THE REGIONAL IMPACTS OF
NEAR-TERM TRANSPORTATION
ALTERNATIVES: A CASE
STUDY OF LOS ANGELES

PREPARED FOR THE SOUTHERN CALIFORNIA
ASSOCIATION OF GOVERNMENTS

W. T. MIKOLOWSKY, J. R. GEBMAN, R-1524-SCAG
W. L. STANLEY, G. M. BURKHOlz JUNE 1974
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The preparation of this Report was financed through a grant from the U.S. Department of Transportation, Urban Mass Transportation Administration; under the Urban Mass Transportation Act of 1964, as amended.

Published by The Rand Corporation
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Rand
SANTA MONICA, CA 90406
PREFACE

The work described in this report was performed by The Rand Corporation under a contract with the Southern California Association of Governments (SCAG) and supported by the grant from the U.S. Department of Transportation, Urban Mass Transit Administration. The study was an element of the SCAG Short-Range Program which aimed at:

- Development of a transportation control strategy for the Los Angeles Air Quality Control Region that would satisfy requirements specified by the U.S. Environmental Protection Agency for improvements in air quality by 1977.
- Formulation of an Energy Conservation Action Plan as required by the U.S. Department of Transportation.

In this study we have evaluated the air quality and energy consumption impacts of alternative transportation strategies in the Los Angeles region, as well as the impacts on regional costs and transportation service.

Rand began work on this study on January 7, 1974; a formal briefing on the final results of the study was presented to SCAG on April 8, 1974. Briefings have also been given to various other governmental and public groups. This quick response was possible only because much of the required methodology had been developed at Rand over a three-year period during projects sponsored by the Department of Transportation and the Environmental Protection Agency. Many refinements to the existing methodology, however, have been made for the present study.

This report on the final results of the study for the SCAG Short-Range Transportation Program is intended for three audiences. First, and perhaps foremost, it is directed at the people of the Los Angeles Air Quality Control Region. We have attempted to eliminate unnecessary complexity in the main text so that it can be understood by the informed layman.

Second, we hope this report will provide useful insights for decisionmakers faced with considering alternatives that could have far-reaching implications on air pollution and transportation in the Los Angeles region.

Finally, the report should be useful to transportation planners and air pollution analysts concerned with other regions throughout the country as well as Los Angeles. The latter group should find the material contained in the appendixes of special interest.
SUMMARY

This study of the regional impacts of transportation alternatives for Los Angeles was performed in support of the Southern California Association of Governments' (SCAG) Short-Range Program, which is focused on the transportation needs of the region over the next five years. The general goals of the SCAG program are improved air quality and reduced petroleum consumption by motor vehicles. A specific objective of the program is to achieve a 20 percent reduction in regional vehicle miles traveled (VMT) by 1977 to comply with U.S. Environmental Protection Agency (EPA) requirements.

Previous studies in this field have mainly concentrated on the prediction of the transportation service impacts of the systems under consideration and the related capital and operating costs. However, it has become necessary to consider a much wider range of potential impacts of new systems to satisfy legal requirements and to meet the goals of greater community involvement. To this end, Rand has developed a comprehensive methodology that can be used to predict, quantitatively, a wide range of such impacts. This work was initiated in 1971 under U.S. Department of Transportation sponsorship and has been continued under U.S. Environmental Protection Agency, County of San Diego, and now SCAG, sponsorship, supplemented by Rand Corporation funds.

The purpose of the systems impact assessment performed in this study is not to select a recommended system for implementation but rather to provide a consistent and comprehensive comparison of several transportation system alternatives in terms of their impacts on the region and its people. One of the alternatives is a "do-nothing" case in which we assume a continuation of historical trends.

The three primary objectives of this study are summarized below.

1. Determine pollutant emissions for the years 1970 through 1990 assuming various levels of technological emission controls for both stationary and mobile sources—initially without including specific tactics for reducing vehicle miles traveled in the region—and then relate these emissions to future air quality.
2. Evaluate the effectiveness (in terms of reducing vehicle miles traveled) of transportation management tactics, including bus system improvements and associated costs, carpooling incentives, and economic disincentives (such as mileage and parking surcharges, and also increases in the price of gasoline).
3. Develop feasible transportation strategies for implementation by 1977 and compare them in terms of their regional impacts on air quality, energy consumption, strategy expenditures, transportation service, and the distribution of selected impacts by income group.

A detailed comparison of alternative strategies was made to aid in selecting the most attractive or promising alternatives.

AIR QUALITY IN FUTURE YEARS

The air pollutant of greatest concern in the Los Angeles region is photochemical oxidant—commonly referred to as "smog." In this study, we have expressed future air quality in terms of oxidant, since the National Air Quality Standard for oxidant
will be the most difficult standard to achieve in this region. The magnitude of the smog problem in the Los Angeles region can be seen in Fig. S-1 which shows the number of days the oxidant standard was violated in 1970 at nineteen different locations.

The Federal Clean Air Act requires that all regions of the country be in compliance with all National Air Quality Standards by 1977. The Environmental Protection Agency has promulgated an implementation plan designed to achieve these standards throughout the Los Angeles Air Quality Control Region in 1977. Part of this plan is numerous additional technological controls for reducing emissions from both mobile and stationary sources—collectively we will refer to these as the full technological controls.¹

The effect on regional air pollution of implementing the full technological controls by 1977 is shown in Fig. S-2. These controls will result in far fewer days in violation of the oxidant standard compared with 1970; the worst point in the region, however, will still violate the standard on more than 150 days in 1977.

The class of emissions primarily responsible for photochemical oxidant air pollution is reactive hydrocarbons (RHC). Figure S-3 presents a forecast of regional RHC emissions through 1990 under the full technological controls for the five major types

¹ Examples of the full technological controls are retrofit emission control devices for used cars (e.g., catalytic exhaust gas converters for most 1966-1974 vehicles) and vapor recovery systems to reduce gasoline evaporative losses at service stations (see Sec. II for complete details). Of course, the Federal Motor Vehicle Control Program for new vehicles is also included.
Fig. S-2 — Predicted distribution of air pollution in the Los Angeles Air Quality Control Region for 1977 under the Full Technological Controls

of sources. (We have made these projections through 1990 so that long-term implications of near-term alternatives can also be considered.) By 1977 these controls will reduce RHC emissions more than 60 percent from the 1970 level. To achieve the oxidant standard, EPA has estimated that a 93 percent reduction in RHC emissions is necessary; thus only about 100 tons/day of RHC emissions are allowed if the oxidant standard is to be met. Examination of Fig. S-3 shows that emissions from stationary sources alone will be about equal to the total allowable emissions through 1990. Note also that by 1990 the total emissions will be about equally divided between light-duty motor vehicles, stationary sources, and other types of mobile sources.

Although the full technological controls promulgated by the EPA will not result in the oxidant air quality standard being met by 1977 or even by 1990, their implementation will result in a significant improvement in the quality of the air breathed by the people of the Los Angeles region. We have developed a new measure of air pollution, called the Regional Population Exposure Level, that is representative of the total annual exposure to adverse levels of photochemical smog received by the residents of the region. A forecast through 1990 of the Regional Population Exposure Level to adverse oxidant levels under full technological controls is presented in Fig. S-4. Using this measure to describe air pollution, we see that implementa-

2 The Clean Air Act requires EPA to provide a strategy for meeting all air quality standards in the final implementation plan. The requisite additional emission reductions were to be obtained by imposing a total ban on gasoline and diesel fuel sales in 1977. With no emissions from the motor vehicle sources, Fig. S-3 shows that the allowable RHC emissions level would probably be reached in 1977.
Fig. S-3 — Forecast of reactive hydrocarbon emissions under the full technological controls. This forecast is consistent with current SCAG regional population projections through 1990.

Fig. S-4 — Predicted population exposure to adverse oxidant pollution under the full technological controls.
tion of full technological controls will yield at least an 80 percent reduction in the exposure to adverse levels of photochemical smog in 1977 compared with what was experienced in 1970. By 1990, these controls will result in approximately a 95 percent reduction from the 1970 exposure.

NEAR-TERM TRANSPORTATION MANAGEMENT TACTICS

To this point we have assumed that VMT will continue to grow at the rate commensurate with that observed in 1970-1972. Further near-term improvements in air quality and reductions in gasoline consumption can be obtained through transportation management tactics designed to reduce regional VMT. We have focused our analysis on three types of near-term tactics:

- Bus system improvements
- Carpooling incentives
- Economic disincentives on automobile use, including increasing gasoline prices.

Bus system improvements considered include fare reductions, increased frequency of service, expanded service area, and preferential freeway treatment for express buses. Our analysis revealed that tripling the size of the existing regional bus system will reduce VMT about 8 percent and will increase the required annual subsidy by more than $400 million. Less extensive bus system improvements yield correspondingly smaller reductions in VMT.

Larger reductions in VMT can be achieved through carpooling incentives. Our analysis has shown that preferential freeway treatment for carpools and computer matching to encourage the formation of carpools are mutually reinforcing tactics and could potentially reduce VMT about 20 percent. We should note, however, that carpooling incentives compete with the bus system and cause a slight decrease in bus patronage.

We have considered two types of economic disincentives: mileage surcharges and parking surcharges. The mileage surcharge was represented as an additional gasoline tax, thus allowing the effect of increases in gasoline price through the market mechanism to be evaluated simultaneously with the mileage surcharge tactic. For example, a total gasoline pump price of 85¢ per gallon (say 60¢ per gallon basic pump price plus 25¢ per gallon surcharge) would reduce VMT about 20 percent in the short term. We also estimate that gasoline priced at this level would reduce person trips about 7 percent; these trips forgone may be interpreted as a loss in personal mobility. Parking surcharges applied to all trips appear to be considerably less effective (for equivalent out-of-pocket costs to motorists) than mileage surcharges in reducing VMT, and furthermore such surcharges involve a much larger reduction in person trips. It is significant, however, that when a parking surcharge is applied only to the nonresidential end of home-work trips, it reduced VMT as effectively as a mileage surcharge, but with the added advantage that it causes practically no reduction in total person trips. (We are assuming that all home-to-work trips are essential and will not be forgone regardless of changes in the service characteristics of the transportation system.)

We emphasize that bus system improvements and carpooling incentives will offer the people of the region something positive in return for their reduction in VMT. Improvements in the regional bus system will lessen the adverse impact on personal mobility of increasing gasoline prices as well as provide increased mobility.
COMPARISON OF ALTERNATIVE TRANSPORTATION STRATEGIES

No single transportation management tactic addresses all of the immediate transportation needs of the Los Angeles region. We have combined the individual tactics in different ways to form six alternative transportation strategies. The six strategies have been compared against the "do-nothing" or Reference Case (defined below) in 1977 in terms of their many impacts on the Los Angeles region.

The Reference Case has been defined as a continuation of the trends in 1970-1972. The only emission controls included in the Reference Case are those in effect in 1970 (including the Federal Motor Vehicle Control Program for new vehicles). The six alternative strategies are briefly described below.

Strategy A (FTC Only). Full technological controls only; the pump price of gasoline is assumed to be 60¢ per gallon compared with 40¢ per gallon in the Reference Case (each of the remaining strategies contains all of the elements of Strategy A, plus additional transportation management tactics).

Strategy B (EPA Plan). Final EPA Implementation Plan as promulgated on November 12, 1973 (including the parking surcharge provision which has since been withdrawn).

Strategy C (Big Bus). Emphasis on major bus system improvements only (lower fares, increased frequency of service, expanded service area, and preferential freeway treatment for express buses).

Strategy D (Heavy Carpool). Emphasis on carpooling incentives only (preferential freeway treatment for carpools and buses, and extensive computer matching to encourage formation of carpools).

Strategy E (Bus and Carpool). Combination of moderate bus system improvements with carpooling incentives (lower fares, increased frequency of service, and expanded service area for buses; preferential freeway treatment for carpools and buses, and moderate computer matching to encourage formation of carpools).

Strategy F (Max. Effort). Maximum effort strategy with major bus system improvements and carpooling incentives plus economic disincentives (additional gasoline tax of 26¢ per gallon and a parking surcharge of $1 per day on home-to-work trips with exemptions for carpoolers).

The Reference Case is consistent with current SCAG regional growth projections through 1990. The same growth forecast has been used in each of the six alternative strategies.
Again we emphasize that all six strategies include full technological controls and assume that the basic pump price of gasoline is 60¢ per gallon.

The summary impacts of the six alternative strategies are shown in Table S-1. The impacts are presented using the color scorecard technique, where colors are used to highlight differences between strategies. Such a coloring scheme is sometimes useful as an aid in selecting among alternative strategies where each strategy contains a different mix of desirable and undesirable attributes. We use red to denote the two least attractive strategies in each impact category, green to denote the two most attractive strategies, and yellow to denote the two remaining strategies with impacts in the middle of the range. The reader should be warned that the assignment of color across any particular impact is a subjective process and may vary widely among different individuals, depending on their particular viewpoints and beliefs. For example, large surcharge collections could be considered undesirable (the typical citizen would probably view it that way) or they could be regarded as a benefit, since presumably the resulting revenue would be expended in the public interest. The colors shown in Table S-1 (and later in Chapter V) are offered as an example of the method; they represent the opinions of the authors and are those used in numerous briefings of study results. However, our judgments are by no means infallible, and in fact there is some disagreement among members of the

<table>
<thead>
<tr>
<th>SUMMARY IMPACT</th>
<th>Reference Case</th>
<th>FTC Only</th>
<th>EPA Plan</th>
<th>Big Bus</th>
<th>Heavy Carpool</th>
<th>Bus &amp; Carpool</th>
<th>Max Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annu...ized Strategy Cost ($ million)</td>
<td>32</td>
<td>367</td>
<td>294</td>
<td>106</td>
<td>394</td>
<td>463</td>
<td>674</td>
</tr>
<tr>
<td>Annual Surcharge...ed * ($ million)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>674</td>
</tr>
<tr>
<td>Trips Forgone (% of Reference)</td>
<td>0</td>
<td>4.6</td>
<td>2.6</td>
<td>4.3</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in Vehicle Miles Traveled (% of Reference)</td>
<td>0</td>
<td>45</td>
<td>33</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Buses Required</td>
<td>2080</td>
<td>2080</td>
<td>2350</td>
<td>2350</td>
<td>3290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional Population Exposure Level for Oxidant (% of 1970 Level)</td>
<td>49.3</td>
<td>6.0</td>
<td>7.9</td>
<td>8.2</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Oil Requirements for Motor Vehicle Use (millions of barrels per year)</td>
<td>246</td>
<td>150</td>
<td>178</td>
<td>183</td>
<td>147</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline Price (cents/gallon)</td>
<td>40</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy Designator</td>
<td>Reference</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
</tbody>
</table>

* The least attractive strategies  The most attractive strategies  Remaining strategies

* The revenue from surcharges could, of course, be used to offset some of the strategy costs or could be allocated to other beneficial purposes.
Rand professional staff. *Hence the reader is encouraged to substitute his own color assignments. Furthermore, when using the colored scorecard to aid in the selection of a promising strategy, the reader must attach relative weights to each of the impact categories based on his own value system.*

The eight impact categories presented in the scorecard are representative of the range of impacts evaluated in this study. The impact categories are generally self-explanatory. For example, the "Annualized Strategy Expenditures" are the total annualized cost of the strategies including additional technological controls for both fixed and mobile sources as well as the annual bus subsidy required (the annualized cost of the bus system, including the amortized investment costs of new buses, less the annual revenue from fares).4

The transportation service impacts shown are the trips forgone and the reduction in VMT. The number of buses required in each of the alternative strategies is also included.

The air quality impacts of the strategies are presented in terms of the Regional Population Exposure Level for oxidant. This is the new measure of photochemical air pollution alluded to earlier. From the scorecard, we see that all of the strategies will yield approximately a 90 percent reduction in the annual exposure to adverse photochemical smog levels when compared with the 1970 exposure. The Reference Case ("do-nothing") shows only about a 50 percent reduction. All of the strategies also result in a savings of crude oil required for motor vehicle use.

**POLICY CONCLUSIONS**

The major policy conclusions that can be drawn from this study are:

1. Implementation of extensive technological emission controls for both stationary and mobile sources will result in substantial improvements to air quality by 1977. However, the National Air Quality Standard for oxidant may never be achieved in the Los Angeles Air Quality Control Region under the presently conceived technological emission control strategy (i.e., the oxidant standard may be violated on many days each year).

2. Several transportation management alternatives are available which could yield meaningful reductions in VMT (without recourse to economic disincentives) and could also significantly alleviate losses in personal mobility (as measured by trips forgone) caused by increasing gasoline prices.

3. The reductions in VMT that could be achieved through transportation management strategies would yield savings in total petroleum consumption and—over the next several years—would cause some further improvements in air quality. However, beyond about 1985 and assuming implementation of full technological controls, a reduction in VMT would cause only a very modest improvement in air quality because the emissions from light-duty motor vehicles will then represent only about one-third of the total emissions of reactive hydrocarbon in the region.

4 The careful reader may be surprised that the EPA plan shows smaller strategy expenditures than the Full Technological Controls Only Case since all of the strategies include the same full technological controls. However, the substantial reduction in VMT resulting from the EPA plan causes a significant decrease in the incremental operating costs of the automobile retrofit emission control devices that are part of the full technological controls.
4. Future mass transit systems designed for implementation in the long term (1990) cannot be justified on the basis of anticipated improvements in air quality because reductions in VMT over the long term will have only a small effect on regional air pollution.
ACKNOWLEDGMENTS

This report would not have been possible without the contributions of many people. We especially acknowledge the assistance of Ms. Frances Bolger of the Southern California Association of Governments who served as Project Officer for the study. We also appreciate the efforts of John Beil, Gerald Leonard, and Terrence McKenna of SCAG for providing much of the background information required.

Many other individuals contributed substantially to our basic data requirements: specifically, we thank Ronald Mueller of the U.S. Environmental Protection Agency, Region IX Office; Donald Bratton and John Kinosian of the California Air Resources Board; and Robert Papetti and Edward Schuck of the EPA. Of course, this study was possible only because of the methodology initially developed by Rand colleagues James Bigelow, James DeHaven, Bruce Goeller, Janet Ives, Thomas Kirkwood, Robert Petruschell, and Barbara Woodfill. We are also grateful to Helen Cushman, Anita Noren, and other members of Rand’s highly competent Briefing Art Staff, for the preparation of the visual aids used in the briefings on the study.

The preparation of this report was greatly aided by the comments and criticisms provided by individuals who had attended the several formal briefings describing the essence of the study. We are especially indebted to the following people for their contributions: Graham Smith and Norman Emerson of the City of Los Angeles Mayor's Office, Los Angeles City Councilman Marvin Braude, David Ackerman and Michael Lewis from Los Angeles County Supervisor Schabarum’s office, Robert Bush from Supervisor Hahn’s office, San Bernardino County Supervisor Dennis Hansburger, Gerald Baxter and Charles Boyer from the California Department of Transportation, Terry McGuire from the Staff of the California Air Resources Board, Robert Lunche and his staff at the Los Angeles Air Pollution Control District, John Curtis of the Southern California Rapid Transit District, Peter Fielding of the Orange County Transit District, all of the members of SCAG’s Comprehensive Transportation Planning Committee,1 Laurel Roennau and Arnold Varney from the Citizen’s Advisory Committee on Rapid Transit, and Daniel Link and James McMeekan of Alan M. Voorhees and Associates.2

We also appreciate the efforts of James DeHaven, John Enns, and Bruce Goeller of Rand for their careful and thoughtful review of this report. We also acknowledge Giles Smith, Project Manager, and Howard McFarland, Director of the Rand Program on Transportation and the Environment, for their general supervision and guidance throughout the course of this study. Finally, we would like to express our thanks to Susan McCarthy for her careful reading of the text and her constructive comments.

1 The members of the Comprehensive Transportation Planning Committee were: Chairman Ralph Clark, Supervisor, Orange County; Joseph Aime, Councilman, City of Ontario; Haig Ayanian, Director, California Department of Transportation, District 7; George Bewester, Councilman, City of Perrance; Lawrence Chimbole, Councilman, City of Palmdale; Adelina Gregory, Councilwoman, City of Baldwin Park; Vice Chairman Donald Hage, Councilman, City of Arcadia; William June, Supervisor, Riverside County; John Kanel, Councilman, City of Cypress; William Katona, Councilman, City of San Bernardino; Donald Lawrence, Councilman, City of Los Angeles; Daniel Mikkell, Supervisor, San Bernardino County; James Moe, Director, California Department of Transportation; Irving Morbar, Road Commissioner, Los Angeles County; Peter Schabarum, Supervisor, Los Angeles County; Glenn Schmidt, Supervisor, Ventura County; Jane Tolmach, Mayor, City of Oxnard; Donald Schroeder, Supervisor, Riverside County; Cliff Wanamaker, Councilman, City of Riverside; Robin Young, Councilwoman, City of La Habra; and David Zimmer, Councilman, City of Montebello.

2 Alan M. Voorhees and Associates had contracted with SGAG to analyze and develop the implementation aspects of the SCAG Short-Range Transportation Plan.
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I. INTRODUCTION

The improvement of the regional transportation system in Southern California has been the goal of many studies. Most recently, the fixed-guideway mass transit system [1] proposed by the Southern California Rapid Transit District (SCRTD) is perhaps the best known. A common limitation of all the transportation system studies and proposals is that the resulting impacts on the region are not fully described. In this study, we have attempted to quantify the consequences in terms of a wide variety of impacts, of several near-term\(^1\) transportation alternatives for the Los Angeles region. We are not recommending that any specific transportation alternative be implemented; rather, our goal is to provide a consistent comparison of the alternatives, in terms of their impacts on the Los Angeles region, in the hope that local decisionmakers—as well as the people of Los Angeles—can better realize their implications.

BACKGROUND

The 1970 Amendments to the Federal Clean Air Act required that the U.S. Environmental Protection Agency (EPA) formulate National Air Quality Standards (NAQSSs) that would protect public health from the most common air pollutant species. The Amendments also prescribed that all areas of the nation should comply with these standards by 1975, although extensions to 1977 could be granted to some regions if, in EPA’s judgment, achieving the standards by 1975 would have adverse economic or social consequences for a particular region. Congress directed that the individual states would have the primary responsibility for developing implementation plans to achieve and to maintain the air quality standards in each region. The Environmental Protection Agency was to review and approve these plans if they seemed able to achieve the standards; if the plans were unsatisfactory, EPA was to impose an alternative implementation plan to meet the NAQSSs by the deadline year.

Implementation Plans for Los Angeles

The California Air Resources Board (CARB) initially submitted an implementation plan [2] for EPA approval in January 1972. The Environmental Protection Agency rejected the portion of the plan pertaining to the Los Angeles Air Quality Control Region (LA AQCR),\(^2\) since the provisions for achieving all air quality standards by 1977 (assuming the two-year extension was granted by EPA) were inadequate. Consequently, the Region IX office of the EPA was required by law to promulgate an alternative implementation plan for the LA AQCR that would result in achieving all NAQSSs by 1977. The final version of the EPA plan was published in the Federal Register on November 12, 1973 [3].

\(^1\) By “near-term” or “short-range” we mean transportation system improvements that could be implemented within the next five years. Specifically, we have used 1977 as the target year for reasons discussed below.

\(^2\) The LA AQCR consists of that portion of Los Angeles County south of the crest of the San Gabriel Mountains, all of Orange and Ventura Counties, the western portions of Riverside and San Bernardino Counties, and the coastal portion of Santa Barbara County [2]. The LA AQCR is sometimes called the South Coast Air Basin (SCAB).
The essence of the final EPA plan was to use technological controls to reduce emissions from both stationary and mobile sources to the maximum feasible extent. Additional emission reductions were to be obtained by reducing the daily vehicle miles traveled (VMT) by automobiles. This was to be accomplished in two ways: First, tactics such as imposing surcharges on parking were included, with the goal of reducing VMT about 20 percent; second, any additional emission reductions needed were to be achieved by gasoline rationing. Unfortunately, EPA's supporting calculations [4] indicated that gasoline and diesel fuel sales would have to be totally banned if the standards were to be achieved by 1977.

Opposition to certain elements of the EPA plan was both widespread and vociferous. Specifically, the economic consequences of a total ban on gasoline sales were viewed as catastrophic [5]. Privately, EPA officials admitted that banning gasoline sales was not a practical alternative. However, since the 1970 Amendments required that all regions achieve the standards by 1977, EPA had little choice but to promulgate what was regarded by many as a totally infeasible plan.

Since massive gasoline rationing appeared to be the only tactic that would assure compliance by 1977, EPA (and local officials) began to anticipate Congressional modifications of the deadlines specified in the Clean Air Act. However, EPA believed that a substantial reduction in VMT could still be achieved without gasoline rationing and that this reduction would result in a corresponding improvement in regional air quality. Thus, EPA apparently believed that the transportation control strategy (excluding gasoline rationing) contained in the final implementation plan should be retained.

Even without gasoline rationing, however, there was strong local opposition to the final EPA plan. The imposition of a 25¢ per hour parking surcharge on virtually all nonresidential parking and restrictions on the construction of new parking spaces were particularly controversial issues [6]. Consequently, EPA suggested, and indeed encouraged, that an alternative plan, responsive to local needs and desires, be prepared. The goal of the alternative plan was to be a 20 percent reduction in VMT by 1977, approximately the same reduction EPA anticipated would result from their final plan without gasoline rationing.

The Southern California Association of Governments (SCAG)\(^2\) assumed the responsibility of developing an alternative transportation control strategy for the LA AQCR as part of the development of the SCAG regional transportation plan. Specifically, the development of the alternative plan was made a part of the SCAG Short-Range Program, which was designed to address the immediate transportation problems of the region.

### Energy Conservation

Another facet was added to the requirements of the SCAG Short-Range Program as the "energy crisis" became a reality in the last months of 1973. As a result of an oil embargo imposed by the Arab states, the U.S. was faced with crude oil supplies approximately 10 percent less than the anticipated demand. By early 1974, gasoline shortages resulted in long lines at Los Angeles area service stations, and much recreational travel was eliminated.

The events of late 1973 and early 1974 highlighted the need for energy conservation plans. Specifically, the U.S. Department of Transportation (DOT) required that

\(^{2}\) The SCAG region is composed of all of Los Angeles, Orange, Ventura, Riverside, San Bernardino, and Imperial Counties. As such, it represents all of the LA AQCR except that portion contained in Santa Barbara County.
the Los Angeles region document all transportation-related activities proposed for the next five years. An energy conservation action plan was to be formulated, based on these activities.

Thus, a major stimulus of the study described in this report was the need for a quantitative evaluation of the air quality and energy consumption impacts of alternative near-term transportation plans for the Los Angeles region.

OBJECTIVES OF THE RAND STUDY

To meet the needs outlined above, two major objectives were initially defined for the study:

1. Determination of the effectiveness of specific transportation management tactics that could be implemented in the Los Angeles region by 1977 to reduce VMT, such as bus system improvements, carpooling incentives, and a variety of economic disincentives to discourage people from using private automobiles.
2. Selection of feasible and attractive mixes of those individual tactics and comparison of them in terms of their impacts on air quality, energy consumption, costs, and transportation service, and comparison also of the distribution of selected impacts by household income group.

Since much of the motivation for the study was the need to reduce air pollution in Los Angeles, we first had to predict pollutant emissions for the years 1970 through 1990, assuming various levels of technological control (but without specific tactics for reducing VMT in the region) and then had to relate those emissions to air quality. The results of that analysis thus provided a reference from which to measure the improvements that might be brought about by reducing VMT.

When the study results were briefed to numerous audiences, it became apparent that a lengthy discussion and presentation of data on the emissions and air quality analysis was necessary for the audience to fully understand and interpret the results of the transportation management analysis. Furthermore, the air quality analysis yielded results that were useful in a context broader than merely transportation management. Consequently, although not initially a major study objective, the results of the air quality analysis are given prominent treatment in this report.

METHODOLOGY FOR THE RAND STUDY

The short duration of this study, which was completed in less than three months, and the early availability of substantive results were possible only because much of the required methodology had already been partially developed. For the most part, the principal models used in the study had been originally developed for the San Diego Clean Air Project [7]. In that project, Rand developed a comprehensive methodology for the analysis of alternative air pollution control strategies in terms of

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4 Each such mix is referred to as a strategy.

5 Although 1977 is the present deadline year for achieving the NAQSs throughout the country, it appears likely, at this time, that extensions of as much as 10 years may be granted (see Sec. III). Consequently, we have predicted air quality in each case through 1990, which is the standard long-range planning horizon used by SCAG.

6 The Clean Air Project, a joint venture of San Diego County and The Rand Corporation, sought strategies that would achieve the National Air Quality Standards in San Diego by 1977.
their many impacts upon an urban region. Several components of that methodology were used in the present study. The following two models were particularly important: the Motor Vehicle Emission and Cost (MOVEC) model [8], and the Policy-Oriented Urban Transportation Model [9-11]. Both of these models were extensively modified to address the needs of the SCAG Short-Range Program. For example, the MOVEC model was extended to include in much more detail the effect of emission control devices on automobile fuel economy. The transportation model was modified to allow evaluation of various additional carpooling incentives and parking surcharges.

Rand experience gained in the San Diego Clean Air Project in the control of emissions from stationary sources and aircraft [12] was also useful in the compilation of emission inventories. Finally, insights obtained in the San Diego study permitted Rand to rapidly develop the air quality prediction methodology used in this work.

We emphasize that all of the models used in the analysis for the SCAG Short-Range Program are policy-oriented. The models were designed to predict a wide variety of impacts on the region for a given change in transportation or emission control policy. In general, they are not useful for detailed implementation planning. Rather, they are intended to provide an analytic framework that can be used to investigate a large number of alternative transportation strategies. The decision-makers can then select one (or more) of the most promising and feasible strategies for more detailed implementation analysis.Ø

ORGANIZATION OF THIS REPORT

Section II presents a forecast of regional air quality through 1990, assuming that no reduction in VMT has occurred. In Sec. III, we discuss a new technique for describing regional air pollution; as an example application, we show the effect on air quality of a 20 percent reduction in VMT. The effectiveness of several promising transportation management tactics in reducing VMT is shown in Sec. IV. Section V contains the detailed impact comparison of six alternative regional transportation control strategies. Section VI concludes the report by listing the important policy conclusions and recommendations derived from the study.

The main text is supported by a number of appendixes. Appendix A highlights the technique and the data base for calculating regional emissions. The air quality prediction methodology developed for this study is described in Appendix B. In Appendix C, we discuss the recent modifications made to the urban transportation model. Appendix D has additional detail on the effectiveness of various transportation management tactics in reducing VMT. Finally, Appendix E describes our estimates of automobile fuel economy required for the calculation of regional gasoline consumption.

¹ SCAG presently has Alan M. Voorhees and Associates under contract to study the implementation aspects of the Short-Range Transportation Plan.
II. FORECAST OF REGIONAL AIR QUALITY THROUGH
1990

The Los Angeles Air Quality Control Region has one of the most severe air pollution problems in the United States. The problem is highlighted in Table 1, which compares the National Primary Air Quality Standards for five pollutant species with the maximum concentrations observed in 1970. As shown in Table 1, the species violating the standard by the greatest amount is photochemical oxidant—commonly known in Los Angeles as “smog.” Earlier work at Rand and elsewhere has shown that the photochemical oxidant standard is the most difficult to achieve in this region [13]. Furthermore, the same work demonstrated that achievement of the oxidant standard would result in achieving all of the other air quality standards. Thus in the present study, we will limit our discussion of air pollution to photochemical oxidant.

Table 1 does not provide an adequate description of the air pollution in Los Angeles in 1970, since only the maximum concentration at the worst point is shown. Perhaps a more meaningful measure of air quality is the number of days per year that standards are violated at different points in the region. Figure 1 shows the number of days in 1970 that the NAQS oxidant was violated at each of nineteen different locations in the LA AQCR. Careful examination of Fig. 1 reveals that the spatial distribution of air pollution is much like that expected. The areas near the coastline have relatively few days in violation of the standard (less than 100), and the areas with the most days in violation (200 or more) are located mainly along the base of the San Gabriel Mountains and in the more heavily populated inland valleys.

In this report we will use both of these measuring techniques (estimating both the maximum concentration and the frequency of exposure to concentrations in excess of the standard) to describe regional air pollution for the worst point in the region as well as for the other locations shown in Fig. 1. Later in Sec. III we show how both measures can be expressed as a single metric.

To further describe the magnitude of the air pollution problem in the LA AQCR, we will present a forecast of air quality through the year 1990. In this section, air quality is expressed by the number of days the oxidant standard is expected to be violated. We make the forecast for three separate cases that cover the range of possible technological emission control strategies; however, we assume in this section that there will be no reduction in VMT. In addition, the air quality forecast is made for three sets of technical assumptions—reflecting the current uncertainty in predicting air quality. Finally, we conclude the section by showing the relative contribution of different source types to air pollution in the LA AQCR.

1 Air quality standards are formulated in terms of an ambient concentration measured over a specified averaging time. Standards are not to be violated more than once per year at the worst point in the region. In Table 1, the observed maximums are for the same averaging times as the corresponding standards.

2 The worst point in the region will, in general, be different for each pollutant. In the case of oxidant, the maximum observed concentration in 1970 occurred in Riverside.

3 The portion of Santa Barbara County within the LA AQCR has been omitted from Fig. 1 and similar figures in following sections because ambient oxidant concentrations were not monitored in Santa Barbara during 1970.
Table 1
AN OVERVIEW OF AIR POLLUTION IN THE LOS ANGELES
AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th>POLLUTANT</th>
<th>NATIONAL AIR QUALITY STANDARD*</th>
<th>MAXIMUM OBSERVED IN 1970</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentration</td>
<td>Averaging Time</td>
</tr>
<tr>
<td>Photochemical Oxidant **</td>
<td>0.08 ppm</td>
<td>1 hour</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>9 ppm</td>
<td>8 hours</td>
</tr>
<tr>
<td></td>
<td>39 ppm</td>
<td>1 hour</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>0.05 ppm</td>
<td>annual average</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>0.03 ppm</td>
<td>annual average</td>
</tr>
<tr>
<td></td>
<td>0.14 ppm</td>
<td>24 hours</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>(75 \mu g/m^3)</td>
<td>AGM</td>
</tr>
<tr>
<td></td>
<td>(260 \mu g/m^3)</td>
<td>24 hours</td>
</tr>
</tbody>
</table>

* National primary standard shown for each pollutant. The primary standard is intended to protect the public health; secondary standards are long-range goals intended "to protect the public welfare" (e.g., prevent damage to vegetation). For photochemical oxidant, these standards are identical.

** Photochemical oxidant here denotes a complex mixture of oxidizing substances that are physiologically harmful to humans and plants and are aesthetically objectionable. The National Air Quality Standard for oxidant was set by EPA and is designed to protect all segments of the population from any of the adverse health effects associated with oxidant pollution of the air.

CASES CONSIDERED

We have used the same projection of regional growth for all three cases as described below. The projection is based on an extrapolation of the historical trends observed in the 1970-1972 time frame. The number of vehicle miles traveled is assumed to increase at a rate corresponding to current growth estimates (based on 1970-1972 data) for the Los Angeles region [14]. All regional growth rates used in this study are consistent with current SCAG population projections through 1990 [15]. The details of the assumed growth rate for both VMT and the other emission sources are contained in Appendix A.

We have forecast future air quality for three different cases, which we have identified as the Reference Case, the Nominal Case, and the Full Technological Controls Case. Each case assumes a particular level of technological emission controls, and includes stationary source emission reductions, retrofit of emission control devices on older vehicles, and inspection/maintenance of vehicles in use.

* Our use of the 1970-1972 period as a base allows us to temporarily ignore the effects of recent gasoline shortages and gasoline price increases; later in Sec. IV, we account for these effects.
Fig. 1 — Spatial distribution of air pollution in the Los Angeles Air Quality Control Region for 1970

Reference Case

Our Reference Case is intended to define a baseline against which the improvements in air quality brought about by alternative policies can be shown. In the Reference Case, stationary sources are assumed to be controlled to the level existing in 1970 [16]—again appropriate growth factors have been applied (see Appendix A). The emission control strategy for motor vehicles consists of the Federal Motor Vehicle Control Program for new vehicles. That is, we are assuming that new 1975 vehicles will meet the 1975 Interim California Emission Standards, that the 1976 vehicles will meet the 1976 Federal Statutory Standards, and so on. Again, appropriate growth factors and estimates of increased emissions resulting from the deterioration of control devices on new vehicles have been included. In addition, we have assumed that all light-duty motor vehicles (LDMVs) operating in 1970 and later have crankcase emission control devices to reduce blowby emissions. Most new vehicles have had this device included as original equipment since 1961; older vehicles have had the device retrofitted upon transfer of ownership since 1964 in the LA AQCR [2].

Nominal Case

The Nominal Case is the same as the Reference Case except that additional control tactics for both stationary and mobile sources have been included. The additional tactics are those that presently have legislative authority for implementation and are expected to be substantially realized by the end of 1975.
For stationary sources, the only additional control tactic reduces the evaporative emissions from surface coating operations. These regulations also contain incentives to encourage the use of water-based paints [17].

Emission controls on LDMVs consist of the two programs currently being implemented in California. The first applies to 1955-1965 vehicles. (The first exhaust emission standards for new vehicles in California were for the 1966 models.) Beginning in 1972, these vehicles were required to have an exhaust emission control device installed upon transfer of ownership or at the time of initial registration in California. We have assumed that 80 percent of the 1955-1965 vehicles will have the retrofit installed by 1975.6 The second program applies to 1966-1970 vehicles and is intended to reduce oxides of nitrogen (NOx) emissions. (The emission standards for new 1966-1970 vehicles were formulated in terms of hydrocarbon and carbon monoxide emissions only; as a consequence, NOx emissions increased because of the control techniques used by the vehicle manufacturers. Beginning with the 1971 models, California's new vehicle emission standards included oxides of nitrogen.) Presently this program requires that the vehicle be retrofitted at the time of initial registration or transfer of ownership. However, in 1975 the program requires the mandatory installation of the retrofit on all 1966-1970 vehicles in the LA AQCR [18].

Finally, an additional reduction in emissions from commercial aircraft is included in the Nominal Case. The reduction is a result of modifications to the JT-8D turbine engine used mostly in medium-range aircraft. The modification is due to an agreement between EPA and the airlines and was intended to reduce visible emissions (smoke) from commercial aircraft. By the end of 1975, virtually all affected aircraft nationwide will have the retrofit installed [12].

As the reader can see, most of the control tactics included as part of the Nominal Case are currently being implemented in the LA AQCR. We have assumed that implementation of the Nominal Case is completed by the end of 1975.

**Full Technological Controls Case**

The Full Technological Controls Case consists of the Nominal Case plus all of the technological emission controls specified in the implementation plans for the LA AQCR [3, 18]. These control tactics (with the exception of the stationary source controls) presently lack the enabling legislation required for implementation.

Additional emission reductions from stationary sources are obtained in the Full Technological Controls Case by further controlling petroleum operations and organic solvent users. The intent of these controls is to reduce the emissions of reactive hydrocarbons. Gasoline marketing operations are controlled in two ways. First, the evaporative losses from the filling of underground storage tanks at the service station are reduced.8 Second, substantial emission reductions are obtained by controlling evaporative emissions that normally occur during the filling of vehicle fuel tanks. Remaining stationary source emission reductions result from tightening the existing regulations that apply to organic solvent uses. The use of the degreasing solvent trichloroethylene will be banned throughout the basin, since substitute materials that result in no reactive evaporative emissions are readily available.

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6 Los Angeles County Air Pollution Control District's Rule 66.
7 The EPA technical assumptions, discussed subsequently, assumed that only 67 percent of the vehicles are retrofitted [4].
8 Small differences that exist in the implementation plans prepared by EPA [3] and CARB [18] are included as part of the differences in technical assumptions described next.
9 Los Angeles and Orange Counties have already enacted rules to require these controls [17].
Furthermore, additional reactive hydrocarbon emission reductions are obtained by controlling the solvent loss from commercial dry cleaning operations.

Two additional tactics are included in the Full Technological Controls Case to further reduce the emissions from light-duty motor vehicles. All in-use vehicles are required to undergo an annual inspection (and maintenance if necessary) to ensure that excessive exhaust emissions are not occurring. In addition, the implementation plans provide for the retrofit of oxidizing catalytic exhaust gas converters to reduce emissions of hydrocarbons and carbon monoxide. The EPA plan assumes that 75 percent of the 1971-1974 vehicles and 20 percent of the 1966-1970 models are eligible for this retrofit. On the other hand, the CARB plan intends that 80 percent of the 1971-1974 vehicles and 60 percent of the 1965-1970 vehicles will be retrofitted. The CARB plan also assumes the retrofit of catalytic converters on 1962-1974 heavy-duty gasoline-powered trucks.

The technological emission controls included in this case apparently represent what the respective agencies consider to be the maximum feasible level of control. However, other analyses have indicated that even more stringent technological controls are possible [7, 13]. We have not readdressed these issues, since the goal of the present study emphasizes emission reductions through transportation management.

Emissions for 1970, for the Reference Case in 1977, and for the Full Technological Controls Case in 1977 are contained in Appendix A; emissions for each species by source type are shown.

TECHNICAL ASSUMPTIONS CONSIDERED

Estimating the effect in some future year of a particular control strategy on air quality is a complex technical problem involving numerous detailed calculations. At the present time, no general agreement exists among the agencies (EPA, CARB, Los Angeles Air Pollution Control District (APCD)) responsible for such estimates on exactly how the calculations should be made. To show the range of uncertainty in forecasting future air quality, we have made our forecasts using three different sets of technical assumptions.

What Are Technical Assumptions?

We refer collectively to all of the data and theory required to forecast future air quality as “technical assumptions.” The assumptions have two primary facets: forecasting emissions in some future year for some control strategy, and relating the emission forecast to the ambient air quality of some future year. Calculating emissions is, for the most part, a bookkeeping operation—although many details involved in the calculation are not fully defined. Predicting air quality from the emission forecast is a far more complex problem, since meteorology, topography, atmospheric photochemistry, and the spatial and temporal variation in emissions could be considered. We will treat each of these facets of the assumption separately.

Forecasting Emissions. Given a scenario (e.g., vehicle miles traveled, control strategy, etc.) for some future year, the first step in forecasting air quality is to forecast regional emissions. Experimental data derived from many sources and many assumptions are required in this forecast. Items that are particularly controversial at present include the following:
- Motor vehicle emission factors (i.e., the average mass emissions per mile for each model year in the vehicle fleet).
- Deterioration in the effectiveness of motor vehicle emission control devices as the vehicle accumulates mileage.
- Effectiveness of retrofit control devices and inspection/maintenance programs in reducing emissions.
- Fraction of the total hydrocarbons from each source type that are considered reactive (i.e., that participate in the photochemical reactions that produce oxidant).
- Average annual miles traveled, by age of vehicle.

Both EPA and CARB have developed, essentially independently, estimates for each of the above parameters and have used these estimates in their respective implementation plans. Thus if both agencies were given identical regional scenarios for a future year (or even the base year of 1970) their resulting emission forecasts would be substantially different.

**Relating Emissions to Air Quality.** Using an emission forecast to predict the resulting air quality requires the application of an air quality model. Many air quality models, some of them exceedingly complex, have been developed in recent years. However, implementation plans for all regions of the United States have been prepared using a rollback air quality model.

Rollback models are based on the supposition that average daily regional emissions are directly related to ambient pollutant concentrations. For a given region, we have observed ambient concentrations during some base year; we are also able to estimate the average daily emissions during the base year. By calculating the ratio of the appropriate air quality standard to the maximum observed concentration, we are able to determine the "rollback" in emissions from the base year required to achieve the air quality standard. The simplest form of rollback model assumes that emissions are linearly related to observed concentrations. More complex models have been proposed for photochemical oxidant that result in a nonlinear relationship between emissions and concentrations. Several examples of such models are discussed in Appendix B.

**Three Sets of Technical Assumptions**

Our air quality forecasts for future years use three sets of technical assumptions. The first set corresponds to that used by EPA in their final implementation plan for Los Angeles [3]. (Most of the EPA assumptions for calculating average daily regional emissions are contained in Refs. 4, 19, and 20.) For the EPA technical assumptions, emission forecasts were related to air quality using a nonlinear rollback model—designated by EPA as the Eight-Station Average Model (see Ref. 4 and Appendix B). To illustrate the application of this model, consider Table 1, which shows that an 87 percent reduction from the 1970 maximum photochemical oxidant concentration is required to achieve the NAQS. The EPA model requires that average daily reactive hydrocarbon emissions be reduced by 93 percent to achieve the requisite 87 percent reduction in maximum oxidant concentration.  

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9 A more complete description of these complex air quality models is contained in the summary report of the San Diego Clean Air Project [7]. See also Appendix B.

10 Rollback models traditionally use reactive hydrocarbons (RHC) as the sole proxy for photochemical oxidant concentrations. Oxidants are not emitted to the atmosphere directly but rather are the result of complex chemical reactions in the atmosphere between hydrocarbons and nitrogen oxides—the reaction taking place only in the presence of sunlight.
Our second set of technical assumptions is designated as the CARB assumptions. The set corresponds essentially to that used in Revision 4 of the State Implementation Plan for Los Angeles [18]. For stationary sources, our emission forecast in this assumption set corresponds to that of the Los Angeles Air Pollution Control District [16, 17]. The CARB’s assumptions were used to calculate the emissions from motor vehicle sources. For the CARB assumption set, we applied the same air quality model used in the preparation of the State Implementation Plan—the linear rollback model. Referring to our discussion above, the linear rollback model requires only an 87 percent reduction in reactive hydrocarbon emissions from 1970 to reduce the maximum oxidant concentration by 87 percent. The relationship of the linear rollback air quality models to the other models proposed for the LA AQCR is also discussed in Appendix B.

Finally, Rand has developed a third set of technical assumptions for use in this study. The Rand assumptions are again an outgrowth of the San Diego Clean Air Project [7]. For the emissions calculations, they are based on judgments made by the Rand staff using both EPA and CARB data and other available sources. The Rand assumptions are, in our belief, the most realistic for use in the Los Angeles region. Air quality has been forecast using the EPA Eight-Station Average Air Quality Model. We presently feel that the EPA model yields somewhat conservative results. That is, a given reduction in emissions may yield a greater improvement in air quality than that predicted by their model (see Appendix B).

By using three sets of technical assumptions, we have hopefully bounded the problem of predicting air quality for future years. The EPA set yields the most pessimistic results; the CARB set shows the most optimistic; the Rand set is between these extremes.

FORECAST OF AIR QUALITY

We will now describe future air quality in two ways. First, we will show the number of days that the National Air Quality Standard for oxidant will be violated at the worst point in the LA AQCR. Then, we will show the expected geographic distribution of air pollution in the LA AQCR for 1977.

Air Quality Through 1990 at the Worst Point in the Region

Our forecast of air quality for the Reference and Nominal Cases using the three sets of technical assumptions is shown in Fig. 2 (the Nominal Case is differentiated from the Reference Case in Fig. 2 by shading the Nominal Case uncertainty band—that is, the band representing the difference between technical assumptions). We remind the reader that all of the air quality forecasts contained in this section assume there will be no reduction in vehicle miles traveled. Consider first the

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11 We are grateful to Mr. Donald Bratton of the California Air Resources Board for providing the detailed data required to replicate the emission calculations used in the implementation plan [3].

12 The difference between the EPA Eight-Station Average Model and the linear rollback model may seem at first to be small. Consider, however, that the EPA model allows only 7 percent of the 1970 emissions if the oxidant standard is to be achieved; linear rollback allows 13 percent. Thus the difference in allowable emissions between the two models is a factor of nearly two.

13 Insights into the specifics of the Rand assumptions are contained in Refs. 11 and 12. We have modified them for this study, however, to reflect the most recent information.

14 The worst point is of interest, since the National Air Quality Standard for oxidant allows only one violation per year within the region. Thus the regional emissions must be controlled to prevent more than one violation at the worst point.
Fig. 2 — Predicted air quality for the Reference and Nominal Cases in the terms of the number of days violating the NAQS for oxidants at the worst point in the Los Angeles Air Quality Control Region

Reference Case. For the EPA technical assumptions, the number of days in violation decreases from 254 in 1970 to about 225 days in 1977 and eventually to about 180 days per year in the late 1980s. On the other hand, the CARB assumptions result in about 170 days in violation in 1977, decreasing to approximately 120 days per year in 1990. The Rand assumptions (dashed line in Fig. 2) yield slightly fewer days in violation than the EPA assumptions. The improvement in air quality under the Reference Case is due to the Federal Motor Vehicle Control Program for new cars and the corresponding very low emissions beginning with 1975 automobiles. Note that the replacement of older, more polluting vehicles with the newer models meeting more stringent emission standards should be enough to offset the effect of growth on regional air quality through 1990. We emphasize that the same regional scenario for future years has been used for all three technical assumption sets—the differences shown in Fig. 2 are a consequence of the emission calculations and how these emissions are related to ambient air quality.

The Nominal Case, assuming implementation is completed by 1975, is superimposed on the Reference Case in Fig. 2. For the EPA and Rand assumptions, only modest improvements in air quality (compared to the Reference Case) are predicted. The CARB assumptions, however, show a substantial further reduction in the number of days in violation, decreasing from 120 days per year in 1990 to approximately 70 days under the Nominal Case.
Figure 3 presents a similar forecast of air quality for the Reference and Full Technological Controls Cases. The more extensive emission controls of the latter case result in significant improvements in air quality. Using the EPA technical assumptions, the oxidant standard will be violated on 170 days in 1977 and will decrease to about 130 days by 1990. The CARB assumptions again show even greater improvements; about 70 days in violation in 1977 and only about 10 days per year in the late 1980s.

Three final points should be made regarding Figs. 2 and 3. First, to consider the air quality at only the worst point in the LA AQCR can be potentially misleading. The controls included in the Nominal and Full Technological Controls Cases could

* Shaded area is uncertainty band representing differences between technical assumptions

** Brace shows uncertainty band representing differences between technical assumptions

**Fig. 3 — Predicted air for the Reference and the Full Technological Controls Cases in terms of the number of days violating the NAQS for oxidant at the worst point in the Los Angeles Air Quality Control Region

15 The EPA technical assumptions shown in Figs. 2 and 3 correspond to the recommendations provided in January 1974 by the EPA Region IX office. Since that time, some of the assumptions have been modified further [19]. The latest EPA revision causes the projected air quality under the EPA and Rand assumptions to be essentially identical by 1990 for the Full Technological Controls Case.

16 The worst point in the region, in terms of the number of days the air quality standard for oxidant was violated in 1970, is Azusa, located in Los Angeles County [21]. Depending on the reduction in reactive hydrocarbon emissions from the 1970 level and the air quality model employed, the worst point in the region in future years will be either Azusa or Upland in San Bernardino County (see Appendix B.)
well result in many parts of the region having a greater improvement in air quality than that shown. Second, a metric based on the number of days in violation does not reflect the importance of the maximum expected concentration. Both of these points are addressed in the following paragraphs. Finally, we note the extreme band of technical uncertainty manifested in Fig. 3 for the Full Technological Controls Case. Clearly, whether we have reduced the number of days in violation from the 254 observed in 1970 to 170 days (EPA) or 70 days (CARB) in 1977 will greatly affect our decisions regarding additional air pollution controls. This uncertainty in the air quality forecast is discussed further in Sec. III.

**Spatial Distribution of Air Pollution in 1977**

The air quality at other points in the Los Angeles region will be greatly different from that shown for the worst point in Figs. 2 and 3. To illustrate, Fig. 4 shows the number of days the NAQS for oxidant will be violated at various locations in 1977 for the Full Technological Controls Case. (Figure 4 should be compared with Fig. 1, which presents the same information for 1970.) An examination of Fig. 4 shows that the areas near the coast will have significantly improved air quality (fewer than 50 days in violation). The major problem areas are still located along the base of the San Gabriel Mountains; Upland has the most days in violation (between 150 and 199 days).

Thus far, our description of future air quality has been solely in terms of the number of days violating the oxidant standard. To partially show how the maximum oxidant concentrations will also be reduced throughout the basin, Fig. 5 displays the number of days the CARB First Stage Alert Level for oxidant will be violated in 1977 under the Full Technological Controls Case. In this instance, the air pollution prognosis looks quite promising. Most localities show no First Stage Alert violations; the largest number of violations will occur in Upland (16-20 days in violation in 1977).

**FORECAST OF RHC EMISSIONS BY SOURCE TYPE**

The previous discussion has shown that the NAQS for oxidant will not be achieved by 1990 for any of the technical assumptions, even with implementation of full technological controls. Consequently, we need to consider additional tactics for reducing emissions, such as a reduction in vehicle miles traveled. Before doing this, however, showing the relative contribution of various source types to regional reactive hydrocarbon emissions will provide useful insights into the effect and desirability of additional reductions.

Figure 6a is a forecast of the average daily RHC emission through 1990 for five source types assuming full technological controls and using the EPA technical assumptions. Notice first that the emission total is dominated in the early 1970s by light-duty motor vehicles. By 1977, however, implementation of the additional

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17 Our technique for predicting the spatial distribution of air pollution using rollback air quality models is presented in Appendix B.

18 The First Stage Alert level for oxidant is 0.20 ppm one-hour average. During a first stage alert, persons with respiratory or coronary problems are warned to take precautionary measures; school children are requested to voluntarily curtail strenuous activity; drivers are encouraged to eliminate unnecessary trips [22].

19 Vehicles with a gross weight of 6,000 lb or less. Approximately 90 percent of such vehicles are automobiles.
Fig. 4 — Distribution of air pollution in the Los Angeles Air Quality Control Region for 1977 under the Full Technological Controls case

Fig. 5 — Distribution of air pollution in the Los Angeles Air Quality Control Region in 1977 for the Full Technological Controls case, in terms of the number of days exceeding the first stage alert level for oxidant.
Fig. 6 — Forecast of reactive hydrocarbon emissions by source type, using full technological controls

Above: EPA technical assumptions.
Below: CARB technical assumption.
controls causes such vehicles to contribute only about 50 percent of the emission total. Finally, by the late 1990s, the RHC emissions are about equally divided between light-duty motor vehicles, stationary sources, and other mobile sources.\textsuperscript{20}

Application of the EPA Eight-Station Average Air Quality Model indicates that the daily emission level required to achieve the oxidant standard (i.e., the allowable daily emissions) is only 98 tons/day. Figure 6a shows that the emissions from stationary sources very nearly exceed this level for the entire 20 year period, which is why EPA proposed a total ban on gasoline and diesel fuel sales to achieve the standard in 1977.

It is also interesting to note that transportation management tactics intended to reduce VMT will affect only the light-duty motor vehicles' contribution to the total. Thus a 20 percent VMT reduction in 1977 will cause approximately a 10 percent reduction in daily RHC emissions.

A similar emission forecast for the CARB technical assumptions is shown in Fig. 6b.\textsuperscript{21} Although the magnitude of the emission levels is somewhat different than those shown in Fig. 6a, the forecasts are qualitatively similar. If we apply the linear rollback model to the CARB assumptions, we obtain an allowable RHC emission level of 153 tons/day. From Fig. 6b, we can see that this emission level could be achieved with approximately a 60 percent reduction in VMT by 1990. On the other hand, applying the Eight-Station Average Model to the CARB emissions would give an allowable emission level of only 82 tons/day; again the emissions from stationary sources approximate this level through 1990.

**SOME OBSERVATIONS**

Several important observations can be made using the results presented in this section.

- The Los Angeles Air Quality Control Region will realize substantial improvements in ambient air quality by the implementation of full technological controls.
- The National Air Quality Standard for oxidant may never be achieved in the LA AQCR—even if major reductions occur in vehicle miles traveled.
- By 1990, the emissions of reactive hydrocarbons will be equally divided between light-duty motor vehicles, stationary sources, and other mobile sources.
- In addition to reductions in vehicle miles traveled, further improvements in ambient air quality can be achieved by more stringent controls on stationary sources and mobile sources other than light-duty motor vehicles.

We have also demonstrated several ways that air quality improvements can be described. Unfortunately, to fully describe air quality for future years (i.e., describe both frequency of exposure and maximum concentration throughout the region), several presentation devices are required. A simplified and comprehensive measure of regional air quality is described in the next section.

\textsuperscript{20} Motorcycles are a particularly controversial source of emissions at the present time. In our work we have assumed a motorcycle emission standard that becomes effective in 1977. (See Appendix A for additional details.)

\textsuperscript{21} Figure 6b reflects the CARB assumptions for mobile source emissions and the LA APCD assumptions for stationary sources.
III. A NEW TECHNIQUE FOR DESCRIBING REGIONAL AIR POLLUTION

Regional air pollution for a particular pollutant has traditionally been described using the techniques employed in Sec. II. The primary parameters that need to be taken into account in attempting such a description are:

- The frequency of exposure to adverse levels of air pollution (i.e., the number of days per year the National Air Quality Standard is violated).
- The maximum annual concentration averaged over the time period specified in the corresponding air quality standard, and
- The geographic distribution of air pollution within the region (i.e., the frequency of exposure and maximum concentration at different locations in the region.)

Each of these parameters has been used to some extent in Sec. II (and later in Sec. V) to describe air quality in future years assuming different pollution control strategies.

However, the reader should be aware by now of one major shortcoming of this approach. Namely, several complex figures (or tables) are required to adequately describe regional air pollution under each strategy. The problem becomes more acute when additional strategies are considered—some of which may not appear to have a significant effect when only one air pollution descriptor is considered, but which would be important when all of the facets described above are included.

To alleviate these difficulties, in this section we propose a new technique for describing the effect of different control strategies on regional air pollution. The new technique results in a single metric (or figure-of-merit) that is responsive to all of the parameters listed above. We will illustrate the application of the new metric by considering the effect of a 20 percent reduction in VMT on the Full Technological Controls Case. We begin with some necessary technical background on statistics and air quality.

STATISTICAL METHODS OF DESCRIBING AIR QUALITY

Basic statistics plays a very important role in describing regional air pollution. Two especially useful concepts described here are concentration histograms (or frequency distributions) and cumulative frequency distributions.

Concentration Histograms

We can most easily describe the concentration histogram by considering a hypothetical monitoring site. Let us suppose that our site has monitored oxidant concentrations for an entire year; the observed data have been retained as twenty-four one-hour average oxidant concentrations for each of the 365 days. For each day we can select the maximum one-hour concentration. The resulting 365 daily maximums are used to construct the concentration histogram for the monitoring site in that particular year.

We first divide the continuum of observed concentrations into a number of
concentration intervals, say 0 to 0.1 ppm, 0.1 ppm to 0.2 ppm, and so on. Then we determine the number of days in which the maximum concentration fell within each interval. The results of this exercise are usually presented in bar graph form, similar to that shown in Fig. 7a. In practice, smaller concentration intervals (e.g., 0 to 0.01 ppm, 0.01 to 0.02 ppm, etc.) are generally used.

The concentration histogram is not overly useful by itself; however, it does simplify the explanation and construction of the cumulative frequency distribution.

**Cumulative Frequency Distributions**

Again we consider a number of concentration intervals. Using the concentration histogram (which is a simple frequency distribution), we determine the number of days the maximum concentration was greater than the mid-point of each concentration interval. The resulting distribution for our hypothetical case is shown in Fig. 7b.

The concept of a cumulative frequency distribution is simplified if we go one more step. As shown in Fig. 7b, we can fit a continuous curve to the cumulative frequency distribution developed from the observed data. The resulting curve then serves the same purpose as the original finite distribution. For example, any concentration, say 0.25 ppm, will have been equaled or exceeded (for at least one hour) on approximately 140 days in our hypothetical case (see Fig. 7b).

Cumulative frequency distribution curves can be generated for each monitoring site from the observed data from past years. The distributions for future analysis

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![Cumulative Frequency Distribution Diagram](image_url)

**Fig. 7.** Use of the concentration histogram and the cumulative frequency distribution to describe air pollution at a hypothetical monitoring site.

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1. Generally, the best curve fits will be obtained by using smaller concentration intervals than those used in Fig. 7b.
years are more difficult to develop. We have explained in Sec. II and Appendix A how we forecast regional emissions in future years for different control strategies. The primary function of an air quality model is to take the emission forecast for each case and to develop the resulting cumulative frequency distribution for each monitoring site. Our air quality modeling technique used in the present study is described in Appendix B.

Interpreting the Cumulative Frequency Distribution

Once the cumulative frequency distribution curves are developed for each monitoring site in the analysis year, they can readily be used to obtain the needed air quality descriptors. Three different measures of air pollution using the cumulative frequency distribution are presented in Fig. 8.

Consider first the maximum expected one-hour oxidant concentration. As shown in Fig. 8, the maximum expected concentration is that concentration level which can be expected to be exceeded one day per year. A second measure, the number of days violating the NAQS (i.e., the national health standard) is also readily available. In this case, we use Fig. 8 to predict the number of days 0.08 ppm will be exceeded. Note also that we can use the cumulative frequency distribution to predict the number of days any concentration level is exceeded. For example, in Sec. II we discussed the number of days violating the First Stage Alert Level of 0.20 ppm, one-hour average.

A third measure of air quality at a given monitoring site is also shown in Fig. 8. This measure, the annual exposure to an adverse level of air pollution, forms the basis of our new metric and is discussed in detail below.

Fig. 8 — Use of the cumulative frequency distribution to describe air quality at a particular monitoring site.
THE INDIVIDUAL CUMULATIVE EXPOSURE LEVEL

The NAQS for oxidant implies that oxidant concentrations less the 0.08 ppm (one-hour average) are not harmful to human health. Similarly, an oxidant concentration above the standard that is not likely to occur more than once per year is implicitly allowed by the NAQS. Consequently we have taken the area beneath the cumulative frequency distribution curve, excluding the area permitted by the NAQS, and used the remaining area to represent the total exposure to adverse air pollution levels (that is, levels in excess of the standard) experienced in the vicinity of the monitoring site.

Definition

We have termed this third measure of air quality (the shaded area of Fig. 8) the Individual Cumulative Exposure Level (ICEL). The ICEL is representative of the cumulative exposure to adverse levels of air pollution received by an individual who spends the entire year in the vicinity of the monitoring site. The ICEL is thus a single metric that is responsive to the frequency of exposure to all concentrations exceeding the standard including the maximum expected concentration.

The basic implicit assumption in our development of the ICEL is that the degree of undesirability of an adverse level of air pollution is linearly related to the total exposure to concentration levels in excess of the standard—regardless of how this total exposure comes about. As an illustrative example of this assumption, consider a set of 20 days for which oxidant concentrations have been observed at two different monitoring sites. At one site we assume that the maximum one-hour concentration on each of the 20 days was 0.16 ppm (i.e., twice the NAQS), at the other site, the maximum concentration was 0.24 ppm (i.e., three times the NAQS) on 10 days and less than the standard on the remaining 10 days. The ICEL would indicate that the situations at these two hypothetical monitoring sites are equivalent. In other words, 20 days at twice the standard (20 days × [0.16 ppm − 0.08 ppm]) is the same as 10 days at three times the standard (10 days × [0.24 ppm − 0.08 ppm]).

In the case of photochemical oxidant, it is generally believed that high concentrations may be more dangerous to human health than repeated violations at lower concentrations. We could account for this effect by weighting the higher concentrations to reflect their undesirability. However, we feel that the presently available evidence on the health effects of oxidant is insufficient to support such sophistication [23].

Application

The ICEL will have units of parts-per-million-days. To simplify presentation, we will show ICELs for future years as a percent of the ICEL observed for each monitoring site in 1970.

Using this technique, we present the ICEL at each monitoring site for the Full Technological Controls Case in 1977 in Fig. 9. Again we have assumed no reduction in VMT. The results shown in Fig. 9 are qualitatively similar to those of Fig. 4. The areas of greatest improvement (only 0.5 percent of the 1970 exposure) are located

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2 The ICEL is not, however, the actual total exposure to air pollution levels in excess of the standards. Many days may have more than one hour in violation of the standard. The total exposure could be obtained by using all 8,760 one-hour concentrations occurring during the year in the development of the cumulative frequency distribution. This would greatly complicate the conduct of the analysis while not necessarily providing a much more meaningful measure of air pollution.
Fig. 9—Individual cumulative exposure levels in the Los Angeles Air Quality Control Region for the Full Technological Controls case in 1977

close to the coastline; the least improvement occurs again along the base of the San Gabriel Mountains. Note, however, that even Upland, the worst point in the region in this case, has an ICEL in 1977 that is less than 25 percent of the 1970 exposure—an improvement of at least 75 percent in the adverse exposure to air pollution.

**POPULATION EXPOSURE LEVELS**

At the beginning of this section, we indicated that at least three parameters were required to adequately describe regional air pollution: frequency of exposure, maximum annual concentration, and the geographic distribution of air pollution. The ICEL combines the first two parameters into a single metric. We will now describe our technique for using the ICEL for each monitoring site to define still another metric.

However, first we must explain why the geographic distribution of air pollution is important. Presently, the Clean Air Act requires that all points of a region comply with all National Air Quality Standards by 1977. In other words, the ICEL must be zero throughout the region by 1977. If this level were achieved, the geographic distribution of ICELs would be of little importance. However, as we have shown in Sec. II, achieving the NAPQ for oxidant in the LA AQR is not very likely by that year; it is far more likely that an extension to the Clean Air Act deadline will be granted. Assuming that extensions are granted and assuming a fixed level of expen-

\[3\] A recent proposal by the administration is to extend the compliance year to 1987. (See Ref. 24, p. 795).
ditures for air pollution controls, we will want to implement control strategies that will provide the cleanest possible air to the greatest number of people in the Los Angeles region. Thus we propose that the distribution of people is the most important spatial consideration for our present purposes. 5

The Community Population Exposure Level

Consider again the technique used to generate Fig. 9. We can approximate the population exposure to adverse air pollution by taking the ICEL at each monitoring site and multiplying it by the population of the surrounding community. 6 We term the resulting metric the Community Population Exposure Level (CPEL). The CPEL has units of people-parts-per-million-days.

We could prepare a figure similar to Fig. 9 that would show the distribution of CPELs throughout the region. However, that would defeat our purpose of attempting to develop a single metric that included the effects of all of the parameters.

The Regional Population Exposure Level

A single metric for describing regional air pollution as perceived by the people living in the region can be obtained by summing the CPELs of each monitoring site in the region. We have called this total the Regional Population Exposure Level (RPEL). The RPEL is a single figure-of-merit for describing air pollution; it is responsive to frequency of exposure, maximum concentration, and the geographic distribution of air pollution (in terms of the number of people affected). The RPEL also has units of people-parts-per-million-days. To simplify, we will again present analysis results for future years in terms of a percent of the RPEL observed in 1970.

We illustrate the application of the RPEL in Fig. 10 showing the air quality forecast through 1990 for the Full Technological Controls Case (implemented in 1977) with no reduction in VMT. For the EPA technical assumptions, the RPEL in 1977 would be about 20 percent of the 1970 value. The CARB technical assumptions yield an RPEL of essentially zero in 1977. Thus using the RPEL as the measure of regional air pollution shows that the air quality, as perceived by the people of Los Angeles, will be improved by 80-99 percent in 1977 if full technological controls are implemented.

One of the major advantages of the RPEL can be seen by comparing Fig. 10 with Fig. 3. In both instances, we are showing the effect of full technological controls on air quality through 1990. The most significant observation in this comparison is that the use of the RPEL shows major improvements in regional air quality regardless of which technical assumptions are considered. We feel this smaller variability in

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5 It is also important to realize that we are not advocating abandonment of the goals of the Clean Air Act. Rather, we are suggesting that the available resources for cleaning the air be allocated to yield the greatest benefit to the people of a region with a severe air pollution problem. The metric we have developed can be used to measure the improvement in air quality as perceived by the people of the region as a whole.

6 Many techniques could be used to determine the population surrounding a given monitoring site. For example, we could (somewhat arbitrarily) subdivide the region into nineteen zones with a single site in each one. Then, using census tract data, determine how many people live within each zone. We did not use this technique because people do not tend to spend the entire day within a single zone. Particular sites, such as the one in downtown Los Angeles, may have few people living within the zone, but many people working there in the daytime (when peak oxidant concentrations occur). Therefore, we have simplified the problem by dividing the population of each county by the number of monitoring sites in that county. The resulting figure has been used as the population of the community in the vicinity of each site in that county. Note that the RPEL concept is independent of how the associated population is determined. If more sophisticated techniques become available, they can be readily incorporated.
predicted air quality caused by differences in the technical assumptions coupled with the advantages described earlier causes the RPEL to be a more suitable parameter on which to base public policy.

**The Effect of a 20 Percent Reduction in VMT**

Our final illustration using the Regional Population Exposure Level will show the effect on air quality of a 20 percent reduction in VMT. Figure 11 presents the effect of the reduction in VMT, again assuming implementation of full technological controls in 1977. As shown in Fig. 11, for the EPA technical assumptions the reduction in VMT will result in a further reduction of the 1977 RPEL from 20 percent of the 1970 level to only 15 percent of the 1970 level—an additional 25 percent improvement. This improvement is surprising when considered in the light of Fig. 6, which shows that a 20 percent VMT reduction will yield only about a 10 percent reduction in regional daily reactive hydrocarbon emissions. Yet this 10 percent reduction in emissions translates to a 25 percent reduction in the RPEL for oxidant in 1977, as shown in Fig. 11.

On the other hand, Fig. 11 indicates that the improvement in air quality stemming from a VMT reduction may be short-lived. By 1980 the air quality improvement of a reduction in VMT will be only about 20 percent (EPA technical assumptions); by 1990 the improvement will be barely noticeable. For the CARB assumptions, the improvement is inconsequential in any year from 1977 to 1990. The lack of improvement after 1980 is attributable to the new vehicles achieving the very low emission levels specified by the federal standards for the 1975 and subsequent models.

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*Our analysis here is based on one very important assumption; that is, that all new vehicles will meet the 1976 federal emission standards and that these low emission levels will not grossly deteriorate with accumulated mileage. Data presently available indicate this is a reasonable assumption [25].*
SUMMARY OBSERVATIONS

We now summarize some of the important observations that can be made from the material presented in this section.

- Implementation of full technological controls in 1977 will reduce the RPEL to oxidant to 20 percent or less of the 1970 level.
- A 20 percent reduction in VMT in 1977 (with the Full Technological Controls Case) will further reduce the RPEL to 15 percent or less of the 1970 level.
- The RPEL is a more meaningful descriptor of regional air pollution, since frequency of exposure, maximum concentration, and the population affected are all taken into account.
- As a measure of air quality in future years, the RPEL is less sensitive to the choice of technical assumptions than either frequency of exposure or maximum concentration at the worst point in the region.
- Expressing air quality for future years in terms of the RPEL shows that only minor improvements in air quality can be achieved through VMT reductions after about 1985.

Finally, we note one other aspect of the RPEL when it is used as a means to describe air pollution. The residual exposure for the Full Technological Controls Case in 1977 is almost wholly attributable to the sites located along the base of the San Gabriel Mountains (e.g., Pasadena, Azusa, Upland, etc.). If constant expenditures are to be made with the intent of reducing VMT and consequently of improving air quality, the composition of the RPEL indicates that the highest payoff would be to use these funds to reduce VMT in areas where the population exposure is greatest. Although it is possible that some of the air pollution in, say, Pasadena is a result of pollutant transport from other parts of the region, undeniably the adverse air quality prevalent in Pasadena is aggravated by Pasadena’s emissions. Stated another way, the RPEL highlights the need for considering spatially nonuniform emission control tactics.
IV. THE EFFECTIVENESS OF SEVERAL PROMISING TRANSPORTATION MANAGEMENT TACTICS

We have shown in Sec. III what the effect of a 20 percent reduction in vehicle miles traveled would be on regional air pollution through 1990. In this section we will show the effectiveness, in reducing regional VMT in 1977, of several promising transportation management tactics. In the near term there are three types of tactics that can be considered for VMT reductions: bus system improvements, carpooling incentives, and economic disincentives. We have included the effect of increased pump prices of gasoline as part of the last tactic.

The Policy-Oriented Urban Transportation Model developed by Rand was used to evaluate the effectiveness of each tactic in reducing VMT. Because of the importance of the transportation model in this study, we begin this section by briefly describing the model and presenting an example application.

THE POLICY-ORIENTED URBAN TRANSPORTATION MODEL

The Rand urban transportation model is a policy-oriented tool that can be used to predict the effect of specified changes in the regional transportation system. The model was originally developed as part of the San Diego Clean Air Project [7]. However, we have recently made several refinements to the model, permitting the analysis of additional tactics such as parking surcharges, preferential freeway treatment for carpools, and computer matching for carpoolers. A description of the basic model and the improvements incorporated for this study is contained in Appendix C.

Philosophy Behind the Rand Urban Transportation Model

The Rand urban transportation model is not a forecasting model in the sense that traditional transportation models forecast person trips, vehicle miles traveled, etc., on the basis of inputs which include physical (e.g., details of the highway network) and demographic descriptions of the region. Rather, to use the transportation model, it is first necessary to describe a baseline regional transportation system for the analysis year of interest. The baseline includes forecasts of the number of weekday person trips, weekday vehicle miles traveled, frequency distribution of trip lengths, bus system description, highway network, estimate of network capacity, and so on. We have termed the baseline in this study the Reference Case; the Reference Case is commensurate with current SCAG demographic and transportation system projections through 1990. We have calibrated our transportation model to the Reference Case for analysis year 1977 only—this being the present deadline for full compliance with the National Air Quality Standards.

1 Restricting the analysis to near-term alternatives allows us to rule out a priori any fixed-guideway mass transit systems.
2 Throughout this report, the expression "person trip" denotes a journey made by one individual between a given origin and a given destination. For example, one vehicle carrying four persons from origin A to destination B generates four person trips and one vehicle trip.
3 Personal communication with Ms. Frances Bolger, Southern California Association of Governments, January 30, 1974.
Once the model is calibrated to a Reference Case in some analysis year, the effects of alternative transportation management tactics can easily be evaluated. Some of the measures that can be analyzed with the model include changes in bus system fares, frequency of service, or service area; surcharges on parking or gasoline; preferential freeway treatment for carpools; and computer matching to encourage carpooling. By specifying changes to some or all of the policy measures, the model will predict a wide variety of impacts on the regional transportation system—of particular interest in this instance is the change in weekday VMT.

We emphasize that our transportation model is not simply a modal split model. The transportation model adjusts the demand for travel in accordance with the service characteristics of the specified regional transportation system. For example, major improvements to the bus system will not only cause people to switch from the private automobile mode to the transit mode, but will induce new trips on transit (i.e., trips that were not being made in the Reference Case System). Alternatively, significant economic disincentives, such as 20¢ per gallon additional gasoline tax, will cause some trips to be forgone and will also increase the amount of carpooling and transit ridership. Thus the transportation model predicts many additional impacts, such as total trips forgone, average trip times, speeds, and costs, and the percentage of trips in carpools.

How the transportation model is used to evaluate the effect of a given control strategy can best be illustrated by an example.

Example Application—The Effect of a 25-Cent Bus Fare

Recent action by the Los Angeles County Board of Supervisors has led to a temporary change in the fare structure of the bus systems operating in Los Angeles County. Before the change, the SCRTD basic fare was 90¢, plus 8¢ for each additional transit zone crossed during the trip. A temporary supplemental subsidy provided by the Board allowed a reduction to a 25¢ flat fare for all trips (Los Angeles County only). The transit district reports that the fare reduction has increased average weekday ridership between 15 and 26 percent. These increases were derived as follows. In November and December of 1973, the SCRTD carried an estimated 500,000 passengers on the average weekday. By March of 1974, the effect of increased gasoline prices (and long lines at service stations) had increased ridership to about 560,000 passengers each weekday. After the 25¢ flat fare was implemented in April 1974, bus ridership increased further to 630,000 passengers each weekday. Thus the effect of the flat fare was to increase ridership by 15 percent; the flat fare plus the increase in gasoline prices that occurred during the six month period from November to May increased ridership by 26 percent. We will use the percentage increases for comparison, since our transportation model is calibrated to the regional bus system—not just the SCRTD operations in Los Angeles County.

Early in our study we had used our transportation model to evaluate the effect of bus fare reductions as a tactic for reducing VMT in 1977. Our Reference Case bus system was designed to yield approximately the same level of service in 1977 as the existing regional bus system provided at the beginning of 1974. The bus fare zone structure was approximated by describing the fare in the Reference Case as 25¢ per trip, plus 2¢ per mile traveled on the bus. This resulted in an average fare of 46¢.

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4 Some of the details of our calibration to the Reference Case in 1977 are shown in Appendix C.

5 Personal communication with Mr. Joseph Scatchard, Controllers Officer, Southern California Rapid Transit District, May 17, 1974.
in the Reference Case.\textsuperscript{6} The average peak-period headway\textsuperscript{7} of the Reference Case system was estimated to be 17 minutes; the off-peak headway was 40 minutes. The service area was assumed to be the same as the service area of the existing regional bus system (includes the SCRTD, the Orange County Transit District, and municipal bus lines in Santa Monica and Long Beach, plus eleven other smaller systems). The parameters describing the Reference Case bus system are shown in the first column of Table 2.

Evaluating the effect of different fare reductions is now straightforward. The transportation model is given different fare structures; the model then estimates the resulting changes to the regional transportation system. Table 2 shows the effect of six different fare reductions (compared with the Reference Case bus system) and the 25\% flat fare case is highlighted. Note that the model predicts an increase in daily bus passengers of about 15 percent. Many other important parameters are shown. For example, decreasing the fare to a flat 25\% requires increasing the annual bus subsidy from about $32 to $69 million.

The 15 percent increase in ridership predicted by the model correlates extremely well with the increase observed by SCRTD. The effect of increased gasoline prices can also be shown using our transportation model. In the Reference Case, the pump price of gasoline is assumed to average 40\% per gallon in 1977.\textsuperscript{8} By May 1974, when the reduced fare had been in effect for several weeks, the average price of gasoline had risen to almost 60\% per gallon. The increase in gasoline price caused a corresponding increase in bus ridership that is not taken into account in Table 2. Later in this section, we will consider in detail the effects of these recent increases in the price of gasoline. As a preview, however, with the 60\% per gallon price of gasoline included, the increase in ridership predicted by the model as a result of a flat 25\% fare is about 30 percent. Thus we are nearly in exact agreement with the range of observed data for this particular transportation management tactic.\textsuperscript{9}

The policy orientation of our transportation model has some inherent limitations. For example, Table 2 shows that the number of buses required in the 25\% flat fare case is ten fewer than in the Reference Case. The decrease occurs because the small (1.3 percent) reduction in VMT, brought about by the tactic, lessens congestion of the road network. Consequently, fewer express buses are required to maintain the same level of service. The operational transit planner, on the other hand, tends to see an opposite effect on the number of buses required. In the Reference Case, buses on some of the most heavily traveled routes will be operating with nearly full passenger loads. Lower fares will increase the number of potential riders on these routes, and, hence, more buses must be put in service. The transportation model does not respond to this need, since it views the region in aggregate and is only constrained by the average passenger load throughout the system.

In practice, limitations such as this do not restrict the use of the model, since, as we show in the following paragraphs, improved bus system service characteristics through lower fares should always be accompanied by increased frequency of service

\textsuperscript{6} This average fare is equivalent to the original base fare on the SCRTD (30\%) plus two additional zones (15\%).

\textsuperscript{7} The time between buses in the rush hours.

\textsuperscript{8} The reader is reminded that the Reference Case is based on an extrapolation of trends observed in the 1970-1972 time frame. Thus the recent gasoline price increases are not included in the forecast. Later in this section, the effect of increased pump prices of gasoline (either brought about by the market mechanism or by additional gasoline taxes) is accounted for in detail.

\textsuperscript{9} Note that we are comparing the effect of these policies as observed in 1974 with the effect predicted by the model, which assumes the policies are implemented in 1977. Although the absolute change in ridership will be different for 1974 and 1977, the percentage change should be approximately valid for both years.
and consequently more buses. The reader must realize that the purpose of our transportation model is to provide insights into the relative attractiveness of alternative transportation policies. After completing such a policy analysis, the one or two most attractive alternatives can be selected for more detailed implementation planning.

With this background in mind, we now present several of the more promising transportation management tactics for reducing VMT in 1977. More detailed information on these tactics is contained in Appendix D.

**BUS SYSTEM IMPROVEMENTS**

We have considered three types of bus system improvements that will result in a reduction in VMT: reduction in fares, increased frequency of service, and expanded service areas.

First, different levels of intensiveness of each of the individual tactics were considered. For example, different bus fare structures have been discussed above; the other tactics are discussed in Appendix D.

The individual tactics were then combined with the goal of providing the largest reduction in VMT for the smallest increase in the required annual bus subsidy. Using this technique, we developed twelve composite bus systems for further analysis. Table 3 shows how the twelve composite bus systems were constructed in stages.

Each of the composite systems was evaluated using our urban transportation model. In Fig. 12 we show the reduction in VMT resulting from each bus system in
Table 3
THE STAGED DEVELOPMENT OF THE TWELVE COMPOSITE BUS SYSTEMS

<table>
<thead>
<tr>
<th>STAGE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
</table>
| 0     | REFERENCE BUS SYSTEM: Fare - 25¢ plus 2¢ per mile  
  Peak-period headway - 17 minutes  
  Existing service area (1380 sq. mi.) |
| 1     | LOWER FARE TO 25¢ PLUS 1¢ PER MILE |
| 2     | LOWER PEAK-PERIOD HEADWAY TO 15 MINUTES |
| 3     | LOWER PEAK-PERIOD HEADWAY TO 12.5 MINUTES |
| 4     | INCREASE SERVICE AREA\(^a\) TO 1488 sq. mi. |
| 5     | INCREASE SERVICE AREA\(^a\) TO 1613 sq. mi. |
| 6     | LOWER PEAK-PERIOD HEADWAY TO 10 MINUTES |
| 7     | LOWER FARE TO 25¢ PER TRIP - NO ZONE CHARGES |
| 8     | LOWER FARE TO 20¢ PER TRIP |
| 9     | LOWER FARE TO 10¢ PER TRIP |
| 10    | LOWER PEAK-PERIOD HEADWAY TO 7.5 MINUTES |
| 11    | INCREASE SERVICE AREA IN L.A. COUNTY |
| 12    | LOWER PEAK-PERIOD HEADWAY TO 5 MINUTES |

\(^a\) All increase in stages 4 and 5 is in Orange County

terms of the required additional annual bus subsidy. The composite systems are represented by the circular symbols. For example, the Stage 1 system reduces VMT by about 0.8 percent for an additional annual subsidy of $9 million. At the other extreme, the Stage 12 bus system requires an additional subsidy of over $650 million annually, and reduces VMT by about 9.5 percent.

Our development of the composite bus systems was intended to produce the most cost-effective\(^9\) set of bus system improvements possible. Our success in this respect is also shown in Fig. 12. The triangular symbol represents the cost and effectiveness of reducing the bus fare to zero while making no other improvements; similarly, the square symbol is a result of using zero fare with peak-period headways reduced to 10 minutes\(^11\) but with no increase in the service area. In both instances, substantially larger reductions in VMT can be obtained for the same subsidy expenditure as can be seen by considering the composite bus system curve.

Of course, we realize that many other factors besides the required subsidy must be considered when describing the feasibility of different bus system improvements. For example, the number of buses required by new system may be constrained by the number manufactured annually. Such additional impacts of the twelve composite bus systems are presented in Table 4. Note that the Reference Case bus system requires 2,082 buses (including spares), Stage 5 requires 3,294 buses, Stage 10 requires 5,489 buses, and finally Stage 12 requires over 9,000 buses. The Stage 5 and

\(^9\) Where cost is measured in terms of additional annual bus subsidy required, and effectiveness in terms of the reduction in VMT obtained.

\(^11\) All of our composite bus systems have off-peak period headways of exactly twice the peak-period value.
Fig. 12 — The effectiveness of the composite bus systems in reducing VMT in terms of the additional bus subsidy required

Table 4
DETAILED IMPACTS OF THE COMPOSITE BUS SYSTEMS

<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTION</th>
<th>Reference Bus System</th>
<th>COMPOSITE BUS SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUS FARE (cents)</td>
<td>Stage 1</td>
<td>Stage 2</td>
</tr>
<tr>
<td>per trip per mile</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>HEADWAYS (minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>peak period</td>
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<td>17</td>
</tr>
<tr>
<td>off-peak period</td>
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<td>40</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>square miles</td>
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<td>1380</td>
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</tr>
<tr>
<td>county affected</td>
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<td>ALL</td>
</tr>
<tr>
<td>VMT REDUCTION (%)</td>
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<td>ANNUALIZED SYSTEM COST (M)</td>
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<td>132</td>
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<tr>
<td>ANNUAL SUBSIDY REQUIRED (M)</td>
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<td>43</td>
</tr>
<tr>
<td>AVERAGE MODAL SPLIT (%)</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>DAILY BUS PASSENGERS (thou)</td>
<td>636</td>
<td>705</td>
</tr>
<tr>
<td>AVERAGE TRIP SPEED (mph)</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>AVERAGE BUS OCCUPANCY</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>NUMBER OF BUSES REQUIRED</td>
<td>2082</td>
<td>2082</td>
</tr>
<tr>
<td>BUS SYSTEM EMPLOYEES</td>
<td>7530</td>
<td>7510</td>
</tr>
</tbody>
</table>
possibly the Stage 10 systems are probably realistic for consideration in 1977. Stage 12, however, does not appear to be a practical alternative in the near term.

One final comment regarding our earlier discussion of the limitations of the transportation model with regard to average passenger loads. Note that the average bus occupancy (or passenger load) is shown for each composite bus system in Table 4. In most of the systems, an average of 27 or fewer passengers are carried, compared with the Reference Case system, in which the load averages about 22. Therefore, we feel that with proper scheduling the systems we have developed would not result in overcrowded buses on the more heavily traveled routes.

CARPOOLING INCENTIVES

Three different carpooling incentives were considered as tactics to provide regional reductions in VMT: preferential freeway treatment for carpools (and buses), computer matching for carpoolers, and exemptions for carpoolers from parking surcharges. Again, each of these tactics was evaluated independently; the results are presented in Appendix D.

The evaluation of each tactic indicated that the preferential freeway treatment and computer matching showed the most promise for achieving substantial reductions in VMT. Figure 13 shows the effect on regional VMT of providing preferential freeway treatment for carpools and buses, assuming that 40 percent of the employed people in the region participate in a carpool matching program and are successfully matched. The results are presented in terms of the number of occupants required to qualify for preferential treatment. Figure 13 shows that reductions in VMT approaching 20 percent can be achieved if the required occupancy is 3, 4, or 5.

Two additional pieces of information are shown in Fig. 13. First the effect on modal split for each occupancy is described. In each case, the bus modal split decreases implying that some persons presently making trips by bus will switch to the carpooling mode. The loss in bus revenue will hence cause the required bus subsidy to increase. We also show the resulting average automobile occupancy for essential trips. Essential trips are all work-related. We assume that the demand for such trips is constant; that is, alternative transportation policies will not affect the number of work trips occurring in the region, although the number of vehicle trips may change substantially. For the Reference Case, the essential-trip automobile occupancy is 1.13.

Note also that the reduction in VMT, obtained from providing preferential freeway treatment for buses only, includes the effect of the computer matching. Preferential treatment for buses only, without computer matching, would yield only about a one percent reduction in VMT (see Appendix D).

The effectiveness of the carpooling incentives displayed in Fig. 13 in reducing VMT should be considered upper bound estimates. We say this because of two very important assumptions made in our analysis. In the case of preferential freeway treatment, we have assumed that all qualified carpoolers travel the freeway portion of their trip at the average uncongested freeway speed (implying also that all freeways are modified to provide preferential treatment). At the same time, we are assuming that vehicles not qualifying for preferential treatment encounter the

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12 We have assumed that an average transit bus can seat about 50 passengers.
13 Modal split is the percentage of total daily person trips made on the public transit system.
same time delay as they presently do because of freeway congestion.\footnote{14} Our second assumption is that 40 percent of the work force participate in computer matching and are successfully matched. We believe that 40 percent is an absolute upper limit on the number of employed people who could be incorporated into a matching program.\footnote{15} Even considering these assumptions, however, preferential treatment and computer matching appear to be very attractive tactics.

Finally, we note that the effectiveness of the combined tactics in reducing VMT is greater than the sum of the reductions in VMT realized by the two tactics when evaluated separately (see Appendix D). This synergistic effect can be explained: If only preferential treatment is considered, the potential carpooler must weigh the time advantages of no freeway congestion against the pickup-time penalty associated with collecting the other carpoolers. When computer matching is included, the pickup-time penalties will decrease, since each participant will become aware of additional neighbors closer to the potential carpooler's home who are eligible for his carpool. Without the preferential freeway treatment, computer matching lessens

\footnote{14} Our approach to preferential freeway treatment for carpoolers reflects the policy-orientation of our transportation model. There are at least two ways preferential treatment could be implemented: exclusive freeway lanes for carpoolers, or preferential ramp metering for carpoolers. In the first instance the time delay for non-carpoolers can be guaranteed by limiting the number of non-carpool lanes on each freeway to deliberately ensure congestion. In the second, a time delay could be built into the freeway ramp meter. Note, however, that the manner in which the preferential treatment is provided is an implementation problem. The policy question concerns whether or not the preferential treatment will be effective.

\footnote{15} The sensitivity of the effectiveness of computer matching to the percentage of the work force successfully matched is presented in Appendix D.
only the pickup-time penalty—congestion on the freeway portion of the trip will still be encountered.

ECONOMIC DISINCENTIVES

Two basic types of economic disincentives have been considered in this study. The first is a surcharge based on vehicle miles traveled; this can be most easily implemented by an additional gasoline tax (although many other possibilities exist). The second disincentive is a surcharge on vehicle trips; most logically implemented by imposing a parking surcharge.

To show the effects of using a mileage surcharge as a disincentive, we have chosen to present our results in terms of the equivalent pump price of gasoline. This technique allows us to consider simultaneously the recent (and possibly future) increases in the base price of gasoline and an additional tax. In the next section, we will be careful in our allocation of the extra revenue brought about by increased gasoline prices. That is, some of the revenue (if derived from a tax) can be expended by the government; the remainder will be reflected as increased service station gross revenues.

Mileage Surcharge (Increased Gasoline Price)

The effectiveness of the mileage surcharge tactic has been evaluated for a range of bus system improvements and a range of carpooling incentives. The specific bus improvement and carpooling tactics used in this context were selected in consultation with the SCAG staff and were based on the results presented earlier in this section.

Before describing the results of this part of the analysis, we must first discuss some of the implications of using the increased pump price of gasoline as a surrogate for mileage surcharge. The purpose of a mileage surcharge is to increase the total cost per mile\textsuperscript{15} of driving an automobile. We can best explain further by considering a hypothetical example. Suppose that average cost per mile (excluding fuel) of operating an automobile is $6_\ell$. (This cost includes amortized investment, insurance, license, etc.) Suppose also that the average vehicle travels 10 miles per gallon of gasoline and that the pump price of gasoline is $40_\ell$ per gallon (including taxes). Thus the total cost per mile would be $10_\ell$. Now assume that an additional $20_\ell$ per gallon gasoline tax is imposed. The immediate effect would be to make the fuel cost $6_\ell$ per mile—the total cost would then be $12_\ell$ per mile. However, if the additional gasoline tax remains in effect for some time, motorists will likely begin to adjust their behavior in one very important way—they will buy new cars with much better fuel economy. Suppose that after several years, in our hypothetical example, the gasoline mileage of the average vehicle increases to 15 miles per gallon. The $60_\ell$ per gallon gasoline tax would result in a fuel cost per mile of only $4_\ell$ and the total cost would return to $10_\ell$ per mile. Although fuel consumption would still be decreased, there would be no cost per mile penalty and hence regional VMT would no longer be affected. To achieve the earlier effect on VMT, the total pump price of gasoline would have to be increased again to $90_\ell$ per gallon.

When we evaluate increased gasoline prices using our transportation model, we assume that the fuel economy of the average vehicle does not change from that

\textsuperscript{15} The total cost per mile of driving an automobile plays a central role in our transportation model, as explained in Appendix C.
prescribed in the Reference Case. Thus the effects we present in this section should be regarded as completely valid only in the short term. Stated another way, when we show a result for an $80_5$ per gallon gasoline price, we assume that the price has just changed from the Reference Case value of $40_5$ per gallon. If several years pass between the change in gasoline price and the analysis year, then the reduction in VMT should be less than we show in this section, since motorists will have had time to increase the average fuel economy of the fleet through their choice of new cars with better gasoline mileage. Alternatively, if the policy decision is to maintain the same reduction in VMT obtained initially with a gasoline tax, then the amount of the tax will need to be adjusted upward each year to account for the change in average vehicle fuel economy.

With this preface in mind, we will now discuss the effect on VMT of increases in gasoline price.

A Range of Bus System Improvements. The impacts of gasoline price increases will depend on the level of bus system improvement being considered. Consequently we have analyzed the economic disincentives for three different systems—the Reference Case, Stage 5, and Stage 10 bus systems. Table 5 shows the important characteristics of each system. Stage 5 was chosen since it represents at this time the minimum likely improvement to the regional bus system by 1977. On the other hand, the Stage 10 system with nearly 5,500 buses required can be considered the maximum feasible improvement for 1977.

The reduction in regional VMT caused by increased gasoline prices for each of these bus systems is presented in Fig. 14. The most evident feature of Fig. 14 is that very large VMT reductions can be obtained if gasoline becomes quite expensive. However, some more subtle observations can be made. For example, with the Reference Case bus system, a 20 percent reduction in VMT would occur if gasoline were $85_5$ per gallon. The Stage 10 bus system would yield the same reduction in VMT for a pump price of only about $65_5$ per gallon.

The reductions in VMT shown in Fig. 14 came about because of three basic changes in trip-making behavior. First, some trips made by automobile in the Reference Case will switch to the transit mode. Second, some trips made in low occupancy automobiles will be made in carpools. (Although there are no specific carpooling incentives included in this part of the analysis, the increased cost per mile of driving will induce some people to form carpools and this effect has been included.) Finally, some trips made in the Reference Case will no longer be made; we call these the trips forgone.

The number of trips forgone is one of the important impacts that needs to be included in evaluating economic disincentives. Trips forgone can be used to represent

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17 Fuel economy estimates of the 1958 through 1990 models for our Reference Case are contained in Appendix E.

18 The reader unfamiliar with motor vehicle emission characteristics may be confused at this point. The primary purpose of the reduction in VMT is to reduce emissions. A popular misconception is that motor vehicle emissions are directly related to fuel economy; the available experimental evidence indicates otherwise[26]. Vehicle emission standards are formulated in terms of grams of pollutant per vehicle mile. Therefore, the automobile manufacturers provide only the control devices required to meet the applicable standards. In other words, a 2,500 lb subcompact automobile pollutes as much per mile as does the 5,000 lb luxury automobile; surprisingly enough, these same effects have been noted for vehicles manufactured before the first exhaust emission standards were enforced [26]. These data suggest that increasing the average fuel economy of the fleet will have little, if any, effect on emissions.

19 Figure 14 is also useful for considering alternative ways of alleviating gasoline shortages. If the shortfall in supplies were 10 percent (i.e., VMT would need to be reduced by 10 percent to eliminate the shortfall), then the required free-market price of gasoline would rise to about $60_5$ per gallon (as it recently has) with the Reference Case bus system. Alternatively, the gasoline supply shortfall would be eliminated with the Stage 10 bus system if the price rose only to $46_5$ per gallon.
Table 5
THE BUS SYSTEM IMPROVEMENTS USED IN CONJUNCTION WITH THE ANALYSIS OF THE ECONOMIC DISINCENTIVES

<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTORS</th>
<th>BUS SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REFERENCE</td>
</tr>
<tr>
<td><strong>BUS FARE</strong> (cents)</td>
<td></td>
</tr>
<tr>
<td>per trip</td>
<td>25</td>
</tr>
<tr>
<td>per mile</td>
<td>2</td>
</tr>
<tr>
<td><strong>HEADWAYS</strong> (minutes)</td>
<td></td>
</tr>
<tr>
<td>peak period</td>
<td>17</td>
</tr>
<tr>
<td>off-peak period</td>
<td>40</td>
</tr>
<tr>
<td><strong>SERVICE AREA</strong></td>
<td></td>
</tr>
<tr>
<td>square miles</td>
<td>1380</td>
</tr>
<tr>
<td>population eligible (%)</td>
<td>68</td>
</tr>
<tr>
<td><strong>NUMBER OF BUSES</strong></td>
<td>2082</td>
</tr>
<tr>
<td><strong>ANNUALIZED SYSTEM COST</strong></td>
<td>132</td>
</tr>
</tbody>
</table>

(millions of dollars)

Fig. 14 — The effect of gasoline price on VMT for three bus systems. Stages 5 and 10 are described in Table 3.
the loss of personal mobility brought about by the implementation of such tactics. In Fig. 15, we show the effect on trips forgone of gasoline prices; the effect is shown for all households and for households with less than $5,000 annual income.

Consider first the effect of a 20 percent reduction in VMT on the average household. From Fig. 14, we saw that an 85¢ per gallon price was required with the Reference Case bus system; the resulting trips forgone would be about 6 percent (expressed as a percent of the number of person trips taken in the Reference Case.) The Stage 10 bus system needs only a 65¢ per gallon gasoline price; the corresponding number of trips forgone is less than two percent.

The effect of gasoline price is even more dramatic on the lower income groups. Consider the average price of gasoline in Los Angeles in May 1974, for example—about 60¢ per gallon. This price causes the lower income group households to forgo about 4 percent of their trips with the Reference Case bus system. However, if the Stage 10 bus system were available, these households would not forgo trips, but would actually make more trips than in the Reference Case (trips forgone are about −2 percent).

These examples show the importance of improving the regional transit system to reduce losses in personal mobility caused by increasing gasoline prices, particularly for low income households. Remember, the gasoline price can increase either through additional taxes as part of a strategy to reduce VMT or through the market mechanism that we are presently observing.

![Graph showing the effect of gasoline price on trip-making behavior for two bus systems.](image)

**Fig. 15** — The effect of gasoline price on trip-making behavior for two bus systems

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20 The number of trips forgone is equivalent to the number of person trips that are no longer made because of the policy in effect. We have assumed that only inessential trips (i.e., all non-work-related trips) can be forgone as the result of a particular policy. Note, however, that essential vehicle trips can decrease, and indeed will, as individuals either participate more heavily in carpools or switch from the automobile to the bus mode.
A Range of Carpooling Incentives. We have also considered three different carpooling incentive policies for analysis in conjunction with the increased gasoline prices.

- No additional carpooling incentives (except the disincentive automatically included in the increased cost per mile of driving).
- Preferential freeway treatment for buses and carpools with three or more occupants.
- Preferential freeway treatment plus computer matching with 40 percent of the work force presumed to be successfully matched.

Each incentive has been analyzed with the Reference Case bus system.

Figure 16 presents the effect on VMT of gasoline prices for the three carpooling incentive policies. Once again we see that major reductions in VMT can be obtained with high gasoline prices. Note also in Fig. 16 the saturation effect on a reduction in VMT that occurs after the price of gasoline has passed $1 per gallon. That is, the additional reduction in VMT obtained from the carpooling incentives begins to taper off at about that point.

Finally, one other aspect of the carpooling incentives should be realized. Carpools are formed for essential trips only, and we assume an inelastic demand for essential trips (i.e., all essential trips must be made—either by low occupancy automobile, in carpools, or on transit). Thus the carpooling incentives have no effect on the number of trips forgone as a consequence of increased gasoline price. Specifically, the number of trips forgone at some gasoline price for any of the carpooling policies will be the same as that shown in Fig. 15 for the Reference Case bus system. Therefore, carpooling can be used to achieve substantial reductions in VMT, but reductions in personal mobility caused by increasing gasoline prices can only be alleviated by improvements to the regional bus system.

Parking Surcharges Versus Mileage Surcharges

The parking surcharge aimed at reducing the number of vehicle trips is conceptually more straightforward than using a gasoline tax to provide a mileage surcharge. For example, one of the tactics in the final EPA implementation plan for Los Angeles was an additional parking tax of 25¢ per hour on essentially all non-residential parking [3].

An examination of the travel patterns in the Los Angeles region indicates that parking surcharges may not be the most effective economic disincentive for reducing VMT. Such an analysis reveals that trips less than four miles in length represent only 12 percent of the regional VMT, yet at the same time such trips account for 50 percent of all trips. On the other hand, trips of approximately 11 miles or longer represent almost 55 percent of the regional VMT but account for only 20 percent of the total trips [13]. Thus an economic disincentive, such as a parking surcharge, applied on a per-trip basis may be less effective in reducing VMT than one applied on a per-vehicle-mile basis (e.g., an additional gasoline tax). Stated another way, the parking surcharge will be most visible for short trips which account for only a small percentage of the regional VMT.

In our terminology, essential trips include all work-related trips plus other trips having an inelastic demand, such as trips to the doctor's office.

Although the concept of a parking surcharge is straightforward, implementation tends to be quite complex because of the extensive amount of free parking present today in the Los Angeles region. EPA had developed an implementation approach that included all such parking [3].
To further clarify the differences between mileage and parking surcharges, we have compared their effectiveness in reducing VMT using our transportation model. A uniform basis for the comparison was provided by expressing the reduction in VMT in terms of the annual expenditures by motorists in the region for the mileage or parking surcharges. The expenditure caused by the tactic represents the total out-of-pocket costs to motorists. This comparison is presented in Fig. 17(a). Note that for the same level of expenditure, the mileage surcharge always yields a greater VMT reduction than the parking surcharge. The disparity becomes larger for increasing levels of VMT reduction.

As we explained earlier, however, the effect on personal mobility should also be taken into account when economic disincentives are considered. The relative effects on trips forgone of mileage and parking surcharges are shown in Fig. 17(b). Again the parking surcharge looks somewhat less favorable than mileage surcharge for the range of VMT reduction shown.

Thus far we have considered the mileage and parking surcharges to be in effect for all trips. Of course, the parking surcharge is applicable only to the non-residential end of the trip. We distinguish between two types of trips: essential trips are all home-work related trips, and inessential trips includes all others. As we have already noted, the demand for essential trips remains constant and such trips will be made either in low occupancy automobile, carpool, or on the bus. Inessential trips (e.g., shopping, recreation), however, have an elastic demand, which means that all forgone trips come from this category.

The parking surcharge tactic provides one other flexibility. We believe the surcharge could be implemented in such a way as to affect the essential trips only. The advantage to using the parking surcharge tactic in this context would be that practically no trips would be forgone as a result of the surcharge. Therefore, we also show in Fig. 17(b) the effectiveness in reducing VMT of the parking surcharge on essential trips only. With a VMT reduction of up to about 25 percent, the parking surcharge used in this way is approximately identical in effectiveness to the mileage
Fig. 17 — Relative effectiveness of mileage and parking surcharges in reducing VMT and changing trip-making behavior.

Above: VMT reduction only.
Below: Added curves show trips foregone if there are surcharges on all trips; also the effect on VMT of parking surcharges solely on essential trips.
surcharge. As a point of reference, a $3 per day parking surcharge on the non-
residential end of the home-work trip will yield a reduction in VMT of about 20
percent assuming the Reference Case bus system and no additional carpooling
incentives (see Appendix D for more details).

Since the parking surcharge on essential trips causes practically no trips to be
forgone, we feel that this tactic is more attractive than a mileage surcharge on all
trips when a VMT reduction of 20 percent or less is desired. 23

SUMMARY OBSERVATIONS

In this section, we have provided a number of insights into the effectiveness that
different tactics will have in reducing VMT and some of the consequences implied
by these tactics. Some of the more important observations we have made are summa-
rized below.

• The maximum reduction in VMT achievable by bus system improvements alone
  is about 10 percent. The bus system required to accomplish such a reduction
  should probably be considered impractical for implementation by 1977.
• Reductions in VMT of 20 percent can be obtained by combining preferential
  freeway treatment for carpools and buses, with computer matching to encourage
  and simplify the formation of carpools.
• Substantial reductions in VMT will be achieved with increases in the pump price
  of gasoline. For example, with no bus system improvements or additional car-
  pooling incentives, regional VMT would be reduced by about 20 percent if gaso-
  line were 85¢ per gallon.
• An additional implication of increased gasoline prices is the resulting loss of
  personal mobility that is reflected in the number of trips forgone. Only improve-
  ments to the regional bus system can reduce the number of trips forgone because
  of gasoline price increases.
• The parking surcharge tactic, if applied to essential trips only, is as effective as
  a mileage surcharge in reducing VMT (for VMT reductions less than 20 percent)
  and simultaneously causes no trips to be forgone.

Finally, we reiterate that all of the effects of increased gasoline prices shown in this
section are valid only in the short term, that is, for no more than two or three years
after the increased prices occur.

No one of the individual tactics discussed in this section will fulfillment all of the
near-term transportation needs of the Los Angeles region. Using the insights gained
in this analysis, and in conjunction with the SCAG staff, we combined the individual
tactics in different ways to form a number of near-term regional transportation
strategies. In the next section, we will compare six of the most interesting of these
strategies in terms of the many impacts each strategy would have on the Los Angeles
region.

23 We show in Appendix D that the maximum reduction in VMT obtainable, through tactics that
emphasize essential trips only, is about 30 percent. Larger VMT reductions can be obtained only by
causing some of the inessential trips to switch to the transit mode or to be forgone.
V. THE IMPACTS OF ALTERNATIVE REGIONAL TRANSPORTATION STRATEGIES

The several transportation management tactics described in the previous section were used to form six alternative regional transportation strategies that could be implemented in Los Angeles by 1977. The regional impacts of these six strategies were presented to the SCAG staff and to local decisionmakers in a series of briefings during March, April, and May of 1974. Finally, one of these strategies was selected by SCAG to form the backbone of the SCAG Short-Range Transportation Plan [27] for the Southern California region.

We begin this section by describing the composition of the six strategies. Then we discuss the analysis and presentation technique used to compare the regional impacts of the strategies. A summary of the major impacts of each strategy on the Los Angeles Air Quality Control Region in 1977 is then presented. Finally, we show all of the detailed regional impacts for each of the six strategies.

COMPOSITION OF THE SIX STRATEGIES

The six alternative strategies selected for detailed comparison have been constructed using the full range of near-term transportation management tactics for reducing vehicle miles traveled. A general description of the six strategies (designated A through F) is provided in Table 6. Note that Strategy B corresponds to the final EPA plan as promulgated on November 12, 1973. We have chosen to include the parking surcharge promulgated by EPA in our analysis, even though this provision of the plan has since been revoked.

A more detailed description of the composition of the six strategies is presented in Table 7. The transportation management components of the strategies are expressed in terms of the bus system improvements, carpooling incentives, and economic disincentives employed; corresponding parameters for the Reference Case in 1977 are also shown.

We have assumed the implementation of full technological controls for both fixed and mobile sources in all of the strategies (A through F) excluding the Reference Case, for two reasons:

1. The Los Angeles Air Quality Control Region has one of the most critical air pollution problems in the United States. Consequently, either by regional choice or under EPA mandate, we feel the full technological controls will be implemented by 1977 to improve the air quality to the fullest extent possible.

2. Our earlier work in San Diego [7] and Los Angeles [13] has shown that technological emission controls are far more cost-effective than transportation management controls. That is, the annualized cost per annual ton of reactive hydrocarbons reduced under full technological controls is much less than emission reductions obtained by reductions in vehicle miles traveled, at least for any analysis year after 1975. (See Appendix A.)

Finally, we note that Strategy F is included to represent what could be described as a maximum effort strategy. The bus system improvements and carpooling incentives are probably upper limits of what could be accomplished by 1977. The economic disincentives are also within reasonable bounds.
Table 6
A GENERAL DESCRIPTION OF THE STRATEGIES CONSIDERED

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>FULL TECHNOLOGICAL CONTROLS WITH NO TRANSPORTATION MANAGEMENT TACTICS EXCEPT INCREASES IN THE PRICE OF GASOLINE.</td>
</tr>
<tr>
<td>C</td>
<td>MAJOR BUS SYSTEM IMPROVEMENTS WITH NO CARPOOLS INCENTIVES OR ECONOMIC DISINCENTIVES.</td>
</tr>
<tr>
<td>D</td>
<td>HEAVY RELIANCE ON CARPOOLS, MINOR BUS SYSTEM IMPROVEMENTS, AND NO ECONOMIC DISINCENTIVES.</td>
</tr>
<tr>
<td>E</td>
<td>MAJOR BUS SYSTEM IMPROVEMENTS AND CARPOOLS INCENTIVES BUT NO ECONOMIC DISINCENTIVES.</td>
</tr>
<tr>
<td>F</td>
<td>MAJOR BUS SYSTEM IMPROVEMENTS, HEAVY RELIANCE ON CARPOOLS AND BOTH MILEAGE AND PARKING SURCHARGES.</td>
</tr>
</tbody>
</table>

Table 7
DETAILED COMPOSITION OF THE SIX STRATEGIES CONSIDERED FOR IMPLEMENTATION IN THE LOS ANGELES AIR QUALITY CONTROL REGION IN 1977

<table>
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<td>10</td>
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<td></td>
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<tr>
<td>Per Mile</td>
<td></td>
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<td></td>
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<td>Yes [Buses]</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>% of Work Force Participating</td>
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<td>No</td>
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<tr>
<td>Occupants Required to Quality</td>
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<td>Economic Disincentives</td>
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<tr>
<td>Mileage Surcharge</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>Yes</td>
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<tr>
<td>Cents Per Mile</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
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<td>Equivalent Cents Per Gallon</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>26</td>
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<tr>
<td>Parking Surcharge ($)</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
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<td>Essential Trips</td>
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<td>-</td>
<td>2.00</td>
<td>-</td>
<td>-</td>
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<td>1.00</td>
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<td>Inessential Trips</td>
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<td>-</td>
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<td>Fixed Sources (including aircraft)</td>
<td>Reference</td>
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<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td></td>
</tr>
<tr>
<td>LDV Retrofit-Inspection/Maintenance</td>
<td>Reference</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td></td>
</tr>
</tbody>
</table>
ANALYSIS TECHNIQUE FOR STRATEGY COMPARISONS

The impacts of each of the alternative strategies will be compared against the corresponding impacts of the Reference Case. The reader will recall that the Reference Case has been defined as a continuation of the historic trends observed during the 1970-1972 time frame (see Sec. II). Recall also that the Reference Case formed the basis of the urban transportation model's calibration to the 1977 analysis year.

The interpretation of the comparison between the six strategies is visually aided by our use of colors. For each strategy, the major impacts in several impact categories are presented in a table that resembles a “scorecard.” Colors are used to highlight differences between strategies. Our color coding scheme for each impact category is: red will be used to denote the two least attractive strategies in each impact category; green will be used to denote the two most attractive strategies in each impact category; finally, yellow will be used to denote the two remaining strategies with impacts in the middle of the range. Of course, the above color coding may not apply in the case of ties or near ties between strategies. The reader should realize that the use of colors necessitates our making a number of subjective judgments regarding what is attractive and what is unattractive in each impact category. The colors shown reflect our own judgments and are those used in the numerous briefings of study results. However, our judgments are by no means infallible and the reader is encouraged to use his own value system in his interpretation of the colored scorecards.

The basic pump price of gasoline in 1977 presents our last remaining analytical difficulty. At present, we feel that it is nearly impossible to accurately predict what gasoline will be selling for in 1977. Therefore, we have performed our detailed impact analysis by first assuming that gasoline is priced at 60¢ per gallon in 1977; this was approximately the average pump price in the Los Angeles region in May of 1974. We have then attempted to bound future price changes, repeating the entire impact analysis for a pump price of 40¢ per gallon and then 80¢ per gallon. Our hope in this type of analysis is that changes in gasoline price will not seriously affect the relative attractiveness of the six strategies even though the magnitudes of the impacts in each category are certain to be changed.

We will first present the summary impacts for the alternatives presuming a gasoline price of 60¢ per gallon. Then we will show the same summary impacts for prices of 40¢ and 80¢ per gallon.

SUMMARY COMPARISON OF THE SIX ALTERNATIVE STRATEGIES

The regional impacts of the alternative transportation strategies described by Table 7 are presented in terms of the impacts in four general categories: regional costs (in terms of expenditures), transportation service, air quality, and energy consumption. The summary impacts consist of several important items from each category. Later in this section we will show more detailed impacts for each category and the distribution of certain of the impacts by income group.

Impacts in 1977: Gasoline at 60 Cents per Gallon

The summary impacts in 1977 of the six alternative strategies for the Los Angeles Air Quality Control Region are shown as a colored scorecard in Table 8. As we have described earlier, this first scorecard assumes that the basic pump price of
Table 8
SUMMARY OF THE MAJOR IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION, ASSUMING THE BASIC PRICE OF GASOLINE IS 60 CENTS PER GALLON

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<tr>
<td>Annual Bus Subsidy Required</td>
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<td>12</td>
<td>84</td>
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<td>674</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>674</td>
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<tr>
<td>Transportation Service</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Trips Forgone (% of Reference)</td>
<td>0</td>
<td>4.6</td>
<td>2.6</td>
<td>4.3</td>
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<td>Reduction in Vehicle Miles Traveled (%)</td>
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<td>33</td>
<td>31</td>
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<td>Average Auto Occupancy</td>
<td>1.34</td>
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<td>1.78</td>
<td>1.69</td>
<td>1.99</td>
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<td>Bus System</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trips by Bus (% of all Trips)</td>
<td>2.2</td>
<td>3.6</td>
<td>8.9</td>
<td>4.7</td>
<td>9.8</td>
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<tr>
<td>Number of Buses Required</td>
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<td>2080</td>
<td>2350</td>
<td>2350</td>
<td>3290</td>
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<td>Air Quality</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Days Oxidant Standard Violated (at the worst point in the region)</td>
<td>211</td>
<td>138</td>
<td>147</td>
<td>149</td>
<td>135</td>
<td></td>
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<tr>
<td>Regional Population Exposure Level for Oxidant (% of 1970 Level)</td>
<td>49.3</td>
<td>6.0</td>
<td>7.9</td>
<td>8.2</td>
<td>5.5</td>
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<td></td>
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<tr>
<td>Energy for Motor Vehicle Use (millions of barrels)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Annual Gasoline Consumption</td>
<td>102.4</td>
<td>62.6</td>
<td>75.0</td>
<td>77.0</td>
<td>59.1</td>
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</tr>
<tr>
<td>Annual Diesel Fuel Consumption</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline Price (cents/gal)</td>
<td>40</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Strategies are described in Table 6.

** The revenue from surcharges could, of course, be used to offset some of the strategy costs or could be allocated to other beneficial purposes. Large surcharges might therefore be viewed from some vantage points as desirable.
gasoline is 60¢ per gallon in 1977. The Reference Case, of course, still uses a 40¢ per gallon price; and Strategy F, which has an additional gasoline tax of 26¢ per gallon as a strategy component, shows a total gasoline price of 86¢ per gallon (see the last line of the scorecard).

The first impact category shown is the annual regional expenditures in millions of dollars as a result of each strategy. The first item is the annualized costs of the technological emission controls for both fixed and mobile sources. Strategy A (the full technological controls only strategy) has the largest expenditure at $355 million annually. The lowest annual expenditure is $275 million for Strategy F, our maximum effort strategy. Although each of the six strategies employs the same technological emission controls, different costs are shown for each strategy, since the incremental change in automobile operating costs caused by the retrofit-inspection/maintenance controls will be dependent on the annual miles each automobile is driven (i.e., these costs decrease as VMT decreases). Next we show the required annual bus system subsidy. Strategy F requires the largest subsidy—over $400 million annually; only $12 million is required in subsidy under Strategy A and Strategy B, which is the EPA plan. Note that the subsidy for the EPA plan is less than that required in the Reference Case. Only modest bus system improvements were stipulated in the EPA plan, and the economic disincentive of a parking surcharge causes many trips to be switched to bus—thus increasing the annual revenues from the fare box. The annual out-of-pocket expenditures on either mileage or parking surcharges is shown next. The EPA plan (Strategy B) will result in nearly $1.3 billion being collected annually from the parking surcharge. Strategy F, the only other strategy containing economic disincentives, will result in annual expenditures of $674 million on the parking surcharge on essential trips and the 26¢ per gallon additional gasoline tax. Those surcharge revenues could be used to offset any or all of the costs incurred by these strategies, and in Strategy B roughly a billion dollars would remain that could be allocated to other beneficial purposes.

The regional impacts on transportation service are shown next. The first item describes the loss of personal mobility caused by the strategies (and the increased price of gasoline) in terms of the trips forgone expressed as a percent of the number of person trips in the Reference Case. The EPA plan causes the greatest number of trips to be forgone—more than twice as many as with the next nearest, which is Strategy F. Strategy C, with its major bus system improvements, has the fewest forgone trips. Again, Strategies D and E are about comparable with trips forgone at about 4 percent of the Reference Case total. The regional reduction in VMT is provided next. Both Strategy B and Strategy F yield a reduction in VMT of 45 percent or more. On the other hand, Strategy A with no specific transportation management tactics shows only a 12 percent reduction in VMT. Strategies D and E result in reductions in VMT of 33 and 31 percent, respectively. A measure of the amount of carpooling is contained in the average automobile occupancy for all trips.

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1 These costs include the annual incremental operating costs as a result of the strategy and the investment costs which have been annualized using a capital recovery factor and assuming a discount rate of 7.5 percent. We assume implementation in 1977 and the investment cost is then annualized using the expected life of the particular system [17, 8]. All costs are expressed in 1972 dollars.

2 From the point of view of an economist, revenue from surcharges is not considered a cost in the sense of being part of the cost of the strategy. Rather, the economist would consider this revenue a transfer payment, since presumably the money would be returned to the public as some governmental service or equivalent benefit. However, we have chosen to show the revenue as a cost, believing the people of the region will regard it as such. Second, and in the same vein, the choice of color in the scorecard depends on the viewpoint being taken. If as a local bureaucrat the surcharge revenue will be used to increase your budget, you might tend to show the largest annual revenue in green. Again, we have taken what we believe will represent the public point of view by showing large surcharge revenues as unattractive.
Again, Strategies B and F have the highest occupancies and thus the most carpooling. Strategies A and C have only a slightly larger average automobile occupancy than the Reference Case.

Two of the major impacts on the regional bus system are also included. First, we show the percent of all daily person trips made by bus (i.e., the modal split). The largest modal splits are provided by Strategies C and F—both of which have very large bus systems. The smallest modal splits occur for Strategies A, B, and D, since they do not emphasize bus system improvements. Finally, we show the number of buses required in each strategy. They range from a high of 6,080 buses in Strategy F to only 2,080 buses in Strategy A, which is the same number as in the Reference Case. Strategy E requires about 3,300 buses, a number that is quite feasible by 1977.5

The impacts on regional air quality are the next items shown in the scorecard. We have used two of the descriptors discussed earlier to express the impact of each strategy on air pollution. First, we predict the number of days the National Air Quality Standard for oxidant will be violated at the worst point in the region.6 The standard will be violated on 211 days in 1977 for the Reference Case. The best of the alternatives in terms of air quality, Strategy F, will result in 135 days in violation; Strategy A shows the least benefit with 160 days violating the oxidant standard. We also forecast the RPEL to adverse oxidant concentrations expressed as a percent of the RPEL observed in 1970. Strategy F gives the largest reduction in exposure to adverse oxidant—only 5.5 percent of the 1970 exposure. Again Strategy A has the smallest improvement, but even here the 1977 RPEL is only 11.3 percent of the 1970 value. Strategies D and E, with RPEL impacts in the middle of the range, both provide more than a 90 percent reduction over the 1970 population exposure level. We can also note one of the major advantages of using the RPEL to describe regional air pollution. The previous item showed that the strategies will reduce the number of days on which the oxidant standard is violated to between 135 and 160 days compared with the 211 days in violation in the Reference Case. The RPEL, on the other hand, indicates exposure levels between 6 and 13 percent of 1970, whereas the Reference Case is at 49 percent of the 1970 level. Thus the RPEL which we believe to be a more meaningful measure of regional air pollution shows that significant improvements in air quality can be brought about by any of the strategies—particularly Strategies B and F, and to only a moderately lesser extent by Strategies D and E.6

The last impact category shown in the scorecard reflects the energy consumed by motor vehicles in the region. The annual gasoline consumption in millions of barrels by both light-duty and heavy-duty motor vehicles is presented first.6 Strategy

---

4 Showing the relative attractiveness of the transportation service impacts for each strategy (through the use of color) presents a dilemma. For example, one can readily argue that increased automobile occupancies are unattractive, since some of the privacy associated with automobile use will be eliminated. On the other hand, one of the main objectives of the SCAG Short-Range Program is to provide a significant reduction in regional VMT—thus the largest reductions in VMT are shown as being attractive. Since large VMT reductions in the near term will be accomplished by increasing automobile occupancy or larger bus modal splits, we have chosen to show increases in these parameters as being attractive. However, we have shown large numbers of trips forgone (with their attendant loss of personal mobility) as being unattractive.

5 For each of the strategies, the worst point in the region is Upland located in San Bernardino County. For the Reference Case, the worst point is Azusa (see Sec. III).

6 The number of days violating the oxidant standard and the RPELs shown in the scorecard has been determined using the Rand technical assumptions. The range of technical uncertainty in forecasting future air quality in these terms has been previously demonstrated in Fig. 8 and Fig. 10, respectively.

7 The impacts on gasoline consumption include the change in fuel economy caused by the exhaust emission control retrofit devices, the emissions inspection/maintenance programs, as well as the reduction in vehicle miles traveled.
F results in the lowest consumption of only about 59 million barrels per year. The highest annual consumption, almost 95 million barrels, occurs for Strategy A. Strategies D and E also yield a substantial reduction in gasoline consumption over the Reference Case. Finally, the annual diesel fuel consumption by trucks and buses is presented. In this case, Strategies C and F with their large bus systems have the highest consumption. The remaining strategies are all quite close to the Reference Case in amount of diesel fuel consumed annually.

Having examined each line item on the summary scorecard, we now consider the results on a columnar basis—in other words, the range of impacts for each strategy. Here the colored scorecard should provide the greatest benefit, since our goal is for the reader to select what he considers the most attractive strategy. Using this technique facilitates making the following observations.

- The greatest improvements in regional air quality and energy consumption will be realized by Strategy B (the EPA plan) and Strategy F.
  - Strategy F is comparable to Strategy B in terms of the environmental impacts.
  - Strategy F is more attractive than Strategy B in terms of the required regional expenditures and transportation service impacts.
- Strategy D and Strategy E are perhaps the most attractive alternatives when the entire range of impacts is considered.
  - Strategy D requires the smaller regional expenditure.
  - Strategy E has somewhat more favorable transportation service impacts.

The reader can now make the fullest use of the colored scorecard presentation. To do so, he must color code each impact category according to his own set of values, and he must attach relative weights to each of the impact categories. For example, are air quality benefits more or less important than corresponding drawbacks in transportation service? After making these judgments, the (subjectively) most attractive strategy can be fairly easily selected.

Impacts in 1977: Gasoline at 40 Cents per Gallon

We have repeated the impact analysis of the six alternative strategies for 1977, assuming that the basic pump price of gasoline is 40¢ per gallon. This, of course, is the gasoline price assumption implicit in the forecast of the Reference Case. The resulting summary scorecard for the six alternative transportation strategies is presented as Table 9. Without citing all of the specific details of Table 9, we observe that the relative ranking of the six strategies is identical to the ranking shown in Table 8 where gasoline is assumed to be priced at 60¢ per gallon.

Several examples will highlight how the magnitude of the various impacts has changed, however. The strategy that relied primarily on major improvements to the bus system (Strategy C) now results in a negative number of trips forgone; the bus system improvements are sufficient to induce a large number of new trips. The induced trips occur in this scenario because the effect of increased gasoline price (as an economic disincentive) is no longer present. We also note in Table 9 that both Strategies D and E still yield at least a 90 percent improvement in the population exposure level to oxidant when compared against 1970.

Although it appears unlikely (at the time of this writing) that the basic pump price of gasoline will ever return to 40¢ per gallon, this assumed price is interesting in another context. We described in Sec. IV how our analysis of increased gasoline

\* Such a result is sometimes referred to as responding to latent demand.
Table 9
SUMMARY OF THE MAJOR IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION, ASSUMING THE BASIC PRICE OF GASOLINE IS 40 CENTS PER GALLON

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<td>Regional Expenditures ($ million)</td>
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<td>289</td>
<td>332</td>
<td>337</td>
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<td>22</td>
<td>89</td>
<td>136</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>762</td>
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</tr>
<tr>
<td>Trips Forgone (% of Reference)</td>
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<td>-0.5</td>
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<td>0.7</td>
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<td>Reduction in Vehicle Miles Traveled (%)</td>
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<td>39</td>
<td>24</td>
<td>21</td>
<td>43</td>
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<tr>
<td>Average Auto Occupancy</td>
<td>1.34</td>
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<td>1.69</td>
<td>1.61</td>
<td>1.92</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Trips by Bus (% of all Trips)</td>
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<td>3.3</td>
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<td>Number of Buses Required</td>
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<td>3290</td>
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<tr>
<td>Number of Days Oxidant Standard Violated (at the worst point in the region)</td>
<td>211</td>
<td>143</td>
<td>152</td>
<td>153</td>
<td>140</td>
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<td>Regional Population Exposure Level for Oxidant (% of 1970 Level)</td>
<td>49.3</td>
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<td>9.2</td>
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<td>Energy for Motor Vehicle Use (millions of barrels)</td>
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<td>Annual Gasoline Consumption</td>
<td>102.4</td>
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<td>83.6</td>
<td>86.1</td>
<td>64.7</td>
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<td>3.3</td>
<td>3.6</td>
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<tr>
<td>Gasoline Price (cents/gal)</td>
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<td>40</td>
<td>40</td>
<td>40</td>
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<td></td>
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</tbody>
</table>

The least attractive strategies | The most attractive strategies | Remaining strategies

*Strategies are described in Table 6.

**The revenue from surcharges could, of course, be used to offset some of the strategy costs or could be allocated to other beneficial purposes. Large surcharges might therefore be viewed from some vantage points as desirable.
prices is completely valid only in the short term. If, in fact, the price of gasoline is 60¢ per gallon in 1977, then this price level will have been maintained for over three years. Earlier we explained that motorists will tend to counterbalance the effect on VMT of increased fuel prices by purchasing automobiles with better fuel economy. We think it unlikely that average fuel economy of the automobile fleet in the Los Angeles area will increase enough by 1977 to fully offset the difference between gasoline at 60¢ and 40¢ per gallon. Therefore, we may regard the impacts on transportation service and air quality shown in Table 9 as lower bound estimates of a 60¢ per gallon gasoline price in 1977. For example, the VMT reductions for both Strategies D and E are now much closer to the EPA target of a 20 percent reduction in VMT. In other words, using both Tables 8 and 9 and assuming that gasoline remains priced at 60¢ per gallon through 1977, the reduction in VMT obtained by Strategy E would be between 21 and 31 percent. Currently we believe that the closer estimates of each impact for this scenario are provided by Table 8.

Impacts in 1977: Gasoline at 80 Cents per Gallon

As an upper limit to likely gasoline price increases, we have used 80¢ per gallon. Table 10 contains the corresponding summary impacts in 1977 of the six transportation alternatives. Again we note that the relative ranking of the alternative strategies remains unchanged. Also of interest is the 90 percent or greater improvement in the RPEL observed for all six strategies.

A collective examination of Tables 8, 9, and 10 leads to the following important observation: Although the impacts in each category may change significantly, the relative attractiveness of the six alternative transportation strategies is essentially independent of the basic pump price of gasoline assumed for 1977.

DETAILED IMPACTS OF THE ALTERNATIVE STRATEGIES

The summary scorecard for the 60¢ per gallon scenario is extremely useful for selecting an attractive regional transportation strategy for 1977. However, before the final selection can be made, many other detailed impacts should be considered—particularly for the more promising strategies. We will now present such impacts for each general impact category shown in Table 8 plus the distribution of selected impacts by income group. The impacts will be presented without additional comment, except to further explain some of the impact categories. We again remind the reader that the pump price of gasoline is assumed to be 60¢ per gallon for all of the strategies except Strategy F, where a 26¢ per gallon additional tax raises the total pump price to 86¢ per gallon. The detailed impacts for the Reference Case, of course, assume only a 40¢ per gallon gasoline price.

Detailed Regional Expenditures

The detailed impacts on regional expenditures of the six alternative strategies

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8 The average fuel economy of the fleet can most easily be increased by an influx of small cars. If gasoline price increases occur only in the Los Angeles region (e.g., because of a local gasoline tax increase), then it is at least conceivable that enough of the small car market could be captured by Los Angeles to effect a dramatic change in average fuel economy in three years. However, gasoline prices have increased nationally, and therefore there is a much smaller potential pool of small cars (both new and used) available to the region.

9 Note that most of the regional expenditures and gasoline consumption impacts from Table 9 are not valid in this context.
Table 10

SUMMARY OF THE MAJOR IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION, ASSUMING THE BASIC PRICE OF GASOLINE IS 80 CENTS PER GALLON

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<td>Regional Expenditures ($ million)</td>
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<td>269</td>
<td>293</td>
<td>296</td>
<td>262</td>
<td></td>
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<td>Annualized Cost of Technological Controls</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>1</td>
<td>79</td>
<td>121</td>
</tr>
<tr>
<td>Annual Bus Subsidy Required</td>
<td>32</td>
<td>0</td>
<td>1</td>
<td>79</td>
<td>121</td>
<td></td>
<td></td>
</tr>
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<td>Annual Surcharges Collected**</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>602</td>
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<td>Transportation Service</td>
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</tr>
<tr>
<td>Trips Forgone (% of Reference)</td>
<td>0</td>
<td>7.6</td>
<td>5.5</td>
<td>7.3</td>
<td>7.0</td>
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<tr>
<td>Reduction in Vehicle Miles Traveled (%)</td>
<td>0</td>
<td>5.5</td>
<td>5.1</td>
<td>40</td>
<td>38</td>
<td>54</td>
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<tr>
<td>Average Auto Occupancy</td>
<td>1.34</td>
<td>2.05</td>
<td>1.85</td>
<td>1.76</td>
<td>2.05</td>
<td></td>
<td></td>
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<tr>
<td>Bus System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trips by Bus (% of all Trips)</td>
<td>2.2</td>
<td>3.9</td>
<td>9.9</td>
<td>5.1</td>
<td>10.4</td>
<td></td>
<td></td>
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<tr>
<td>Number of Buses Required</td>
<td>2080</td>
<td>2350</td>
<td>2350</td>
<td>3290</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Quality</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Number of Days Oxidant Standard Violated</td>
<td>211</td>
<td>134</td>
<td>142</td>
<td>144</td>
<td>133</td>
<td></td>
<td></td>
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<tr>
<td>(at the worst point in the region)</td>
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<tr>
<td>Regional Population Exposure Level for Oxidant (%)</td>
<td>49.3</td>
<td>5.2</td>
<td>6.9</td>
<td>7.1</td>
<td>4.8</td>
<td></td>
<td></td>
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<tr>
<td>(of 1970 Level)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Energy for Motor Vehicle Use (millions of barrels)</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Annual Gasoline Consumption</td>
<td>102.4</td>
<td>57.3</td>
<td>68.1</td>
<td>69.6</td>
<td>54.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Diesel Fuel Consumption</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline Price (cents/gal)</td>
<td>40</td>
<td>.80</td>
<td>.80</td>
<td>.80</td>
<td>.80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Strategies are Described in Table 6.

**The revenue from surcharges could, of course, be used to offset some of the strategy costs or could be allocated to other beneficial purposes. Large surcharges might therefore be viewed from some vantage points as desirable.
are presented in Table 11. The line items are, with few exceptions, self-explanatory; the cost of fixed source controls include both stationary sources and aircraft [7, 12, 13]. The net annual expenditures are determined as explained for the first summary scorecard (Table 8).

We provide three additional impacts in Table 11 pertaining to gasoline sales. First, we show the change in total out-of-pocket expenditures by motorists for gasoline. Then the change in net annual service station revenues for gasoline sales (excluding all gasoline taxes) is shown. Finally, we present the change in annual gasoline tax revenues that will be realized by the state and federal governments (based on the current gasoline tax rates, excluding sales tax).

**Table 11**

**THE DETAILED REGIONAL EXPENDITURE IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION**

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Fixed Source Controls (annualized)</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<tr>
<td>Retrofit-IM Controls</td>
<td>0</td>
<td>636</td>
<td>636</td>
<td>636</td>
<td>636</td>
<td>636</td>
<td>636</td>
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<tr>
<td>Investment Cost</td>
<td>0</td>
<td>196</td>
<td>123</td>
<td>178</td>
<td>151</td>
<td>156</td>
<td>116</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>0</td>
<td>348</td>
<td>275</td>
<td>330</td>
<td>303</td>
<td>368</td>
<td>268</td>
</tr>
<tr>
<td>Annualized Total</td>
<td>32</td>
<td>12</td>
<td>12</td>
<td>350</td>
<td>84</td>
<td>128</td>
<td>400</td>
</tr>
<tr>
<td>Total Annual Bus Subsidy Required</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>555</td>
</tr>
<tr>
<td>Annual Mileage Surcharge Collected †</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>119</td>
</tr>
<tr>
<td>Annual Parking Surcharge Collected †</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>119</td>
</tr>
<tr>
<td>Gasoline Price (cents/gal)</td>
<td>40</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Annual Gasoline Sales Revenue (excluding all taxes)</td>
<td>0</td>
<td>525</td>
<td>-290</td>
<td>322</td>
<td>24</td>
<td>74</td>
<td>177</td>
</tr>
<tr>
<td>Change in Current Gasoline Tax Annual Revenues</td>
<td>0</td>
<td>-58</td>
<td>-207</td>
<td>-95</td>
<td>-150</td>
<td>-140</td>
<td>-223</td>
</tr>
</tbody>
</table>

* All expenditures in millions of dollars.

** Strategies are described in Table 6.

† The revenue from surcharges could, of course, be used to offset some of the strategy costs or could be allocated to other beneficial purposes.

**Detailed Transportation Service Impacts**

Table 12 contains the detailed transportation service impacts of the alternative strategies in 1977. Most impacts are shown for both essential and inessential trips.10 The first category, for example, shows the daily vehicle miles traveled for both trip types as well as the total for each strategy. Further down the list of impacts the percentage of person trips in carpools with three or more occupants is shown. Both the EPA Plan and Strategy F result in more than 85 percent of all essential person trips being made in such carpools. Table 12 also contains the average times for

10 The reader is again reminded that essential trips are all home-work and work-related trips; inessential trips include all other trip types.
Table 12
THE DETAILED TRANSPORTATION SERVICE IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Vehicle Miles Traveled (millions)</td>
<td>76</td>
<td>69</td>
<td>29</td>
<td>58</td>
<td>37</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>Essential Trips</td>
<td>63</td>
<td>70</td>
<td>58</td>
<td>68</td>
<td>70</td>
<td>70</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td>139</td>
<td>140</td>
<td>87</td>
<td>126</td>
<td>107</td>
<td>111</td>
<td>81</td>
</tr>
<tr>
<td>Daily Person Trips</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>Essential Trips</td>
<td>20.4</td>
<td>19.1</td>
<td>19.6</td>
<td>19.1</td>
<td>19.2</td>
<td>19.5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29.6</td>
<td>28.2</td>
<td>29.0</td>
<td>28.8</td>
<td>28.3</td>
<td>28.3</td>
<td>27.6</td>
</tr>
<tr>
<td>Trips by Bus (% of all Trips)</td>
<td>2.3</td>
<td>3.3</td>
<td>8.9</td>
<td>3.3</td>
<td>4.7</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>Average Auto Occupancy</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>Essential Trips</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>Average for all Trips</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>Essential Trips in Carpoools (%)</td>
<td>6.4</td>
<td>12.5</td>
<td>85.5</td>
<td>12.7</td>
<td>48.6</td>
<td>40.9</td>
<td>87.4</td>
</tr>
<tr>
<td>($ or more occupants)</td>
<td>Average Essential Trip Times (min.)</td>
<td>26.4</td>
<td>25.4</td>
<td>26.9</td>
<td>23.8</td>
<td>26.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Trips by Auto</td>
<td>47.9</td>
<td>39.8</td>
<td>28.7</td>
<td>28.9</td>
<td>82.0</td>
<td>81.8</td>
<td>79.8</td>
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<tr>
<td>Average</td>
<td>27.7</td>
<td>27.5</td>
<td>29.2</td>
<td>26.3</td>
<td>28.7</td>
<td>29.6</td>
<td>31.6</td>
</tr>
<tr>
<td>Average Essential Trip Costs ($)</td>
<td>0.94</td>
<td>1.03</td>
<td>0.51</td>
<td>0.96</td>
<td>0.56</td>
<td>0.63</td>
<td>0.47</td>
</tr>
<tr>
<td>Trips by Auto</td>
<td>0.47</td>
<td>0.51</td>
<td>0.41</td>
<td>0.30</td>
<td>0.25</td>
<td>0.28</td>
<td>0.10</td>
</tr>
<tr>
<td>Average</td>
<td>0.91</td>
<td>0.99</td>
<td>0.51</td>
<td>0.82</td>
<td>0.54</td>
<td>0.59</td>
<td>0.41</td>
</tr>
<tr>
<td>Average Essential Trip Costs ($)</td>
<td>0.43</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>Trips by Bus</td>
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<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Overall Average</td>
<td>0.43</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*All impacts shown exclude heavy trucks and motorcycles.
**Strategies are described in Table 6.

Note that the average time for trips by bus (includes walking to the bus stop, waiting for the bus, and the line-haul time) is longer for all of the strategies than it is in the Reference Case. This increase in time occurs in spite of improved bus system service, because the average trip distance by bus increases considerably under the strategies (remember, the increased gasoline price will have its greatest effect on longer trips). The average cost of each person trip is also shown. Note that the average cost of an essential trip is less than the Reference Case for most of the strategies because of carpooling or switching to the bus. Inessential trip costs, on the other hand, increase slightly over those in the Reference Case.

Transportation service impacts pertaining to the regional bus system in Table 13. First the service characteristics of the bus system are repeated. This is followed by system cost information and the average bus modal split by trip type. We again show the average weekday passenger trips and the resulting average bus occupancy for each strategy. The average bus occupancies for each strategy appear to be low enough to not aggravate the limitation of our bus system analysis described in Sec. IV. The table is concluded by showing the number of buses and employees required to operate the system in each strategy.

Detailed Air Quality Impacts

Table 14 presents some detailed air quality impacts for each of the alternatives. For each strategy, we show the number of days the NAQS for oxidant will be violated
Table 13
THE DETAILED BUS SYSTEM IMPACTS, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
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<tr>
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</tr>
</thead>
<tbody>
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<td>Bus Fare (cents)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Per Trip</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Per Mi&lt;sup&gt;®&lt;/sup&gt;</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
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<td>Headways (minutes)</td>
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<tr>
<td>Peak Period</td>
<td>17</td>
<td>17</td>
<td>15</td>
<td>7.5</td>
<td>15</td>
<td>12.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Off-Peak Period</td>
<td>40</td>
<td>40</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>25</td>
<td>15</td>
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<tr>
<td>Service Area</td>
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<tr>
<td>Square Miles</td>
<td>1380</td>
<td>1380</td>
<td>1380</td>
<td>1613</td>
<td>1380</td>
<td>1613</td>
<td>1786</td>
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<tr>
<td>Population Eligible (%)</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>77</td>
<td>68</td>
<td>77</td>
<td>81</td>
</tr>
<tr>
<td>System Cost ($ million)</td>
<td>132</td>
<td>132</td>
<td>163</td>
<td>437</td>
<td>163</td>
<td>241</td>
<td>492</td>
</tr>
<tr>
<td>Annualized Total Cost</td>
<td>32</td>
<td>12</td>
<td>12</td>
<td>350</td>
<td>84</td>
<td>128</td>
<td>400</td>
</tr>
<tr>
<td>Annual Subsidy Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Modal Split (%)</td>
<td>6.2</td>
<td>6.9</td>
<td>7.6</td>
<td>16.3</td>
<td>7.8</td>
<td>10.4</td>
<td>16.8</td>
</tr>
<tr>
<td>Essential Trips</td>
<td>0.3</td>
<td>0.4</td>
<td>1.3</td>
<td>5.4</td>
<td>1.1</td>
<td>1.9</td>
<td>6.3</td>
</tr>
<tr>
<td>Inessential Trips</td>
<td>22</td>
<td>29</td>
<td>29</td>
<td>34</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Overall Average</td>
<td>2.2</td>
<td>2.5</td>
<td>3.6</td>
<td>5.9</td>
<td>3.3</td>
<td>4.7</td>
<td>9.8</td>
</tr>
<tr>
<td>Daily Bus Passengers (thousands)</td>
<td>636</td>
<td>704</td>
<td>903</td>
<td>2557</td>
<td>920</td>
<td>1321</td>
<td>2708</td>
</tr>
<tr>
<td>Average Bus Occupancy</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Average Peak Period Bus Speed (mph)</td>
<td>16</td>
<td>16</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Number of Buses Required</td>
<td>2080</td>
<td>2080</td>
<td>2350</td>
<td>5490</td>
<td>2350</td>
<td>3094</td>
<td>6078</td>
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<tr>
<td>Bus System Employees</td>
<td>7510</td>
<td>7510</td>
<td>9490</td>
<td>26580</td>
<td>9490</td>
<td>14300</td>
<td>30000</td>
</tr>
</tbody>
</table>

* Strategies are described in Table 6.

and the number of days the First Stage Alert<sup>11</sup> level will be exceeded at each of eight different locations in the region. The locations were selected to represent a cross-section of the varying levels of air pollution that occur within the LA AQCR. Note that the better strategies result in only one First Stage Alert being called in the locations shown.

Next, the 1977 expected maximum one-hour concentration of oxidant is shown for each of the locations. This is followed by the ICEL for oxidant (see Sec. III), also at each station. For each of the strategies, the largest values for the ICEL occur in Pasadena, Riverside, and San Bernardino. We conclude the table by presenting the RPEL for oxidant.

Detailed Energy Consumption Impacts

Detailed impacts on energy consumption for motor vehicle use are shown in Table 15. We begin by showing the gasoline consumption by vehicle type followed by the diesel fuel consumption by vehicle type. Finally, a representation of the total energy consumption by motor vehicles is provided in the barrels of crude oil required to produce the needed gasoline and diesel fuel. Included in the crude oil calculation is the increase in crude oil required to produce a barrel of unleaded gasoline compared to gasoline containing lead (see Appendix E). (Catalytic exhaust gas converters used to reduce emissions on 1975 and later model new cars, and as part of the full technological controls, installed as retrofit devices on many older cars required unleaded gasoline to assure durability of the catalytic element [8].)

<sup>11</sup> The First Stage Alert level for oxidant is 0.20 ppm, one-hour average.
### Table 14
THE DETAILED AIR QUALITY IMPACTS, IN 1977, OF SIX ALTERNATIVE REGIONAL TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Number of Days National Air Quality Standard for Oxidant Violated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>76</td>
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<td>6</td>
<td>11</td>
<td>7</td>
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<td>Burbank</td>
<td>163</td>
<td>60</td>
<td>29</td>
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<td>26</td>
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<tr>
<td>Camarillo</td>
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<td>4</td>
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<td>123</td>
<td>90</td>
<td>116</td>
<td>104</td>
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<td>86</td>
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<td>Riverside</td>
<td>202</td>
<td>127</td>
<td>99</td>
<td>117</td>
<td>109</td>
<td>110</td>
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<td>San Bernardino</td>
<td>153</td>
<td>93</td>
<td>63</td>
<td>86</td>
<td>74</td>
<td>76</td>
<td>59</td>
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<tr>
<td>Number of Days First Stage Alert Level for Oxidant Exceeded</td>
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</tr>
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<td>49</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Riverside</td>
<td>54</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>San Bernardino</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Maximum Expected One-Hour Oxidant Concentration (ppm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camarillo</td>
<td>.18</td>
<td>.10</td>
<td>.09</td>
<td>.10</td>
<td>.09</td>
<td>.10</td>
<td>.09</td>
</tr>
<tr>
<td>Long Beach</td>
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<td>.06</td>
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<td>.18</td>
<td>.20</td>
<td>.19</td>
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<td>.18</td>
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<tr>
<td>Riverside</td>
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<td>.22</td>
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<td>.23</td>
<td>.24</td>
<td>.21</td>
</tr>
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<td>San Bernardino</td>
<td>.31</td>
<td>.18</td>
<td>.15</td>
<td>.18</td>
<td>.17</td>
<td>.17</td>
<td>.15</td>
</tr>
<tr>
<td>Individual Cumulative Exposure Level for Oxidant (% of 1970 Level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaheim</td>
<td>36.5</td>
<td>2.8</td>
<td>0.9</td>
<td>2.3</td>
<td>1.3</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Burbank</td>
<td>45.6</td>
<td>6.4</td>
<td>2.5</td>
<td>5.2</td>
<td>3.6</td>
<td>3.9</td>
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<td>Camarillo</td>
<td>29.1</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
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<tr>
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<td>1.0</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Long Beach</td>
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<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Pasadena</td>
<td>53.7</td>
<td>14.3</td>
<td>7.8</td>
<td>12.7</td>
<td>10.2</td>
<td>10.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Riverside</td>
<td>54.9</td>
<td>14.8</td>
<td>8.0</td>
<td>13.0</td>
<td>10.6</td>
<td>10.9</td>
<td>7.3</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>53.2</td>
<td>12.8</td>
<td>6.4</td>
<td>11.1</td>
<td>8.6</td>
<td>9.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Regional Population Exposure Level for Oxidant (% of 1970 Level)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>49.3</td>
<td>11.3</td>
<td>5.6</td>
<td>9.9</td>
<td>7.9</td>
<td>8.2</td>
<td>5.5</td>
</tr>
</tbody>
</table>

*Strategies are described in Table 6.*

### Distribution of Impacts by Income Group

Table 16 contains the distribution of selected impacts by income group. We present the results in terms of the effect on households from two income groups: households with greater than $15,000\(^{12}\) annual income; and households with less than $5,000 annual income. The first set of distributed impacts deals with transportation service. The reduction in vehicle miles traveled under each strategy is nearly the same for both income groups. The same statement cannot be made for the trips

\(^{12}\) Forecasts of 1977 household incomes in 1972 dollars.
Table 15
THE DETAILED ENERGY CONSUMPTION IMPACTS, IN 1977,
OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR
THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Gasoline Consumption (millions of barrels)</td>
<td>93.3</td>
<td>85.8</td>
<td>53.5</td>
<td>77.8</td>
<td>65.9</td>
<td>67.9</td>
<td>50.0</td>
</tr>
<tr>
<td>Light-Duty Motor Vehicles</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Heavy-Duty Trucks</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Total All Types</td>
<td>102.4</td>
<td>94.9</td>
<td>62.6</td>
<td>86.8</td>
<td>75.0</td>
<td>77.0</td>
<td>59.1</td>
</tr>
<tr>
<td>Annual Diesel Fuel Consumption (millions of barrels)</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Heavy-Duty Trucks</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>1.6</td>
<td>0.7</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Total All Types</td>
<td>3.2</td>
<td>3.2</td>
<td>3.3</td>
<td>4.2</td>
<td>3.3</td>
<td>3.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Equivalent Crude Oil Requirements for Motor Vehicle Use (millions of barrels per year)</td>
<td>246.3</td>
<td>220.4</td>
<td>150.3</td>
<td>207.3</td>
<td>177.5</td>
<td>180.1</td>
<td>147.4</td>
</tr>
</tbody>
</table>

* Strategies are described in Table 8.

forgone. Under Strategy B, the upper income group forgo 13.8 percent of their trips and the lower income households forgo over 20 percent. This situation is reversed when major bus system improvements are made, such as in Strategy F. Here the upper income households forgo 6.1 percent and the lower income households only 4.9 percent of their total trips. Strategy E is also nearly balanced in this respect. Note also that the upper income groups have longer trip times both by automobile and bus than the lower income households. This occurs because of the longer commuting distances of the upper income group.

The distribution of some of the strategy costs is also shown in Table 16. First, the investment cost for emission control retrofit devices is shown. The investment cost in dollars per household is shown for two payment plans that could be used to finance the retrofit devices. The first plan assumes that everyone pays for his own retrofit; it results in both household income groups having approximately the same outlay. This happens in spite of the lower income group generally owning older vehicles because the upper incomes own more cars per household. The second payment plan assumes that the cost of the retrofit device is made proportional to the average household income. In this instance, all households in the region will pay for part of the retrofit device even if they do not own a vehicle, since all benefit from improved air quality. Finally the average trip costs are shown. Very little difference between income groups is evident in the overall average trip costs for any of the strategies, except perhaps Strategy A and Strategy C. We believe that Table 14 is useful in providing insights into some of the social consequences of the transportation alternatives.

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13 These costs are the same for all strategies, since the same full technological controls are employed in each strategy.
14 We are not necessarily advocating the income-proportional payment plan but merely include it to show that alternative financing schemes will have significantly different impacts.
Table 16
THE DISTRIBUTION OF SELECTED IMPACTS BY INCOME GROUP, IN 1977, OF SIX ALTERNATIVE TRANSPORTATION STRATEGIES FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th>DETAILED IMPACTS*</th>
<th>STRATEGY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference Case</td>
</tr>
<tr>
<td><strong>TRANSPORTATION SERVICE</strong></td>
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</tr>
<tr>
<td>REDUCTION IN VEHICLE MILES TRAVELED (%)</td>
<td>0</td>
</tr>
<tr>
<td>TRIPS FORGONE (% OF REFERENCE)</td>
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</tr>
<tr>
<td>AVERAGE TRIP TIMES (MIN.)</td>
<td>18.6</td>
</tr>
<tr>
<td>Trips by Auto</td>
<td>70.0</td>
</tr>
<tr>
<td>Trips by Bus</td>
<td>68.8</td>
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<tr>
<td>Overall Average</td>
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</table>

**COSTS**

<table>
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<tr>
<th>LDMV RETROFIT INVESTMENT</th>
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<tr>
<td>User Pays Payment Plan (S/household)</td>
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<tr>
<td>Income Proportional Payment Plan</td>
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<td>AVERAGE TRIP COSTS ($)</td>
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<tr>
<td>Trips by Auto</td>
</tr>
<tr>
<td>Trips by Bus</td>
</tr>
<tr>
<td>Overall Average</td>
</tr>
</tbody>
</table>

* Households with annual income greater than $15,000.
Households with annual income less than $5,000.
** Strategies are described in Table 6.
THE SCAG SHORT-RANGE TRANSPORTATION PLAN

In the next section, we describe some of the policy conclusions and recommendations that can be derived from our study for SCAG. Before doing so, however, we should note how the results presented in this section were used by the SCAG staff.

A final briefing on the detailed comparison of alternatives was presented to SCAG on April 8, 1974. Of course, key SCAG staff members had been aware of the basic results for several weeks prior to this formal presentation. During this time period the SCAG Short-Range Transportation Plan for the region was being prepared. What we have described as Strategy E eventually provided the backbone of the SCAG plan [27]. The SCAG Comprehensive Transportation Planning Committee approved the Short-Range Transportation Plan on March 28, 1974. Subsequently, it was approved by the Executive Committee of SCAG on April 11, 1974.

Thus the results of this study have served as positive inputs to the local decision-makers who are involved in further developing the transportation system in the Los Angeles region.
VI. POLICY CONCLUSIONS AND RECOMMENDATIONS

The goal of this study has been to define near-term transportation alternatives for the Los Angeles region and to present many of the impacts these alternatives would have on the region. Since much of the motivation for the study was provided by the need to reduce air pollution in Los Angeles, we concentrated a large portion of our resources (both in the study and in this report) on describing and predicting air quality in future years. Consequently, we discuss regional air pollution and regional transportation separately in this section. Since the two are inexorably related, however, any discussion of one will inevitably refer at some point to the other.

REGIONAL AIR POLLUTION

We have used several techniques in this report to describe regional air pollution. Included were the annual maximum one-hour oxidant concentrations and the number of days the National Air Quality Standard for oxidant will be violated each year. Taken together and when presented for a number of locations throughout the region, these parameters provided a complete though somewhat complex description of regional air pollution both in 1970 and for future years. We have attempted to develop a more relevant description of air quality by developing a new metric called the Regional Population Exposure Level and applying it to describe photochemical oxidant air pollution. The RPEL has been shown to be responsive to maximum annual concentration, frequency of exposure to adverse pollutant levels, and the geographic distribution of air pollution in terms of the number of people affected. Also of importance, the RPEL has proven to be less sensitive to the choice of technical assumptions that are necessary in forecasting air quality in future years. All of these advantages being considered, we feel the Regional Population Exposure Level is the most meaningful single parameter for describing air pollution as perceived by all of the people of the region.

Implementation of extensive technological emission controls for both stationary and mobile sources will result in substantial improvements to air quality by 1977. The technological controls specified in the EPA implementation plan [3] for the Los Angeles Air Quality Control Region will reduce the number of days on which the National Air Quality Standard for oxidant is violated at the worst point in the region from 254 in 1970 to at most 170 days in 1977. More impressively, these controls will yield in 1977 at least an 80 percent improvement in the RPEL for oxidant versus the 1970 exposure level.

In spite of this improvement in regional air quality, we have also seen that the National Air Quality Standard for oxidant may never be achieved in the Los Angeles Air Quality Control Region. By the late 1980s, when the full benefit of the stringent federal emission standards for new automobiles will be substantially realized and assuming all of the controls contained in the implementation plan are enacted, the oxidant standard will be violated on as many as 135 days per year at the worst point in the region. The emissions responsible for the repeated violation of the oxidant standard will be approximately equally divided among three general source types: light-duty motor vehicles (mostly private automobiles), stationary sources, and other mobile sources (e.g., heavy-duty trucks, motorcycles, and aircraft). Even if the emis-
sions from light-duty motor vehicles were eliminated entirely, the oxidant standard could be violated on as many as 75 days per year in 1990.

Thus if Los Angeles is ever to fully achieve the NAQS for oxidant, additional emission reductions will be required. Specific possibilities for reducing emissions of reactive hydrocarbons from stationary sources include further controlling surface coating and other operations using organic solvents [12]. More stringent emission standards for heavy-duty motor vehicles (both gasoline and diesel powered) should be considered. Also, additional reductions of aircraft emissions may be feasible either through technological controls or through management of ground operations where the most significant emissions occur [12].

The final alternative is to reduce the emissions from motor vehicles directly by reducing VMT. For example, a 20 percent reduction in VMT in conjunction with the full technological controls will result in the oxidant standard being violated on no more than 162 days in 1977. The corresponding RPEL will be at worst only 15 percent of the 1970 value. However, by 1990 this same reduction in VMT will result in 126 days in violation of the oxidant standard and an RPEL of only 4 percent of 1970. The corresponding air quality parameters for 1990 without any reduction in VMT are 134 days in violation and an RPEL equal to about 5 percent of 1970. We conclude, therefore, that reductions in VMT will provide the greatest benefit to regional air quality in the late 1970s and early 1980s.

Finally, our experience with the RPEL for oxidant has shown us that the highest population exposures occur in communities located along the base of the San Gabriel Mountains (e.g., Pasadena and Azusa). Although not specifically addressed by this study, we believe that greater reductions in the RPEL may be possible by concentrating additional emission controls (either technological or transportation management) in these areas. Of course, more detailed studies should be performed to verify this hypothesis.

**REGIONAL TRANSPORTATION ALTERNATIVES**

We have described in detail the effects of the three types of near-term transportation management tactics (bus system improvements, carpooling incentives, and economic disincentives) that are presently available for bringing about a reduction in regional VMT. We began by showing the effect that various degrees of intensity of each of the tactics would have on daily VMT.

Consider first the bus system improvements. Increasing the size of the regional bus system from 2,080 buses in the Reference Case to over 9,000 buses would reduce VMT almost 10 percent. However, a more reasonable increase in the size of the system, say to 3,300 buses, would reduce VMT only about 3 percent. These bus system improvements were characterized by lower fares, increased frequency of service, and an expanded service area.

Carpooling incentives appear to be capable of reducing VMT significantly. Preferential freeway treatment for buses and carpools could reduce VMT by as much as 10 percent. Computer matching to encourage the formation of carpools will reduce VMT only about 4 percent if at least 40 percent of the work force participate and are successfully matched. However, combining the preferential freeway treatment and computer matching tactics could reduce VMT almost 20 percent. We have also shown that increased levels of carpooling will lower bus ridership, hence requiring an increase in the annual bus subsidy.

We have discussed at length two kinds of economic disincentives: a surcharge on a per-vehicle-mile-traveled basis, and a surcharge on a per-vehicle-trip basis. We
have characterized the mileage surcharge as an additional gasoline tax, which allowed simultaneous consideration of this tactic and increases in the price of gasoline caused by the market mechanism. Large reductions in VMT can be achieved if gasoline becomes very expensive. For example, gasoline at \( \$5 \) per gallon would reduce VMT by about 20 percent in the short term. Bus system improvements and carpooling incentives coupled with increased gasoline prices will reduce VMT even more. One of the major unwanted impacts of rising gasoline prices is the resulting loss of personal mobility which we have evaluated in terms of the number of trips forgone. The impact on mobility of increased gasoline prices, which is most severe among the lower income groups, can be alleviated only by improving the regional bus system.

Finally we have shown that a parking surcharge (i.e., an economic disincentive on a per-trip basis) on all non-residential parking is less effective than a mileage surcharge in reducing VMT when expressed in terms of the total out-of-pocket costs to motorists. Furthermore, the parking surcharge causes many more trips to be forgone than does the mileage surcharge for the same reduction in VMT. We have also identified a more attractive application of the parking surcharge tactic. Namely, if the parking surcharge is collected at the non-residential end of home-work trips only, it is as effective as a mileage surcharge up to about a 20 percent reduction in VMT, and more important, does not cause many trips to be forgone.

The three types of transportation management tactics have been combined in different ways to form six alternative regional transportation strategies. We have compared these six strategies in terms of a wide range of impacts on the Los Angeles Air Quality Control Region. None of the strategies will result in achieving the National Air Quality Standard for oxidant by 1977. However, all of the strategies show a considerable improvement in air quality when compared with the 1970 observed air quality. Most of the strategies also provide a substantial reduction in the fuel consumption by motor vehicles. Some of the strategies have attractive impacts on transportation service; others look more attractive in terms of the required annual regional expenditures. When the entire range of impacts is considered, Strategy E, consisting primarily of carpooling incentives and fairly substantial bus system improvements, may be the most attractive. Strategy E was subsequently used by SCAG to form the nucleus of the SCAG Short-Range Transportation Plan.

We observe that all of the six alternative transportation strategies that we have presented should be consistent with the long-term transportation goals of the region. We say this, since most of the alternatives are quite flexible and even a greatly expanded bus system is compatible with a fixed-guideway system in terms of providing necessary feeder service.

Finally, we feel compelled to make one last observation. In the past, much of the motivation for improving mass transit in Los Angeles has been based on the need to reduce air pollution. We have shown in this study that if the 1975 automobiles and later models achieve the existing federal emission standards for new vehicles, and if the resulting emission levels of new cars do not increase more than about twofold after ten years of operation, then only insignificant further improvements in air quality can be realized in 1990 by the reductions in VMT capable of being induced by any mass transit system. We therefore conclude that future mass transit system alternatives should not be judged on their ability to improve air quality, but rather in terms of the necessary resource allocations and the transportation service provided to the people of the Los Angeles region.
Appendix A

FORECASTING REGIONAL EMISSIONS THROUGH 1990

An extensive data base and many technical assumptions are required to make the forecast of regional emissions through 1990. This appendix contains much of the detailed information that is needed for such calculations. We begin by describing the techniques we have used to estimate emissions from motor vehicles. This is followed by estimates of the emissions from sources other than motor vehicles. We then present complete emission inventories of all species for several important cases. The forecast of reactive hydrocarbon (RHC) emissions from all sources through 1990 for three cases using three different sets of technical assumptions is shown next. Finally, we conclude the appendix by displaying the approximate cost-effectiveness of different tactics for reducing RHC emissions.

EMISSIONS FROM MOTOR VEHICLE SOURCES

Central to the calculation of emissions from motor vehicle sources is some measure of the average daily activity of the motor vehicles in the region. The traditional approach, and the one we have employed, is to use estimates of average daily vehicle miles traveled (VMT) by type of vehicle in conjunction with emission factors expressed in terms of mass emissions per vehicle mile (i.e., grams/mile). The composite emission factor vector representing the average emissions per mile for each species in some analysis year under some technological control strategy is dependent on many parameters including,

- Emission factors by vehicle model year.
- Emission factor deterioration functions by vehicle age and model year.
- Average speed correction functions for each species.
- Vehicle population distribution by age of vehicle.
- Vehicle mileage distribution by age of vehicle.
- Effectiveness of technological emission control tactics on each model year.
All of these parameters are taken into account by our Motor Vehicle Emissions and Cost (MOVEC) Model (8) which has been used in this study to determine the required composite emission factors. Our principal data sources for what we have called the Rand technical assumptions are the \textit{EPA} for the new vehicle emission factors, (19,26,28) and speed correction functions; \textit{CARB} for the age deterioration functions, (26) effectiveness of the technological control devices, \textit{SCAG} for vehicle age distributions by age of vehicle; (30,31) and the Department of Motor Vehicles for vehicle age distributions. \footnote{Personal communication with Ralph D. Cook, California Department of Motor Vehicles, November 1972, and Donald N. Bratton, California Air Resources Board, January 1974.} By specifying the VMT and average speed, the MOVEC model uses these data to compute regional emissions for each class of motor vehicle. We describe our estimates of the required average vehicle miles traveled below.

The basis estimates of average weekday VMT are presented in Table A-1. We show values for six vehicle classes; each class has emission factors, etc., and new vehicle emission standards that are unique to that class. Estimates are provided for the 1970 Base Case and the 1977 Reference Case. As noted in the table, the estimates for 1977 are consistent with current SCAG population forecasts for the region.

The number of vehicle miles traveled on the average weekday is required for calibrating the Rand urban transportation model to the Reference Case (see Appendix C). However, average daily emissions should be based on the average daily vehicle miles traveled (i.e., including weekend days). Thus the average weekday VMT shown in Table A-1 has been converted to the average daily VMT shown in Table A-2 by multiplying the weekday values by 342/365 where 342 represents the number of equivalent weekdays in a calendar year. (11) Also shown in Table A-2 are the annual growth rates for 1977 through 1990 used in our long-range forecasts. Special notice should be taken of footnote c. The growth rates shown in Table A-2 for two-cycle and four-cycle motorcycles will result in approximately the same motorcycle average daily VMT in 1990 as that predicted by using a 1.8 percent per year growth rate for both types. All of the growth rates discussed in this section have been compounded annually.

Since we have also calculated the costs of the technological emission-control strategies, we require the number of vehicles of each type in each analysis year. These data are presented in Table A-3.
Table A-1

ESTIMATES OF WEEKDAY VEHICLE MILES TRAVELED: LOS ANGELES AIR QUALITY CONTROL REGIONa

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Average Weekday Vehicle Miles (mi/day)</th>
<th>1970 (32)</th>
<th>1977b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-duty motor vehicles</td>
<td></td>
<td>136,902,300</td>
<td>158,867,000</td>
</tr>
<tr>
<td>Heavy-duty gasoline-powered trucks</td>
<td></td>
<td>4,768,900c</td>
<td>5,264,900</td>
</tr>
<tr>
<td>Heavy-duty diesel-powered trucks</td>
<td></td>
<td>1,469,800c</td>
<td>1,622,700</td>
</tr>
<tr>
<td>Diesel-powered intracity buses</td>
<td></td>
<td>220,300</td>
<td>279,500</td>
</tr>
<tr>
<td>Four-cycle motorcycles</td>
<td></td>
<td>1,538,600</td>
<td>1,785,500</td>
</tr>
<tr>
<td>Two-cycle motorcycles</td>
<td></td>
<td>943,100</td>
<td>1,028,500</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>145,843,000</td>
<td>168,848,000</td>
</tr>
</tbody>
</table>

aFor the Reference Case and assuming no reduction in vehicle miles traveled.
bBased on Ref. 30, but adjusted to reflect current SCAG population growth forecasts.
cAssuming 20,000 miles per year per vehicle are traveled within the Los Angeles Air Quality Control Region (see Table A-3).

Table A-2

ESTIMATED VMT: LOS ANGELES AIR QUALITY CONTROL REGION
(Used to Calculate Average Daily Emissions)

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Average VMT (mi/day)a</th>
<th>1970</th>
<th>1977</th>
<th>Annual Increase in VMT, 1977 to 1990b (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-duty motor vehicles</td>
<td>128,275,600</td>
<td>148,856,200</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Heavy-duty gasoline-powered trucks</td>
<td>4,468,400</td>
<td>4,933,100</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Heavy-duty diesel-powered trucks</td>
<td>1,377,200</td>
<td>1,520,400</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Diesel-powered intracity buses</td>
<td>206,400</td>
<td>261,900</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Four-cycle motorcycles</td>
<td>1,538,600</td>
<td>1,785,500</td>
<td>4.6c</td>
<td></td>
</tr>
<tr>
<td>Two-cycle motorcycles</td>
<td>943,100</td>
<td>1,028,500</td>
<td>-10c</td>
<td></td>
</tr>
</tbody>
</table>

aBased on Table A-1 and assuming that there are 342 equivalent weekdays in the calendar year. (34) The average daily miles for motorcycles is assumed to be the same on weekdays and weekend days.
bUsing current SCAG population growth forecasts and assuming that vehicle miles traveled grow at a rate that is 50 percent greater than the population growth; compounded annually.
cAssuming that new two-cycle motorcycles are substantially replaced by four-cycle motorcycles or that the emission characteristics of the new two-cycles become essentially the same as those of the four-cycles. (35)
Table A-3

ESTIMATED NUMBER OF VEHICLES: LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Number of Vehicles 1970(2,36)</th>
<th>1977a</th>
<th>Annual Increase in VMT, 1977 to 1990 (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-duty motor vehicles</td>
<td>5,598,600</td>
<td>6,496,843</td>
<td>1.8</td>
</tr>
<tr>
<td>Heavy-duty gasoline-powered trucksb</td>
<td>81,550</td>
<td>90,030</td>
<td>1.8</td>
</tr>
<tr>
<td>Heavy-duty diesel-powered trucksb</td>
<td>25,130</td>
<td>27,750</td>
<td>1.8</td>
</tr>
<tr>
<td>Diesel-powered intracity buses(33)</td>
<td>1,820</td>
<td>2,310</td>
<td>1.8</td>
</tr>
<tr>
<td>Four-cycle motorcycles(4)</td>
<td>144,000</td>
<td>167,160</td>
<td>4.6c</td>
</tr>
<tr>
<td>Two-cycle motorcycles(4)</td>
<td>88,260</td>
<td>96,260</td>
<td>-10c</td>
</tr>
</tbody>
</table>

a Using VMT estimates from Table A-2 and assuming the average annual miles per vehicle is the same as 1970.

b Personal communication with Mr. Ralph D. Cook, California Department of Motor Vehicles, November 1972.

c Assuming that new two-cycle motorcycles are substantially replaced by four-cycle motorcycles, or that the emission characteristics of the new two-cycles become the same as those of the four-cycles.

The resulting emissions by species for each motor vehicle class are shown as line items in the region-wide emission inventories presented later in this appendix (see Tables A-8, A-9, and A-10).

EMISSIONS FROM SOURCES OTHER THAN MOTOR VEHICLES

Determining the emissions from sources other than vehicles for each analysis year and for each technological control strategy under consideration is tedious operation. The emissions by species from these sources for the 1970 Base Case are presented in Table A-4. Except for reactive hydrocarbons, the emission rates for each species were derived from CARB(2) and LA APCD(16) sources. We show three sets of RHC emissions: EPA(4), CARB(2), and LA APCD(16). Each agency has determined RHC emission levels from total hydrocarbon emissions, but each assumes that different amounts of the total should be classified as reactive (i.e., eligible for the photochemical reaction that generates oxidant). For the Rand technical assumptions we have used the EPA values for reactive hydrocarbon emissions.
even though we believe these estimates to be somewhat pessimistic.\(^{(7,12,13)}\)

For EPA technical assumptions (described in Sec. II and discussed later in this appendix), of course, we also use the EPA values. For what we have described as the CARB technical assumptions, however, we have used the LA APCD estimates of reactive hydrocarbons shown in Table A-4.\(^1\)

The 1970 Base Case was used directly to develop the emission rates through 1990 for the Reference Case. The annual compound growth rates for each source type used to forecast the emissions through 1990 are presented in Table A-5. Thus in the Reference Case, the emissions from each source are assumed to be controlled only to the level existing in 1970.

We show a similar emission inventory for the Nominal Case in 1977 in Table A-6. Note that only the EPA and LA APCD estimates for RHC emissions are included since they represent the extremes. We have assumed implementation of the Nominal Case by 1975. A corresponding 1975 inventory (not shown here) was developed by reducing the emission levels shown in Table A-6 to compensate for the annual growth factors displayed there. Again, the Nominal Case through 1990 was developed using these growth factors for each source type.

The reader will recall from Sec. II that the Full Technological Controls Case for these emission sources provided additional reductions in reactive hydrocarbons only. The effect of these controls on the petroleum industry and organic solvent users is presented in Table A-7. The complete emission inventories for all species under the Full Technological Controls Case can thus be obtained by replacing the appropriate elements of Table A-6 with the corresponding emissions shown in Table A-7. The development of this case through 1990 used the growth factors given in Table A-6.

**COMPLETE EMISSION INVENTORIES FOR 1970 AND 1977**

Using the information and techniques described above, we are able to generate a complete emissions inventory for any analysis year under a given control strategy. We show three such inventories in this section,

\(^1\)The LA APCD assumptions are the most optimistic of the three in terms of achieving the NAQS for oxidant. Since we are trying to bound the problem and the CARB estimates for motor vehicle sources are the most optimistic, we have married the CARB and LA APCD assumptions for the respective sources and called them the CARB technical assumptions.
### Table A-4

**Los Angeles Air Quality Control Region Emission Inventory: 1970 Base Case (Tons/day)**

(For All Sources Other Than Motor Vehicles)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Reactive Hydrocarbons</th>
<th>CO</th>
<th>NO\textsubscript{2}</th>
<th>SO\textsubscript{2}</th>
<th>Pb</th>
<th>P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>THC</td>
<td>EPA</td>
<td>CARB</td>
<td>LA APCD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroleum industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>114.0</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>27.9</td>
</tr>
<tr>
<td>Refining</td>
<td>43.0</td>
<td>5.0</td>
<td>5.0</td>
<td>4.7</td>
<td>5.0</td>
<td>22.0</td>
</tr>
<tr>
<td>Marketing</td>
<td>146.0</td>
<td>137.6</td>
<td>68.1</td>
<td>49.2</td>
<td>...</td>
<td>11.0</td>
</tr>
<tr>
<td>Organic solvent users</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface coating</td>
<td>250.0</td>
<td>49.2</td>
<td>49.2</td>
<td>48.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Dry cleaning</td>
<td>31.2</td>
<td>6.1</td>
<td>6.1</td>
<td>5.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Degreasing</td>
<td>103.0</td>
<td>22.6</td>
<td>22.6</td>
<td>20.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Other</td>
<td>173.0</td>
<td>32.9</td>
<td>32.9</td>
<td>12.0</td>
<td>...</td>
<td>1.0</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>...</td>
<td></td>
<td>...</td>
<td>15.0</td>
<td>...</td>
<td>0.2</td>
</tr>
<tr>
<td>Metallurgical industry</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Mineral industry</td>
<td>1.0</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>...</td>
<td>5.5</td>
</tr>
<tr>
<td>Incineration</td>
<td>22.4</td>
<td>1.9</td>
<td>1.9</td>
<td>0.3</td>
<td>69.7</td>
<td>6.2</td>
</tr>
<tr>
<td>Combustion of fuels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam power plants</td>
<td>7.0</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>...</td>
<td>135.0</td>
</tr>
<tr>
<td>Other industrial</td>
<td>6.8</td>
<td>0.1</td>
<td>0.1</td>
<td>...</td>
<td>1.1</td>
<td>88.8</td>
</tr>
<tr>
<td>Domestic and commercial</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>60.1</td>
</tr>
<tr>
<td>Agriculture</td>
<td>22.4</td>
<td>...</td>
<td>9.8</td>
<td>7.1</td>
<td>24.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Subtotal</td>
<td>927.2</td>
<td>253.8</td>
<td>196.1</td>
<td>161.6</td>
<td>103.3</td>
<td>360.2</td>
</tr>
<tr>
<td>Aircraft operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbine engines</td>
<td>58.3</td>
<td>25.8</td>
<td>21.7</td>
<td>20.4</td>
<td>44.1</td>
<td>13.1</td>
</tr>
<tr>
<td>Piston engines</td>
<td>27.6</td>
<td>12.2</td>
<td>11.3</td>
<td>9.6</td>
<td>155.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Ships and railroads</td>
<td>5.4</td>
<td>5.4</td>
<td>...</td>
<td>...</td>
<td>9.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Subtotal</td>
<td>91.3</td>
<td>43.4</td>
<td>33.0</td>
<td>30.0</td>
<td>208.3</td>
<td>26.2</td>
</tr>
<tr>
<td>Grand total</td>
<td>1018.5</td>
<td>299.2</td>
<td>229.1</td>
<td>191.6</td>
<td>311.6</td>
<td>386.4</td>
</tr>
</tbody>
</table>

Sources: References 2, 4, 16, and 18.

### Table A-5

**Annual Growth Rates for Emission Sources Other Than Motor Vehicles**

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Annual Growth Rate (percent), 1970 to 1990</th>
<th>Source Type</th>
<th>Annual Growth Rate (percent), 1970 to 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum industry</td>
<td>2.0</td>
<td>Incineration</td>
<td>1.2</td>
</tr>
<tr>
<td>Organic solvent users</td>
<td>1.2</td>
<td>Combustion of fuels</td>
<td>1.2</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>1.6</td>
<td>Agriculture</td>
<td>-1.1</td>
</tr>
<tr>
<td>Metallurgical industry</td>
<td>1.6</td>
<td>Aircraft operation</td>
<td>1.4</td>
</tr>
<tr>
<td>Mineral industry</td>
<td>-0.4</td>
<td>Ships and railroads</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Source: Personal communication with Ms. Frances Bolger, Southern California Association of Governments, January 7, 1974.
Table A-6

LOS ANGELES AIR QUALITY CONTROL REGION EMISSION INVENTORY: 1977 NOMINAL CASE (TONS/DAY)

(For All Sources Other Than Motor Vehicles)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>THC</th>
<th>EPA</th>
<th>LA APCD</th>
<th>CO</th>
<th>NO\textsubscript{X}</th>
<th>SO\textsubscript{2}</th>
<th>Pb</th>
<th>F.M.</th>
<th>Annual Growth 1975 to 1990 (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>131.0</td>
<td>...</td>
<td>...</td>
<td>32.1</td>
<td>6.3</td>
<td>0.5</td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Refining</td>
<td>51.8</td>
<td>5.8</td>
<td>9.4</td>
<td>5.8</td>
<td>25.3</td>
<td>47.5</td>
<td>4.8</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Marketing</td>
<td>170.2</td>
<td>158.3</td>
<td>46.5</td>
<td>...</td>
<td>12.7</td>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic solvent users</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Surface coating</td>
<td>136.0</td>
<td>25.8</td>
<td>4.6</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Dry cleaning</td>
<td>35.0</td>
<td>6.6</td>
<td>1.6</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Degreasing</td>
<td>114.2</td>
<td>24.6</td>
<td>11.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>188.2</td>
<td>35.8</td>
<td>23.4</td>
<td>...</td>
<td>1.1</td>
<td></td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6</td>
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<tr>
<td>Metallurgical industry</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Mineral industry</td>
<td>1.0</td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td>18.5</td>
<td>-0.4</td>
<td></td>
</tr>
<tr>
<td>Incineration</td>
<td>24.4</td>
<td></td>
<td>0.3</td>
<td>35.8</td>
<td>3.7</td>
<td>0.3</td>
<td>12.3</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Combustion of fuels</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Steam power plants</td>
<td>7.6</td>
<td>0.2</td>
<td>0.1</td>
<td>136.8</td>
<td>125.3</td>
<td>7.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Industrial</td>
<td>7.4</td>
<td>0.1</td>
<td>0.1</td>
<td>1.2</td>
<td>86.6</td>
<td>29.1</td>
<td>8.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic and commercial</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>65.4</td>
<td>1.8</td>
<td>8.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>20.7</td>
<td></td>
<td>6.6</td>
<td>17.3</td>
<td>0.3</td>
<td>1.5</td>
<td>8.6</td>
<td>-1.1</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>887.9</td>
<td>258.4</td>
<td>98.5</td>
<td>63.8</td>
<td>372.2</td>
<td>274.6</td>
<td>99.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Turbine engines</td>
<td>26.0</td>
<td>11.5</td>
<td>9.1</td>
<td>19.7</td>
<td>14.4</td>
<td>3.3</td>
<td>10.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piston engines</td>
<td>30.4</td>
<td>13.5</td>
<td>10.6</td>
<td>171.0</td>
<td>8.1</td>
<td>1.1 0.22</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ships and railroads</td>
<td>6.0</td>
<td>6.0</td>
<td>...</td>
<td>10.1</td>
<td>6.8</td>
<td>1.2</td>
<td>4.0</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>62.4</td>
<td>31.0</td>
<td>19.7</td>
<td>200.8</td>
<td>29.3</td>
<td>5.6</td>
<td>0.22</td>
<td>14.8</td>
<td></td>
</tr>
<tr>
<td>Grand total</td>
<td>950.3</td>
<td>289.4</td>
<td>118.2</td>
<td>264.6</td>
<td>403.5</td>
<td>280.2</td>
<td>0.22</td>
<td>113.9</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: References 4, 16, and 17.

all using the Rand technical assumptions. The effect of the other technical assumptions is shown subsequently.

The average daily emission of each species from all sources is shown in Table A-8 for a 1970 Base Case. We next present the 1977 Reference Case emissions inventory in Table A-9. Finally, Table A-10 contains the complete inventory for the Full Technological Controls Case in 1977.

The interested reader can use these tables in conjunction with the VMT estimates presented in Table A-2 to calculate the composite motor vehicle emission factors for each case.
Table A-7

LOS ANGELES AIR QUALITY CONTROL REGION EMISSION INVENTORY:
1977 FULL TECHNOLOGICAL CONTROLS CASE
(For All Sources Other Than Motor Vehicles)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>THC (tons/day)</th>
<th>RHC (tons/day)</th>
<th>EPA</th>
<th>LA APCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum industry&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>131.0</td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refining</td>
<td>51.8</td>
<td>5.8</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Marketing</td>
<td>22.1</td>
<td>20.6</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Organic solvent users&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface coating</td>
<td>136.1</td>
<td>26.8</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Dry cleaning</td>
<td>3.5</td>
<td>0.7</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Degreasing</td>
<td>11.4</td>
<td>2.5</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>188.2</td>
<td>35.8</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>Other stationary sources</td>
<td>61.5</td>
<td>0.5</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>605.5</td>
<td>92.7</td>
<td>52.0</td>
<td></td>
</tr>
<tr>
<td>Aircraft, ships, and railroads</td>
<td>62.4</td>
<td>31.0</td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td>Grand total</td>
<td>667.9</td>
<td>123.7</td>
<td>71.7</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: References 4, 16, and 17.

<sup>a</sup>Only the petroleum industry and organic solvent users show a reduction of hydrocarbon emissions from these controls. All other sources are as shown in the 1977 Nominal Case (Table A-6).

Table A-8

LOS ANGELES AIR QUALITY CONTROL REGION EMISSION INVENTORY<sup>a</sup>
(1970 Base Case)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Emissions (tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>THC</td>
</tr>
<tr>
<td>Stationary sources</td>
<td>927.2</td>
</tr>
<tr>
<td>Aircraft, ships, and railroads</td>
<td>91.3</td>
</tr>
<tr>
<td>Heavy-duty gasoline trucks</td>
<td>96.7</td>
</tr>
<tr>
<td>Heavy-duty diesel trucks</td>
<td>5.2</td>
</tr>
<tr>
<td>Diesel powered buses</td>
<td>0.8</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>23.5</td>
</tr>
<tr>
<td>Light-duty motor vehicles</td>
<td>1387.4</td>
</tr>
<tr>
<td>Total</td>
<td>2532.1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Using the Rand technical assumptions.
### Table A-9

**LOS ANGELES AIR QUALITY CONTROL REGION EMISSION INVENTORY:**

**1977 REFERENCE CASE**

<table>
<thead>
<tr>
<th>Source Type</th>
<th>THC</th>
<th>RHC</th>
<th>CO</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{2}</th>
<th>Pb</th>
<th>P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary sources</td>
<td>1039.9</td>
<td>286.9</td>
<td>115.9</td>
<td>404.0</td>
<td>289.4</td>
<td>0.0</td>
<td>143.8</td>
</tr>
<tr>
<td>Aircraft, ships, and railroads</td>
<td>100.8</td>
<td>47.9</td>
<td>229.0</td>
<td>29.0</td>
<td>5.7</td>
<td>0.2</td>
<td>30.5</td>
</tr>
<tr>
<td>Heavy-duty gasoline trucks</td>
<td>59.4</td>
<td>48.0</td>
<td>557.7</td>
<td>38.3</td>
<td>1.4</td>
<td>1.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Heavy-duty diesel trucks</td>
<td>2.9</td>
<td>2.9</td>
<td>17.7</td>
<td>28.8</td>
<td>4.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Diesel powered buses</td>
<td>0.5</td>
<td>0.5</td>
<td>3.1</td>
<td>5.0</td>
<td>0.7</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>26.1</td>
<td>24.4</td>
<td>95.5</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Light-duty motor vehicles</td>
<td>560.6</td>
<td>419.1</td>
<td>3862.8</td>
<td>388.2</td>
<td>29.5</td>
<td>12.9</td>
<td>46.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1790.2</td>
<td>829.7</td>
<td>4882.6</td>
<td>893.9</td>
<td>330.8</td>
<td>14.5</td>
<td>225.8</td>
</tr>
</tbody>
</table>

*Using the Rand technical assumptions.*

### Table A-10

**LOS ANGELES AIR QUALITY CONTROL REGION EMISSION INVENTORY:**

**1977 FULL TECHNOLOGICAL CONTROLS CASE**

<table>
<thead>
<tr>
<th>Source Type</th>
<th>THC</th>
<th>RHC</th>
<th>CO</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{2}</th>
<th>Pb</th>
<th>P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary sources</td>
<td>604.6</td>
<td>92.7</td>
<td>63.8</td>
<td>372.2</td>
<td>274.6</td>
<td>0.0</td>
<td>99.1</td>
</tr>
<tr>
<td>Aircraft, ships, and railroads</td>
<td>62.4</td>
<td>31.0</td>
<td>200.8</td>
<td>29.3</td>
<td>5.6</td>
<td>0.2</td>
<td>14.8</td>
</tr>
<tr>
<td>Heavy-duty gasoline trucks</td>
<td>59.4</td>
<td>48.0</td>
<td>557.7</td>
<td>38.3</td>
<td>1.4</td>
<td>1.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Heavy-duty diesel trucks</td>
<td>2.9</td>
<td>2.9</td>
<td>17.7</td>
<td>28.8</td>
<td>4.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Diesel powered buses</td>
<td>0.5</td>
<td>0.5</td>
<td>3.1</td>
<td>5.0</td>
<td>0.7</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>26.1</td>
<td>24.4</td>
<td>95.5</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Light-duty motor vehicles</td>
<td>356.5</td>
<td>239.2</td>
<td>2064.5</td>
<td>300.9</td>
<td>29.5</td>
<td>3.2</td>
<td>46.0</td>
</tr>
<tr>
<td><strong>Total all sources</strong></td>
<td>1112.4</td>
<td>438.7</td>
<td>3003.1</td>
<td>775.1</td>
<td>315.9</td>
<td>4.8</td>
<td>165.4</td>
</tr>
</tbody>
</table>

*Using the Rand technical assumptions.*
EFFECT OF DIFFERENT TECHNICAL ASSUMPTIONS

We have expressed future year air quality in this report in terms of photochemical oxidant. In Sec. I, we observed that oxidant exceeded the NAQS by a higher percentage than any other air pollutant. Then, in Sec. II, we explained that emissions of reactive hydrocarbons were used as the sole proxy for atmospheric photochemical oxidant concentrations (see Appendix B also). We also noted in Sec. II that the technical assumptions required to forecast future air quality could be divided into two main components: those used in forecasting future emission levels, and those relating these emissions to future air quality. Because of their importance, we will now show the differences in the RHC emission forecasts through 1990 due to the three sets of technical assumptions.

The RHC emission forecast through 1990 for the Reference, Nominal, and Full Technological Controls Case is presented in Fig. A-1, using the Rand technical assumptions. The emissions are described in terms of the 1970 Base Year emission level for RHC; under the Rand assumptions the average RHC emissions in 1970 were about 1461 tons/day (see Table A-8). As shown in Fig. A-1, the full technological controls will result in about an 80 percent reduction in RHC emissions by the late 1980s.

The forecast of RHC emissions under the EPA technical assumptions is compared with the forecast under the Rand assumptions in Fig. A-2. As described earlier in this appendix, the Rand and EPA technical assumptions are the same for non-motor-vehicle sources. Thus the differences reflected in Fig. A-2 are wholly attributable to motor vehicle sources—principally

![Graph showing RHC emission forecasts](image)

Fig. A-1 — Forecasts of reactive hydrocarbon emissions from all source types, based on the Rand technical assumptions
light-duty motor vehicles. The EPA assumptions are fully described in Refs. 4, 19, and 20. Note that in every instance in Fig. A-2, the EPA technical assumptions project a smaller percentage reduction in emissions than do the Rand assumptions.\(^1\) As a point of reference, the average emissions in 1970 under the EPA assumptions were approximately 1400 tons/day.

Finally, in Fig. A-3 we present a similar comparison of the RHC emission forecast for the Rand and CARB\(^2\) technical assumptions. The CARB assumptions used here correspond to those used in the most recent revision to the State Implementation Plan.\(^{17,18}\) In this comparison, we see that the CARB assumptions always show a greater percentage reduction in RHC emissions than do the Rand technical assumptions. Under the CARB assumptions, 1190 tons/day of RHC emissions occurred in the 1970 Base Case.

We remind the reader that the scenarios for Figs. A-2 and A-3 are identical. The differences arise wholly in the technical assumptions used to calculate reactive hydrocarbon emissions.

\(^1\)As noted in Sec. II, recent EPA revisions to their assumptions have yielded results that are much closer to the Rand results.\(^{19}\)

\(^2\)Actually, the CARB assumptions for motor vehicle sources and the LA APCD assumptions for all other sources.
COST-EFFECTIVENESS OF RHC EMISSION REDUCTION TACTICS

We conclude this appendix by providing some insights into the cost-effectiveness of the various tactics available for reducing reactive hydrocarbon emissions. By cost-effectiveness we mean the annualized cost of the tactic per ton of RHC removed annually. The issue of cost-effectiveness has not been specifically addressed by the present study, but was a central focus of earlier Rand studies of air pollution and urban transportation. (7,13)

The approximate cost-effectiveness of the available tactics is displayed in Fig. A-4. Note that we have divided the tactics into three general categories.

- Fixed-source controls and aircraft.
- Light-duty motor vehicle retrofit and inspection/maintenance controls.\(^2\)
- Transportation management controls.\(^3\)

---

1 Approximate in the sense that Fig. A-4 is based on an analysis of the San Diego Air Quality Control Region. Many of the technical assumptions and some of the cost estimates would need to be modified for Los Angeles, but the results would not be dramatically different.

2 The cost-effectiveness of the retrofit-I/M tactics are dependent on any VMT reductions that have occurred. In Fig. A-4, we have assumed an average VMT equivalent to our Reference Case.

3 In turn, the cost-effectiveness of the transportation management controls depends on the retrofit-I/M tactics imposed; Fig. A-4 is based on tactics equivalent to our Nominal Case (i.e., the current CARB retrofit program).
Fig. A-4 — The approximate cost-effectiveness, in 1977, of tactics available for reducing RCH emissions as determined in the San Diego Clean Air Project.\(^1\) The first item reflects a cost savings.

An examination of Fig. A-4 leads to the following very important observations.

- **Fixed-source controls** are generally at least an order of magnitude more cost-effective than LDNV retrofit-inspection/maintenance controls.

- Similarly, retrofit-inspection/maintenance controls are about an order of magnitude more cost-effective than most transportation management controls.\(^1\)

We have concluded from such analyses that the maximum available (or feasible) technological emission controls should always be employed before

\(^1\)A possible exception to this rule may be found in the carpooling incentives. We have not yet determined the cost-effectiveness of the carpooling policies.
additional transportation management tactics are considered. Consequently, in our analysis of the six alternative transportation strategies in Sec. V, we used the Full Technological Controls Case as an integral component of each of the six alternative transportation strategies.
Appendix B

TECHNIQUES FOR PREDICTING AIR QUALITY

Predictions of future air quality require the application of an air quality model. In simplest terms, an air quality model relates emission rates to ambient atmospheric pollutant concentrations. These models are called upon to answer two questions:

1. Given an emission rate (in tons/day), what is the resulting air quality?
2. What reduction in emissions is necessary in the region of interest to achieve a specified level of air quality?

We begin with the first question. Many complex mathematical models simulating atmospheric processes have been developed. Such models attempt to account for regional meteorology and topography as well as spatial and temporal emission patterns. Many of them include such effects as pollutant transport on the macroscale, turbulent diffusion, vertical temperature gradients, and atmospheric photochemistry. Typically these large-scale simulation models are calibrated to several days in some past year for which sufficient physical data have been collected. They then forecast air quality in future years by using the forecast patterns of emissions in conjunction with the data representing the calibration days. Thus, for each day, the result is a rather complete time-and-space history of the concentrations for both the calibration year and the analysis year. To analyze more than a few days would consume prohibitive amounts of electronic computer and human resources. These facts lead to two general conclusions regarding the large-scale physical simulation models:

- By our criterion for describing air pollution (presented in Secs. II and III) these models do not adequately predict future air quality.
- Such models make no attempt to answer explicitly the second question presented above.

---

1 Perhaps the most widely accepted model of this type today is the one developed by Systems Applications, Inc. (37)
Hence we believe such air quality models are inappropriate for policy studies such as ours, in which many alternatives must be considered, and in which, furthermore, the resulting air quality predictions must be made meaningful to the layman.

At the other extreme of the range of air quality models are the rollback models. Such models are based on the assumption that ambient concentrations are functionally related to average regional emissions. The functional relationship is developed by relating concentrations observed in some past year to an estimate of coincident emissions for that year; air quality can then be predicted by using a future year's emission forecast and the developed functional relationship between emissions and observed concentrations.

Traditionally, rollback models have been used in implementation planning because they can answer the second question. We will illustrate using a simple example. In 1970, the maximum observed one-hour average oxidant concentration in the LA AQCR was 0.62 ppm; the corresponding air quality standard is 0.08 ppm. If we assume a linear proportionality between RHC emissions and oxidant concentrations, the following equation will hold:

\[
\frac{\bar{E}_S}{\bar{E}_B} = \frac{0.08}{0.62} = 0.13
\]

where \(\bar{E}_S\) = average daily emissions that will result in meeting the standard
\(\bar{E}_B\) = average daily emissions in the base year of 1970.

The allowable average daily emissions for meeting the standard cannot exceed 13 percent of the average for 1970. In other words, an 87 percent rollback from 1970 in RHC emissions is required. This particular air quality model is referred to as the linear rollback model. Its usefulness for implementation planning should be obvious.\(^1\)

Rollback models need not be linear. Indeed, as we show subsequently, many nonlinear models have been developed for use in the Los Angeles

---

\(^1\)A basic assumption of all rollback models when used for implementation planning is that all emission sources within the region are reduced by the same percentage. Since this will seldom occur in practice, it is assumed that sufficient atmospheric mixing will exist to smooth out the effect of any remaining local "hotspots." For oxidant, this appears to be a reasonable assumption since several hours must pass from the time the RHC emissions occur until photochemical processes produce the atmospheric oxidant concentrations.
region. We have modified those models so that they can be used to answer the first question above as well as the second. In this appendix, we describe the rollback models that were considered and briefly explain how we applied them in this study. We conclude the appendix by showing some sensitivities of future air quality to certain key assumptions.

**ROLLBACK MODELS CONSIDERED**

We have identified nine different rollback air quality models that can be used to relate reactive hydrocarbon emissions to atmospheric oxidant concentrations. Again we emphasize that all of the models assume that a functional relationship exists between average daily regional emissions of reactive hydrocarbons and ambient oxidant concentrations.

The nine models can best be illustrated by discussing them in terms of their standard application: for a given percentage reduction in regional reactive hydrocarbons from the base year of 1970, what is the expected maximum annual one-hour oxidant concentration? Figure 8-1 presents each of the nine models in terms of this application. We immediately observe that the range of the resulting oxidant concentrations for any RHC emission reductions is quite significant.

---

1 Because of the short duration of the study, we were compelled to use existing methodology. Given more time, we would have preferred to develop our own rollback model. However, as the reader will see, the models considered in this analysis cover a wide range of possibilities, and undoubtedly are adequate for bounding the solution as we have attempted to do.

2 Oxidant concentrations in the atmosphere are the result of complex chemical reactions between hydrocarbons and oxides of nitrogen occurring only in the presence of solar radiation. It is well established that the amount of oxidant produced is dependent on the relative concentrations of reactive hydrocarbons and oxides of nitrogen as well as the absolute amount of reactive hydrocarbons. Strategies intended to reduce oxidant concentrations are usually formulated in terms of reducing emissions of reactive hydrocarbons. (Reactive hydrocarbons are emphasized rather than total hydrocarbons since many hydrocarbons such as methane do not participate in the photochemical reaction, and furthermore have no known health effects, at least for the concentrations observed in the most heavily polluted urban atmospheres.) Because of the known dependence on oxides of nitrogen, however, most researchers agree that the relationship between reactive hydrocarbon concentrations and oxidant concentrations is not linear. The standard modeling approach is to assume that a linear relationship does exist between emissions of RHC and the concentrations of RHC in the atmosphere. A nonlinear relationship is then developed between those hydrocarbon concentrations and the resulting oxidant concentrations; hopefully, this relationship accounts for the dependence of the reaction on atmospheric NO and NO\textsubscript{X} concentrations. An alternative approach has been developed by the Los Angeles Air Pollution Control District that explicitly includes both RHC and NO\textsubscript{X} emissions in the model formulation. We briefly discuss the LA APCD model later in the appendix.
Fig. B-1 — Application of nine rollback models developed for the Los Angeles Air Quality Control Region

The first two models shown in Fig. B-1 are linear rollback models. Model 1, based on the 1970 Riverside maximum concentration, corresponds to the example discussed earlier in this appendix; Model 2 has the same formulation except a 0.03 ppm natural background for oxidant is assumed. The resulting rollback equation is then

$$\frac{E_S}{E_B} = 0.08 - 0.03 = 0.08$$

In other words, a 92 percent reduction is required, instead of 87 percent, when no background concentration is included. Models 3, 4, and 5 were made available by EPA for our earlier study of Los Angeles. Model 3 was developed by Schuck and Papetti, were included as part of the technical support document for EPA’s final implementation plan for the LA AQCR.

The 1974 EPA models were developed by relating the RHC concentrations observed early in the morning (6 to 9 a.m.) to the oxidant concentrations...
observed later in the day. Models 7, 8, and 9 considered aerometric data from only one station each in their respective developments. Because of pollutant transport due to the mean wind field, the morning RHC concentrations observed at a single station will seldom be responsible for oxidant concentrations observed at the same station several hours later. The remaining model, designated the Eight-Station Average Model, was developed in a similar fashion, but the aerometric data from the eight monitoring sites were considered simultaneously. Pollutant transport is, hence, at least partially, taken into account. Of the 1974 EPA models, we believe the Eight-Station Average Model is the most realistic for application in Los Angeles; EPA has also suggested that this is the best rollback model currently available. Consequently, we have incorporated the Eight-Station Average Model as the Rand and EPA technical assumptions. CARB has used the linear rollback model in preparing the State Implementation Plan; thus linear rollback was included in the CARB technical assumptions.

The air quality descriptors presented in Secs. II and III require extending the basic rollback model methodology described thus far. In particular, our main requirement of an air quality model is that it be capable of generating cumulative frequency distributions for each monitoring site. We will describe our approach in subsequent paragraphs, but first we will complete our discussion of candidate air quality models by briefly describing the approach advocated by the Los Angeles Air Pollution Control District. (38)

We have noted how both RHC and nitrogen oxide emissions are responsible for atmospheric oxidant concentrations. The chemical processes can be simulated in a laboratory by injecting measured concentrations of RHC and NO\textsubscript{x} into a closed chamber whose initial conditions approximate the unpolluted atmosphere near sea level. After the mixture is irradiated for several hours (to simulate sunlight), the resulting maximum oxidant concentrations are measured. By varying the initial RHC and NO\textsubscript{x} concentrations, it is possible to obtain oxidant isoconcentration curves as a function of the initial precursor concentrations. Although the exact behavior of the isoconcentration lines (especially at low concentrations) is dependent on the particular set of "smog chamber" results that are being used, the general shape of the lines developed by most researchers are very much the

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Fig. B-2—Conceptual oxidant isoconcentration lines based on typical smog chamber experiments.  

same. Typical conceptual results of the smog chamber work are presented in Fig. B-2.

The LA APCD has developed an air pollution control philosophy that is based primarily on these smog chamber results. Consider the six points shown in Fig. B-2. Suppose that Point 1 were representative of the RHC and NOx emissions occurring in the Los Angeles Basin. Starting at Point 1 and reducing only RHC emissions by moving to Point 2 would probably result in only a small improvement in maximum oxidant concentrations; indeed the oxidant concentrations might even increase. On the other hand, starting at Point 3, such an emission control strategy, say moving to Point 4, would significantly reduce oxidant concentrations.

The LA APCD has indicated that Point 1 is representative of the emission situation in Los Angeles in the early 1960s. Controls since implemented have decreased RHC emissions, but increased NOx emissions; therefore, Point 5 is representative of the early 1970s. Note that in
both cases, the maximum oxidant concentrations would be about the same. An examination of the Los Angeles aerometric data for the past several years shows this to be essentially correct. (39) That is, despite RHC emission reductions, only modest reductions in maximum daily oxidant concentrations have been observed.

The important decision to be made using this approach is what control strategy should be used for the next several years. If we are, in fact, at Point 5 in Fig. B-2, then additional RHC emission reductions look quite attractive. However, we also have an air quality standard for nitrogen dioxide that must be achieved. Because of the shape of the isoconcentration line at very low RHC levels, the LA APCD suggests that NO<sub>x</sub> emissions should be controlled just enough to meet the NO<sub>2</sub> air quality standard (e.g., Point 6, assuming for the moment that the O<sub>x1</sub> line is the NAQS for oxidant). We substantially agree with this point of view.

The LA APCD has also pointed out that if Point 6 is achieved by technological controls to effect the necessary emission reductions, then further emission reductions by reducing VMT may not reduce oxidant concentration (assuming now that O<sub>x1</sub> is greater than the NAQS). Since both species will be reduced by an equal percentage, the initial concentrations would tend to move Point 6 directly towards the origin; if the shape of the curve were as shown, then very little reduction in oxidant concentrations would result. We believe that the shape of the isoconcentrations lines in this regime have not been sufficiently determined to fully support this viewpoint.

Although we are able to develop many useful insights into the chemistry of oxidant air pollution using Fig. B-2, the approach outlined above could also conceivably be modified for direct use in policy studies such as ours. The most important technical shortcoming of the smog chamber work is that the effect of RHC and NO<sub>x</sub> emissions being continuously added to the atmosphere during the course of the day is not included. However, we do feel that additional work could result in a more sophisticated rollback model that would simultaneously include the effect of both RHC and NO<sub>x</sub> emissions.

**GENERATING CUMULATIVE FREQUENCY DISTRIBUTIONS**

Our application of the rollback models in the generation of cumulative frequency distributions for each monitoring site is straightforward. Recall from Sec. III that we have collected the maximum one-hour oxidant concentrations for each day in 1970 for each of the monitoring sites to gen-
erate the cumulative frequency distributions for 1970. Then using any of the rollback models, we assume that a given percentage reduction in average daily reactive hydrocarbon emissions will reduce each of the daily maximum concentrations by the same percentage that the annual maximum one-hour concentration is reduced as shown in Fig. B-1. In other words, we have replaced the scale of the ordinate axis in Fig. B-1 with one that shows 100 percent for 0.62 ppm, 50 percent for 0.31 ppm, etc. A percentage reduction in RHC emissions attributable to a control strategy in a future year will then translate into some corresponding percentage reduction to each of the daily maximum one-hour concentrations. The cumulative frequency distributions can easily be developed by reducing the daily maximum concentrations observed in 1970 by this percentage. This technique implicitly contains all of the assumptions common to rollback models when used in more traditional ways.

An important observation can be extracted by illustrating the application of our technique. We have generated cumulative frequency distributions for each monitoring site for a series of five percent incremental reductions in reactive hydrocarbon emissions from the 1970 level. For each percentage reduction in emissions, it is easy to obtain the corresponding number of days the National Air Quality Standard for oxidant will be violated at each station (see Sec. III). We show the result of this exercise in Fig. B-3 for eight specific monitoring sites.\footnote{The EPA Eight-Station Average Model was used in the development of Fig. B-3. The eight monitoring sites that provided the historical aerometric data for the EPA model are not the same as the monitoring sites used in this illustrative example.} Using Fig. B-3, the number of days the NAQS for oxidant will be violated at any of the sites shown can be easily determined for any percentage reduction in RHC emissions. For example, a 40 percent reduction in emissions will cause the standard to be violated on about 225 days in Pasadena, but only on 15 days in Long Beach.

A careful examination of Fig. B-3 reveals that each of the monitoring sites is associated with a uniquely shaped curve. This is a direct result of the cumulative frequency distribution for each site having somewhat different characteristics. We believe this to be an important result, since much of the early work on air pollution control was based on Larsen's observation\cite{40} that the cumulative frequency distribution for all species and all averaging times in all cities tended to have the shape of a log-
normal distribution. Some of the stations in the LA AQCR (e.g., Long Beach, Burbank) fit the log-normal distribution quite well; others (e.g., Riverside, San Bernardino) do not. Careful analysis showed that the shape of the cumulative frequency distribution is dependent on the location of the monitoring site with sites along the base of the San Gabriel Mountains displaying the least tendency toward the classical log-normal distribution. Because of these anomalies, we based our analysis on the actual observed 1970 concentrations—rather than on a curve fit of these data as suggested by Larsen and others.

**SOME SENSITIVITIES TO KEY ASSUMPTIONS**

This appendix is concluded by demonstrating the sensitivity of predicted air quality to certain key assumptions. Air quality through 1990 was predicted for the Full Technological Controls Case under all three sets of technical assumptions in Fig. 3, Sec. II. We show the same prediction in Fig. B-4 except that the EPA Eight-Station Average Model of air quality is used in conjunction with all three sets of technical assumptions for
Fig. B-4 — Sensitivity of predicted air quality to the technical assumptions used to calculate emissions: Full Technological Controls Case

calculating emissions. A comparison of Figs. 3 and B-4 shows that the magnitude of the uncertainty band caused by differences in technical assumptions is much smaller when the same air quality model is used throughout. For example, by 1990, Fig. B-4 indicates that the standard will be violated between 80 and 140 days per year; the range from Fig. 3 is 15 to 140. We therefore can conclude that predicted air quality in terms of the number of days violating the oxidant standard is quite sensitive to the choice of rollback air quality model for the analysis.

Finally, in Fig. B-5, we show the sensitivity of predicted air quality to the assumed regional VMT growth rate. Figure B-5 is the same as Fig. B-4 except that the predicted air quality for two different growth assumptions is shown for 1977 through 1990 under the Rand assumptions. Using a short dash, we show the prediction if vehicle miles traveled grow at an annual compound rate of 1.8 percent. This is also the growth rate used in the other technical assumptions, and it corresponds with current SCAC regional forecasts (see Appendix A). The same air quality prediction is made using 2.6 percent as the annual VMT growth rate. The result (shown as a long-dashed line) indicates that predicted future year air quality

1Recall that the linear rollback model has otherwise been used as part of the CARB technical assumptions.
is not very sensitive to the assumed regional growth scenario. Indeed, the differences in predicted air quality reflected in the technical assumptions overshadows the small difference observed for an almost 50 percent larger VMT growth rate assumption—at least through 1990.

Fig. B-5 — Sensitivity of predicted air quality to the assumed regional growth rate of VMT: Full Technological Controls Case
Appendix C

THE RAND POLICY-ORIENTED URBAN TRANSPORTATION MODEL

The Rand urban transportation model was originally developed as part of the San Diego Clean Air Project;\(^{7,9}\) an earlier version of the model had been used in a previous study of Los Angeles sponsored by EPA.\(^{13}\) The original version of the transportation model is fully documented in Refs. 9, 10, and 11. In this appendix, we will give the reader an intimation of how the transportation model is formulated by describing in detail the major modifications made for the present study. (However, to understand the model fully, reference must be made to the original documentation.) After describing the modifications in some detail, we will briefly discuss the way the model has been calibrated to the 1977 Reference Case.

MODIFICATIONS TO THE RAND URBAN TRANSPORTATION MODEL

The major modifications made to our transportation model were motivated by our desire to analyze additional transportation control tactics. For example, a mileage surcharge was the only available economic disincentive in the original model; for this study we also wished to investigate a parking surcharge (i.e., an economic disincentive based on the trip rather than on the mile). We have also modified the model so that a wide variety of carpooling incentives could be evaluated. The carpooling incentives include:

- Preferential freeway treatment for carpools (and express buses);
- Computer matching to encourage formation of carpools;
- Parking surcharge exemptions for carpoolers.

The following paragraphs will show how these carpooling incentives were modeled in the context of the original methodology. In the interest of achieving a unified description of the modified model and to provide the reader with a glimpse of the transportation model's basic formulation, we have liberally included material from the original model documentation.\(^9\)
The Concept of Automobile Unattractiveness

Any description of the carpool modeling approach must be prefaced with a review of those parameters which the transportation model uses to characterize the perceived cost (unattractiveness) of an automobile trip. The logit modal split model \(^{41}\) adapted for use in this study characterizes the unattractiveness, \(U\), of a trip by a particular mode as

\[
U = 0.09157 \cdot XT + 0.05625 \cdot LT + 0.01062 \cdot C
\]

where \(XT\) = excess time (walking and waiting time in minutes),
\(LT\) = line-haul time (minutes in the vehicle),
\(C\) = total cost (in cents),

and the coefficients express the relative value travelers in the region place on trip cost, line-haul time, and excess time.

The task then is to cast the carpool modeling approach in terms of the three service characteristics shown above. Equation (1) may be rewritten specifically to express the unattractiveness, \(U_A\), of the automobile mode,

\[
U_A(D) = 0.09157 \cdot XT_A \\
+ 0.05625 \cdot \sum \frac{\delta_{iA}(D)}{V_{iA}} \\
+ 0.01062 \cdot [PC/n + CM/n \cdot D],
\]

where
\(D\) = trip distance,
\(XT_A\) = excess time (walking and waiting),
\(\delta_{iA}(D)\) = distance traveled on street type \(i\) during an average trip of total distance \(D\) for an automobile,\(^1\)
\(V_{iA}\) = average automobile speed on street type \(i\),\(^1\)
\(PC\) = cost per trip of automobile (parking, tolls, etc.),

\(^1\)Reference 7 presents the details on how these parameters are determined for a given region. It is sufficient here to say that we assume for an average trip of a given distance, \(D\), that specific fractions of the total trip distance are driven on residential streets, arterial streets, and freeways, with different average speeds associated with travel on every street type.
\[ n = \text{automobile occupancy}, \]
\[ CM = \text{cost per mile of automobile (including all investment and operating costs)}. \]

Equation (2) allows us to include in the automobile unattractiveness expression both the carpool pickup time penalties reflected as increases in the excess time, and the pickup distance penalties which are reflected as an increase in the effective trip distance \( D \). With the assumption that all riders in an essential (home-work) trip carpool evenly divide the costs of the trip, we can compute the unattractiveness for any size of carpool.

We must now develop expressions for the time and distance pickup penalties associated with \( n \)-person carpools.

**Basic Carpool Modeling Approach**

To estimate the penalties for a person-trip of distance \( D \) made in a carpool of size \( n \), we must first estimate the proportion of an individual's neighbors who share a common work trip distance. In Los Angeles, work trip distances are distributed approximately exponentially, with an average distance, \( D_0 \), of about 9.9 miles. The fraction of neighbors, \( p \), at a given point whose home-work trip is of distance \( D \) is given by

\[ p \propto \exp(-D/D_0), \tag{3} \]

or, if we introduce a constant of proportionality, \( K_1 \),

\[ p = K_1 \exp(-D/D_0) \tag{4} \]

where \( p = \text{proportion of neighbors at a given point whose home-work trip is of distance } D \).

The number of neighbors per square mile, \( N \), at a given point who commute the same distance is given by

\[ N = \delta \rho p = K_2 \rho \exp(-D/D_0), \tag{5} \]

where \( \rho = \text{residential density (people per square mile)} \)
\( \delta = \text{fraction of neighbors employed}, \)
\( K_2 = \text{new constant of proportionality containing } \delta. \)
N may also be thought of as the number of work trip origins per square mile for work trips of distance D in each neighborhood.

Obviously, not all of these work trips of distance D will end where the individual desiring to carpool works since not everyone commutes in the same direction. Assume that the number of different job destinations (work trip destinations in the same neighborhood), \( J_n \), a distance D from a given point is proportional to the distance D, or

\[
J_n \propto D
\]  

(6)

or introducing another constant of proportionality, \( K_3/D_0 \), we get

\[
J_n = K_3 D/D_0
\]

(7)

Hence, the density of neighbors who are eligible to join a carpool, PEN, is given by

\[
PEN = N/J_n, \quad \text{or} \quad \frac{K_2}{K_3} \cdot \frac{\rho \exp(-D/D_0)}{D/D_0}
\]

\[
= K_4 \rho \left(\frac{D_0}{D}\right) \exp(-D/D_0).
\]

(8)

Notice in the expression, \( N/J_n \), that work trip origins and work trip destinations cancel if the carpool is formed, leaving PEN with units of \((\text{square miles})^{-1}\). Note also that as the length of the work trip increases, the density of pool-eligible neighbors suffers a corresponding decrease.

If we assume a uniform density of pool-eligible neighbors (PEN) for a given neighborhood, the distance penalty, \( \Delta D \), involved in collecting a rider is inversely proportional to the square root of this density. Thus,

\[
\Delta D \propto \frac{1}{\sqrt{\text{PEN}}}
\]

or

\[
\Delta D = \frac{K_5}{\sqrt{\text{PEN}}}
\]

(9)
where the correct dimensionality has been maintained.

Referring then to Eq. (8), we obtain

\[ \Delta D = K_6 \cdot \frac{1}{\sqrt{D}} \cdot \sqrt{D/D_0} \cdot \exp \left( \frac{1}{2} \frac{D}{D_0} \right) \]  

(10)

\( K_6 \) is a constant which is varied in the model calibration process so that the model matches the Reference Case estimates of automobile occupancy for home-work trips (and as such, takes into account factors such as variable departure times). The time penalty, \( \Delta T \), is just

\[ \Delta T = \Delta D/V, \]

(11)

where \( V \) is the average automobile speed of 15 mph for residential streets.

For an \( n \) person carpool, these pickup penalties are given by

\[ \Delta D_n = (n - 1) \cdot \Delta D \]

(12)

\[ \Delta T_n = (n - 1) \cdot \Delta T \]

(13)

Computationally, the distance penalty, \( \Delta D_n \), is added to \( D \) in Eq. (2), and the time penalty, \( \Delta T_n \), is added to \( \Delta T_A \) in Eq. (2) for each value of automobile occupancy. Thus, for an essential trip of distance \( D \), we have six values of automobile unattractiveness, which we shall designate \( K(n,D) \). The task then is to determine the average automobile occupancy for a trip of this length.

An automobile occupancy study performed in San Diego\(^{(42)}\) indicated that the logarithm of \( \pi_n \), the proportion of people in cars of occupancy \( n \), is linear in \( n \).\(^1\) This is mathematically equivalent to saying that there exists a value of "X" for which \( \pi_n \) can be computed as follows,

\[ \pi_n = \frac{X^{n-1}}{1 + X + X^2 + X^3 + X^4 + X^5}, \quad 1 \leq n \leq 6 \]

(14)

\(^1\)Lacking any comparable information for Los Angeles, and noting the similarities between these regions, this relationship was used in the present study.
The value of $X$ varies as the unattractiveness of the automobile mode changes with policy.\footnote{1}

For trips of distance, $D$, and for a particular value of $X$, the average unattractiveness of an essential trip, $U_A(X,D)$, will be

$$U_A(X,D) = \sum_{n=1}^{6} \frac{K(n,D) \cdot X(D)^{n-1}}{\sum_{n=1}^{6} X(D)^{n-1}}$$

We now make the assumption that people will use their cars so as to make them least unattractive. Thus for each trip distance, $D$, they should choose the value of $X(D)$ that minimizes $U_A(X,D)$, subject to the reasonable constraint, $X \geq 0$, or stated mathematically, the minimum average unattractiveness, $\bar{U}_A(D)$, is given by

$$\bar{U}_A(D) = \min_X [U_A(X(D),D)]$$

Having found $X$ by a root-finding procedure, it is easy to compute the average essential trip automobile occupancy, $O(D)$, for a trip of distance $D$, giving the minimum unattractiveness,

$$O(D) = \frac{\sum_{n=1}^{6} [X(D)]^{n-1}}{\sum_{n=1}^{6} [X(D)]^{n-1}}$$

The importance of being able to compute the proportion of people in cars of occupancy $n$, and indeed the proportion of cars with each occupancy level, will become apparent in our later discussions of distributions of parking costs, trips in carpools, etc. Having a method for calculating automobile unattractiveness and occupancy, we can now discuss the methodology employed in modeling carpooling incentives.

\footnote{1}If the fraction of small cars in the fleet continues to increase, the maximum number of seats available (on the average) may drop below six. This may reduce the potential capacity of carpools and hence the effectiveness of carpooling incentives.
The carpooling incentives previously mentioned all operate on one or more of the three basic variables in the unattractiveness function, excess time, line-haul time, and cost. Preferential freeway treatment shortens the line-haul time of the trip. Computer matching to encourage carpooling can shorten the excess time and reduce the costs of the trip. Parking surcharge exemptions reduce trip costs.

**Preferential Freeway Treatment for Carpooling**

The transportation model's network loading function computes automobile speeds on five kinds of streets.

1. residential
2. unlikely-to-congest arterial
3. congestion-prone arterial
4. unlikely-to-congest freeway
5. congestion-prone freeway.

The network loading function assumes that even during peak periods, no appreciable congestion occurs on any street types but (3) and (5) above. In the transportation model, the line-haul time for express buses or carpools qualifying for preferential freeway treatment is determined by assuming the entire freeway portion of the trip takes place on unlikely-to-congest freeways at free-flow speeds. The savings in trip-time is reflected in the increased attractiveness of the bus mode, or in the increased attractiveness of carpools with occupancies sufficient to qualify for preferential treatment.

Preferential freeway treatment could be implemented in a number of ways, including ramp metering, exclusive lanes, etc. Since successful implementation of policies to reduce VMT will also tend to reduce congestion, the attractiveness of an exclusive uncongested lane for carpools might become meaningless on a totally uncongested freeway. In this case, preferential freeway treatment might consist of holding low occupancy automobiles at the freeway entrance ramp to increase the attractiveness of the carpool mode. With the transportation model, the analyst can specify whether preferential freeway treatment is to be used as a tactic, and whether buses or carpools or both receive preferential treatment. The user

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1 For Los Angeles, the peak period stretches from about 6:00 to 9:00 a.m. and from 3:00 to 6:00 p.m. (43)
also specifies the number of automobile occupants required to qualify the carpool for the preferential treatment.

**Computer Matching to Encourage Formation of Carpoools**

The use of computer programs utilizing the working hours and origindestinations of large numbers of commuters as inputs to match those with similar commuting patterns has been suggested as a possible tool for promoting carpools, thus reducing the VMT. We believe the effect of computer matching on an individual is to increase his awareness of neighbors eligible for participation in his carpool. We express the increase in awareness of pool-eligible neighbors by a simple multiplier, $K_{cm}$, for Eq. (8).\(^1\)

$$PEN_{(with \ cm)} = K_{cm} \cdot PEN$$  \hspace{1cm} (18)

Note from Eq. (9) that carpool pickup distance penalties are inversely proportional to the square root of pool-eligible neighbors. For this reason, an exceptionally efficient computer matching scheme that could quadruple awareness of the number of pool-eligible neighbors would only halve distance pickup penalties.

Lacking any satisfactory outside estimate for this awareness multiplier we polled employees at Rand in Santa Monica (about 14 percent of the total work force) who had recently participated in a computer matching program and found that successfully matched participants were made aware of about 2.5 times more pool eligible neighbors than before the computer match. Finally, since there will never be complete participation by the entire work force and since not even all of those participating will be successfully matched, we must introduce one more complication. The transportation model user must specify the percentage of the work force successfully matched as well as the increased awareness factor. Computationally we determine values for automobile occupancy and automobile unattractiveness with and without computer matching. The automobile occupancy and unattractiveness with computer matching reflect a reduction in distance and time pickup penalties, which translates to smaller trip costs and less excess trip-time with consequent increases in automobile occupancy and automobile mode attractiveness.

\(^1\) $K_{cm}$ will vary according to the number of participants in the matching scheme, and the sophistication of the computer program doing the matching.
The two values for automobile occupancy and unattractiveness are combined using the simple linear weighting scheme shown below.

\[ O(D) = f_p O(D)_p + (1 - f_p) \cdot O(D)_{NP} \quad (19) \]

\[ \tilde{U}_A(D) = f_p \tilde{U}_A(D)_p + (1 - f_p) \cdot \tilde{U}_A(D)_{NP} \quad (20) \]

where:

- \( O(D) \) = weighted automobile occupancy,
- \( \tilde{U}_A(D) \) = weighted automobile unattractiveness,
- \( f_p \) = fraction of work force participating in computer matching and successfully matched,
- \( O(D)_p, \tilde{U}_A(D)_p \) = automobile occupancy, automobile unattractiveness for work force participating in computer matching and successfully matched,
- \( O(D)_{NP}, \tilde{U}_A(D)_{NP} \) = automobile occupancy, automobile unattractiveness for work force not participating in computer matching,
- \( D \) = automobile trip distance.

It is this weighted automobile unattractiveness, \( \tilde{U}_A(D) \), which is compared to the unattractiveness of the bus mode in order to estimate modal split.\(^1\)

Note that nothing in the methodology for examining computer matching is uniquely tied to using a computer for the matching except that on the scale of a city the size of Los Angeles, any significant level of work force participation will require high-speed data processing to realistically and efficiently accomplish the matching task.

Parking Surcharges and Parking Surcharge Exemptions

Imposition of parking surcharges has often been mentioned as a potential tactic for discouraging automobile use. Parking surcharge tactics may be two-pronged, with different surcharges for long-term parking (7 to 9 hours in duration) to discourage automobile use for home-work trips and for short-term parking to discourage other types of trips.\(^2\)

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\(^1\)See the discussion beginning on p. 24 of Ref. 9.

\(^2\)The corresponding policy inputs to the transportation model are the long-term parking fee (including surcharge) and the short-term parking fee. The fee represents the average parking costs at the nonresidential trip end. We have assumed the long-term fee applies only to essential trips and the short-term fee only to inessential trips.
policies often include parking surcharge exemptions for high-occupancy automobiles as an incentive to carpool. In addition to the effect of parking surcharges on automobile attractiveness and occupancy, an item of substantial importance in calculating total regional costs of a transportation strategy is the revenue collected from that surcharge. Clearly the parking surcharge exemption policy can have a significant impact on the revenues collected.

We first assume that parking surcharges are collected only at the nonresidential destination of each trip. In a study of the Los Angeles region, data on typical trip patterns revealed that each vehicle made 4.7 vehicle trips per active vehicle weekday. This study also revealed a series of recurring trip patterns shown in Fig. C-1. These patterns suggest that we use 50 percent of the total long-term parking fee (parking charge plus parking surcharge) in calculating the attractiveness of each essential (home-work) trip, since almost half of the essential trips end at home. Of the inessential trips 50 percent have nonresidential destinations on the four-trip day and 67 percent on the five-trip day. Simple interpolation yields a 62 percent factor for a 4.7 trip day. Accordingly, 62 percent of the total short-term parking fee (parking charge plus parking surcharge) is used in calculating the attractiveness of each inessential trip. This scaled parking charge is the cost per trip in Eq. (2).

After implementing this approach in the modified transportation model, a richer data base was acquired from the same driving pattern survey. The more descriptive information may lend itself to a more sophisticated modeling approach for future applications of the transportation model.

The computation of the change in automobile attractiveness with a parking surcharge and perhaps a parking surcharge exemption is straightforward. The scaled parking charge per trip in Eq. (2) contains both the component for the parking facility operator, and the parking surcharge component, for the responsible government organization. The transportation model computes automobile unattractiveness for automobile occupancies from one to six. If the user specifies a parking surcharge exemption for automobiles with n or greater occupants, then the unattractiveness is computed with only the basic scaled parking charge (no surcharge) for those automobile occupancies. The same computational procedure as outlined before is used to find the average automobile occupancy which minimizes automobile unattractiveness.

The computation of parking revenues is slightly more complicated.
Fig. C-1 — Recurring trip patterns in the Los Angeles Region\(^{(44)}\)

With a parking surcharge exemption policy, we must know the distribution of automobile occupancies for a given trip distance, if we are to compute parking revenues collected. The average parking charge per essential person trip by automobile, \(\bar{F}_E(D)\), weighted for the distribution of automobile occupancies is given by
\[
\overline{P}_E(D) = \frac{6}{n} \sum_{n=1}^{\infty} \frac{X(D)^n - 1}{n} \cdot p_n
\]

(21)

where \( p_n \) = scaled parking cost per essential vehicle trip for an automobile of occupancy \( n \).

\( p_n \) may or may not include a parking surcharge, depending on the automobile occupancy required to qualify for an exemption, if indeed a parking surcharge is being imposed.

Since the number of essential vehicle trips by automobile and the automobile occupancy vary with trip distance, the parking revenues that are collected when an exemption policy is in effect can also vary. Accordingly, to compute total essential trip parking revenues collected, \( P_{TE} \), we must integrate over all trip distances,

\[
P_{TE} = \int D \cdot T_{AE}(D) \cdot \overline{P}_E(D)
\]

(22)

where \( P_{TE} \) includes basic parking charges and surcharges,

\( T_{AE}(D) \) = essential person trips by automobile as a function of trip distance.

The total parking revenues from essential trips excluding surcharges, \( P_{TE}^* \), are given by

\[
P_{TE}^* = \int \frac{T_{AE}(D)}{O(D)} \cdot P_{ER}
\]

(23)

where \( P_{ER} \) = scaled parking charge per essential vehicle trip excluding surcharge.

Total parking surcharge revenue collected is just the difference between \( P_{TE} \) and \( P_{TE}^* \). The integrations to obtain \( P_{TE} \) and \( P_{TE}^* \) are done numerically within the transportation model. Automobile trips are grouped into 0.5 mile cohorts for trips up to 50 miles in length. Partial sums for \( P_{TE} \) and \( P_{TE}^* \) are accumulated as each of the 100 cohorts is processed.

The accumulated surcharge revenues for essential trips constitute part of the regional expenditures for the transportation management policy.
and as such are now included in computations of total strategy costs in the transportation model. In addition, the parking cost per essential person trip by automobile is now included in the average trip-cost output of the model where applicable.

For the present study, automobile occupancy was assumed constant at 1.54 occupants for inessential trips. Therefore, many of the calculations described above are not required for the computation of parking revenues from inessential trips. Total inessential trip parking revenues, $P_{TI}$, are just

$$P_{TI} = T_{AI} \cdot \frac{P_{I}}{O_{I}}$$  \hspace{1cm} (24)

where $T_{AI}$ = total inessential person trips by automobile,

$P_{I}$ = scaled parking cost per inessential vehicle trip,

$O_{I}$ = inessential automobile occupancy.

The parking surcharge revenues collected, $P_{SI}$, are given by

$$P_{SI} = T_{AI} \cdot \frac{(P_{I} - P_{IR})}{O_{I}}$$  \hspace{1cm} (25)

where $P_{IR}$ = scaled parking cost per inessential vehicle trip excluding surcharge.

No parking surcharge exemptions are assumed for inessential trips. The effect of parking surcharges on inessential trips is also included in computations of total strategy costs.

**Fraction of Essential Person Trips in Carpoools**

Another desirable output which was added to the transportation model during the present study was the percentage of essential person trips by automobile as a function of automobile occupancy and household income group. This measure of how much carpooling is taking place under a certain transportation management strategy is given by

$$t_{n}(I) = \frac{\int_{D} \pi_{n}(D) \cdot T_{AE}(I,D)}{\int_{D} T_{AE}(I,D)} \quad \text{for} \quad n = 1,6$$  \hspace{1cm} (26)

$$I = 1,4$$
where \( t_n(I) \) = fraction of essential person trips in automobiles of occupancy \( n \) (1 to 6) by households in income groups 1 (1 to 4).\(^1\)

\( T_{AE}(I,D) \) = essential person trips by automobile, of distance \( D \), taken by income group \( I \).

The interested reader should refer to the original transportation model documentation\(^7\) for the full calculation procedure to obtain \( T_{AE}(I,D) \).

The Synthesis of Carpooling Incentives

Each of the three carpooling incentives has been discussed separately to best describe the methodological approach. However, it should be noted that whenever the computer matching incentive is in force, there is always a participating and a nonparticipating group. This implies two sets of average automobile occupancy and automobile unattractiveness for a given trip distance, one for each group. This, in turn, implies that the effect of the other incentives—preferential freeway treatment and parking surcharge disincentives and exemptions—must also be computed separately for the two groups. Many of the necessary computations use the same linear weighting scheme used in Eqs. (19) and (20).

The capability to analyze several carpooling incentives in concert has proved extremely useful. For example, in Sec. IV and Appendix D, we have shown that computer matching by itself is not a very effective tactic for reducing VMT; but coupling computer matching with preferential freeway treatment can yield VMT reductions that are larger than the sum of the VMT reductions predicted for the individual tactics.

Many additional minor modifications have been made to the Rand transportation model (e.g., more detailed calculations of annual fuel consumption and fuel costs). Our recent experiences have indicated that the modified version of the transportation model is a much more powerful tool for the analysis of alternative transportation policies.

CALIBRATION OF THE URBAN TRANSPORTATION MODEL

Before the Rand urban transportation model can be used to evaluate the effect of alternative transportation strategies, the model must be calibrated to a predetermined regional forecast for the year of interest.

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\(^1\) We group households into four annual income categories, less than \$5,000, \$5,000 to \$9,999, \$10,000 to \$14,999, and greater than \$15,000.
For this study, we have calibrated the model for 1977 to the regional forecast described in Sec. II as the Reference Case.

Although the data required to calibrate the transportation model are fairly extensive, they are far fewer than those required by traditional transportation planning models. The key items required to describe the Reference Case include:

- Average number of weekday person trips,
- Average weekday vehicle miles traveled,
- Frequency distribution of trip lengths,
- Average trip speed,
- Parameterization of the regional bus system:
  --fare structure
  --average headways
  --service area (population eligible for bus)
- Regional road network:
  --estimates of network capacity
  --fraction of streets by type which are congestion prone
  --average free-flow speeds by street type
- Distributional characteristics by income group:
  --number of households
  --number of employed persons
- Automobile operating costs:
  --pump price of gasoline
  --average parking fees.

Once these parameters are determined, an attempt is made to have the transportation model replicate the Reference Case by adjusting calibration constants imbedded in the model. The calibration is a tedious iterative procedure requiring many computer runs. After a reasonable match is achieved for the key parameters, the calibration constants become inviolate for the analysis of the alternative transportation management tactics.

We next note the data sources used to specify the Reference Case and then show a comparison of the calibrated model with the target values derived from the Reference Case forecast for several selected parameters.

Data Sources for the 1977 Reference Case

In our earlier study of Los Angeles for EPA,\(^{(13)}\) the transportation model was calibrated to the 1977 analysis year. More recent data have
changed the definition of the Reference Case from that used in the earlier study, yet much of the data accumulated for that calibration were still valid. In particular, the frequency distribution of trip lengths and the description of the regional road network for the present study are identical to that used in our earlier work. (13)

All of the other parameters, however, have been updated to reflect the latest available information. Specifically the average number of weekday trips was obtained from LARTS forecasts and updated to reflect the latest SCAG demographic forecasts. The resulting weekday VMT has already been presented in Table A-1. The average weekday automobile trip speed was based on a study by the System Development Corporation, in which vehicles in the region were instrumented and accurate records of the typical driving cycles were obtained.

The regional bus system in the Reference Case was intended to provide the same level of service as the existing bus system. The Reference Case bus system thus had the following service characteristics:

- Fare: 25¢ per trip plus 2¢ per mile,
- Frequency of service:
  - 17 minute peak-period headways
  - 40 minute off-peak headways
- Service area:
  - 1380 square miles covered
  - Serving 68 percent of the population of the LA AQCR.

Note that the fare structure presented above was intended to represent the SCDID zone system existing at the beginning of 1974.

Table C-1 presents the number of households in each income group for 1977. (The distributional data in Table C-1 are used also by the MOVEC model in determining the distributional impacts of the retrofit–inspection/maintenance strategy under consideration.) The number of employed persons in each income group is shown in Table C-2. Both tables are based on the most recent SCAG demographic forecasts.

1*Our transportation model treats only trips by light-duty motor vehicles and buses. Trips by other types of vehicles (e.g., heavy-duty trucks, motorcycles) are assumed to remain unchanged from the Reference Case—regardless of the transportation strategy being considered.
Table C-1

FORECAST OF DISTRIBUTIONAL CHARACTERISTICS FOR 1977 BY ANNUAL HOUSEHOLD INCOME FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th>Annual Income of Household (dollars)</th>
<th>Number of Households</th>
<th>Vehicles Owned per Household</th>
<th>Percent of Households Owning Vehicles</th>
<th>Total Income of all Households ($ M1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 5,000</td>
<td>634,200</td>
<td>0.80</td>
<td>62.3</td>
<td>1,800</td>
</tr>
<tr>
<td>5,000-9,999</td>
<td>1,454,100</td>
<td>1.46</td>
<td>92.2</td>
<td>10,700</td>
</tr>
<tr>
<td>10,000-14,999</td>
<td>1,144,700</td>
<td>1.80</td>
<td>96.7</td>
<td>14,700</td>
</tr>
<tr>
<td>15,000 and over</td>
<td>634,600</td>
<td>2.00</td>
<td>98.4</td>
<td>14,700</td>
</tr>
</tbody>
</table>

SOURCES: Reference 46; also personal communication with Ms. Frances Bolger, Southern California Association of Governments, January 7, 1974.

Finally, as was noted previously, we have assumed that the average pump price of gasoline is 40c per gallon in the Reference Case in 1977. This price corresponds to that existing in the region in the summer of 1973, and is implicit to the LARTS and SCAC forecasts alluded to in the preceding paragraphs. The average long-term parking cost in the Reference Case is 12c, and the short-term cost is assumed to be 6c. (32)

We again remind the reader that our Reference Case is based on an extrapolation of the historic trends observed in the 1970 to 1972 time frame. All data sources cited above are consistent with this definition.

Table C-2

FORECAST OF EMPLOYMENT IN 1977 BY ANNUAL INCOME FOR THE LOS ANGELES AIR QUALITY CONTROL REGION

<table>
<thead>
<tr>
<th>Annual Income (dollars)</th>
<th>Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5,000</td>
<td>578,100</td>
</tr>
<tr>
<td>5,000-9,999</td>
<td>1,189,100</td>
</tr>
<tr>
<td>10,000-16,999</td>
<td>1,316,000</td>
</tr>
<tr>
<td>15,000 or more</td>
<td>1,616,800</td>
</tr>
</tbody>
</table>

Comparison of the Calibration with the Target Values

Our present calibration to the 1977 Reference Case is compared with the target values of selected key parameters in Table C-3. Note that the target value for person trips is expressed as a range of acceptable values—the uncertainty is due to the poor definition of the number of person trips by vehicles other than LDVs. A careful examination of Table C-3 reveals that all calibrated values are quite close to the targets. The target values, of course, have been derived from the data sources cited previously.

Table C-3

COMPARISON OF THE CALIBRATED TRANSPORTATION MODEL WITH THE 1977 REFERENCE CASE REGIONAL FORECAST

<table>
<thead>
<tr>
<th>TRAVEL PARAMETER</th>
<th>CALIBRATED VALUE</th>
<th>TARGET VALUE</th>
<th>TARGET SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE WEEKDAY PERSON TRIPS</td>
<td>29,560,000</td>
<td>29,535,000 - 29,850,000</td>
<td>LARTS</td>
</tr>
<tr>
<td>AVERAGE WEEKDAY AUTO* VMT</td>
<td>158,900,000</td>
<td>158,867,000</td>
<td>LARTS</td>
</tr>
<tr>
<td>AVERAGE WEEKDAY AUTO OCCUPANCY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESSENTIAL TRIPS</td>
<td>1.13</td>
<td>1.14</td>
<td>LARTS / SCAG</td>
</tr>
<tr>
<td>INESSENTIAL TRIPS</td>
<td>1.54</td>
<td>1.54</td>
<td>LARTS / SCAG</td>
</tr>
<tr>
<td>AVERAGE FOR ALL TRIPS</td>
<td>1.34</td>
<td>1.35</td>
<td>LARTS</td>
</tr>
<tr>
<td>AVERAGE WEEKDAY TRIP LENGTHS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESSENTIAL TRIPS</td>
<td>10.0 MI</td>
<td>9.9 MI</td>
<td>LARTS / SCAG</td>
</tr>
<tr>
<td>INESSENTIAL TRIPS</td>
<td>6.3 MI</td>
<td>6.3 MI</td>
<td>LARTS / SCAG</td>
</tr>
<tr>
<td>AVERAGE FOR ALL TRIPS</td>
<td>7.4 MI</td>
<td>7.4 MI</td>
<td>LARTS</td>
</tr>
<tr>
<td>AVERAGE AUTO TRIP SPEED</td>
<td>24.5 MPH</td>
<td>24.8 MPH</td>
<td>SDC (1970)</td>
</tr>
</tbody>
</table>

*Actually, Light-Duty Motor Vehicles - LDVs

The important bus system parameters are similarly compared in Table C-4. In this case, we show several of the important consequences of the Reference Case bus system compared with comparable figures for the existing bus system. Again, our calibration appears to have achieved the desired objective of providing approximately the same level of bus service (i.e., modal split) as exists presently.

Before using the calibrated model to evaluate the alternative tactics, the results of the calibration were provided to the SCAG staff.¹ We proceeded with the analysis only after receiving their concurrence on the validity of the calibration to the 1977 Reference Case.

¹Personal communication with Ms. Frances Bolger, Southern California Association of Governments, January 30, 1974.
Table C-4
COMPARISON OF SELECTED PARAMETERS FOR THE EXISTING BUS SYSTEM WITH THE 1977 REFERENCE CASE BUS SYSTEM\(^a\)

<table>
<thead>
<tr>
<th>System Parameters</th>
<th>Reference System</th>
<th>Existing System (33)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual passenger trips</td>
<td>217,480,000</td>
<td>217,290,000</td>
</tr>
<tr>
<td>Average modal split</td>
<td>2.2%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Route miles</td>
<td>4140</td>
<td>4208</td>
</tr>
<tr>
<td>Number of buses</td>
<td>2082</td>
<td>2150</td>
</tr>
</tbody>
</table>

\(^a\)The Reference Case bus system was developed so that the transportation model's calibration to the 1977 Reference Case would include a bus system providing the same level of service as the system existing in early 1974.

The reader interested in additional details of the 1977 Reference Case should consult Sec. V. Tables presenting the detailed impacts of the alternative strategies also contain the corresponding details of the Reference Case (e.g., weekday person trips by trip type).
Appendix D

THE EFFECTIVENESS OF TRANSPORTATION MANAGEMENT TACTICS

The most promising combinations of transportation management tactics for reducing vehicle miles traveled were discussed in detail in Sec. IV. This appendix presents the effectiveness of the individual tactics that were used to form the combinations described in the main text. Three general types of transportation management tactics are again included.

- Bus system improvements,
- Carpooling incentives,
- Economic disincentives.

Economic disincentives include both mileage and parking surcharges. The details of the parking surcharges alone are presented here; equivalent details on the mileage surcharge tactic are included in Sec. IV.

**BUS SYSTEM IMPROVEMENTS**

Three basic types of bus system improvements can be employed for reducing miles traveled by LDMV.

- Reduction in fares,
- Increased frequency of service,
- Expanded service areas.

In the first two types, the goal is to make transit more attractive so that some trips presently being made in automobiles will be switched to the bus mode. The last tactic simply makes bus service available to people not presently served. With each improvement, the increased bus ridership will include both switchers from the automobile mode and new or induced riders, attracted only because of improved service.

We have already discussed in detail the impacts of reduced fares (see Sec. IV). The same impacts for increased frequency of service are presented in Table D-1. The bus headways in the Reference Case are 17 minutes in the peak-period and 40 minutes in the off-peak period. Starting with
Table D-1
THE IMPACTS IN 1977 OF INCREASED BUS SYSTEM FREQUENCIES OF SERVICE AS PREDICTED BY THE POLICY-ORIENTED URBAN TRANSPORTATION MODEL

<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTION</th>
<th>Reference Bus System</th>
<th>INCREASED FREQUENCY OF SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>BUS FARE (cents)</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>per trip</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>per mile</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>HEADWAYS (minutes)</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>peak period</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>off-peak period</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>SERVICE AREA</td>
<td></td>
<td>1380</td>
</tr>
<tr>
<td>population eligible (%)</td>
<td>68</td>
<td>1380</td>
</tr>
<tr>
<td>county affected</td>
<td></td>
<td>ALL</td>
</tr>
<tr>
<td>VMT REDUCTION (%)</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>ANNUALIZED SYSTEM COST ($M)</td>
<td>132</td>
<td>.9</td>
</tr>
<tr>
<td>ANNUAL SUBSIDY REQUIRED ($M)</td>
<td>32</td>
<td>1.5</td>
</tr>
<tr>
<td>AVERAGE MODAL SPLIT (%)</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>DAILY BUS PASSENGERS (thou)</td>
<td>636</td>
<td>3.6</td>
</tr>
<tr>
<td>AVERAGE TRIP SPEED (mph)</td>
<td>14</td>
<td>4.4</td>
</tr>
<tr>
<td>AVERAGE BUS OCCUPANCY</td>
<td>22</td>
<td>1325</td>
</tr>
<tr>
<td>NUMBER OF BUSES REQUIRED</td>
<td>2062</td>
<td>1380</td>
</tr>
<tr>
<td>BUS SYSTEM EMPLOYEES</td>
<td>7510</td>
<td>2062</td>
</tr>
</tbody>
</table>

15 minute peak-period headways, we have evaluated the impacts of decreasing the time between buses by 2.5 minute increments. In each case, the off-peak period headway is exactly twice the peak-period headway.

Similarly, the effect of expanded bus service area is shown in Table D-2. The Reference Case bus service area is 1,380 square miles, which is approximately the area served by the regional bus systems at the beginning of 1974. This service area resulted in about 68 percent of the population of the LA AQCR being eligible for transit (i.e., within one-half mile of a bus stop). In Table D-2, we show the effect of expanding the service area, in stages, into Los Angeles, Orange, San Bernardino, Riverside, and finally into Ventura Counties. The maximum expansion has a service area of 2,917 square miles and 89 percent of the regional population are eligible for transit.

Relative Effectiveness of Bus System Improvements

Although Table 2 (showing the impacts of bus fare reductions in Sec. IV) and Tables D-1 and D-2 provide much useful information, it is difficult to determine which tactics will provide the greatest VMT reduction for the least cost. Therefore, in Fig. D-1, we present the relative
effectiveness of each of the tactics in reducing VMT in terms of the respective increases in the annual bus subsidies required. Figure D-1 shows that all of the tactics except expanding the service area into San Bernardino, Riverside, and Ventura Counties1 provide comparable marginal VMT reductions per dollar expended in subsidy. We used this information to develop the 12 composite bus system improvements described in Sec. IV.

We ranked each of the individual tactics in terms of the greatest marginal VMT reduction obtained for the smallest required increase in bus subsidy. We somewhat arbitrarily limited the fare reduction to a flat 10¢ per trip under the equally arbitrary assumption that everyone should pay something for transit—even if only this token amount.

**Effect of Preferential Freeway Treatment for Buses**

The effect on vehicle miles traveled of providing preferential freeway treatment for express buses has also been evaluated. Our approach to modeling this effect was to assume that if preferential treatment is afforded express buses on freeways, the buses will travel at the average

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1 This lack of effectiveness in these counties is due to the relatively sparse population.
uncongested freeway speed (45 miles per hour). That is, the express buses will never encounter any congestion on the freeway.

Of course, the effect of such preferential treatment will depend on the other service characteristics of the system. These in turn are dependent on the degree of bus system improvements being considered. To show the range of the likely effects of preferential treatment for express buses, we have evaluated this tactic for six of the 12 composite bus systems. The resulting impacts are presented in Table D-3. The effectiveness of preferential treatment for express buses in reducing VMT is graphically depicted in Fig. D-2. There we see that the preferential treatment will yield an additional VMT reduction of 0.4 to 1.2 percent, depending on what other bus system improvements have been employed.

CARPOOLING INCENTIVES

The reduction of VMT due to coupling preferential freeway treatment for carpools with computer matching for carpools was also discussed in Sec. IV. We show below the effects of these tactics when evaluated independently. In addition, we will show the effect on VMT of exempting carpoolers from a parking surcharge.

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1Such preferential treatment could be implemented by providing exclusive lanes or preferential ramp metering or some combination of the two.
Table D-3
THE IMPACTS IN 1977 OF PROVIDING PREFERENTIAL TREATMENT FOR EXPRESS BUSES AS PREDICTED BY THE POLICY-ORIENTED URBAN TRANSPORTATION MODEL

<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTION</th>
<th>Reference Bus System</th>
<th>Preferential Freeway Treatment for Buses*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stage 2</td>
<td>Stage 4</td>
</tr>
<tr>
<td>BUS FARE (cents)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>per trip</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>per mile</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HEADWAYS (minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>peak period</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>off-peak period</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>SERVICE AREA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>square miles</td>
<td>1380</td>
<td>1380</td>
</tr>
<tr>
<td>population eligible (%)</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>county affected</td>
<td>ALL</td>
<td>ALL</td>
</tr>
<tr>
<td>VMT REDUCTION (%)</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>ANNUALIZED SYSTEM COST ($M)</td>
<td>132</td>
<td>163</td>
</tr>
<tr>
<td>ANNUAL SUBSIDY REQUIRED ($M)</td>
<td>32</td>
<td>81</td>
</tr>
<tr>
<td>AVERAGE MODAL SPLIT (%)</td>
<td>2.2</td>
<td>2.9</td>
</tr>
<tr>
<td>DAILY BUS PASSENGERS (thousand)</td>
<td>636</td>
<td>852</td>
</tr>
<tr>
<td>AVERAGE TRIP SPEED (mph)</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>AVERAGE BUS OCCUPANCY</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>NUMBER OF BUSES REQUIRED</td>
<td>2082</td>
<td>2348</td>
</tr>
<tr>
<td>BUS SYSTEM EMPLOYEES</td>
<td>7510</td>
<td>9490</td>
</tr>
</tbody>
</table>

* The several stages are briefly described in Table 3.

Fig. D-2 — Effect on 1977 VMT of providing preferential freeway treatment for express buses
Figure D-3 presents the effect on VMT of basing preferential freeway treatment to carpools on the number of vehicle occupants. Also shown is the resulting effect on modal split in each instance. (The modal split of the Reference Case bus system, 2.2 percent, is shown as the horizontal dashed line. We also show the resulting average, essential trip, automobile occupancy for each of the policy alternatives (1.13 in the Reference Case). Note that the effectiveness of this tactic is greatly reduced if four or more occupants are required to qualify for preferential treatment.

![Diagram showing effect on VMT and modal split](image)

**Fig. D-3 — Effect on 1977 VMT of providing preferential freeway treatment for carpools and buses**

The effect of computer matching on VMT is displayed in Fig. D-4. Here the policy is expressed in terms of the percentage of the work force who participate in, and are successfully matched by, the computer matching program. Being successfully matched does not necessarily imply that the participant will join a carpool. Rather, an individual who is successfully matched is assumed to become aware of 2.5 times as many neighbors who would be eligible for his carpool (see Appendix C). The decision to join or not join a carpool is based on the relative time penalties due to carpooler pickup versus the savings in trip costs, which are assumed to be split evenly among people in the same carpool (see Appendix C). Our present
feeling is that 40 percent is probably the upper limit of the work force who could be successfully matched; 20 percent appears to be a more reasonable objective, at least in the short term.

We again comment on the remarkable synergistic effect that occurs for coupling preferential freeway treatment with computer matching. Figure D-3 shows that preferential treatment for carpools with 3 or more occupants will result in about 9.5 percent VMT reduction. Computer matching, assuming 40 percent of the work force is successfully matched, will yield a VMT reduction of about 5 percent, as is shown in Fig. D-4. However, we have shown in Sec. IV that coupling these two policies will result in a VMT reduction of almost 19 percent—a reduction significantly greater than the simple sum of the VMT reductions for the tactics individually.

The last carpooling incentive that we have considered is giving exemptions from parking surcharges to qualified carpoolers.\(^1\) We have evaluated this strategy for a $1.00 per day parking surcharge on the nonresidential end of all essential trips, expressing the policy again in

\(^1\) Initially, we wanted to consider the effect of providing free parking to carpoolers throughout the region. Unfortunately, the average daily parking charge on essential trips is only 12c, as a regionwide average. Thus providing free parking to carpoolers would be an inconsequential economic incentive.
terms of the number of occupants required to qualify for exemption. The resulting VMT reductions are presented in Fig. D-5. Note that the VMT reduction, although significant, is approximately the same in all cases—even if everyone pays (no exemptions). We therefore concluded that parking surcharge exemptions were not an effective incentive for reducing vehicle miles traveled since the same reduction occurred whether or not exemptions were granted. In other words, the VMT reduction shown in Fig. D-5 is wholly a consequence of imposing the surcharge.

![Graph showing reductions in VMT and modal split](image)

**Fig. D-5** — The effect on 1977 VMT of exempting carpools from a one-dollar parking surcharge on essential trips, work destination only

**ECONOMIC INCENTIVES**

The two types of economic disincentives we have considered are mileage surcharges and parking surcharges. As was noted previously, the mileage surcharge is fully discussed in Sec. IV. For completeness, we conclude this appendix with equivalent results for parking surcharges.

The parking surcharge tactic discussed here is assumed to apply only to the nonresidential end of essential trips; no parking surcharge is imposed on inessential trips. We have shown in Sec. IV that implementing a parking surcharge in this fashion has two distinct advantages:
1. The parking surcharge on essential trips only is approximately as effective as the mileage surcharge on all trips in reducing VMT when the costs are expressed in terms of the annual regional expenditures by motorists on surcharges.

2. The parking surcharge on essential trips only causes practically no trips to be forgone, since the demand for essential trips is assumed to be inelastic.

We will again show the effectiveness of the parking surcharge for a range of bus system improvements and a range of carpooling incentive policies.

The effectiveness of the parking surcharge in reducing VMT is shown for three different bus systems in Fig. D-6. We have expressed the parking surcharge policy in terms of the daily surcharge imposed on the non-residential end of all essential trips. The bus systems used in this evaluation are the same as those used in Sec. IV in conjunction with the analysis of mileage surcharges: the Reference Case bus system, the Stage 5 bus system, and the Stage 10 bus system. An examination of Fig. D-6 reveals that the differential VMT reduction provided by the parking surcharge is virtually independent of the bus system under consideration.

Finally, we show in Fig. D-7 the effect a parking surcharge would have on VMT for different carpooling incentive policies. Besides the no-additional-carpooling-incentives case (which includes the Reference Case bus system), we have considered the following policies.

- Parking surcharge exemptions for carpools with 3 or more occupants.
- The above plus preferential freeway treatment for carpools with 3 or more occupants (and buses).
- All of the above, plus computer matching with 40 percent of the work force being successfully matched.

Again we see in Fig. D-7 that parking surcharge exemptions yield only modestly larger VMT reductions than the surcharge alone. The reader should remember, however, that exemptions from parking surcharge will lessen the motorist's out-of-pocket costs of the surcharge. For this reason, we have included the parking surcharge exemptions in our maximum effort strategy (Strategy F, see Sec. V).

We can also observe from Fig. D-7 that if all the carpooling incentive policies are in effect, we begin to encounter a saturation effect
after the surcharge is increased above about $1.00 per day. That is, given all these incentives and disincentives on essential trips, it appears that the maximum total VMT reduction that could be obtained is approximately 30 percent. Greater reductions in vehicle miles traveled can only be achieved by concentrating on the inessential trips with additional economic disincentives, and to a lesser extent, with bus system improvements.

![Graph showing reduction in LDMV miles traveled vs. parking surcharge](image)

**Fig. D-6** — Effect on 1977 VMT of parking surcharges, on essential trips only, for three different bus systems

![Graph showing reduction in LDMV miles traveled vs. parking surcharge](image)

**Fig. D-7** — Effect on 1977 VMT of parking surcharges, on essential trips only, for four carpooling incentive policies
Appendix E

ESTIMATES OF AUTOMOBILE FUEL ECONOMY

Significant variations in the fuel economy of the average automobile have been observed over the past fifteen years. Even larger changes can be expected between now and 1990. We present our estimates for the average fuel economy of each model year through 1990 in this appendix. For the 1958 to 1974 vehicles, available data are sufficient for fairly accurate estimates. On the other hand, the fuel economy of post-1974 vehicles will depend on many factors, and consequently, we have again tried to bound the problem by generating several estimates. We conclude the appendix by showing the gasoline consumption by light-duty motor vehicles through 1990 for the Full Technological Controls Case.

AVERAGE FUEL ECONOMY BY MODEL YEAR OF VEHICLE

Many different parameters affect the fuel economy of the average vehicle, even when measured over a specified driving cycle to eliminate the effect of personal driving habits. However, two factors tend to dominate: average vehicle weight, and the emission control system installed.

For the 1958 to 1974 Vehicles

The relative contribution of these two factors affecting fuel economy has been separated in a recent study by EPA. (47) A large number of vehicles representing the range of model years from 1958 to 1972 were tested for fuel consumption over the Federal Driving Cycle. The results of these tests were used to develop the following general relationship.

\[
\text{mpg} = \frac{C}{\text{G.W.}}
\]

where \( \text{mpg} = \) gasoline mileage in miles per gallon, 
\( \text{G.W.} = \) vehicle gross weight in pounds, 
\( C = \) mileage factor in pound-miles/gallon.
The mileage factor, C, was found to be nearly constant for vehicles of each model year having similar emission control systems.\(^1\) The emission controls on any given vehicles, of course, are dependent on the applicable new vehicle exhaust emission standard. The EPA study thus provided estimates of the mileage factor, C, for each model year between 1958 and 1972.

The average gasoline mileage of all vehicles in each model year can then be estimated if the average vehicle gross weight for each model year is known. This sales-weighted average gross weight for passenger cars sold nationally has recently been developed in a study by the Aerospace Corporation.\(^{50}\) The results of this study directly provide the required average vehicle weight by model year.

By combining these two data sources and using the equation presented earlier, the average mileage by model year (for 1958 to 1972 models) can easily be determined. The result would be the miles per gallon achieved by the average automobile as measured over the Federal Driving Cycle. However, we actually need the average mileage of light-duty motor vehicles (which include light trucks). Furthermore, the average speed in the Los Angeles region is about 25 miles per hour whereas the average speed for the Federal Driving Cycle is only about 20 miles per hour. We have therefore corrected the average mileage determined by the above procedure to reflect these effects. Lacking more specific information, a correction was made such that the average LDWV mileage for the fleet in 1970 was 13.22 miles per gallon—a figure based on Federal Highway Administration national estimates.\(^{51}\) This correction amounted to increasing the average gasoline mileage calculated for each model year by about 3 percent.

The resulting estimates for average mileage and average weight by model year are presented in Fig. E-1. Consider first the weight trends. The introduction of domestic compacts in 1960 and domestic subcompacts in 1970 lowered the average weight in those and subsequent model years substantially. Corresponding improvements in fuel economy were one of the consequences. The effect of emission controls on fuel economy can also be seen in Fig. E-1. Notice the large decrease in gasoline mileage

\(^{1}\) The relationship shown is valid only when the fuel economy is measured over the Federal Driving Cycle, developed to represent the typical urban trip.\(^{48}\) If fuel economy is measured under steady-state cruising conditions, the results can be quite different.\(^{49}\) Since we are attempting to develop fuel economy estimates for vehicles operating in the Los Angeles region, use of the results measured over the Federal Driving Cycle is appropriate. However, we will subsequently show how these data have been corrected to reflect the higher average speeds observed in Los Angeles.
for the 1966 model years when the first exhaust emission standards were enforced in California. A further drop in mileage can be observed for the 1971 vehicles with the implementation of the first oxides of nitrogen emission standard for vehicles sold in California plus the widespread introduction of lower compression ratio engines capable of operating on low-lead or unleaded gasoline.\footnote{The gasoline mileage of pre-1958 model years was assumed to be the same as the 1958 models.}

Comparable detailed data for the 1973 and 1974 model years were not available at the time of this study. We have assumed that vehicles of both model years average about 12 miles per gallon. This is consistent with the figure reported for 1973 vehicles by EPA\cite{52} suitably corrected as before. The actual figure for 1974 models will depend on two counter-balancing factors. A more stringent nitrogen oxides emission standard for vehicles sold in California will tend to cause poorer fuel economy. On the other hand, the recently observed trend towards buying smaller cars will cause a decrease in the gross weight of the average 1974 model. We have simply assumed that these effects cancel each other.
For the 1975 to 1990 Vehicles

The gasoline mileage of future model years will depend on whether or not the current trend of buying smaller automobiles continues and on the types of technological improvement introduced to reduce gasoline consumption. We are unable to predict to what extent these factors will affect average fuel economy with any degree of certainty. Therefore, we have generated three sets of estimates—designated pessimistic, intermediate, and optimistic—in an attempt to bound the range of possibilities.  

The pessimistic estimates assume that vehicles of all model years between 1975 and 1990 will average only 13 miles per gallon. As shown in Fig. E-1, this is approximately the average mileage achieved in the 1960s. It assumes some modest reduction in fuel consumption when compared with the 1973 and 1974 vehicles.\(^{(52)}\)

The intermediate estimate includes improved fuel economy because of smaller (or lighter) vehicles as well as technological improvements. We have assumed that the fuel consumption of 1975 models is reduced by 10 percent from the 1973-74 models because of the installation of a catalytic emission control system. This results in an average mileage of 13.4 miles per gallon for 1975 models. By 1980, we have assumed that fuel consumption is further reduced by

- 5 percent due to aerodynamic improvements,
- 5 percent due to improved tires,
- 15 percent due to a reduction in vehicle size, weight, or both.

The 1980 vehicles have a resulting mileage of 17.5 miles per gallon. By 1985, we assume a further reduction in fuel consumption of 16 percent due to smaller or lighter vehicles. The 1985 model vehicle then averages 20.6 miles per gallon. Finally, by 1990 a further reduction in fuel consumption of 15 percent due to the introduction of high-efficiency, low-emission engines is assumed. The 1990 models average 24.2 miles per gallon under this intermediate estimate.

The optimistic estimate is the same as the intermediate except that additional technological improvements are included. An additional 5 percent reduction in fuel consumption due to an improved emission control

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\(^{(52)}\) The authors are grateful to Mr. Thomas Kirkwood of The Rand Corporation for his assistance in generating these estimates which are based on some preliminary findings from a study sponsored by the National Science Foundation.
system will improve mileage to 18.4 miles per gallon for the model year 1980. The 1985 models will average 27.7 miles per gallon because of a 20 percent reduction in fuel consumption achieved by the introduction of a continuously variable transmission. These improvements will then result in an average of 32.6 miles per gallon in vehicles of the 1990 model year.

The three sets of mileage estimates for post-1974 models are presented in Fig. E-2. Note that we have assumed that fuel economy changes occur gradually over time. For example, the intermediate estimate increases linearly from 13.4 mpg for 1975 models to 17.5 mpg for the 1980 models. Excluding a massive changeover to very small automobiles, our optimistic estimate is probably an upper bound on the likely improvements in fuel economy. Note that the average miles per gallon in 1990 for this estimate is about triple that of 1974. We feel at present that the intermediate estimate provides a more realistic approximation, particularly if gasoline prices continue to rise moderately. The pessimistic estimate would be likely to occur only if gasoline prices suddenly returned to the levels of 1972 and remained there through 1990.

For these reasons, we have used the intermediate estimates for all of the light-duty motor vehicle fuel consumption data presented in the main text. In the following paragraphs, we will show the regional gasoline consumption by light-duty motor vehicles through 1990 for the Full Technological Controls Case under each of the three estimates.

![Graph](image)

**Fig. E-2** — Three fuel economy estimates for LDMV of the model years 1975 to 1990.
GASOLINE CONSUMPTION THROUGH 1990

Calculating the average fuel consumption of the vehicle fleet in some analysis year under some technological emission control strategy is much like calculating the average emissions. The emission factors for vehicles of each model year are replaced by the gasoline mileage, the effectiveness of the retrofit control devices in reducing emissions is replaced by the effect of the control device on fuel consumption, etc. Because of this similarity, we have modified our MOVEC Model\(^\text{8}\) to perform the fuel consumption calculations at the same time the emission calculations are being made.

To explain further, in the MOVEC Model we have assumed that for any year, the vehicle fleet has elements from 20 model years, \(Y_i, i = 1, 20\). For example, an analysis year of 1977 would imply that \(Y_1 = 1977\) (the 1977 model year), \(Y_2 = 1976\), \ldots, \(Y_{20} = 1958\). Using notation similar to that of the MOVEC documentation, the average mileage of the fleet in a given year for some specified technological control strategy can be expressed as

\[
\text{mpg} = \frac{1}{\sum_{i=1}^{20} \frac{1}{mpg_i} + \frac{\Delta f_i}{100} \left(\hat{\Delta V}_i / 100\right)}
\]

where \(\text{mpg}\) = average mileage of the fleet;

\(mpg_i\) = average mileage of the \(Y_i\) model year vehicles without additional emission controls;

\(\Delta f_i\) = percentage increase in fuel consumption for model year \(Y_i\) under the specified technological emission control strategy;

\(\hat{\Delta V}_i\) = percentage of the total vehicle miles traveled attributable to model year \(Y_i\).

Thus, the gasoline mileage of each model year, \(mpg_i\), and the increase in fuel consumption for each retrofit-inspection/maintenance strategy, \(\Delta f_i\), are input to MOVEC\(^1\) and the total fuel consumption follows directly from dividing the VMT by the average mileage, \(\text{mpg}\).

\(^1\)For the reader familiar with the MOVEC Model, we take this opportunity to describe the additional modifications made to MOVEC for the present study. Foremost are the modifications that make MOVEC fully compatible with the EPA technical assumptions. Exhaust emission deterioration factors may now be input as functions of model year. In addition, each
Using this methodology, the average daily gasoline consumption by light-duty motor vehicles through 1990 has been determined for the Full Technological Controls Case. The results for each of the post-1974 gasoline mileage estimates are presented in Fig. E-3. The VMT growth rates used in the development of Fig. E-3 are those presented in Appendix A; that is, we have assumed no reduction in VMT in this instance. We see in Fig. E-3 that the pessimistic estimates imply an average daily gasoline consumption of about 14 million gallons in 1990, compared with almost 10 million gallons in 1970. The intermediate estimate, however, shows only about 9 million gallons per day in 1990, with the peak consumption occurring in the mid-1970s. The optimistic estimate implies only about 7 million gallons consumed per day in 1990, almost a 30 percent reduction from the 1970 level.

Fig. E-3 — Average daily gasoline consumption by LDMV for the Full Technological Controls Case

retrofit-I/M tactic can be specified as applicable to only certain percentages of the vehicles in each model year. Other modifications have been included to reflect the greater interest in fuel consumption. For each retrofit-I/M tactic, MDVCEC determines the change in fuel costs, the change in total fuel consumption, and the change in total crude oil requirements due to the tactic. (We assume that 100 barrels of crude oil will yield 46.25 barrels of typical leaded gasoline, based on the average yield of U.S. refineries in 1972.) (53) The latter is important since lead-free gasoline required by catalytic converters will increase the amount of crude required to produce a barrel of gasoline by about 1 percent. Finally, the pump price of gasoline has been made an exogenous input.
There is one important observation that can be made from Fig. E-3. Using the pessimistic estimate, a VMT reduction of about 30 percent in 1990 will yield the same daily fuel consumption observed in 1970. However, the intermediate assumptions will reduce gasoline consumption to below the 1970 level without any VMT reduction. Therefore, we once again see that technological improvement can have a more positive effect in the long term (in this case, on gasoline consumption), than transportation management tactics designed to reduce VMT.
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# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AGM</td>
<td>Annual geometric mean</td>
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<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
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<tr>
<td>CO</td>
<td>Carbon monoxide</td>
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<tr>
<td>CPEL</td>
<td>Community Population Exposure Level</td>
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<tr>
<td>DOT</td>
<td>United States Department of Transportation</td>
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<tr>
<td>EPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>ICEL</td>
<td>Individual Cumulative Exposure Level</td>
</tr>
<tr>
<td>LA APCD</td>
<td>Los Angeles Air Pollution Control District</td>
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<tr>
<td>LA AQCR</td>
<td>Los Angeles Air Quality Control Region</td>
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<tr>
<td>LARTS</td>
<td>Los Angeles Regional Transportation Study</td>
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<tr>
<td>LDMV</td>
<td>Light-duty motor vehicles (less than 6,000 lb gross weight)</td>
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<tr>
<td>MOVEC</td>
<td>Motor Vehicle Emission and Cost Model</td>
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<tr>
<td>MPC</td>
<td>Minimum pollution capability</td>
</tr>
<tr>
<td>mpg</td>
<td>Miles per gallon</td>
</tr>
<tr>
<td>NAQS</td>
<td>National Air Quality Standard</td>
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<tr>
<td>NO\textsubscript{x}</td>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td>Ox</td>
<td>Oxidant</td>
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<tr>
<td>Pb</td>
<td>Lead</td>
</tr>
<tr>
<td>P.M.</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts-per-million (used as a measure of air pollution concentrations in the atmosphere)</td>
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<tr>
<td>RHC</td>
<td>Reactive hydrocarbons</td>
</tr>
<tr>
<td>RPEL</td>
<td>Regional Population Exposure Level</td>
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<td>SCAB</td>
<td>South Coast Air Basin (same as the Los Angeles Air Quality Control Region)</td>
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<td>Southern California Association of Governments</td>
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<tr>
<td>SCRTD</td>
<td>Southern California Rapid Transit District</td>
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<tr>
<td>SO\textsubscript{2}</td>
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</tr>
<tr>
<td>THC</td>
<td>Total hydrocarbons</td>
</tr>
<tr>
<td>VMT</td>
<td>Vehicle miles traveled</td>
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