san diego
Clean Air Project

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A GENERALIZED BUS SYSTEM COST MODEL

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COUNTY OF SAN DIEGO

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PREFACE

This report is part of Rand research on the San Diego Clean Air Project, which was performed for the Integrated Regional Environmental Management (IREM) Project of San Diego County's Environmental Development Agency.* The Clean Air Project was supported by a grant to San Diego County from the United States Environmental Protection Agency (EPA) and by a matching contribution from local sources.

As a joint venture of San Diego County and The Rand Corporation, the Clean Air Project sought strategies for meeting the National Air Quality Standards in San Diego as specified by the 1970 amendments to the Clean Air Act. It represented a pioneering effort to analyze a comprehensive menu of alternative strategies in terms of their impacts on the quality of life in a region.

A joint San Diego County/Rand report on the project has been produced that summarizes the policy results of the Clean Air Project and provides an overview of the analysis methodology:


In addition, Rand has published, as technical appendices, a series of reports that describe in greater detail the components of the Rand-developed methodology for analyzing the numerous and extensive impacts of air pollution control strategies on an urban region.** The appendices to the summary report are as follows:

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* Under Contract No. 6704-0270-E. The office managing IREM has since become the county's Office of Environmental Management (OEM).

** Rand's contract with San Diego required only that the material in the technical appendices be provided to San Diego in the form of informal working notes, solely for San Diego's use; it did not provide resources for their formal publication and widespread distribution. In answer to considerable outside interest, Rand has used its own resources for some expansion and refinement of these informal notes and for their publication as appendices to the project's summary report.


This particular report describes a generalized bus system cost model developed for use in the San Diego Clean Air Project. Because expanded and improved bus systems are potentially important for reducing automobile mileage and associated emissions, it is important to be able to estimate their costs. These costs, however, are highly nonlinear and thus cannot accurately be estimated by simple linear extrapolations from the costs of existing systems. Hence, this generalized bus system cost model has been developed for several applications in the project.

First, used separately, the model can estimate the annualized costs of providing a particular quantity and quality of bus service to a region, and can show the sensitivity of cost to changes in vehicles, service characteristics, load factor, system size, and the operating policies and institutional form of the bus operator. Because it requires only a small number of relatively gross design and policy descriptions as inputs rather than detailed engineering design specifications, the model can be easily used to examine the relationship between aggregate changes in the design and costs of a regional bus system. Besides the detailed costs of a particular bus system alternative, the model also estimates a variety of economic and financial impacts such as employment, fuel consumption, and taxes.

Second, the model (in aggregate form) is a component of an overall transportation model that evaluates the effect of changes in the
transportation technology and management policies for auto, bus, and highway systems on the quantity, quality, and cost of transportation service.

It should be emphasized that the primary purpose of this report is to describe the generalized bus system cost model. This model is but one component of the overall methodology that Rand has developed for analyzing alternative air pollution control strategies in terms of their many impacts on an urban region (and also for analyzing strategies whose primary goal is transportation improvement rather than air quality improvement). This report is not meant to describe the policy results of the San Diego study, nor the data inputs leading to those results, nor the other components of the overall methodology. Each of these topics is discussed in detail in the other reports of the San Diego Clean Air Project.
A generalized bus system cost model has been developed as one component of an overall methodology for analyzing alternative air pollution control strategies. Bus systems, with different vehicles, routes, and sizes, are components of such strategies. The costs of proposed bus systems, however, cannot accurately be estimated by simple linear extrapolations from the costs of existing systems; bus system costs appear to exhibit decreasing returns to scale and extreme sensitivity to average bus speed and load factors. Thus, there is a need for a generalized bus system cost model, one that can quickly and easily estimate the costs of many different alternatives and highly unconventional designs.

Given a relatively small number of gross design and policy inputs, the bus system cost model described in this report will quickly provide good estimates of the true cost of providing a particular quantity and quality of bus service to a region, show the sensitivity of cost to various changes in bus system design and operational policy, and--in addition--produce estimates of a variety of economic and financial impacts such as employment, fuel consumption, and taxes.

The approach to cost classification and estimation used in the model is quite conventional for models of this kind. Initial investment costs are estimated first and include the total costs of vehicles, yards and shops, other equipment, other facilities, and land; these initial investment costs are annualized into equal annual payments using a capital recovery factor approach. Recurring annual operating costs such as drivers' and helpers' wages, fuel expenses, equipment maintenance and garage are then estimated; operating cost elements closely parallel those used by the American Transit Association.

All of the above costs are then used to estimate net return on investment, depreciation, corporate profits taxes, and bond interest if debt financing is used. The model permits the user to specify both a useful life and a salvage value at the end of that time for each asset. These are used in calculating the after-tax return on investment, depreciation, and corporate profits taxes. For tax computations,
the model applies straight-line depreciation, although it could be modified to use other methods. The model also allows the user to choose between various proportions of debt (bond) and equity (common stock) financing. We obtain the total annualized costs by combining the after-tax return on investment, corporate profits taxes, bond interest, and depreciation with the other recurring annual costs.

All cost estimates are made using cost-estimating relationships (CERs) which have been empirically derived from a cross-section of data on approximately 100 bus companies operating in the United States and Canada and from information supplied directly by bus manufacturers. A CER is an equation or function that has cost as the dependent variable and one or more system characteristics or design specifications as the independent variables; for example, the purchase cost of a bus is estimated as a function of the number of seats.

For the most part, the generalized cost-estimating relationships (CERs) were obtained by plotting a dependent variable against an independent variable, fitting a curve visually, and then expressing the relationship mathematically. Numerous checks of reasonableness have been made and, in our judgment, the cost-estimating relationships are thoroughly adequate for the purpose they serve. For example, costs for the SCRTD (Southern California Rapid Transit District) were not included in the data base, yet our relationships predict them quite well. It is true, of course, that for extrapolations well beyond the range of the data base the estimates are subject to considerable uncertainty. But we have tried to minimize this uncertainty by choosing functional forms that seem physically suitable for expressing the individual estimating relationships.

The bus system cost model has been developed and used in two different forms: detailed and aggregate. The detailed form of the model is a separate, free-standing computer program that provides extensive cost breakdowns and also estimates a variety of economic and financial impacts for a particular bus system alternative. The detailed model has been carefully programmed* so that no numbers are "wired-in," providing maximum flexibility for change and ease of specification for the

*In the PL-1 programming language.
user. Indeed, the model may be thought of as a generalized transportation system cost model. Although CERs for bus systems are presently "plugged-in" to the model, CERs representing some other mode (e.g., rail transit) could be plugged in instead, and the model would then provide cost estimates for that mode. Significantly, "plug sockets" for all types of cost-estimating relationships that might become relevant, not merely those presently incorporated, are readily available, e.g., the model can accept CERs describing guideway construction or electricity consumption without appreciable modifications to the computer code.

The aggregate form of the model is part of the Policy-Oriented Urban Transportation model, another component of the overall analysis methodology, that is used to evaluate the effect of changes in transportation policy on the quantity, quality, and cost of transportation service. The aggregate form of the model is obtained by collapsing the full model into a single function that gives a bus system's total annualized cost (for use by the transportation model) as a function of the number of buses, bus-miles, and bus-hours required. The coefficients of this aggregate form are generated by running the full model with all the other variables fixed at values that represent the institutional and cost parameters of the bus company, e.g., its debt/equity ratio and its fuel cost per gallon.
The authors wish to thank the following individuals for their valuable contributions to this work: Lawrence Taylor of the Environmental Development Agency of San Diego for his help in obtaining data about bus operations in San Diego and for his many useful suggestions; The San Diego Technical Review Committee for their helpful comments and review of the initial research; Professor Gerry Fleischer of the University of Southern California for his substantive review and constructive evaluation of the suitability of the capital recovery factor approach used in this model; Phil Patterson of the Environmental Protection Agency for insightful comments and constructive criticisms; and finally our Rand colleagues Jim Bigelow and Burke Burr for providing necessary insights and help with both data collection and review of the model during its preparation, Richard Stanton for programming the final model, and project leader Bruce Goeller for his guidance, suggestions, and encouragement.
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1. INTRODUCTION

The bus system cost model described here is one component of an overall methodology that has been developed for analyzing alternative air pollution control strategies in San Diego County. Because of the wide range of possible bus systems to be considered, the model is highly general. It uses a small number of relatively gross design and policy inputs to provide estimates that are representative of actual costs and to examine the sensitivity of those estimates to variations in major system characteristics. Models that seek precision and therefore require detailed system design and engineering work to obtain the inputs are impractical for considering many alternatives or highly unconventional designs.

NEED FOR A NEW BUS SYSTEM COST MODEL

Before undertaking the development of a new cost model, several existing models were reviewed and found to be sufficiently lacking in enough different respects to make the development of a new model tailored specifically to our particular needs essential. In some instances we were able to make use of work already completed. Notable examples are work done by the General Research Corporation (1) and at Rand by Meyer, Kain, and Wohl. (2)

In general, we required a model with the following characteristics: (1) it would have to be able to handle system configurations ranging from demand-responsive systems using small vehicles to regularly scheduled systems employing the standard 50-passenger bus; (2) the output from the cost model would have to be tailored for financial and economic impact analyses, i.e., labor costs, taxes by recipient, major investment items by kind, etc., had to be easily identifiable; (3) the output would have to reflect equally well the cost implications of the special characteristics of either publicly or privately owned companies; and (4) it would be limited to those design inputs that could be generated within the framework of the overall transportation model.
COST ANALYSIS METHODS

The approach to cost classification and estimation used in the model is quite conventional for models of this kind. Initial investment costs are estimated first and include the total costs of vehicles, yards and shops, other equipment, other facilities, and land. Recurring annual operating costs such as drivers' and helpers' wages, fuel expenses, equipment maintenance and garage are then estimated. Operating cost elements closely parallel those used by the American Transit Association.

Initial investment costs are annualized using a capital recovery factor approach, which is fully described in Principles of Engineering Economy. A simplistic view of the capital recovery factor is that of amortizing a loan over a given number of periods with equal periodic payments that include payments on the principal and interest on the unpaid balance; this is the way one typically pays off a home mortgage or a car loan. Of course, inherent in this approach is the assumption that the bus company is a continuing business. Because there is no sinking fund providing for vehicles and structures replacement, the annual payments thus continue for the life of the company.

All of the above costs are then used to estimate net return on investment, depreciation, corporate profits taxes, and bond interest if debt financing is used. The model permits the user to specify both a useful life and a salvage value at the end of that time for each asset. These are used in calculating the after-tax return on investment, depreciation, and corporate profits taxes. For tax computations, the model applies straight-line depreciation although it could be modified to use other methods. (We note that the 1970 annual report of the San Diego Transit Company states that they use straight-line depreciation.)

The model allows the user to choose between various proportions of debt (bond) and equity (common stock) financing. When bond financing is used in some amount, it is assumed that the stipulated fraction applies equally to all assets and is the same throughout the life of the assets. Bond interest is deductible from gross income for corporate
profits tax computation and is so treated. When bonds are used, interest is a fixed annual expense, which, if not allowed by the regulating agency, will reduce after-tax return on total investment. Also, with bond financing, the return on equity investment may well be greater than the return on total investment allowed by a regulatory agency.

When we combine after-tax return on investment, corporate profits taxes, bond interest, and depreciation with the other recurring annual costs, we refer to the total as total annualized costs. Because we include after-tax return on investment as a cost, we speak of annual revenue required and total annualized cost as being equivalent. If fares are insufficient to generate a revenue equal to annual cost, a subsidy is required.

All cost estimates are made using cost estimating relationships (CERs) which have been empirically derived from a cross-section of data on approximately 100 bus companies operating in the United States and Canada (4) and from information supplied directly by bus manufacturers--GMC is the notable example. (5) A CER is an equation or function that has cost as the dependent variable and one or more system characteristics or design specifications as the independent variables. For example, the purchase cost of a bus is estimated as a function of the number of seats.

INPUT EXAMPLES

The inputs can conveniently be classified as (1) system design specifications such as number of seats per bus, fuel type (gasoline, diesel, etc.), fraction of buses in maintenance, and extra buses to cover downtime from scheduling and maintenance; (2) inputs related to form of ownership, e.g., public or private; (3) inputs generated in the overall transportation model such as number of buses required in the peak period, annual bus-miles driven, and annual bus-hours; (4) financial inputs including required after-tax return on investment, debt/equity ratio, bond interest rate, and relevant corporate profits tax rates (Federal, state); (5) all parameter values for the numerous cost-estimating relationships, e.g., fuel cost per gallon, fuel tax rates, land cost per square foot, useful lifetimes and salvage values for each kind of asset.
OUTPUT EXAMPLES

Output information consists of (1) total system cost split between initial investment and annual operating costs; (2) total annualized cost which includes an annualization of the investment costs using the capital recovery factor approach and both direct and indirect annual operating costs; (3) separately identifiable financial information such as after-tax return on investment, corporate profits taxes paid (Federal, state), bond interest paid, and subsidies if required; (4) the cost per trip and the cost per passenger mile that would need to be charged if revenue were to equal cost; (5) information required for the economic impact analyses, including the cost of labor, buses, other equipment, structures, land, fuel, interest, and fuel taxes (Federal, state, and local); (6) the coefficients of an aggregate form of the entire model, whose use is described below.

DIFFERENT FORMS OF THE MODEL: DETAILED VERSUS AGGREGATE

The bus system cost model has been developed and used in two different forms: detailed and aggregate. The detailed form of the model, primary subject of this report, is a separate, free-standing computer program that provides extensive cost breakdowns and also estimates a variety of economic and financial impacts for a particular bus system alternative. The detailed model has been carefully programmed* so that no numbers are "wired-in," providing maximum flexibility for change and ease of specification for the user. Indeed, the model may be thought of as a generalized transportation system cost model. Although CERs for bus systems are presently "plugged-in" to the model, CERs representing some other mode (e.g., rail transit) could be plugged-in instead and the model would then provide cost estimates for that mode. Significantly, "plug sockets" for all types of cost-estimating relationships that might become relevant, not merely those presently incorporated, are readily available, e.g., the model can accept CERs describing guideway construction or electricity consumption without appreciable modifications to the computer code.

*In the PL-1 programming language.
The aggregate form of the model is part of the Policy-Oriented Urban Transportation model, another component of the overall analysis methodology, that is used to evaluate the effect of changes in transportation policy on the quantity, quality, and cost of transportation service. The aggregate form of the model is obtained by collapsing the full model into a single nonlinear function that gives a bus system's total annualized cost (for use by the transportation model) as a function of the number of buses, bus-miles, and bus-hours required. The coefficients of this aggregate form are generated by running the full model with all the other variables fixed at values that represent the institutional and cost parameters of the bus company, e.g., its debt/equity ratio and its fuel cost per gallon. Although this report briefly mentions the aggregate form of the model, it concentrates on describing the composition and derivation of the detailed bus system cost model.

DATA SOURCES

Data were obtained from three primary sources. Operating cost, activity, and equipment inventory data were obtained for a cross-section of approximately one hundred U.S. and Canadian transit companies. (4) Data on the cost of buses were obtained from the major bus manufacturers. (5,7,8) Data on structures, nonrevenue equipment, and parking requirements reflect an updating and modification of estimates made by Meyer, Kain, and Wohl (2) (pre-1965) and revised several years later by the General Research Corporation. (1)

DEVELOPMENT OF COST-ESTIMATING RELATIONSHIPS (CERs)

For the most part, the generalized cost-estimating relationships (CERs) were obtained by plotting the relevant cost against an appropriate independent variable, fitting a curve visually, and expressing the relationship mathematically. Numerous checks of reasonableness have been made and, in our judgment, the cost-estimating relationships are thoroughly adequate for the purpose they serve. For example, costs for the SCRTD (Southern California Rapid Transit District) were not included in the data base, yet our relationships predict them quite well. It is
true, of course, that for extrapolations well beyond the range of the
data base the estimates are subject to considerable uncertainty. But
we have tried to minimize this uncertainty by choosing functional forms
that seem physically meaningful—as well as mathematically suitable—
for expressing the individual estimating relationships.

ORGANIZATION OF THIS REPORT

Section II presents an overview of the Bus System Cost Model and
shows the general computational flow as well as how the various cat-
egories of output are prepared. Section III illustrates how cost-
estimating relationships are developed with a simplified example; simi-
lar techniques were used to develop the many cost-estimating relation-
ships that constitute the model. Section IV presents the complete
model in mathematical form and includes a detailed list of all inputs
and outputs. Section V presents a typical printout and sample sensi-
tivity analyses. Appendix A presents some of the details involved in
developing the various cost-estimating relationships to help the reader
understand the data and assumptions upon which they are based.* Appen-
dix B presents a description of the overall study methodology for analy-
zing the many impacts of transportation and air pollution control
strategies on an urban role, and shows the Bus System Cost Model's
role.

*This appendix is a collection of notes, tables, and graphs which
are informal, handwritten, and quite detailed. Time and money con-
straints made it impossible to put them into more formal form.
II. MODEL OVERVIEW

The flow chart in Fig. 1 describes the general outline of the cost model and will be used as a guide for the following discussion. Arrayed to the left of the dashed line are the inputs required by the model. Their source, as well as examples of specific input variables, are shown in the boxes. The supply model is another part of the overall transportation model mentioned earlier.

The first step is to use the appropriate inputs from the supply model, the system design specifications, and the necessary parameters for the relevant cost-estimating relationships to estimate annual operating and initial investment costs by cost element. When this step has been completed, total investment by cost element is printed out for use in various economic impact analyses. The next step is to use the financial analysis inputs as indicated to estimate annualized investment cost, bond interest cost, various taxes, return on investment, depreciation, etc. The financial analysis parameters are selected to reflect different forms of ownership and financing arrangements. When these costs have been calculated, they are brought together with the annual operating costs estimated earlier, and the entire set is divided, by cost element, into direct, indirect, and other costs.

In the overall transportation model there is provision for a linear program that determines the minimum-cost combination of buses, bus-miles, and bus-hours for meeting a particular demand pattern and desired service characteristics. This program uses a linear approximation of total annualized bus system cost as its objective function. The total annualized costs obtained in the previous step are used to prepare the required linear cost approximation function.

Using the total annualized costs (annual operating plus annualized investment plus corporate profits taxes and bond interest), another classification of costs by cost element is made (see upper right corner of Fig. 1). Those costs that are related to passenger trips such as advertising and administration and general are separated from those that are more related to passenger miles—fuel, drivers' wages,
BUS SYSTEM COST MODEL

**Inputs**
- **From Supply Model**
  - PAX Trips
  - PAX Miles
  - Buses
  - Bus Miles
  - Bus Hours
- **System Design**
  - Seats per Bus
  - Minimum Load Factors
- **Parameters for CERs**
- **Parameters for Financial Analysis**
  - Rate of Return
  - Asset Lives
  - Tax Rates
- **From Supply Model**
  - Operating Revenue

**Outputs**
- **Costs Related to PAX Trips**
  - Advertising
  - Property Taxes
  - Admin. & Gen.
- **Costs Related to PAX Miles**
  - Drivers' Wages
  - Fuel
  - Bus Maint.

**Outputs**
- **Total System Cost Data**
- **Linear Cost Equation for L.P.**

**Cost > Revenue?**
- **Yes**
  - Fare Equation for Next Iteration
- **No**
  - Reduce Fares for Next Iteration
  - Required Subsidy

Fig. 1--Bus System Cost Model Flow Chart
etc. A total cost is computed for each group and divided by the appropriate input from the supply model to obtain the required coefficients for the break-even fare equation. This equation can be used to get fares for the next iteration of the transportation model or bus fare may be specified exogenously by the user.

The total annualized costs are also printed out at this point in a format designed to further facilitate economic impact analysis. This format is shown in the section on the detailed model that follows.

A fare specified for the previous iteration was used to influence bus demand and hence revenue in the supply model. The annual revenue was calculated and is now compared with the annualized cost. If revenue is less than cost, a subsidy is implied. The amount of this subsidy is printed out. The last step, not shown in Fig. 1, is to collapse the entire model so that total annualized cost is expressed as a non-linear function of three variables—buses, bus-miles, and bus-hours. This is in fact the form of the model that is actually used in the transportation model and in conjunction with the bus system design model for many sensitivity analyses.
III. DEVELOPMENT OF A COST-ESTIMATING RELATIONSHIP: FUEL COST EXAMPLE

To illustrate for the casual reader how cost-estimating relationships are developed, we here present a simplified example.* Annual fuel cost is to be estimated as a function of bus size (indicated by number of seats), annual miles driven, type of fuel used (gasoline or diesel), and the cost (less taxes) of a gallon of fuel. The process is indicated graphically in Fig. 2.

The first step was to relate fuel consumption measured in gallons per mile to average vehicle operating weight. For this purpose, data on vehicles ranging from passenger cars to large trucks (including buses)—both diesel and gasoline-powered—were collected from various sources. The data were adjusted for driving patterns and plotted as shown in the left-most graph in Fig. 2. The overall average obtained from the American Transit Association data⁴ for the typical diesel bus is indicated by the large dot on the lower curve. The relationship between the curves agrees closely with current theory. Diesel is more efficient than gasoline for two reasons—it contains more BTUs per gallon than gasoline, and diesel engines are more efficient than gasoline engines. When the theoretical values of these differences are combined, they account quite well for the difference between the two curves.

The next step was to use data on various size buses obtained from bus manufacturers⁵,⁷,⁸ to relate average operational weight to number of seats. The result is shown in the center graph, Fig. 2. Each of the curves shown in the left and center graph were first drawn free hand and then expressed mathematically. The mathematical expressions were combined to obtain the final cost-estimating relationship shown in the graph on the right of Fig. 2. Fuel costs per gallon are left to be specified when running the model so that prices relevant to a particular geographic area and special purchase arrangements, such as quantity discounts, can be taken specifically into account. Some

*As part of the simplifications, certain details considered in developing the actual cost-estimating relationship are omitted here; they may be found in Appendix A.
DEVELOPMENT OF A COST ESTIMATING RELATIONSHIP: FUEL COST (Less Tax)

**AVERAGE COST PER GALLON**
- DIESEL $0.13
- GASOLINE $0.15

**ANNUAL FUEL COST**
- DIESEL: $(0.036 + 0.00328S)(\text{COST/GALLON}) \times \text{ANNUAL BUS MILES}$
- GASOLINE: $(0.069 + 0.00448S)(\text{COST/GALLON}) \times \text{ANNUAL BUS MILES}$

Fig. 2--Development of a Cost Estimating Relationship:
Fuel Cost (Less Tax) Example
typical fuel prices are shown along with the estimating relationships developed in the lower part of Fig. 2. It should be noted that since this illustration was prepared, the actual form of the fuel cost-estimating relationship has been changed somewhat (see notes in Appendix A). However, this in no way degrades the use of this as an illustration of a general method. The methods used here are similar to those used to derive most of the cost-estimating relationships used in the Bus System Cost Model.
IV. BUS SYSTEM COST MODEL DETAILS

The presentation of the model follows the form in which it was prepared for programming. It is sufficiently well annotated so that both the input definitions and the computational procedures should be self-evident. Reference to Appendix A and the Engineering Economy text (3) cited earlier may help. A complete set of hand calculations have been made to check the computer program. The model is divided into seven parts:

- Input Specification
- Preliminary Calculations
- Calculation of Initial Investment Costs
- Calculation of Annual Operating Costs and Annualized Investment Costs
- Calculation of Break-Even Fare Equation
- Calculation of Coefficients for Aggregate Form of the Cost Model
- Calculation of Coefficients for Linear Program Cost Function

INPUTS

First, the inputs from the transportation model are presented. These inputs, denoted by the variable $w_i$, where $i$ is the particular input, are used to describe the magnitude of the bus system in terms of number of buses and required activity rates. Also included is the total passenger revenue generated which comes from the supply model.

Bus system design inputs labeled $d_i$ are next presented, followed by parameter values for the CERs, $c_i$, and financial analysis inputs $f_i$. The cost inputs contain all of the cost factors and parameter values that are used in the generalized cost estimating relationships.

*The model is programmed in PL-1.*
## Definition of Inputs

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<th>Variable Name</th>
<th>Description</th>
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<td>Run Number</td>
<td>&quot;Inputs from the Transportation Model&quot;</td>
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<tr>
<td>w₁</td>
<td>Number of Buses</td>
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<td>w₂</td>
<td>Annual Bus Miles</td>
<td>Required</td>
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<tr>
<td>w₃</td>
<td>Annual Bus Hours</td>
<td>Required</td>
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<td>w₄</td>
<td>Annual Revenue from</td>
<td>Fare (Dollars)</td>
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<tr>
<td>w₅</td>
<td>Annual Passenger</td>
<td>Miles</td>
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<td>w₇</td>
<td>Annual Passenger</td>
<td>Trips</td>
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<tr>
<td></td>
<td>Number of Seats</td>
<td>Per Bus</td>
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<td>d₂</td>
<td>Average Number of</td>
<td>Buses in Shop (Fraction of Total)</td>
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<tr>
<td>d₃</td>
<td>Extra Buses</td>
<td>Required for Downtime, Scheduling, etc. (Fraction of Total)</td>
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<td>Constant for Bus</td>
<td>Procurement Equation (Dollars)</td>
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<td>c₃</td>
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<td>Cost Per Bus (Dollars): For Air Conditioning--3,400 ≤ c₄ ≤ 4,600</td>
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<td>State User Tax on Fuel (Dollars Per Gallon): Private = 0.07, Public = 0.01</td>
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<td>Annual Property Tax Rate (Fraction of Investment): Private = 0.03, Public =?</td>
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<td>Shop Construction Cost (Dollars Per Square Foot)</td>
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<td>Cost of Paving (Dollars Per Square Foot of Parking Area)</td>
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<td>16.64</td>
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<td>Investment in Special Control Structures (Dollars)</td>
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## Definition of Inputs (cont'd)

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<td>Materials and Other for Maint. and Operation of Special Control Fac. ($)</td>
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<td>Bus Life (Years)</td>
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<td>Bus Salvage Value (Fraction of Investment Cost)</td>
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<td>f_{5}</td>
<td>Equipment Life (Years)</td>
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<td>Structure Salvage Value (Fraction of Investment Cost)</td>
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<td>Federal Corporate Profits Tax Rate (Fraction)</td>
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<td>Fraction of Investment Financed with Bonds</td>
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<tr>
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<td>Annual Bond Interest Rate (Fraction)</td>
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</table>
PRELIMINARY CALCULATIONS

These calculations, as indicated by their name, include most of the initial calculations that are necessary to transform the raw inputs into the form in which they will be used in subsequent calculations. In large part they consist of the calculation of capital recovery, depreciation, profit, gradient, tax, and bond interest factors.

Other preliminary calculations include such things as the initial cost of one bus, the square feet of shops required, fuel consumption in gallons per bus-mile, and annual fuel consumption for all buses. With the single exception of $f_R$, composite corporate profits tax rate, all preliminary calculations carry $p_I$ as a variable name.

Number of Buses Required

$p_{30} = (1 + d_3)w_1$

Initial Cost of One Bus (Base Cost)

$p_1 = c_2 + c_3d_1 + c_4$

Square Feet of Shops Required

$p_2 = d_2(1 + d_3)(c_{24} + c_{25}d_1)w_1$

Square Feet of Parking Area Required

$p_3 = p_2/d_2$

Square Feet of Land Required

$p_4 = p_2 + p_3$

Fuel Cons. in Gal/Bus Mi--Incl. Oil

$p_5 = c_{131}(1 + c_{11})(c_{12} + c_{13}d_1)$

Annual Fuel Cons. in Gal

$p_6 = p_5w_2$

Capital Recovery Factors:

Buses

$p_7 = \left[ f_1 \left( \frac{f_1}{1 + f_1} \right)^{f_2} \right] \cdot \left[ 1 - f_3 \right] + f_1f_3$

Equipment

$p_8 = \left[ f_1 \left( \frac{f_1}{1 + f_1} \right)^{f_4} \right] \cdot \left[ 1 - f_5 \right] + f_1f_5$

Structures

$p_9 = \left[ f_1 \left( \frac{f_1}{1 + f_1} \right)^{f_6} \right] \cdot \left[ 1 - f_7 \right] + f_1f_7$

Land

$p_{10} = f_1$

*The gradient factor is used to convert an (arithmetic) gradient series of cash flows to an equivalent uniform series.
Depreciation Factors (Straight-Line):

Buses \[ P_{11} = \frac{(1 - f_3)}{f_2} \]

Equipment \[ P_{12} = \frac{(1 - f_5)}{f_4} \]

Structures \[ P_{13} = \frac{(1 - f_7)}{f_6} \]

Profit Factors (After-Tax Return on Investment):

Buses \[ P_{14} = P_7 - P_{11} \]

Equipment \[ P_{15} = P_8 - P_{12} \]

Structures \[ P_{16} = P_9 - P_{13} \]

Land \[ P_{17} = P_{10} \]

Gradient Factors:

Buses \[ P_{18} = \frac{1}{f_1} - \frac{f_2}{f_1} \left[ \frac{f_1}{(1 + f_1)^2} - 1 \right] \]

Equipment \[ P_{19} = \frac{1}{f_1} - \frac{f_4}{f_1} \left[ \frac{f_1}{(1 + f_1)^4} - 1 \right] \]

Structures \[ P_{20} = \frac{1}{f_1} - \frac{f_6}{f_1} \left[ \frac{f_1}{(1 + f_1)^5} - 1 \right] \]

Land \[ P_{21} = \frac{1}{f_1} \]
Composite Corporation Profits Tax Rate: \[ f_8 = f_{81} + f_{82} - f_{81}f_{82} \]

Corporate Profits Tax Factors:

**Buses**

\[ p_{22} = f_1 \left( \frac{f_8}{1 - f_8} \right) \cdot \left( f_{1} - f_{9}f_{10} \right) \cdot \left( f_3 + (1 - f_3) \left( 1 - \frac{p_{18}}{f_2} \right) \right) \]

**Equipment**

\[ p_{23} = f_1 \left( \frac{f_8}{1 - f_8} \right) \cdot \left( f_{1} - f_{9}f_{10} \right) \cdot \left( f_5 + (1 - f_5) \left( 1 - \frac{p_{19}}{f_4} \right) \right) \]

**Structures**

\[ p_{24} = f_1 \left( \frac{f_8}{1 - f_8} \right) \cdot \left( f_{1} - f_{9}f_{10} \right) \cdot \left( f_7 + (1 - f_7) \left( 1 - \frac{p_{20}}{f_6} \right) \right) \]

**Land**

\[ p_{25} = f_1 \left( \frac{f_8}{1 - f_8} \right) \cdot \left( f_{1} - f_{9}f_{10} \right) \]

Bond Interest Cost Factors:

**Buses**

\[ p_{26} = f_9f_{10} \left( f_3 + (1 - f_3) \left( 1 - \frac{p_{18}}{f_2} \right) \right) \]

**Equipment**

\[ p_{27} = f_9f_{10} \left( f_5 + (1 - f_5) \left( 1 - \frac{p_{19}}{f_4} \right) \right) \]

**Structures**

\[ p_{28} = f_9f_{10} \left( f_7 + (1 - f_7) \left( 1 - \frac{p_{20}}{f_6} \right) \right) \]

**Land**

\[ p_{29} = f_9f_{10} \]
INITIAL INVESTMENT

The variable \( x_1 \) is used to identify all initial investment costs. These costs are those that would be required as one-time outlays necessary to provide the equipment, structures, land, etc., that are required by any operating bus system. To the extent that for a particular analysis any or all of these items are considered already available, the calculations should be appropriately adjusted. The categories identified as having to do with Special Control Facilities and Equipment are included to pick up the costs of the dispatching, routing, and control facilities and equipment for demand-responsive systems. As of the moment, these costs are simply inputs as work to develop CERs has not been accomplished. For economic impact analysis, all investment items are summarized into the categories--Buses, Yards and Shops, and Special Control Facilities (Summary A) and Equipment, Structures, and Land (Summary B).

**Buses (Incl. Sales Tax)**

\[ x_1 = p_1p_{30}(1 + c_5) \]

**Yards and Shops:**

- **Structures**
  \[ x_2 = c_{23}p_2 \]
- **Equipment**
  \[ x_3 = c_{26}p_2 \]
- **Paving for Parking Area**
  \[ x_4 = c_{27}p_3 \]
- **Land**
  \[ x_5 = c_{28}p_4 \]
- **Total Yards and Shops**
  \[ x_6 = x_2 + x_3 + x_4 + x_5 \]

**Special Control Facilities:**

- **Structures**
  \[ x_7 = c_{30} \]
- **Equipment**
  \[ x_8 = c_{31} \]
- **Land**
  \[ x_9 = c_{32} \]
- **Total Special Control Facilities**
  \[ x_{10} = x_7 + x_8 + x_9 \]

**Initial Investment Cost Summary A**

- **Buses**
  \[ x_1 \]
- **Yards & Shops**
  \[ x_6 \]
- **Special Control Facilities**
  \[ x_{10} \]
- **Total Initial Investment**
  \[ x_{11} \]
Initial Investment Cost Summary B

\[ x_{13} = x_1 + x_3 + x_8 \]
\[ x_{14} = x_2 + x_4 + x_7 \]
\[ x_{15} = x_5 + x_9 \]
\[ x_{11} \]

ANNUAL OPERATING COSTS AND ANNUALIZED INVESTMENT COSTS

The annual operating cost elements follow those of The American Transit Association\(^{(4)}\) as closely as possible. In all cases an attempt was made to divide the costs into the categories "labor" and "materials and other." In some cases, such as drivers' and helpers' wages, the split was obvious. In others, rough estimates based on experience had to be made. All annual operating costs and annualized investment costs are designated with the variable \( y_1 \). User taxes are kept separate from the cost of fuel to facilitate economic impact analysis. User taxes on fuel are also split between State and Federal. The computation of State sales tax on fuel follows the current California practice of figuring the tax on the sum of fuel cost less taxes and both State and Federal user tax. Bond interest, depreciation, corporate profits taxes, and net return on investment would be adjusted by input choice to reflect the desired form of corporate ownership and financial structure. By controlling the inputs, a wide range of possible configurations can realistically be considered. The split between direct and indirect operating cost is somewhat arbitrary, but although one might argue about where some of the cost elements should be placed, the high-cost items seem to fall naturally on one side of the split.

Cost Summary A indicates the classification of costs into Direct Operating Costs, Indirect Operating Costs, and Others. In Summary A the detailed cost elements are shown for definitional purposes. Cost Summary B indicates them in terms of the major components of total annualized cost. Cost Summary C presents the total annualized costs.

*Structures for yards and shops -- \( x_{12} = x_2 + x_4 \).
by resource category, e.g., labor, fuel, materials, etc., and Summary D is an aggregation of the major categories shown in Summary C. For each of the four summaries, the total shown is the total annualized cost of the bus system. The final equation, given after the four summaries, indicates how the required subsidy is calculated.
Annual Operating Costs (Detail)

Equipment Maintenance and Garage:
  Labor
  Materials & Other
  Total Equipment Maintenance & Garage

Drivers' and Helpers' Wages

Fuel and Oil Not Including Taxes

Other Transportation Cost:
  Labor
  Materials & Other
  Total Other Transportation Cost

Administration and General Costs:
  Labor
  Materials & Other
  Total Administration and General Costs

Maintenance and Operation of Special Control Facilities:
  Labor
  Materials & Other
  Total M&O of Special Control Facilities

\[ y_1 = c_6 c_{33} w_2^{d_1} c_7 \]
\[ y_2 = y_1 (1 - c_{33}) / c_{33} \]
\[ y_3 = y_1 + y_2 \]
\[ y_4 = 1.1 \times 10^6 c_8 (w_3 \times 10^{-6}) c_9 \]
\[ y_5 = c_{10} p_6 \]
\[ y_6 = c_{14} c_{34} (y_4 + y_5) \]
\[ y_7 = y_6 (1 - c_{34}) / c_{34} \]
\[ y_{35} = y_6 + y_7 \]
\[ y_{11} = c_{36} (c_{15} w_2^{c_{16}} - 0.091 y_4) \]
\[ y_{12} = y_{11} (1 - c_{36}) / c_{36} \]
\[ y_{13} = y_{11} + y_{12} \]
\[ y_{14} = c_{37} \]
\[ y_{15} = c_{38} \]
\[ y_{16} = y_{14} + y_{15} \]
Insurance and Safety Cost:
   Labor
   Materials & Other
   Total Insurance and Safety Cost

Traffic and Advertising Cost:
   Labor
   Materials & Other
   Total Traffic and Advertising Cost

User Taxes on Fuel:
   Federal
   State
   Total User Tax on Fuel

State Sales Tax on Fuel

Other Operating Taxes and Licenses

Property Taxes

Bond Interest Costs:*
   Buses
   Equipment

\[ y_{17} = .02c_{39}d_1 \left( c_{170} + c_{171}w_2w_3w_4 \right) \]
\[ y_{18} = y_{17}(1 - c_{39})/c_{39} \]
\[ y_{19} = y_{17} + y_{18} \]
\[ y_{20} = c_{40}c_{18}c_{19}w_2 \]
\[ y_{21} = y_{20}(1 - c_{40})/c_{40} \]
\[ y_{22} = y_{20} + y_{21} \]
\[ y_{23} = c_{20}p_6 \]
\[ y_{24} = c_{21}p_6 \]
\[ y_{25} = y_{23} + y_{24} \]
\[ y_{44} = c_5(y_5 + y_{25}) \]
\[ y_{26} = c_{29}d_1(1 + d_3)w_1 \]
\[ y_{27} = c_{22}(x_6 + x_{10}) \]
\[ y_{280} = p_{26}x_1 \]
\[ y_{281} = p_{27}(x_3 + x_8) \]

*Detail is not calculated in the computer program.
Structures
Land
Total Bond Interest Cost

Depreciation Costs:
Buses
Equipment
Structures
Total Depreciation Cost

Corporate Profits Taxes:*
Buses
Equipment
Structures
Land
Total
Federal Portion
State Portion

Profit (After-Tax Return on Investment):*
Buses

\[ Y_{282} = P_{29} X_{14} \]
\[ Y_{283} = P_{29} X_{15} \]
\[ Y_{28} = Y_{280} + Y_{281} + Y_{282} + Y_{283} \]
\[ Y_{29} = P_{11} X_{1} \]
\[ Y_{30} = P_{12}(X_{3} + X_{8}) \]
\[ Y_{31} = P_{13} X_{14} \]
\[ Y_{32} = Y_{29} + Y_{30} + Y_{31} \]
\[ Y_{333} = P_{22} X_{1} \]
\[ Y_{334} = P_{23}(X_{3} + X_{8}) \]
\[ Y_{335} = P_{24} X_{14} \]
\[ Y_{336} = P_{25} X_{15} \]
\[ Y_{33} = Y_{333} + Y_{334} + Y_{335} + Y_{336} \]
\[ Y_{331} = Y_{33} f_{81} (1 - f_{82}) / f_{8} \]
\[ Y_{332} = Y_{33} f_{82} / f_{8} \]
\[ Y_{340} = P_{14} X_{1} \]

*Detail is not calculated in the computer program.
Equipment

Structures

Land

Total Profit (After-Tax Return on Investment)

\[ y_{341} = p_{15}(x_3 + x_8) \]

\[ y_{342} = p_{16}x_{14} \]

\[ y_{343} = p_{17}x_{15} \]

\[ y_{34} = y_{340} + y_{341} = y_{342} + y_{343} \]
Annualized Cost Summary A

Direct Operating Costs:

- Equipment Maintenance & Garage $Y_3$
- Drivers' and Helpers' Wages $Y_4$
- Fuel & Oil (Less Taxes) $Y_5$
- Fuel & Oil Federal User Tax $Y_{23}$
- Fuel & Oil State User Tax $Y_{24}$
- Fuel & Oil State Sales Tax $Y_{44}$
- Depreciation--Buses $Y_{29}$
- Other Operating Taxes & Licenses $Y_{26}$
- Insurance & Safety $Y_{19}$

Total Direct Operating Cost $Y_{36}$

Indirect Operating Costs:

- Other Transportation Cost $Y_{35}$
- Administration & General $Y_{13}$
- M&O of Special Control Facilities $Y_{16}$
- Traffic & Advertising $Y_{22}$
- Depreciation--Equipment $Y_{30}$
- Depreciation--Structures $Y_{31}$
- Property Taxes $Y_{27}$
- Bond Interest $Y_{28}$

Total Indirect Operating Cost $Y_{37}$

Corporate Profits Taxes $Y_{33}$
Profit (After-Tax Return on Investment) $Y_{34}$

Total Annualized Costs $Y_{42}$

Annualized Cost Summary B

Direct Operating Costs $Y_{36}$
Indirect Operating Costs $Y_{37}$
Corporate Profits Taxes $Y_{33}$
Profit (After-Tax Return on Investment) $Y_{34}$

Total Annualized Costs $Y_{42}$
### Annualized Cost Summary C

#### Labor:
- Equipment Maintenance & Garage $y_1$
- Drivers' and Helpers' Wages $y_4$
- Insurance & Safety $y_{17}$
- Other Transportation Cost $y_6$
- Administration & General $y_{11}$
- M&O of Special Control Facilities $y_{14}$
- Traffic and Advertising $y_{20}$

**Total Labor Cost** $y_{38}$

#### Fuel and Oil (Less Taxes)
- Federal Taxes:
  - User Tax on Fuel $y_{23}$
  - Corporate Profits Tax $y_{331}$

**Total Federal Taxes** $y_{39}$

#### State Taxes:
- User Tax on Fuel $y_{24}$
- Other Operating Taxes & Licenses $y_{26}$
- Sales Tax on Fuel $y_{44}$
- Corporate Profits Tax $y_{332}$

**Total State Taxes** $y_{40}$

#### Local Taxes:
- Property Taxes $y_{27}$

#### Bond Interest
- $y_{28}$

#### Materials & Other:
- Equipment Maintenance & Garage $y_2$
- Depreciation--Buses $y_{29}$
- Depreciation--Equipment $y_{30}$
- Depreciation--Structures $y_{31}$
- Insurance and Safety $y_{18}$
- Other Transportation $y_7$
- Administration & General $y_{12}$
M&O of Special Control Facilities \( y_{15} \)
Traffic and Advertising \( y_{21} \)
Profit (After-Tax Return on Investment) \( y_{34} \)
Total Materials & Other \( y_{41} \)
Total Annualized Costs \( y_{42} \)

Annualized Cost Summary D

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<td>Local Taxes</td>
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<td>Bond Interest</td>
<td>( y_{28} )</td>
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<td>Materials &amp; Other</td>
<td>( y_{41} )</td>
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<tr>
<td>Total Annualized Costs</td>
<td>( y_{42} )</td>
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Annual Subsidy Required

\[ y_{43} = y_{42} - w_{4} \]
CALCULATION OF FARE TO BREAK-EVEN

The break-even fare equation is developed by distributing the entire annualized operating cost to the passengers whose demand generated the system and hence the costs.

It is assumed that certain costs are more appropriately dependent on number of passenger trips and others on total passenger miles. Implicit in this is a fare per customer that consists of a fixed amount per trip plus an amount that varies uniformly with the length of his trip.

The identification of cost elements to the two categories (related to passenger miles and related to passenger trips) is shown below. Experience has shown that approximately 80 percent of the total cost is relatable to passenger miles where the entire cost, including corporate profits taxes and after-tax return on investment, is included in the fare calculation.

Calculation of Break-Even Fare Equation Coefficients

<table>
<thead>
<tr>
<th>Annual Cost</th>
<th>Costs Related to Passenger Miles</th>
<th>Costs Related to Passenger Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Maintenance &amp; Garage</td>
<td>$y_3$</td>
<td></td>
</tr>
<tr>
<td>Drivers' &amp; Helpers' Wages</td>
<td>$y_4$</td>
<td></td>
</tr>
<tr>
<td>Fuel &amp; Oil (Less Taxes)</td>
<td>$y_5$</td>
<td></td>
</tr>
<tr>
<td>Other Transportation Cost</td>
<td></td>
<td>$y_{35}$</td>
</tr>
<tr>
<td>Administration &amp; General</td>
<td></td>
<td>$y_{13}$</td>
</tr>
<tr>
<td>M60 of Spec. Control Fac.</td>
<td></td>
<td>$y_{16}$</td>
</tr>
<tr>
<td>Insurance and Safety</td>
<td>$y_{19}$</td>
<td></td>
</tr>
<tr>
<td>Traffic &amp; Advertising</td>
<td></td>
<td>$y_{22}$</td>
</tr>
<tr>
<td>User Taxes on Fuel &amp; Oil</td>
<td>$y_{25}$</td>
<td></td>
</tr>
<tr>
<td>State Sales Tax on Fuel &amp; Oil</td>
<td>$y_{44}$</td>
<td></td>
</tr>
<tr>
<td>Other Operating Taxes &amp; Licenses</td>
<td>$y_{26}$</td>
<td></td>
</tr>
<tr>
<td>Property Taxes</td>
<td></td>
<td>$y_{27}$</td>
</tr>
</tbody>
</table>
Bond Interest Costs:

- Buses: \( P_{26} x_1 \)
- Equipment: \( P_{27} (x_3 + x_8) \)
- Structures: \( P_{28} x_{14} \)
- Land: \( P_{29} x_{15} \)

Depreciation Costs:

- Buses: \( P_{11} x_1 \)
- Equipment: \( P_{12} (x_3 + x_8) \)
- Structures: \( P_{13} x_{14} \)

Corporate Profits Taxes:

- Buses: \( P_{22} x_1 \)
- Equipment: \( P_{23} (x_3 + x_8) \)
- Structures: \( P_{24} x_{14} \)
- Land: \( P_{25} x_{15} \)

Profit (After-Tax Return on Investment):

- Buses: \( P_{14} x_1 \)
- Equipment: \( P_{15} (x_3 + x_8) \)
- Structures: \( P_{16} x_{14} \)
- Land: \( P_{17} x_{15} \)

Total Annual Cost: \( TOC_{M} \quad TOC_{T} \)

Calculation of Coefficients

\[
\text{Cost Per Passenger Mile} = \alpha = \frac{TOC_{M}}{w_5}
\]
\[
\text{Cost Per Passenger Trip} = \beta = \frac{TOC_{T}}{w_7}
\]

Note: \( w_5 \) and \( w_7 \) are from this iteration of the Transportation model. The break-even fare equation will be applied in the next iteration.

Break-Even Fare Equation

\[ F = \alpha w_5 + \beta w_7 \]
AGGREGATE BUS COST MODEL

The transportation model incorporates an aggregate form of the generalized bus cost model for costing alternative bus systems. The full model is run before analysis with the transportation model is begun to generate coefficients for the aggregate bus cost model. Then, after preferred bus systems have been selected, the full model may be run again for each one to evaluate their detailed impacts.

The aggregate bus cost model is obtained by collapsing the full model into a single function that gives total annualized cost as a function of number of buses required in the peak hour, number of bus-miles, and number of bus-hours. The coefficients of this function (the aggregate model coefficients) are generated by running the full model with all the other variables fixed at values that represent the institutional and cost parameters of the bus company, e.g., its form of ownership (public or private), debt/equity ratio, tax rates, fuel cost per gallon, and so forth. The coefficients are developed in such a way that their values are completely independent of the number of buses required in the peak hour, number of bus-miles, and number of bus-hours.

Where buses, bus-hours, and bus-miles are calculated using the equations presented with the bus system design model (see the report on the Urban Transportation Model), the aggregate form is an extremely useful tool for performing sensitivity analyses like those that are shown as examples in Section V.

Calculation of Coefficients for Aggregate Form of Bus System Cost Model*

Preliminary Calculations:

\[ a_1 = p_{11} + p_{14} + p_{22} + p_{26} \]
\[ a_2 = p_{12} + p_{15} + p_{23} + p_{27} \]
\[ a_3 = p_{13} + p_{16} + p_{24} + p_{28} \]
\[ a_4 = p_{17} + p_{25} + p_{29} \]

*Note that even though \( w_1 \) and \( w_2 \) are used in the calculations of \( k_i \), this is only a computational convenience, and the values of \( k_i \) are in fact independent of the values of \( w_1 \) and \( w_2 \).
Constant Term:
\[ k_0 = 0.02 d_1 c_{170} + y_{16} + c_{22} x_{10} + a_2 x_8 + a_3 x_7 + a_4 x_9 \]

Coefficient of \( w_1 \):
\[ k_1 = \left[ a_1 x_1 + a_2 x_3 + a_3 x_{12} + a_4 x_5 + c_{22} x_6 + y_{26} \right] / w_1 \]

Coefficient of \( w_2 \):
\[ k_2 = \left[ y_3 + y_5 (1 + c_{14}) + y_{23} + y_{24} + y_{44} \right] / w_2 \]

Coefficient of \( w_2 c_{16} \):
\[ k_3 = c_{15} \]

Coefficient of \( w_2 c_{19} \):
\[ k_4 = c_{18} \]

Coefficient of \( w_2 c_{172} \):
\[ k_5 = 0.02 d_1 c_{171} \]

Coefficient of \( w_3 c_9 \):
\[ k_6 = c_8 (1 + 1.1 c_{14}) \times 10^6 (1-c_9) \]

Aggregate Bus Cost Equation:
\[ TAC = k_0 + k_1 w_1 + k_2 w_2 + k_3 w_2 c_{16} + k_4 w_2 c_{19} + k_5 w_6 c_{172} + k_6 w_3 c_9 \]

Aggregate Form of Bus System Cost Model:
\[ TAC = k_0 + k_1 w_1 + k_2 w_2 + k_3 w_2 c_{16} + k_4 w_2 c_{19} + k_5 w_2 c_{172} + k_6 w_3 c_9 \]

**Calculation of Coefficients for Linear Program Objective Function**

The estimates of buses, bus-miles, and bus-hours that the aggregate bus system cost model uses to calculate costs come from the bus system design model, a component of the Policy-Oriented Urban Transportation model. That design model assumes the geographic pattern of demand and the structure of the bus routes are somewhat more uniform than may
often occur in practice; assuming such uniformity can make the resulting
cost estimates somewhat conservative because opportunities for sav-
ings and economies of scale can arise from making less uniform, more
specialized allocation of resources. To obtain a more efficient alloca-
tion of bus resources and to thus "tune" our estimates of bus system
costs, we anticipate that sometime in the future we will incorporate a
linear program into the transportation model. Given a geographic pattern
of demand, a route structure on an actual network, and a desired level of
service,* this linear program will assign the buses to prospective routes
so as to minimize the total annualized costs of the bus system. This
assignment should produce better estimates of the buses, bus-hours, and
bus-miles required to provide a desired level of service, since they
better reflect nonuniformity. The objective function for this linear
program will be a linear approximation to the aggregate form of the bus
system cost model, which is quite nonlinear.

In preparation for the eventual addition of this linear program,
the generalized Bus System Cost model includes in its output the coef-
ficients of a linear approximation to the aggregate form of the bus cost
model. These coefficients are obtained by taking the partial derivatives
of total annualized cost with respect to buses, bus-miles, and bus-hours.
It should be noted that in the approximation function the independent vari-
ables have a bar over them, e.g., $\bar{W}_2$, and $\bar{W}_3$. This is to indicate that they
represent the characteristics of the particular bus system at which the ap-
proximation is made. For this reason an initial guess must be made to get
the process started. It is assumed that the approximation will be continued
in an iterative fashion with successive loops through the transportation
model so that the final values of these variables will reflect the nonuniform
operational characteristics of the bus system actually selected. These values
are then used in the aggregate form of the bus cost model to obtain the final
estimate of total annualized cost. The equations for the calculation of these
coefficients follow.

*The mechanism by which the transportation model would obtain these
factors is relatively simple in practice but hard to explain. We will not
discuss it further here. We note, however, that we have successfully demon-
strated and tested a prototype linear program for this application.
The linear program objective function is:

\[ z = q_1 w_1 + q_2 w_2 + q_3 w_3 \]

where:

\[ q_1 = \frac{\partial \text{TAC}}{\partial w_1} = k_1 \]

\[ q_2 = \frac{\partial \text{TAC}}{\partial w_2} = k_2 + c_{16} k_4 w_2^{-1} + c_{19} k_4 w_2^{-1} + c_{172} k_4 w_2^{-1} \]

\[ q_3 = \frac{\partial \text{TAC}}{\partial w_3} = c_9 k_6 w_3^{-1} \]

\[ w_1 = \text{number of buses in the peak hour} \]
\[ w_2 = \text{number of bus miles} \]
\[ w_3 = \text{number of bus hours} \]
\[ z = \text{linear approximation to TAC} \]

SAMPLE PRINTOUT FROM THE MODEL

Table 1 presents a sample computer printout for the bus system cost estimates. In the upper part of the table total annualized costs by cost element are presented. The breakout by column is intended to facilitate economic impact analysis, e.g., labor cost, taxes by collection agency, etc. In this table total annualized cost is identified as total required annual revenue. These would, in fact, be equal assuming all passengers had paid the break-even fare. However, actual revenue received may be either more or less than cost. If it is less, then a subsidy is implied, and if more, a reduction in fares for the next iteration is suggested. The required subsidy is calculated by subtracting actual revenue from required revenue and shown in the bottom line of the top part of the table. Total initial investment costs (before annualization) are shown next, and selected system design and activity characteristics are shown following them.

To facilitate cross-reference, Table 2 shows the correspondence between the values shown in the Table 1 printout and the variables used in the model that were described earlier in this section.

Table 3 displays another sample printout from the model; this one shows the symbols and values for all of the input and output values for this run of the model, as well as the results of all intermediate calculations.*

*Many values are expressed in scientific notation for compactness, where E indicates the exponent of the power of 10; e.g., 1.2E+03 = 1.2 \times 10^3 = 1200.
### Table 1

**SAMPLE PRINTOUT: BUS SYSTEM COST ESTIMATES**

<table>
<thead>
<tr>
<th>ALL NO.</th>
<th>1,098</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRIVATE</strong></td>
<td></td>
</tr>
<tr>
<td><strong>BUS SYSTEM COST ESTIMATES</strong> (MILLIONS OF DOLLARS)</td>
<td></td>
</tr>
<tr>
<td><strong>ANNUALIZED COSTS</strong></td>
<td><strong>LAVOR</strong></td>
</tr>
<tr>
<td><strong>DIRECT OPERATING COSTS</strong></td>
<td></td>
</tr>
<tr>
<td>EQUIPMENT, MAINT, GARAGE</td>
<td>13,160</td>
</tr>
<tr>
<td>DRIVERS AND HELPERS WAGES</td>
<td>70,292</td>
</tr>
<tr>
<td>FUEL AND OIL LESS TAxS</td>
<td></td>
</tr>
<tr>
<td>FUEL AND OIL USE BY TAX</td>
<td></td>
</tr>
<tr>
<td>DEPRECIATION OF EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>OTHER OPERATING TAXES AND LICENSES</td>
<td></td>
</tr>
<tr>
<td>INSURANCE AND SAFETY</td>
<td>3,066</td>
</tr>
<tr>
<td><strong>SUBTOTAL DIRECT OPERATING COSTS</strong></td>
<td></td>
</tr>
</tbody>
</table>

| **INDIRECT OPERATING COSTS** | | | | | | | | | |
| OTHER TRANSPORTATION | 4,790 | | | | 4,790 | | 4,790 |
| ADMINISTRATION AND GENERAL | 8,394 | | | | 8,394 | | 16,788 |
| SPECIAL CONTROL FACILITIES & EQUIPMENT | 3,000 | | | | 3,000 | | 6,000 |
| TRAFFIC AND ADVERTISING | 2,926 | | | | 2,926 | | 5,852 |
| DEPRECIATION OF EQUIPMENT | | | 0,315 | | 0,315 | | 0,315 |
| DEPRECIATION OF STRUCTURES | | | 0,674 | | 0,674 | | 0,674 |
| PROPERTY TAXES | | | | | 4,281 | | 4,281 |
| BOND INTEREST | | | | | | | | |
| **SUBTOTAL INDIRECT OPERATING COSTS** | | | | | | | 30,914 |

| **CORPORATE PROFITS TAX** | 0,411 | 0,055 | 0,466 |
| **AFTER TAX RETURN ON INVESTMENT** | 8,737 | 0,137 |
| **TOTAL = REQUIRED ANNUAL REVENUE** | 103,036 | 11,394 | 11,826 | 4,230 | 0,674 | 4,281 | 49,680 | 162,555 |
| **ACTUAL REVENUE RECEIVED FROM FARES** | | | | | | | 40,000 |
| **REQUIRED ANNUAL SUBSIDY** | | | | | | | 122,555 |
### Table 1 (cont'd)

<table>
<thead>
<tr>
<th>TOTAL INITIAL INVESTMENT (MILLIONS OF DOLLARS)</th>
<th>EQUIPMENT</th>
<th>STRUCTURES</th>
<th>LAND</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUSES</td>
<td>96.316</td>
<td>4.435</td>
<td>8.538</td>
<td>14.431</td>
</tr>
<tr>
<td>YARDS AND SHOPS</td>
<td>1.476</td>
<td>5.000</td>
<td>2.000</td>
<td>6.000</td>
</tr>
<tr>
<td>SPECIAL CONTROL FACILITIES</td>
<td>1.000</td>
<td>5.000</td>
<td>2.000</td>
<td>6.000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>98.994</td>
<td>9.435</td>
<td>10.538</td>
<td>18.907</td>
</tr>
</tbody>
</table>

### SYSTEM CHARACTERISTICS

<table>
<thead>
<tr>
<th>Nu. of Buses</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Seats per Bus</td>
<td>50</td>
</tr>
<tr>
<td>Annual Bus Miles</td>
<td>12200000</td>
</tr>
<tr>
<td>Annual Bus Hours</td>
<td>76000000</td>
</tr>
<tr>
<td>No. of Passenger Miles</td>
<td>521999744</td>
</tr>
<tr>
<td>Annual Passenger Trips</td>
<td>470249944</td>
</tr>
</tbody>
</table>

| Cost Related to Pax Trips | 37639342.0000 |
| Fake per Trip (beta) | 0.0000 |
| Cost Related to Pax Miles | 12445472.0000 |
| Fake per Mile (alpha) | 0.0239 |

### LP COEFFICIENTS

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>1.0000000077344</td>
</tr>
<tr>
<td>Bus Miles</td>
<td>0.02097</td>
</tr>
<tr>
<td>Bus Hours</td>
<td>10.10072</td>
</tr>
</tbody>
</table>

### Aggregate Cost Model Coefficients

| Constant      | 5.9668E+06 |
| Buses (x1)    | 1.0668E+04 |
| Bus Miles (x2) | 2.1173E-01 |
| Bus Miles (x2)(x2) | 9.3040E-04 |
| Bus Miles (x2)(x2)(x2) | 2.0940E-06 |
| Bus Hours (x3)(x3) | 7.9590E-06 |
| Bus Hours (x3)(x3)(x3) | 4.0000E-01 |
### Table 2

**CORRESPONDENCE BETWEEN BUS SYSTEM COST ESTIMATES ON PRINTOUT AND VARIABLES IN THE MODEL**

<table>
<thead>
<tr>
<th>Annualized Costs (Millions of Dollars)</th>
<th>Labor</th>
<th>Fuel &amp; Oil</th>
<th>Federal</th>
<th>State</th>
<th>Local</th>
<th>Bond Interest</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Operating Costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Maintenance &amp; Garage</td>
<td>Y1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y2</td>
<td></td>
<td>Y3</td>
</tr>
<tr>
<td>Drivers' &amp; Helpers' Wages</td>
<td>Y4</td>
<td>Y5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel &amp; Oil Less Taxes</td>
<td></td>
<td></td>
<td></td>
<td>Y23</td>
<td>Y24</td>
<td></td>
<td></td>
<td>Y25</td>
</tr>
<tr>
<td>Taxes on Fuel &amp; Oil (State User)</td>
<td></td>
<td></td>
<td></td>
<td>Y44</td>
<td></td>
<td></td>
<td>Y29</td>
<td>Y29</td>
</tr>
<tr>
<td>Taxes on Fuel &amp; Oil (State Sales)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation of Buses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y26</td>
<td></td>
</tr>
<tr>
<td>Other Operating Taxes &amp; Licenses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y18</td>
<td>Y19</td>
</tr>
<tr>
<td>Insurance &amp; Safety</td>
<td>Y17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal Direct Operating Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td>Y23</td>
<td>Y24</td>
<td>Y44</td>
<td>Y29</td>
<td>Y36</td>
</tr>
<tr>
<td>Indirect Operating Costs:</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Transportation</td>
<td>Y6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y7</td>
<td></td>
<td>Y35</td>
</tr>
<tr>
<td>Administration &amp; General</td>
<td>Y11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y12</td>
<td>Y13</td>
</tr>
<tr>
<td>Special Control Facilities &amp; Equip. M&amp;O</td>
<td>Y14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y15</td>
<td>Y16</td>
</tr>
<tr>
<td>Traffic &amp; Advertising</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y21</td>
<td>Y22</td>
</tr>
<tr>
<td>Depreciation of Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y30</td>
<td>Y30</td>
</tr>
<tr>
<td>Depreciation of Structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y31</td>
<td>Y31</td>
</tr>
<tr>
<td>Property Taxes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y27</td>
<td></td>
</tr>
<tr>
<td>Bond Interest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y28</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal Indirect Operating Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y37</td>
</tr>
<tr>
<td>Corporate Profits Tax</td>
<td>Y33</td>
<td>Y331</td>
<td>Y332</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After-Tax Return on Investment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y34</td>
</tr>
<tr>
<td>Total Required Annual Revenue</td>
<td>Y38</td>
<td>Y39</td>
<td>Y40</td>
<td>Y27</td>
<td>Y28</td>
<td>Y34</td>
<td>Y34</td>
<td>Y42</td>
</tr>
<tr>
<td>Less Actual Revenue Received from Fares</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Annual Subsidy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y43</td>
</tr>
</tbody>
</table>
Table 2 (cont'd)

<table>
<thead>
<tr>
<th>Total Initial Investment (Millions of Dollars)</th>
<th>Equipment</th>
<th>Structures</th>
<th>Land</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>x_1</td>
<td>x_3</td>
<td>x_5</td>
<td>x_6</td>
</tr>
<tr>
<td>Yards &amp; Shops</td>
<td></td>
<td>x_12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special Control Facilities</td>
<td>x_8</td>
<td>x_7</td>
<td>x_9</td>
<td>x_10</td>
</tr>
<tr>
<td>Total</td>
<td>x_13</td>
<td>x_14</td>
<td>x_15</td>
<td>x_11</td>
</tr>
</tbody>
</table>

Design Data

No. of Buses \( p_{30} \)
No. of Seats Per Bus \( d_1 \)
Annual Bus Miles \( w_2 \)
Annual Bus Hours \( w_3 \)
No. of Passenger Miles \( w_5 \)
Annual Passenger Trips \( w_7 \)
### Table 3

**SAMPLE PRINTOUT: INPUTS AND CALCULATED VALUES**

<table>
<thead>
<tr>
<th>A1</th>
<th>6.06000E+03</th>
<th>A2</th>
<th>1.22000E+08</th>
<th>A3</th>
<th>8.00000E+06</th>
<th>A4</th>
<th>9.00000E+07</th>
<th>A5</th>
<th>5.21999E+09</th>
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</thead>
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<td>A6</td>
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<td>1.22000E+01</td>
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<td>8.00000E+01</td>
<td>A10</td>
<td>5.21999E+01</td>
</tr>
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<td>2.20249E+01</td>
<td>A13</td>
<td>1.22000E+01</td>
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<td>A20</td>
<td>5.21999E+01</td>
</tr>
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<td>A22</td>
<td>2.20249E+01</td>
<td>A23</td>
<td>1.22000E+01</td>
<td>A24</td>
<td>8.00000E+01</td>
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<td>5.21999E+01</td>
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<td>8.00000E+01</td>
<td>A30</td>
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<td>A32</td>
<td>2.20249E+01</td>
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<td>A34</td>
<td>8.00000E+01</td>
<td>A35</td>
<td>5.21999E+01</td>
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<td>A36</td>
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<td>A37</td>
<td>4.20249E+01</td>
<td>A38</td>
<td>1.22000E+01</td>
<td>A39</td>
<td>8.00000E+01</td>
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<td>1.22000E+01</td>
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<td>8.00000E+01</td>
<td>A45</td>
<td>5.21999E+01</td>
</tr>
<tr>
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<td>A48</td>
<td>1.22000E+01</td>
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<td>8.00000E+01</td>
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<tr>
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<td>A54</td>
<td>8.00000E+01</td>
<td>A55</td>
<td>5.21999E+01</td>
</tr>
</tbody>
</table>
V. ILLUSTRATIVE APPLICATIONS OF THE BUS SYSTEM COST MODEL

The following section presents four examples that illustrate application of the Bus System Cost Model.

Figure 3 relates total annualized cost to annual bus-miles assuming a nominal 50-passenger GMC diesel bus operating at two average velocities. It is evident from these curves that increased velocity results in decreased cost and that diseconomies of scale exist. Increases in average velocity reduce cost because, all other things being equal, a fixed number of passenger miles can be accomplished in a shorter period of time. A reduction in bus-hours leads to a similar reduction in driver-hours and, because drivers' wages account for a large part of annual cost, a significant reduction in total annual cost.

The diseconomies of scale were first observed in the data and, as the fact was somewhat surprising, our results were discussed with several persons currently involved in the operation of transit companies. They were not surprised, and together we agreed that as transit companies become larger, they make less efficient use of drivers' time, spend proportionately more on advertising, have a proportionately larger and more expensive administrative structure, etc. The less efficient use of drivers' time seems to be the main factor.

To give some idea of the validity of the model, the experience of both the San Diego Transit Corporation (SDTC) and of the Southern California Rapid Transit District (SCRTD) as reported in the 1971 Transit Operating Report of the American Transit Association is indicated on the curves of Figs. 3 and 4. SDTC, which supposedly has an average bus speed of about 12 miles per hour, falls right on the 12-mile-per-hour curve. SCRTD falls somewhat below the 12-mile-per-hour curve, but although average speed data were not available, it probably achieves a somewhat greater speed than San Diego because line-haul distances are longer.

Figure 4 shows the cost per bus mile for operating the same buses at the same average velocities as were shown in Fig. 3. In addition,
Fig. 3 — Aggregate bus cost model: sample output
Fig. 4—Aggregate bus cost model: sample output
curves for a 20-passenger gasoline-powered bus have also been included. Here the diseconomies of scale are more evident. The curves also show that doubling the average velocity of the 50-passenger bus has a much greater effect on cost per bus-mile than does reducing the size of the bus from 50 to 20 passengers.

Figure 5 shows the effect of load factor on the cost per passenger-mile for the same buses shown in Fig. 4. Observe that as the average load factor moves from 1.0 to 0.5 as indicated the cost per passenger mile doubles.

Figure 6 shows the results of a somewhat more detailed analysis of the numerous factors that influence the annual cost of operating a bus system. Here total annual cost is plotted against annual passenger miles. The major thrust of this analysis was to provide some indications of what it might cost to provide a bus system that could (1) handle all passenger miles now traveled in San Diego, or (2) handle 80 percent of the passenger miles now traveled in Los Angeles. Figure 6 makes clear how sensitive costs are to the assumptions one makes about load factors and velocities (peak-hour and average). The figures spotted along several of the curves are the number of buses necessary to handle the peak-hour load. Note that the number of buses required is most dependent on the peak-hour operating factors. Other analyses with the model indicate that whether the bus company is privately or publicly operated has only a minor impact on the annual cost as does the type of fuel used (diesel versus gasoline).

All of the examples presented in this section are intended to illustrate the use of the Bus System Cost Model; they are not results of substantive analyses.

*Assumed average of 1.2 passengers per auto.
Fig. 5—Aggregate bus cost model; sample output
$V_p = \text{Velocity during peak hour (mph)}$

$V_a = \text{Average velocity (mph)}$

$L_p = \text{Load factor during peak hour}$

$L_a = \text{Average load factor}$

- Number of buses (thousands)

---

Fig. 6--Incremental Annual Bus System Cost vs Incremental Annual Passenger Miles (50-Passenger Diesel Buses Operated by a Public Corporation)
Appendix A

NOTES ON THE DEVELOPMENT OF COST-ESTIMATING RELATIONSHIPS
DEVELOPMENT OF BUS FUEL COST ESTIMATING RELATIONSHIPS: DIESEL AND GASOLINE POWERED BUSES
RELATIONSHIP BETWEEN VEHICLE EMPTY WT (INCL. TIRES & FUEL) 
AND NUMBER OF PASSENGER SEATS

DATA FROM GMC LOCAL REPRESENTATIVE BY PHONE 12/17/72; MR. BOYCE JOHNSON, 487-1946
SANTA MONICA, CALIF.

<table>
<thead>
<tr>
<th>NO. OF SEATS PER BUS</th>
<th>NO. OF CYL.</th>
<th>AIR CON/DX.</th>
<th>WT. EMPTY *</th>
<th>BASE COST **</th>
<th>LENGTH FT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
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<td>NO</td>
<td>14,800</td>
<td>33,000</td>
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<td>15,200</td>
<td>34,400</td>
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<td>30,600</td>
<td>35</td>
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<td>6</td>
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<td>21,400</td>
<td>36,500</td>
<td>40</td>
</tr>
<tr>
<td>63</td>
<td>6</td>
<td>NO</td>
<td>21,030</td>
<td>34,500</td>
<td>40</td>
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<tr>
<td>63</td>
<td>6</td>
<td>YES</td>
<td>22,045</td>
<td>39,100</td>
<td>40</td>
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</table>

* INCLUDES 6 TIRES PER BUS AND 6 TIRES PER BUS (Δ 360.185) AND FUEL
** DOES NOT INCLUDE SALES TAX

INCREMENTAL FOR AIR CONDITIONING

<table>
<thead>
<tr>
<th>NO. OF SEATS PER BUS</th>
<th>NO. OF CYL.</th>
<th>AIR CON/DX.</th>
<th>Δ WEIGHT LBS.</th>
<th>Δ COST **</th>
<th>LENGTH FT.</th>
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<tr>
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<td>725</td>
<td>3,400</td>
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<tr>
<td>45</td>
<td>6</td>
<td>YES</td>
<td>1020</td>
<td>4,550</td>
<td>35</td>
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<td>1050</td>
<td>4,500</td>
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<tr>
<td>63</td>
<td>6</td>
<td>YES</td>
<td>1085</td>
<td>4,600</td>
<td>40</td>
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</table>

DATA FROM GORD - MINIBUS BY PHONE 12/1/72; MR. JIM HOLLER, 747-6777 LOS ANGELES

MINIBUS WITH PERIPHERAL SEATING & OTHER UNSPECIFIED GOODIES BUT BASIC BUS:

EMPTY WEIGHT 9,800 LBS
BASE COST (TAXES NOT INCL.) 17,444 DOLLARS
NO. OF SEATS 19-21

DATA FROM FLEXIBLE RE FLEXETTE, SALES BROCHURE NO. 947431, THE FLEXIBLE COMPAQ
LODONVILLE, OHIO 10/16/72

21 FT./19 PASSENGER COACH:
WEIGHT LOADED 11,000 LBS
LESS PASS WT. 6,150 LBS 8,850 LBS = EMPTY WEIGHT

ESTIMATE FOR TYPICAL PASSENGER CAR
4 PASSENGER SEATS
3,000 LBS. EMPTY WEIGHT
FIG. 1

VEHICLE WEIGHT EMPTY INCL.
TIRES AND FUEL

\[ W_E = 1000 + 394 L_1 \]

- \( \bigcirc \) = GM WITH AIR CONDITIONING
- \( \square \) = SICK M.G. MINIBUS
- \( + \) = FLEXIBLE FLEXETTE
- \( \triangle \) = TYPICAL PASSENGER CAR

VEHICLE WEIGHT EMPTY (LBS, NOT NET)

NUMBER OF PASSENGER SEATS PER BUS


**RELATIONSHIP BETWEEN FUEL CONSUMPTION AND AVERAGE GROSS WT. OF VEHICLE**

**DATA USED IN COMPUTING STATE ROAD USER TAXES AND PROPERTY TAXES ON SELECTED VEHICLES, 1956 REGISTRATION YEAR**

**MULTI-UNIT DIESEL POWERED TRUCKS AND GASOLINE POWERED PASSENGER CARS**

**“DIESEL TRUCKS”**

<table>
<thead>
<tr>
<th></th>
<th>NO. 9 DIESEL</th>
<th>NO. 10 DIESEL</th>
<th>NO. 11 DIESEL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROSS WEIGHT (lbs)</strong></td>
<td>23,000</td>
<td>36,000</td>
<td>25,000</td>
</tr>
<tr>
<td><strong>TRACTOR TRUCK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SEMI-TRAILER</strong></td>
<td>27,000</td>
<td>24,000</td>
<td>19,000</td>
</tr>
<tr>
<td><strong>FULL TRAILER</strong></td>
<td></td>
<td></td>
<td>55,000</td>
</tr>
<tr>
<td><strong>COMBINATION</strong></td>
<td>60,000</td>
<td>62,000</td>
<td>68,000</td>
</tr>
<tr>
<td><strong>GROSS WEIGHT AVERAGE (lbs)</strong></td>
<td>37,148</td>
<td>54,756</td>
<td>59,545</td>
</tr>
<tr>
<td><strong>AVERAGE MILES PER GALLON</strong></td>
<td>6.0</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>AVERAGE GALLONS PER MILE</strong></td>
<td>0.167</td>
<td>0.213</td>
<td>0.285</td>
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</tbody>
</table>

**“PASSENGER CARS”**

<table>
<thead>
<tr>
<th></th>
<th>NO. 1 LIGHT GASOLINE PASSENGER</th>
<th>NO. 2 MEDIUM GASOLINE PASSENGER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROSS WEIGHT (lbs)</strong></td>
<td>3,814</td>
<td>4,705</td>
</tr>
<tr>
<td><strong>GROSS WEIGHT AVERAGE (lbs)</strong></td>
<td>3,167</td>
<td>3,953</td>
</tr>
<tr>
<td><strong>AVERAGE MILES PER GALLON</strong></td>
<td>11.5</td>
<td>14.5</td>
</tr>
<tr>
<td><strong>AVERAGE GALLONS PER MILE</strong></td>
<td>0.061</td>
<td>0.069</td>
</tr>
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</table>

**DATA ON FUEL CONSUMPTION FOR DIESEL POWERED INTRAURBAN DIESEL POWERED BUSES FROM AMERICAN TRANSIT ASSOCIATION, 1971 TRANSIT OPERATING REPORT**

**Fig. 2**

- **AVERAGE** = 4.96
- **SAMPLE SIZE** = 770 TRANSIT BUS

**Fig. 3**

- **AVERAGE** = 12.3 CENTS/GAL
- **SAMPLE SIZE** = 72 TRANSIT BUS

**AVERAGE COST OF DIESEL OIL AS A FRACTION OF THE COST OF DIESEL FUEL**

| 0.0713 | BASED ON EXPERIENCE OF 72 TRANSIT COMPANIES |
**DATA FROM AMARILLO TRANSIT SYSTEM (AUGUST, 1972) ON OPERATION OF 18 FLEXETTES - 19 PASSENGER, GASOLINE POWERED, AUTOMATIC TRANS. MINIBUSSED**

**Stated Average Fuel Consumption** = 6.46 miles/gal = 0.155 gal/mile

Weight Loaded (See Data Page 1) = 11,000 lbs

**DATA FROM 1971 ATA TRANSIT OPERATING REPORT OF COST PER GALLON OF GASOLINE**

<table>
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<tr>
<th>Transit #</th>
<th>$/Gal</th>
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<tbody>
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<td>1</td>
<td>12.5</td>
</tr>
<tr>
<td>2</td>
<td>12.7</td>
</tr>
<tr>
<td>3</td>
<td>15.9</td>
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<tr>
<td>4</td>
<td>9.9</td>
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<td>5</td>
<td>7.1</td>
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<td>11.8</td>
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<tr>
<td>7</td>
<td>13.3</td>
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<tr>
<td>8</td>
<td>14.5</td>
</tr>
<tr>
<td>9</td>
<td>15.9</td>
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<tr>
<td>10</td>
<td>11.5</td>
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<tr>
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</tr>
<tr>
<td>15</td>
<td>23.6</td>
</tr>
<tr>
<td>16</td>
<td>15.6</td>
</tr>
</tbody>
</table>

\[
\frac{232.5 \text{ L}}{16} = 14.52 \approx 15
\]
1. Plot data on multi-unit diesel powered trucks and connect with smooth curve.

2. Plot data on gasoline powered passenger cars.

3. Plot data from APA assuming average 50 passenger bus with average gross weight as follows:

   Vehicle empty weight from: \( W_e = 100 + 394 \times (50) = 30,700 \)

   Assume 50 percent load factor: 15,150

   Average gross weight: 24,450

   Average gallons per mile: \( \frac{1}{5} \)

4. Extrapolate curve for multi-unit diesel powered trucks to the left until weight equal to that of bus, (free hand extrapolate).

5. Assume bus efficiency less than truck due to continual stopping and starting and that ratio is constant with average gross weight of vehicle. Create bus curve based on truck curve and ratio between APA point and point on extension of truck curve at 24,450 lbs.

6. Theory indicates that consumption should be approx. 50% greater than diesel (all other things being equal). Diesel fuel has more Btu's per gallon and the diesel engine is inherently a more efficient engine. A comparison between diesel bus curve and the data points for passenger cars is not inconsistent with this. Draw gasoline powered bus curve from diesel curve but up 50%.

7. Plot data on flexible tires to support gasoline bus curve.
Fig. 4 - 54 -

Fuel Consumption vs Average Gross Wt.
for Diesel and Gasoline Powered Buses

Note: Curves should not be used for buses with average gross weights greater than 30-40 thousand lbs

- ■ = Multi-Unit Diesel Trucks
- ○ = Gasoline Powered Passenger Cars
- ★ = ATA Average Diesel Powered 50 Pass. Buses
- ▲ = Gasoline Powered Flexible "Flairlette"
Relationship between fuel consumption and number of seats

Assume average bus load factor of 50 percent. Thus from equation in Fig. 5, average gross weight may be calculated as follows:

\[ W_g = 1000 + 394 L_1 + 150 L_1^2 \]

<table>
<thead>
<tr>
<th>No. Seats</th>
<th>( W_g )</th>
<th>Gallons/mile gasoline</th>
<th>Gallons/mile diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5,490</td>
<td>0.087</td>
<td>0.054</td>
</tr>
<tr>
<td>20</td>
<td>10,380</td>
<td>0.14</td>
<td>0.095</td>
</tr>
<tr>
<td>30</td>
<td>16,010</td>
<td>0.19</td>
<td>0.130</td>
</tr>
<tr>
<td>40</td>
<td>19,740</td>
<td>0.25</td>
<td>0.167</td>
</tr>
<tr>
<td>50</td>
<td>24,450</td>
<td>0.305</td>
<td>0.200</td>
</tr>
<tr>
<td>60</td>
<td>29,160</td>
<td>0.355</td>
<td>0.255</td>
</tr>
</tbody>
</table>

* Read from curves in Fig. 21

**Fig. 5**

Fuel consumption vs no. of seats

Diesel & gasoline powered buses

Gasoline: \( r_g = 0.030 + 0.0054 L_1 \)

Diesel: \( r_d = 0.020 + 0.0036 L_1 \)
ESTIMATING RELATIONSHIP FOR FUEL CONSUMPTION

DIESEL POWERED BUSES: (INCL. ALLOWANCE FOR LUBRICATING OIL)

\[ P^D = 1.07 (0.040 + 0.0036 L_1) \]

GASOLINE POWERED BUSES: (INCL. ALLOWANCE FOR LUBRICATING OIL)

\[ P^G = 1.5 P^D \]

DIESEL FUEL COST PER GALLON FROM ATA 1971 TRANSIT OPERATING REPORT

SEE FIG. 3 PAGE 3 = 13.0 CENTS PER GALLON = C_{10}

GASOLINE COST PER GALLON (ESTIMATE BASED ON 1971 ATA TRANSIT OPERATING REPORT

= 15 CENTS PER GALLON = C_{10}

ANNUAL FUEL COST ESTIMATING RELATIONSHIP

\[ M_f = C_{10} C_{13} W_2 (1 + C_{11})(C_{12} + C_{13} L_1) \]

WHERE:

- \( M_f \) = ANNUAL COST OF FUEL AND LUBRICATING OIL IN DOLLARS
- \( C_{10} \) = FUEL COST PER GALLON IN DOLLARS: DIESEL = .13; GASOLINE = .15
- \( C_{11} \) = FRACTION OF FUEL COST FOR LUBRICATING OIL = 0.07
- \( C_{12} \) = CONSTANT IN FUEL CONSUMPTION EQUATION = 0.020
- \( C_{13} \) = COEFFICIENT IN \( L_1 \) = 0.0036
- \( C_{13} \) = FUEL TYPE MULTIPLIER: DIESEL = 1, GASOLINE = 1.5
- \( L_1 \) = NUMBER OF SEATS PER BUS
- \( W_2 \) = ANNUAL BUS MILES
DEVELOPMENT OF RUS PROCUREMENT COST ESTIMATING RELATIONSHIP
ESTIMATING BUS PROCUREMENT COST VS EMPTY WEIGHT

DATA FROM GMC LOCAL REP. AND FROM SCRTD MINIBUS - SEE PAGE 1 OF SECTION ON FUEL COST ESTIMATING RELATIONSHIP. [CJ] [10]

\[ C = 2500 + 1.5W_e \]

\[ W_e = 1500 + 39.4S \]

- GMC BUSES WITHOUT AIR CONDITIONING [CJ]
- SCRTD MINIBUS [10]
- FLEXIBLE FLEXETTE [1]
- TYPICAL PASSENGER CAR
ESTIMATING BASE COST AS A FUNCTION OF NO. OF SEATS

\[ C = 2500 + 1.5 \times W_E \]

\[ W_E = 1500 + 374 \times S \]

\[ C = 2500 + 1.5(1500 + 394 \times S) \]

\[ C = 4750 + 591 \times S \]

BUS COST ESTIMATING RELATIONSHIP

\[ Y_1 = (1 + C_5)(C_2 + C_4 + C_3 \times d_3)(1 + d_3) \times W_1 \]

WHERE:

- \( Y_1 \) = Initial investment in buses (dollars)
- \( C_2 \) = Constant for bus procurement eq. : \$4,750
- \( C_3 \) = Coeff. of no. of seats in bus procurement eq. : \$591
- \( C_4 \) = Cost of air cond. or other spec. : per bus : \$300 / AIR COOLED
- \( C_5 \) = State sales tax rate (fraction) : .05
- \( W_1 \) = No. of seats per bus
- \( d_3 \) = Extra buses req. for downtime etc. (fraction of total) : .20
- \( W_1 \) = No. of buses req. in peak hour

* AVERAGE FROM ATA 1971 TRANSIT OPERATING REPORT - 247
DEVELOPMENT OF ANNUAL DRIVERS AND HELPERS WAGES ESTIMATING RELATIONSHIP
<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>ANNUAL BUS HOURS</th>
<th>DRIVER AND HELPER DAILY HOURS</th>
<th>HELPER'S WAGES</th>
<th>SYSTEM</th>
<th>ANNUAL BUS HOURS</th>
<th>DRIVER AND HELPER DAILY HOURS</th>
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<td>43</td>
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<td>123</td>
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<td>12</td>
<td>B-105</td>
<td>89</td>
<td>123</td>
<td>383</td>
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<td>123</td>
<td>123</td>
<td>B-107</td>
<td>89</td>
<td>123</td>
<td>383</td>
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<td>B-118</td>
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<td>123</td>
<td>B-108</td>
<td>97</td>
<td>123</td>
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<td>B-119</td>
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<td>123</td>
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<td>97</td>
<td>123</td>
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<td>B-120</td>
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<td>123</td>
<td>B-110</td>
<td>89</td>
<td>123</td>
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<td>B-121</td>
<td>37</td>
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<td>123</td>
<td>B-111</td>
<td>89</td>
<td>123</td>
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<tr>
<td></td>
<td>AVG. = 57.3</td>
<td>AVG. = 180.4</td>
<td></td>
<td>AVG.</td>
<td>206.0</td>
<td>AVG. = 469.4</td>
<td></td>
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</table>

Note: (SOLID BUS ONLY AS BUS HOURS APPEAR IN AVG. REPORTED AS BUS MILES, HOWEVER SEE NEXT PAGE)
ANNUAL DRIVERS AND HELPERS WAGES
ANNUAL BUS MILES - TOTAL
ANNUAL BUS HOURS - TOTAL

SUSPECT THAT BUS MILE FIGURE IS O.K. BUT BUS HOURS IS WRONG. CHECKED THIS HYPOTHESIS AS FOLLOWS.

USE DERIVED ESTIMATING RELATIONSHIP AND ANNUAL DRIVERS AND HELPERS WAGES TO ESTIMATE ANNUAL BUS HOURS: DIVIDE REPORTED ANNUAL BUS MILES BY ESTIMATED ANNUAL BUS HOURS AND CHECK REASONABLENESS OF CALCULATED AVERAGE VELOCITY.

\[ y^4 = 4.93 \times 10^{-6} \]

\[ y^4 = 27.172 \times 10^6 \]

\[ y^4 = \exp\left(\frac{\ln(27.172)}{4.93}\right) = 4.192 \times 10^6 \text{ ANNUAL BUS HOURS} \]

\[ y^4 = 58.784 \times 10^6 \text{ ANNUAL BUS MILES} \]

\[ \frac{58.784 \times 10^6 \text{ ANNUAL BUS MILES}}{4.192 \times 10^6 \text{ ANNUAL BUS HOURS}} = 14.0 \text{ MILE/HOUR} \]

THIS IS A COMPLETELY REASONABLE VELOCITY SO CONCLUDE:

- ANNUAL BUS MILES REPORTED CORRECTLY
- ANNUAL BUS HOUR REPORTED INCORRECTLY

ADDITION OF FRINGE BENEFITS

AN EXAMINATION OF THE BREAKDOWN OF THE COMPONENTS OF THE I.C.C. ACCOUNTS FOR TRANSPORTATION EXPENSE ($400) AND FOR ADMINISTRATION AND GENERAL EXPENSE ($400) AT LEAST SOME FRINGE BENEFITS ARE PICKED UP IN EMPLOYEES' WELFARE EXPENSES ($42). WE DESIRED TO INCLUDE ALL FRINGE BENEFITS FOR DRIVERS AND HELPERS IN THE DRIVERS AND HELPERS WAGES CATEGORY SO THE ESTIMATING RELATIONSHIP DERIVED PREVIOUSLY WAS ALTERED BY MULTIPLYING BY 1.1 (ADJUST 10% TO COVER FRINGE BENEFITS NOT ALREADY INCLUDED IN ESTIMATE). THE ESTIMATING RELATIONSHIP FOR ADMINISTRATION AND GENERAL EXPENSE IS, OF COURSE, REDUCED BY THE SAME AMOUNT (10% OF $4). IN THE MODEL, THE ESTIMATING RELATIONSHIP FOR DRIVERS AND HELPERS WAGES INCLUDES FRINGE BENEFITS AND APPEARS AS FOLLOWS.

\[ y^4 = 1.1 \times 10^6 c_6 (w^3 \times 10^{-6}) \]

WHERE:  
\[ c_6 = 4.93 \]
\[ c_4 = 1.1 \]
DEVELOPMENT OF EQUIPMENT MAINTENANCE
AND GARAGE COST ESTIMATING
RELATIONSHIP
EQUIPMENT MAINTENANCE & GARAGE CONSISTS OF THREE COMPONENTS AS FOLLOWS:

1. REPAIRS TO REVENUE EQUIPMENT (REPORTED SEPARATELY)
2. TIRES AND TUBES (OBTAINED BY SUBTRACTION)
3. OTHER (REPORTED SEPARATELY)
4. TOTAL

ITEMS 1, 2, & 4 WERE DEALT WITH BY TAKING OFF THE ANNUAL COST AND TAKING OFF THE ANNUAL BUS MILES FOR EACH OF THE 98 TRANSIT COMPANIES. THE PAIRED DATA POINTS WERE ORDERED ON ANNUAL BUS MILES AND DIVIDED INTO GROUPS OF APPROXIMATELY 10 DATA POINTS EACH, FOR EACH GROUP AVERAGES WERE CALCULATED FOR BOTH ANNUAL COST AND ANNUAL BUS MILES. REGRESSION LINES WERE FIT TO THE POINTS REPRESENTED BY THE PAIRED AVERAGES. EACH LINE WAS FORCED THROUGH THE ORIGIN. ACTUALLY, THIS WAS INDICATED BY THE DATA SO THE ADJUSTMENT HAD LITTLE EFFECT ON THE SLOPES. ALL THREE CATEGORIES OF COST WERE LINEAR WITH BUS MILES. THE RESULTS ARE SHOWN BELOW, IN FIGS. 1, 2, & 3.

FIG. 1

REPAIRS TO REVENUE EQUIPMENT

\[
C_1 = 0.025 \text{ PER BUS MILE}
\]
FIG. 1

TIRES AND TUBES

\[ C_2 = \frac{0.00983}{\text{PER BUS MILE}} \]
Fig. 3
Total Equipment Maintenance and Garage

Annual Cost (1000's of Dollars)

Annual Bus Miles (Millions)

$C_4 = \frac{\$0.158}{\text{Bus Mile}}$

Calculation of Other Equipment Maint. & Garage by Subtraction

Total Eq. Maint. & Garage (Fig. 3) $\quad \$0.158 \text{ / Bus Mile}$
Repairs to Rev. Equr. (Fig. 1) $\quad \$0.0819 \text{ / Bus Mile}$
Tires & Tubes (Fig. 2) $\quad \$0.0983 \text{ / Bus Mile}$
Sub Total $\quad \$0.2803 \text{ / Bus Mile}$
Other Eq. Maint. & Garage (by Subtraction) $\quad \$0.0447 \text{ / Bus Mile}$
ESTIMATE REPAIRS & TIRES & TUBES FOR TYPICAL PASSENGER CAR WITH 30,000 MILES PER YEAR (LIKE BUS) AT:

$0.025 PER MILE


<table>
<thead>
<tr>
<th>NUMBER OF SEATS/BUS</th>
<th>77</th>
<th>47.3</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAINTENANCE &amp; GARAGE $/MILE</td>
<td>.0343</td>
<td>.0801</td>
<td>.058</td>
</tr>
<tr>
<td>TIRES AND TIRES</td>
<td>.0174</td>
<td>.059</td>
<td>.068</td>
</tr>
<tr>
<td>TOTAL</td>
<td>.1517</td>
<td>.139</td>
<td>.058</td>
</tr>
</tbody>
</table>

These 1967 prices and should be inflated to 1971 to be comparable with ATA data (P. K. 1, 2, 3). Also looks like GRC main. & garage cost is comparable to ATA Repairs to Revenue. Note: incl. as running costs. If latter is true atd no. of .091/.3 for ata (avg bus size 47.3) may reflect price changes between 1967 and 1971 to.

\[
\frac{0.9173}{0.893} = 1.027 \quad \text{SEEMS LOW}
\]

However probably other data differences as well. Assuming data are at least reasonably consistent and that ata data is for a bus of approx. 50 passengers (average), we can put at as below.

\[
C_{12} = 0.0155^p 0.457
\]

- GRC DATA [1, 2]
- AVG. FROM ATA (SEE PAGE 2) [3]
- EST. FOR TYP. PASS. CAR

Note: probably not good for buses with more than 50 seats.
THE INCLUSION OF OTHER EQUIPMENT MAINT. & GARAGE IS ACCOMPLISHED BY MULTIPLYING FUNCTION JUST DERIVED BY THE RATIO OF TOTAL EQUIP. MAINT. & GARAGE TO THE TOTAL LESS OTHER AS FOLLOWS (DATA FROM PAGE 3).

\[
C_{H243} = \left( \frac{0.158}{0.0912} \right) \times 0.015 \times \frac{S}{0.457}
\]

\[
= 0.0258 \times S \times 0.457
\]

ESTIMATING RELATIONSHIP FOR TOTAL EQUIPMENT MAINTENANCE & GARAGE

\[
\frac{N_8}{n} = C_6 W_2 L_1
\]

WHERE:

- \( N_8 \) = TOTAL ANNUAL EQUIPMENT MAINT. & GARAGE
- \( C_6 \) = COEFFICIENT : 0.0258
- \( L_1 \) = EXPONENT : 0.457
- \( W_2 \) = ANNUAL BUS MILES
- \( L_1 \) = NO. OF SEATS PER BUS

NOTE SPLIT BETWEEN LABOR AND MATERIAL IS ESTIMATED TO BE

\[
C_{33} = 0.70 \ \therefore \ C_3 = \text{LABOR}
\]

\[
1 - C_{33} = 0.30 \ \therefore \ C_3 = \text{MATERIALS}
\]
DEVELOPMENT OF ESTIMATING RELATIONSHIPS
FOR ANNUAL:

- TRAFFIC AND ADVERTISING EXPENSE
- INSURANCE AND SAFETY EXPENSE
- GENERAL AND ADMINISTRATION EXPENSE
<table>
<thead>
<tr>
<th>SYSTEM KEY NO.</th>
<th>ANNUAL BUS MILES 1,000.0</th>
<th>ANNUAL TRAFFIC AND ADVERTISING EXPENSE (1,000.0)</th>
<th>ANNUAL INS. &amp; SAFETY EXPENSE (1,000.0)</th>
<th>ANNUAL ADMINISTRATION &amp; GENERAL EXPENSE (1,000.0)</th>
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<td>20</td>
<td>184</td>
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<td>65</td>
<td>215</td>
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<td>B-69</td>
<td>2081</td>
<td>13</td>
<td>65</td>
<td>217</td>
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<td>B-44</td>
<td>2121</td>
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<td>227</td>
<td>352</td>
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<td>2119</td>
<td>9</td>
<td>87</td>
<td>244</td>
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<td>427</td>
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<td>B-38</td>
<td>5094</td>
<td>199</td>
<td>307</td>
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<td>B-41</td>
<td>8136</td>
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<td>165</td>
<td>716</td>
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<td>B-26</td>
<td>8890</td>
<td>170</td>
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<td>AVE.</td>
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ESTIMATING RELATIONSHIP FOR
ANNUAL INSURANCE AND SAFETY EXPENSE

USING ACTUAL MILES AND CALCULATING
ACTUAL DOLLARS

\[ Y = 78,448 + 7.759 \times 10^{-6} W^2 
\]

\[ Y = c_{170} + c_{171} W^2 \]

ANNUAL BUS MILES IN MILLIONS
Estimating Relationship for Annual Administration & General Expense

Using Hotai Miles and Calculating Hourly Dollars and BxP for Drivers & Helpers Fringe Benefits

\[ y_{13} = 9.54 \times 10^{-4} w_2^{1.18} \]

After Hotai for Fringe Benefits and As Used in the Model

\[ y_{13} = c_{15} w_2 - .091 y_4 \]

\[ c_{15} = 9.54 \times 10^{-4} \]
\[ c_{16} = 1.18 \]
\[ w_2 = Annual \text{ Bus Miles} \]
DEVELOPMENT OF COST ESTIMATING RELATIONSHIP:
INVESTMENT IN YARDS AND SHOPS
1. Estimate bus length as a function of no. of seats.

<table>
<thead>
<tr>
<th>NO OF SEATS</th>
<th>LENGTH IN FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>53</td>
<td>40</td>
</tr>
<tr>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>22</td>
<td>23</td>
</tr>
</tbody>
</table>

DATA FROM GML

MINIBUS & FLEXETTE

2. Assume avg. bus is 8 ft. wide and calc. bus area in ft²

\[
\text{Bus Area} = a = 8(12.5 + 0.52 A)
\]

\[
a = 100 + 4.16 A
\]

3. Assume parking & yard area per bus is 4 x bus area thus

\[
\text{Parking & Yard Area} = 4A = 4(100 + 4.16 A)
\]

\[
A = 400 + 16.64 A
\]

Note: includes parking, bus service area, driveway, & maneuvering space

4. Assume land rates are equal to parking and yard area thus land cost is

\[
\text{Land Cost} = (\text{Land Cost/ft}^2)(\text{Parking & Yard Area})
\]

5. Paving for parking & yard area: $6.50/ft²

\[
\text{Paving Cost} = 6.50 (\text{Parking & Yard Area})
\]

6. Garage Area @ $20/ft²

Assume: 5% of buses in garage at one time

\[
\$20/ft² \text{ for construction}
\]

\[
\$10/ft² \text{ for equipment}
\]
7. Estimate square feet of shop

\[ p_2 = d_2 (1 + d_3) (c_23 + c_25 d_1) w_1 \]

8. Estimate square feet of parking area

\[ p_3 = p_2 / d_2 \]

9. Estimate square feet of land required

\[ p' = p_2 + p_3 \]

10. Estimate initial investment in yards & shop

- Structures: \( y_2 = c_23 p_2 \)
- Equipment: \( y_3 = c_24 p_2 \)
- Paving: \( y_4 = c_27 p_3 \)
- Land: \( y_5 = c_28 p' \)
- Total: \( y_6 = y_2 + y_3 + y_4 + y_5 \)

Where:

- \( w_1 \) = number of buses req. in peak hour
- \( d_1 \) = number of seats per bus
- \( d_2 \) = fraction of buses in shop
- \( d_3 \) = extra buses for lighting, etc. (fraction of total)
- \( c_23 \) = shop construct cost \((\$/ft^2)\)
- \( c_24 \) = shop equip cost \((\$/ft^2)\)
- \( c_27 \) = cost of paving \((\$/ft^2)\)
- \( c_28 \) = cost of land \((\$/ft^2)\)
DEVELOPMENT OF COST ESTIMATING RELATIONSHIP FOR OTHER OPERATING TAXES AND LICENSES
### Estimating Other Operating Taxes and Licenses

<table>
<thead>
<tr>
<th></th>
<th>SFORI</th>
<th>SAN DIEGO</th>
<th>OAKLAND</th>
<th>LONG BEACH</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Operating Taxes &amp; Licenses</td>
<td>$1,992,000</td>
<td>$277,972</td>
<td>$697,059</td>
<td>$170,920</td>
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</tr>
<tr>
<td>Gallons of Fuel Consumed</td>
<td>13,034,000</td>
<td>1,603,133</td>
<td>5,121,337</td>
<td>1,700,067</td>
<td></td>
</tr>
<tr>
<td>Fuel Tax Rate (Fed + State Public)</td>
<td>$.05/gal</td>
<td>$.05/gal</td>
<td>$.05/gal</td>
<td>$.05/gal</td>
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<td>Total Fuel Tax</td>
<td>$651,640</td>
<td>$80,107</td>
<td>$256,066</td>
<td>$50,353</td>
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<tr>
<td>Other Operating Taxes &amp; Licenses</td>
<td>1,341,000</td>
<td>1,971,845</td>
<td>440,963</td>
<td>120,547</td>
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</tr>
<tr>
<td>Number of Buses Owned</td>
<td>1685</td>
<td>228</td>
<td>715</td>
<td>133</td>
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<tr>
<td>Other Operating Taxes &amp; Licenses/Bus</td>
<td>$795</td>
<td>$868</td>
<td>$617</td>
<td>$907</td>
<td>~ $8.50</td>
</tr>
</tbody>
</table>

**Average Cost per Seat:** \[ \frac{550}{50} = \$11.00 \]

**Thus:** Other Operating Taxes & Licenses = \[ \frac{W_1 d_1 (1 + d_8)}{W_2} \]

**Where:**
- \( W_1 \) = No. of Buses Required in Peak Hour
- \( d_1 \) = No. of Seats Per Bus
- \( d_8 \) = Extra Buses for Downtime B/c. Fract. of \( W_1 \)
- \( C_29 \) = Other Operating Taxes & Licenses $/Seat = $17.00

**Note:** Data on Selected California Bus Companies from 1971 ATA Transit Operating Report [4]
Appendix B
DESCRIPTION OF OVERALL STUDY METHODOLOGY

METHODOLOGY COMPONENTS

This appendix presents summary descriptions of the important analytical models and methods that were used in evaluating alternative air quality control strategies for San Diego. Our tools reflect the policy orientation of the study. They were designed to assist in the evaluation of a large number of conceptual strategies defined in relatively gross terms and to emphasize breadth of scope rather than depth of detail:

All of the models and methods have been tailored to San Diego's particular characteristics, but at the same time have purposely been made general enough to be easily adapted for use in similar studies of other regions. To provide flexibility, the inputs necessary to describe a strategy have been held to a minimum. They have been carefully selected to capture the most important characteristics of the alternative strategies and to be useful in estimating the full range of impacts.

The methodology includes the following major components:

- The Fixed Source Analysis Techniques (12) evaluate the cost and effectiveness of controls on fixed sources, which include aircraft. They also estimate the distribution of costs among various civilian industries and the military.
- The MOVEC (Motor Vehicle Emission and Cost) Model (13) evaluates the cost and effectiveness of retrofit and inspection/maintenance strategies for in-use vehicles. MOVEC also reports detailed impacts for each retrofit-I/M strategy considered, including the increase in fuel consumption and the distribution of retrofit-I/M costs among different income groups.
- The Transportation Model (6) evaluates the costs and effects of

*To illustrate, the tools were originally developed in the San Diego Clean Air Project and tailored to the San Diego region. They were transferred and tailored to the Los Angeles region in just a few weeks to study oxidant control strategies for Los Angeles.
transportation management strategies such as added gasoline taxes or improved bus service. Unlike other models, it considers induced changes in the amount of person-trips, carpooling, and congestion. It also reports detailed transportation service impacts, both in aggregate and as distributed among four income groups and two trip purposes, plus various economic impacts.

- The Bus System Cost Model is used to estimate the annualized costs of providing a particular quantity and quality of bus service to a region. An aggregate form of the model (the Aggregate Bus Cost Model) is incorporated in the overall transportation model where it is used to estimate total annualized cost for each bus system considered. The full model, run separately, estimates not only the detailed costs of each promising bus alternative, but also a variety of economic and financial impacts such as employment, fuel consumption, and taxes.

- Given a fixed source control strategy, a menu of vehicle retrofit-inspection/maintenance strategies, and a menu of transportation management strategies, the Tradeoff Model\(^{(14)}\) is used to find the best combination, i.e., the superior strategy. The best combination is defined as the one that meets the desired air quality standard for the minimum value of the total cost proxy, where this proxy includes both the net expenditure for strategy components and the monetary proxy for the social cost of forgone travel.\(^{*}\) Tradeoff reports a variety of economic, environmental, and transportation service impacts for the superior strategy it selects; most of the transportation service impacts come directly from the Transportation Model which operates within Tradeoff as a subroutine. Tradeoff also performs sensitivity analysis automatically for certain factors; for example, if alternative air quality standard levels are specified for a particular species, then Tradeoff will automatically select the superior strategy

\(^{*}\)All expenditures and costs are expressed as annual values; the investment costs have been annualized by means of a capital recovery factor approach. The "net expenditures" reflect the transfer of mileage surcharge revenue to offset the cost of bus improvements to whatever extent possible. When people are forced to alter their normal behavior by forgoing trips or switching to less desirable modes, they experience a loss in social value—"the social cost of forgone travel." We use the number of forgone trips as a proxy for this social cost and monetize it by multiplying this number by the dollar value of a forgone trip (suitably derived).
for each level from the given menu, thereby showing how superior strategy composition and cost vary with the level of the standard.

- The Air Quality Model determines the percentage reduction in base year emissions required to meet each air quality standard. This percentage is then multiplied by the total emissions in some base year* to determine the allowable emissions under that standard for any year.

- Techniques for the calculation of total base year emissions are described in Ref. 13.

- The Lareen Model (16) is used to estimate how air quality varies between different parts of the region. Specifically, it predicts the number of days the air quality standard for a particular species will be violated at each site in the region that has been historically monitoring that species. It, of course, does this for all species.

We shall now give an overview of the primary interactions and data flows among the various components of the overall methodology.

INTERACTIONS AND DATA FLOWS BETWEEN METHODOLOGY COMPONENTS

Figure B-1 presents a system flowchart of the Rand-developed methodology used to analyze the impacts of regional air quality control strategies. This flowchart shows the primary interactions and data flows between the major methodology components. Many of these components (e.g., the MOVEC and Bus System Cost Models) are useful as freestanding analysis tools. However, as indicated in the flowchart, the Tradeoff Model serves as the hub of the overall methodology. We shall describe the overall methodology from the perspective of the Tradeoff Model.

The initial inputs (upper-right-hand corner of the flowchart) to the Tradeoff Model are the case description, the dollar value of a trip forgone, and the bus system coverage (in terms of area and population served); the case description includes items such as the analysis year, regional population, and basic transportation information.

*The base year is some past year having detailed air quality measurements available and for which sufficient information exists to compile a total emissions inventory.
FIGURE B-1—METHODOLOGY COMPONENTS: INTERACTIONS AND DATA FLOWS
The next inputs to Tradeoff (moving from right to left on the flowchart) are the Aggregate Bus Cost Model coefficients; the Transportation Model uses these to estimate the cost of the bus system in terms of the number of buses, annual bus-miles, etc. These coefficients are generated by the Bus System Cost Model from parameters describing the institutional characteristics and cost situation of the local bus company.

Various strategy components are input next: (1) A menu of bus systems is described in terms of alternative combinations of headways and fares. (2) The allowable range of LDMV mileage surcharge is input. (3) An analysis of the fixed sources (including aircraft) is made. The cost of a specific fixed source control strategy is then input directly to the Tradeoff Model, while the corresponding fixed source emissions are then input to the MOVEC Model and subsequently passed to Tradeoff along with emissions from all sources other than LDMVs (e.g., heavy-duty trucks) previously input to MOVEC. (4) Composite cost and effectiveness parameters for each of the LDMV retrofit-I/M strategies being considered are input to Tradeoff for use in calculating the effects of retrofit strategies; these parameters are calculated by MOVEC from a menu of retrofit-I/M strategies and a semipermanent data set which includes a particular choice of technical assumptions, as well as the vehicle use characteristics, etc. The total emissions in the base year are input to Tradeoff from MOVEC; these were calculated in a separate analysis and provided to MOVEC. Tradeoff then determines the allowable emissions under a particular standard by multiplying the base year emissions by the percentage reduction in base year emissions required to meet that standard.

This required percentage reduction in base year emissions is the final input to Tradeoff; the Air Quality Model calculates one such percentage for each quality standard being considered.*

*To automatically investigate the sensitivity of results to the choice of standard and air quality model, Tradeoff can, in one run, consider five alternative standard levels for a particular species and employ three alternative air quality models besides linear rollback.
Using all the above information, Tradeoff calculates the costs and emissions for all possible combinations from a given menu of strategy components and then selects the best combination, i.e., the superior strategy. This selection process, as defined earlier, involves meeting the standards while minimizing the total cost proxy. The effects of transportation management strategies—including the amount of foregone travel, carpooling, and congestion—are calculated by the Transportation Model operating as a subroutine within Tradeoff. The emissions that Tradeoff calculates for each combination, with vehicle emissions corrected for speed, are compared to the allowable emissions under a particular air quality standard to determine whether it meets that standard.

Along with various economic, environmental, and transportation service impacts for the superior strategy selected, Tradeoff also outputs the actual percentage reduction in emissions. This is used by the Larsen Model to predict the number of days a particular air quality standard will be violated in different parts of the region.

GENERAL ANALYTICAL APPROACH

The primary goal in the San Diego Clean Air Project is to help County decisionmakers identify a preferred strategy for air pollution control in San Diego. But, given both fixed and mobile sources, potential strategies involve a multitudinous array of controls—so myriad that it becomes impractical to evaluate all feasible combinations. It therefore becomes necessary to use a three-step process in the search for a preferred strategy.

Identifying Promising Component Strategies

First, we identify a reasonable number of the most promising component strategies for fixed sources controls (including aircraft), retrofit-inspection/maintenance, and transportation management. The most "promising" component strategies are those that are most "cost-effective" in reducing emissions. By use of a cost-effectiveness criterion, we screen feasible combinations of control tactics so as to obtain a manageable number of promising component strategies to be subjected to further analysis. The screening process for fixed source
strategies employs the fixed source analysis techniques, that for retrofit-inspection/maintenance strategies employs the MOVEC Model, and that for transportation management strategies employs both the Transportation and Tradeoff Models. In this context, the cost of component strategy is its annualized cost (for procurement and operation) and its effectiveness is the amount by which it reduces emissions, primarily of reactive hydrocarbons, the most troublesome pollutant in San Diego.

**Identifying Superior Strategies**

Second, superior combinations of the promising component strategies are identified by using the Tradeoff Model. Given a specific fixed source strategy, a specific menu of retrofit strategies, and a specific menu of transportation management strategies, Tradeoff finds the best combination of what it was given—a superior strategy. Generally, a set of Tradeoff runs must be made in order to (1) consider a full menu of fixed source strategies, since Tradeoff can consider only one per run, and (2) refine the original menu of transportation management strategies with experience, since their effectiveness is partially dependent on the retrofit strategies' effectiveness. From this set of Tradeoff runs comes a set of superior strategies for further evaluation.*

*Here, the criterion for identifying superior strategies—meeting the air quality standards while minimizing the total cost proxy—has been more comprehensive than the cost-effectiveness criterion that was used to identify promising component strategies. But this is still not a sufficiently comprehensive criterion for selecting the preferred strategy for implementation.

**Evaluating and Comparing Superior Strategies**

Finally, the set of superior strategies are evaluated and compared in terms of their many impacts on the region. These many impacts—

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*Indeed, there will usually be several sets generated for purposes of sensitivity analysis: one set may be made for one year and under one set of technical assumptions; another set may be made for another year; and another set for another set of assumptions.
transportation service, economic, environmental, distributional--are estimated for each superior strategy and then presented to the decision-makers for the comparison of alternatives. The various impacts are shown on a "scorecard," a table which shows, by color code, each strategy ranking for a particular impact. The decisionmakers can then add to this factual knowledge their feeling for human and societal values--the intangibles--necessary for humane decisionmaking. (Reference 18 describes the scorecard concept and general approach.)

Most of the impacts for the scorecard are calculated directly by the various methodology components discussed previously. A few other impacts, primarily various kinds of employment, are calculated by applying ad hoc techniques to certain outputs from the methodology components. For example, the cost estimates that MOVEC provides for the installation and maintenance of retrofit devices are used to calculate the nonrecurring and recurring direct employment for mechanics.* Similarly, the reduction in annual miles, estimated by the Transportation Model, is used to calculate the reduction in direct employment for service station attendants.** Such changes in the direct employment of one sector of the regional economy produce changes in the employment of interrelated sectors called "indirect employment"; e.g., an increase in mechanics should increase employment for their local suppliers. The San Diego Input/Output Model (17) is used to estimate these indirect employment effects.***

* The nonrecurring and recurring direct employment are estimated by taking the total annual labor cost for retrofit installation and maintenance, respectively, and dividing them by an estimate of the average salary (including overhead) of a semiskilled mechanic in San Diego.

** Reductions in service station employment are estimated by assuming service station employment is proportional to annual miles driven.

*** Significantly, the employment impacts considered are limited to those occurring in San Diego in the near-term. Most of the fixed source and retrofit control devices mentioned are manufactured outside San Diego; it has not been practical to estimate their direct employment effects or other regions or their indirect effects on San Diego. Furthermore, given the complex interrelations among the various sectors of the San Diego, national, and world economies and the great uncertainties about the future, it has not been practical to estimate long-term economic impacts on the San Diego economy.
REFERENCES


5. Informal conversation with Don C. Johnson, GMC local representative, Santa Monica, California, on December 17, 1972.


9. Informal conversations with operations manager of the Santa Monica Municipal Bus Company.

10. Telephone conversation re Minibus with Jim Holger, Southern California Rapid Transit District, on December 8, 1972.


