.0 passenger-miles per bus-mile. Dial-a-ride and jitney services have been considered as reasonable modes to substitute for the bus transit route. To properly consider all aspects of this change, emission rates of the existing service and of the two alternatives must be known.

Analysis

As occupancy rates for this route are known, existing emission rates per passenger-mile should be calculated from model emission rates per vehicle-mile. Bus emission rates are 35.1 gm/vehicle-mile of CO, 5.4 gm/vehicle-mile of HC, and 3.5 gm/vehicle-mile of NOX (see Table 9; col. 4, 5, and 6). Dividing by average occupancy 6.0 passenger-miles per vehicular-mile obtains emissions in gppm for each pollutant. With the foregoing values, and using emissions per passenger-mile (see Table 10; col. 7, 8, and 9) for the alternative being considered, the following information results:

	CO (gppm)	HC (gppm)	NOX (gppm)
Existing bus	4.9	0.8	3.7
Dial-a-Ride	27.8	4.2	3.3
Jitney	9.3	1.5	1.2

From these data, it can be determined that dial-a-ride emits over five times more CO and HC than the existing bus, and jitneys emit twice as much. Yet, buses produce about 12 percent more NOX than dial-a-ride and about three times more NOX than jitneys.

Summary

With the foregoing information, a better evaluation on effects in the atmosphere could be made. Carbon monoxide is nonreactive but contributes to localized air pollution, whereas both HC and NOX are reactive and contribute to smog and regional pollution. Because of the geographic and weather characteristics of Jacksonville, smog should not be a problem. Yet, CO concentrations reach high levels along some segments of the corridor served by the beach bus route because all traffic moves along the same corridor. On the basis of air pollution considerations, the best course of action is to retain bus service. If, for other unspecified reasons, either dial-a-ride or jitneys must be selected, the jitney still emits much fewer CO pollutants than dial-a-ride and would be the better choice.

References

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B-2. *Transit Development Program Update: 1976-1980.* Kimley-Horn and Assoc. and Simpson and Curtin, Jacksonville, Fla. (Feb. 1976).

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