NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 15

Transit Capital Investment To Reduce Operating Deficits — Alternative Bus Replacement Strategies

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AREAS OF INTEREST

Finance
Vehicle Characteristics
(Public Transit)

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NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one is which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services, (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance.

Research Programs for the NCTRP are developed annually by the Technical Steering Group, which identifies key problems, ranks them in order of priority, and establishes programs of projects for UMTA approval. Once approved, they are referred to the National Research Council for acceptance and administration through the Transportation Research Board.

Research projects addressing the problems referred from UMTA are defined by panels of experts established by the Board to provide technical guidance and counsel in the problem areas. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out by these agencies under contract to the National Reserch Council, and administration and surveillance of the contract work are the responsibilities of the National Research Council and Board.

The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

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

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

Public transit officials concerned with cost control will be interested in this report on bus replacement and rehabilitation strategies. The methodology presented in the report provides decision-makers with useful information on trade-offs between the expected capital and operating cost for (1) continued operation of an existing vehicle, (2) replacement with a new vehicle, and (3) rehabilitation of the existing vehicle. The methodology should also prove helpful in evaluating the justification for procurement of a higher initial cost vehicle by taking into consideration lower operational and maintenance costs over time, thus providing a "best buy" over a lower initial cost vehicle.

Given the considerable cost of operating, maintaining, and replacing buses today, methods which provide guidance on the replacement or rehabilitation of buses have the potential for significant cost savings. In the past these methods have been handicapped because of the difficulty of estimating maintenance costs over time, both for buses that have been rehabilitated and those that have not. This study (NCTRP Project 31-2, "Transit Capital Investment to Reduce Operating Deficits: Alternative Bus Replacement Strategies") attempted to overcome that deficiency by determining a statistically significant correlation between operating and maintenance costs and vehicle age. However, due to data limitations, no such correlation was found. Despite this constraint, the approach presented allows an operator to examine the cost implications of varying vehicle retirement or rehabilitation age from that normally used.

This report presents the results of a survey of a number of transit agencies concerning their current replacement and rehabilitation practices. In addition, operating and maintenance cost data by individual subsystem were collected and analyzed from 11 transit agencies. The information is presented on the basis of cost per mile versus age and cumulative mileage. Data are also provided on the cost of rebuilding four major components: engine, transmission, body, and frame.

A method was developed to determine useful bus life which accounts for annualized capital cost, costs to rebuild the four components mentioned above, and the remaining operating and maintenance costs. The distinguishing feature of the approach is to account for the timing of major component rebuilds. One of the inputs is the user's estimate of the service or active life of a bus. The methodology then evaluates the cost implications of shorter and longer life spans for active vehicles of an individual operator. Therefore, the method does not answer the question, What is the *optimal* life of a bus? The technique, nevertheless, in comparison with an agency's current bus replacement strategy, does offer the potential for reducing costs.

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The research reported herein was performed under NCTRP Project 31-2 by Fleet Maintenance Consultants, Inc., with the assistance of Price Waterhouse and Transportation Finance Group. Richard W. Drake, Senior Associate Fleet Maintenance Consultants, Inc., Douglas W. Carter, Manager Price Waterhouse and John J. Gaudette, Principal of Transportation Finance Group, served as co-principal investigators with Mr. Drake having overall responsibility for the successful completion of the Project.

Mr. Frank Cihak of the American Public Transit Association provided valuable assistance to the research project by assisting in obtaining points of contact and mailing addresses of transit agencies across the country. Tom Walsh, a senior consultant with Price Waterhouse, was responsible for most of the data analysis.

Without the cooperation of the many transit agencies, the project would not have been possible. Staff members from these agencies willingly took time from their busy work days to assist in the project. They are too numerous to name individually. Those agencies that contributed detailed operating and maintenance cost data for their bus fleets are acknowledged: Albuquerque Transit System; Des Moines Metropolitan Transit Authority; Montgomery County Transit System, Maryland; PACE, Regional Transit Authority, Chicago; Phoenix Transit System; Pierce Transit, Tacoma; Pinellas Suncoast Transit Authority; Regional Transportation District, Denver; Seattle Metro; Southern California Rapid Transit District; and Washington Metropolitan Area Transit Authority.

TRANSIT CAPITAL INVESTMENT TO REDUCE OPERATING DEFICITS—ALTERNATIVE BUS REPLACEMENT STRATEGIES

SUMMARY

In past years transit agencies seldom had to make trade-off decisions between capital and operating budgets because funds were segregated by program category and federal funding was ample. As plans to reduce the federal contributions become more real, transit programs are forced to compete with other community needs at the local level. Transit authorities are being asked to review the basis on which both capital and operating expenditures are planned. Past policies have tended to favor capital expenditures based on federal and state contributions.

A comprehensive search of the literature for cost-effective capital investment techniques other than vehicle replacement demonstrated that four types can lead to operating cost reductions for revenue enhancements. These four nonvehicle replacement strategies are in the areas of fixed facility improvements, vehicle enhancement equipment, maintenance diagnostic equipment, and maintenance management information systems. Suggested research projects for future consideration are included in the recommendations resulting from this study.

A broad-based survey of U.S. transit agency current and planned vehicle replacement practices was conducted to identify factors considered important in making replacement decisions. The respondents represent almost 20 percent of the transit systems in the United States and operate approximately one-half of the active buses in the country. The survey found that transit systems do not routinely consider operating and maintenance cost reductions as the driving factor in their bus replacement decisions. Ninety-six percent of the respondents reported that the availability of federal funds is the primary or secondary consideration when scheduling fleet replacements. When federal and local funds are available, the simple criterion of bus age was ranked as either the primary or secondary consideration by 92 percent of the reporting agencies. The survey results also show increased emphasis being placed on supporting capital investments in the maintenance areas. Almost one-half of the systems are in the process of acquiring air starters and over one-third are buying brake retarders.

Large transit systems with more than 1,000 buses in their fleets replace their buses at a median retirement age of 11 years with 34 percent retired in 10 years or less. Small- and medium-sized systems have a median retirement age at 14 and 17 years, respectively. The median cumulative mileage at retirement of buses by the large systems was reported at 350,000 miles, while the small and medium systems reported 450,000 and 500,000 miles, respectively. The survey also shows that during the next 5 years the agencies that were surveyed plan to replace 28 percent of their active fleets at an average age of 16 years, which is greater than the 12 years accepted under UMTA policy.

An essential part of the research entailed the collection and analysis of detailed operating and cost data from eleven operators that are a representative cross section

of transit agencies across the country. Most of the operators had implemented automated cost reporting systems only within the past 2 to 3 years. Since cost monitoring at a detailed level is a new capability industry-wide, historical subfleet cost data were not available at any participating operator, with most able to provide only 1 or 2 years of detailed data by vehicle type and by vehicle subsystem. Therefore, the research team was not able to prepare a complete profile of vehicle operating and maintenance costs for a single vehicle fleet at a single vehicle operator. Rather, data were compiled by vehicle fleet by operator and for 1 to 2 years and statistical analyses conducted to profile life-cycle costs over similar fleets.

As was expected, fuel and lubricants, servicing of vehicles, and routine preventive maintenance accounted for almost one-half (49 percent) of the operating and maintenance costs of vehicles. The remaining 51 percent was devoted to repair of vehicle subsystems. Some of these costs were found to change substantially in relation to the age of the vehicles. The most significant changes are rebuild and rehabilitation activities for engine, transmission, body and vehicle frame.

A practical methodology was developed for use by transit managers for evaluating capital investments from an operating cost perspective. The method has broad applicability and is sensitive to local conditions and fleet composition. The methodology provides the decision-makers with clear and useful information as to the capital and operating cost trade-offs between continued operation of an existing vehicle, replacement with a new vehicle, and rehabilitation of the existing vehicle.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

Although transit capital investments can have a significant impact on operating costs and, hence, on deficits, capital investment decisions are infrequently made to optimize this condition. Routine capital investment decisions are more often driven by federal funding availability, which are based on federal vehicle replacement and rehabilitation guidelines.

Transit agencies are beginning to rethink capital investment strategies as a result of the current funding outlook. While future capital funding appears constrained, the operating funding outlook is even more pessimistic. This provides a strong impetus for transit operators to leverage capital investments to reduce operating cost deficits. Simply replacing vehicles at 12 years of age, or when local matching funds are available, does not ensure cost-effective investment, and there is the added complexity of choosing between vehicle replacement and rehabilitation.

Simple rules of thumb or ad hoc capital investments do not adequately reflect the operating and maintenance cost implications imposed by local operating conditions, fleet composition, and vehicle deployment. Managers and policymakers for cost-effective capital investments are often stymied by a dearth of relevant vehicle operating and maintenance cost information. Operators who are only now getting good, reliable subfleet operating and maintenance cost data need a framework for applying this information in making vehicle replacement/rehabilitation decisions.

This research report is designed to provide transit managers and policymakers guidance in using revenue vehicle capital investments to reduce operating deficits. The study will produce an investment decision support methodology sensitive to local operating characteristics, vehicle deployment, and subfleet type.

The objectives of the study are two-fold: (1) to develop a reliable methodology for making cost-effective capital investment decisions for vehicle replacement and rehabilitation, and (2) to provide estimates and parameters for this methodology based on data gathered from several transit agencies. The study also provides a hypothetical application of the methodology to demonstrate its use.

RESEARCH APPROACH

The approach to the study was to develop a methodology for use by transit managers to determine optimal fleet replacement strategies that is realistic in that it would take into consideration the differences among bus agencies in terms of such factors as fleet age, fleet composition, and deployment. The approach recognized that local conditions can significantly influence operating costs and should provide managers with a method for evaluating investment options based on the system's site-specific characteristics.

The approach was pragmatic in that it recognized the limited resources, information and analytic capabilities of bus agencies. While establishing subfleet life-cycle cost estimates can be a complex problem involving many considerations, it is important to recognize that development of a sophisticated computer program may not be in the best interest of the transit community at large. This study was intended to produce a simple, nonautomated investment/operating cost planning and analysis methodology that has applicability to a broad range of bus operators. The study was conducted in three tasks, as follows:

1. A search of the literature was carried out to identify cost-effective capital investments other than bus replacement and to summarize past and current research on bus replacement schedules, life-cycle cost analysis, and bus purchasing guidelines to serve as a base for evaluating alternative bus investment strategies.
2. A survey of transit agencies was conducted to identify current bus replacement and rehabilitation practices and expand the results of the documentation research.
3. An analysis of detailed operating and maintenance cost data was executed using a representative cross section of transit agencies to develop methods for supporting fleet replacement scheduling decisions.

Identification of Cost-Effective Capital Investments Other Than Bus Replacement

There are many types of transit capital investments, other than bus replacement, which can contribute to a reduction in operating deficits by cost reduction or revenue enhancement. Industry literature documents a wide expanse of cost-effective investment strategies ranging from major fixed facility investments to investments in more efficient vehicle components. The Urban Mass Transportation Information Service (UMTRIS) was used as the primary source in this research effort. UMTRIS is a centralized source for identifying transit-related literature and is an extensive computer data base containing abstracts on all transit-related subjects. UMTRIS is part of the Transportation Research Information Service (TRIS) and is administered by the Transportation Research Board. The UMTRIS listing is supplemented by data gleaned from several other industry data sources, including:

- Urban Mass Transportation Administration (UMTA) Transit Research Information Center (TRIC).
- UMTA Abstracts.
- The National Transportation Information Service, Innovation in Public Transportation.
- Public Technology, Inc.

Summary of Past and Current Research on Bus Replacement

Substantial industry literature exists on the major forms of transit bus rehabilitation, bus purchasing, bus replacement, and life-cycle cost analysis. Again, for this search, UMTRIS was used as the primary source of identifying the relevant literature. In addition, officials of UMTA and the American Public Transit Association (APTA) were interviewed in connection with bus replacement strategies. Managers at several transit agencies, including San Jose's SCCTA, San Francisco's Muni, Los Angeles' SCRTD, and Detroit's DOT were contacted concerning life-cycle costing strategies.

Identification of Current Bus Replacement Practices

To identify the current bus replacement practices, a survey of a broad cross section of United States transit agencies was designed to ensure that it was representative of the range of agency sizes and geographic locations. The survey addressed the vehicle procurement strategies of all types of mass transit buses that were 30 ft or longer.

Agency Selection

The 1985 Transit Passenger Vehicle Fleet Inventory published by the American Public Transit Association was used as the source document to prepare a mailing list for the survey. Emphasis was given to agencies with bus fleets in excess of 50 buses, because the agencies would more likely need to address the capital replacement issues. A total of 160 agencies was selected that included all geographic regions of the country.

Survey Instrument

The survey instrument was designed to be short and concise in order to require minimal effort by each agency. The intent was to maximize participant response and, thus, obtain as large a cross section of transit agencies as possible. The survey instrument is provided in Appendix D.

The decision whether to replace or rehabilitate a revenue vehicle was addressed by level of consideration given to the following factors:

1. Age of vehicle in years.
2. Cumulative mileage.
3. Cumulative hours.
4. Local fund availability.
5. Federal fund availability.
6. Life cycle costs.
7. Major system failures.

The basis for scheduling the replacement investment decision for the revenue vehicles was evaluated by the consideration given to these factors:

1. Planned per UMTA guidelines.
2. Portion of the fleet each year.
3. Bulk procurements for economies of scale.
4. Bulk procurements for economies of financing.
5. Local fund availability.
6. Federal fund availability.

It was recognized that different factors influence the basis for scheduling rehabilitation decisions. The level of consideration given to these factors was asked:

1. UMTA Guidelines.
2. Major system failures.
3. Life-cycle cost analysis.
4. Lack of federal funds for new buses.
5. Lack of local funds for new buses.

Procurement guidelines used by the transit agencies for the purchase of revenue vehicles were investigated by asking which of the following four procurement methods are used.

1. Low bid.
2. Evaluation of price offsets.
3. Life-cycle costing determination.
4. Competitive negotiation.

The questionnaire included brief queries directed at assessing the evolving sophistication of the fleet management effort at transit agencies. Information on planned investments in fixed facilities, vehicle enhancement equipment (e.g., brake retarders and air starters), and maintenance diagnostic equipment (e.g., brake test equipment, dynamometers, electrical system testers). The final element of the survey instrument included a roster of actual bus retirements and rehabilitation over the time period of 1980 to 1985 and those planned for the 1986 to 1990 time frame.

Data Collection and Tabulation

The survey instrument was mailed to 160 transit agencies. In the cover letter with the survey package, a target date was given and each agency's cooperation was requested. Immediately following that date, telephone calls were placed to each agency soliciting their cooperation. Information received from the agencies was sorted and tabulated by type of response, size of agency, and location. The size of the sample results in a representative summary of current transit bus replacement practices.

Development of Methodology for Fleet Replacement Decisions

The objective of this study is to develop a universal tool to evaluate cost-effective bus investment strategies based on each agency's site specific characteristics; therefore, a representative cross section of bus agencies in different parts of the country was required.

Agency Selection

Three criteria were considered in selecting the agencies for the study. They were climatic conditions, fleet size, and data availability.

1. *Climatic Conditions.* The United States has hundreds of localized climates when the specifics of temperature, humidity, wind speeds, and sunshine are considered, but when viewed in terms of potential impact on bus maintenance, they can be grouped into major regions with similar winter and summer climatic conditions. Figure 1 shows the different areas.

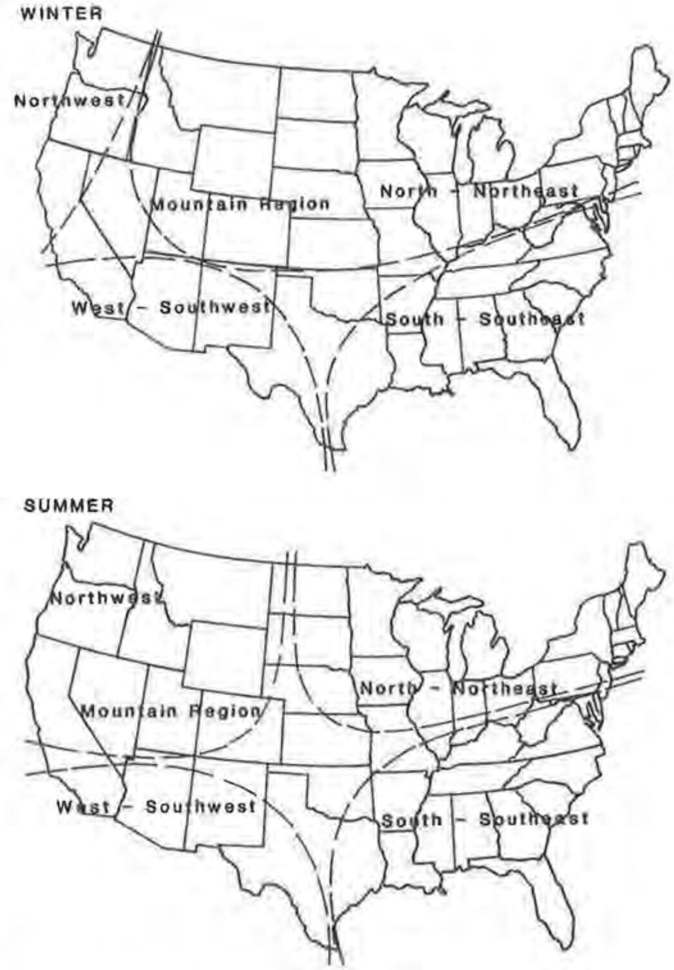

Figure 1. Regions with similar climates.

a. North-Northeast Region has severe winter conditions with most local areas experiencing biting cold temperatures for much of the winter. Average daily low temperatures range from 8 F to 20 F, and buses must operate in an environment with considerable snow and ice. Summers, however, are moderate with average daily high temperatures of 85 F.
b. South-Southeast Region is characterized by hot humid summers with temperatures ranging up to 95 F. Functioning air conditioning systems are mandatory in most areas within the region during the summer months. Winters are mild with occasional cold weather. Winter temperatures average in the high 30's and low 40's.
c. Southwest Region has a summer climate that is very hot with temperatures frequently in excess of 100 F. However, since this is the arid portion of the country, humidity is very low. Winters are very moderate with average lows around 40 F.
d. Northwest Region climate is cool with considerable rain and fog. The northern portion receives considerably more rain than does the southern portion. Temperatures are moderate year round. Average winter low temperatures are around 40 F and summer temperatures rarely reach 90 F.

Air conditioners are generally not required on buses in this region.

e. Mountain Region climate features low relative humidity and abundant sunshine. Winters are cold and stormy with mean temperatures ranging from 18 F to −40 F. Summer maximum temperatures can sometimes reach over 90 F. However, these temperatures are accompanied by low humidities which allow for comfort. Air conditioning systems on buses are optional in this region.

2. *Fleet Size.* Bus agencies were grouped into three size categories. Bus agencies with more than 1,000 buses are considered for the purposes of this research project to be large. They are multifacility agencies with considerable variations in their bus types. Many of the maintenance functions are centralized for economies in the work force and facility costs. The bus replacement and rehabilitation function is of considerable size.

Agencies with bus fleets between 250 and 1,000 are grouped in the medium-sized category. Within this group, some operate from a single facility, while others have multiple facilities.

Those agencies with less than 250 buses are considered to be small. While they may experience the same maintenance problems as the medium and large agencies, in many instances their size enables them to implement unique solutions to problems. They may also be more constrained in terms of replacement strategies due to the relative size of individual procurements.

3. *Data Availability.* A most important criterion in the final selection was the availability of required data on operating and maintenance costs and utilization by type of vehicle and by vehicle subsystem. It was not expected that each agency could provide all of the data on every item.

Selected Agencies

One objective of the study was to obtain useful data from ten agencies representing a cross section of the characteristics of U.S. transit agencies. An attempt was made to have three large, four medium, and three small responsive participants. To support this objective, the data collection guide was forwarded to 13 bus operators known to have modern computerized maintenance management information systems and interviews conducted at each. There were difficulties in gleaning responses from some operators when it was found that their management information systems could not produce the data. None of the agencies could produce more than 2 years of data on their different bus types.

North-Northeast Region

The data collection guide was forwarded to three operators with acceptable vehicle cost information in this region: the Suburban Bus Division of the Regional Transportation Authority, Illinois (PACE); the Westchester County Transit System, New York; and the Des Moines Metropolitan Transit Authority, Iowa.

South-Southeast Region

Selected participants in this region included the Washington Metropolitan Area Transit Authority, District of Columbia; the Montgomery County Transit System, Maryland; and the Pinellas Suncoast Transit Authority, Florida.

West-Southwest Region

Transit operators that participated in this region included three systems: the Southern California Rapid Transit District, California; the Phoenix Transit System, Arizona; and the Albuquerque Transit System, New Mexico.

North-Northwest Region

Study participants included three bus systems from this region: the Seattle Metro, Washington; the Regional Transportation District, Colorado; and Pierce Transit, Washington.

Data Collection

A plan was developed to define the data required for the study and the techniques to be used to collect life-cycle cost data from the selected bus agencies. The major elements of the plan included: (1) a listing of the primary vehicle operating and maintenance cost categories, focusing on those areas most likely to be influenced by vehicle age; (2) site-specific criteria that were anticipated to impact vehicle operating cost efficiency and account for regional cost variances; (3) the data collection guide and corresponding glossary to be used to capture the information required to evaluate capital investment strategies from an operating cost perspective.

Vehicle Operating and Maintenance Cost Categories

For the most part, public transit agencies around the country do not use a common breakdown of major vehicle cost centers in their maintenance reporting systems. There does not even appear to be a common definition of maintenance costs—some operators report actual costs based on the individual mechanic's wage rate, others use average costs; some limit costs to labor expenditures, others include materials and overhead costs. The listing of cost data was coordinated with agency data availability and simplified to enhance comparability between agencies.

1. *Bus Subfleet Cost Per Mile.* Total operating and maintenance cost per vehicle-mile by vehicle manufacturer, model, and year built by fiscal year (i.e., from FY 1976 through FY 1985, inclusive) was requested to evaluate cost progression. This information was intended for use in evaluating the effect of age and mileage on aggregate operating and maintenance costs. Because valid subfleet cost data have only recently become available through improved maintenance information systems, the study team found historical cost data to be extremely limited. At best, the agencies would provide data only for the past 2 years. Therefore, the analysis of age and mileage implications on operating and maintenance costs focused on comparing subfleets of different ages over a short time horizon.

2. *Bus Fleet Operating Information.* In addition to routine costs of running repair, inspection, servicing and cleaning of buses, four major repair items were identified as having a sig-

nificant impact on cost and being directly correlated with vehicle age and mileage. Because of the relatively long periocity of these repairs and the cost impact, they should significantly impact the operating cost efficiency of a vehicle capital investment decision. These cost impacts include the rebuilding of the bus power plant, rebuild of the drivetrain (transmission), major refurbishment and repainting of the bus body, and the major rehabilitation of the bus frame and undercarriage. Each of these items comes at a significant operating cost, and each contributes to the overall future efficiency and longevity of a vehicle.

The frequency of these events was expected to vary by type of bus and vehicle deployment. Local operating conditions (e.g., stop-and-go traffic, salt on streets in winter) were anticipated to be a factor contributing to the frequency and cost of these repairs.

Transit agencies with more than one operating garage were requested to provide fleet information for each facility since earlier studies reported that service characteristics may be considerably different at each.

3. *Operating and Maintenance Cost by Subfleet and Subsystem.* Disaggregate operating and maintenance costs by subfleet and individual vehicle subsystem were included to determine the subsystem cost variance for the different bus types and operating conditions. For the purposes of this analysis, 14 vehicle subsystems/cost areas were used:

a. *Servicing and cleaning*—the routine activities associated with fueling and washing of vehicles usually performed on a daily basis. As part of the servicing procedure, all fluids of the vehicle are checked for proper levels and replenished as required. This includes oil, water, coolant, and battery fluid levels. Servicing also includes scheduled thorough interior cleaning of vehicles of which all trash is removed from under seats, windows are washed, seats are cleaned, floors are mopped (if not carpeted) and all surfaces are vacuumed or dusted.

b. *Inspection*—the performance of preventive maintenance and safety checks on vehicles by operators or designated maintenance personnel, which includes statutory inspection of safety-related items on each vehicle required by the state or local authority or is directed by the operating policies of the organization. This inspection is typically performed on a frequent basis (e.g., every 1,500 miles).
Minor inspection includes all of the items required under the statutory safety checks plus additional systems inspections (e.g., fan belts, radiator hoses). Lubrication of vehicles is also performed. This inspection is typically performed every 5,000 to 7,500 miles.
Major inspection includes elements of the minor inspection in addition to in-depth servicing of vehicle subsystems. Engine tune-ups are usually included in a major inspection. Transmission servicing is also performed as well as seasonal servicing of the heating, ventilation, and air conditioning system. An organization may have more than one type of major inspection such as a 15,000 mile, 30,000 mile, and 75,000 mile inspections—each becoming more comprehensive as the interval increases.

c. *Body system*—vehicle system including bumper assembly, exterior paneling, mirrors, windshield and frame, stanchions, seats, floor, floor covering, steps, doors, chimes or buzzer, windshield wipers, interior panels, and glass.

d. *Engine assembly*—vehicle assembly that includes engine cradle, blower, flywheel housing, crankshaft, oil pump, valve covers, heads and valves, injectors, timing gears, camshaft and valve mechanism, oil gauges, oil filters, oil pan and damper.

e. *Braking system*—vehicle system used to stop the vehicle. Brake components include drums, shoes, lining, seals, spiders, cams, and slack adjustments.

f. *Electrical system*—vehicle system that includes generator/alternator, regulator, battery, starter, lighting system, control switches, solenoids, horn, wiring, and cabling.

g. *Air system*—vehicle system that includes compressor, air pipe and tubing, control cyclinders, shift cyclinders, air tanks, air governors, air gauges, safety valve, door interlocks, brake valves, quick release valves, brake diaphragms, air pressure regulator valve, air line shut-off valve, and door regulator valve.

h. *Air conditioning and heating system*—vehicle system that cools vehicle interior during warm weather. It includes the compressor, condenser assembly, evaporator assembly, receiver, dryer, filters, piping, and cables. Also includes vehicle system that provides heat and ventilation to the interior. It includes heating units, blowers and blower motors, water modulation valve, and heater-related cables and wiring.

i. *Drivetrain*—vehicle system consisting of transmission, driveline, and differential.

j. *Suspension and steering system*—vehicle system that includes bellows, leveling valves, shock absorbers, radius bars, lateral bars, and stabilizer. Also includes vehicle system that includes steering wheel, steering column, steering box, drag links, tie rods, tie rod ends, and power steering pump, if included.

k. *Cooling system*—vehicle system that includes radiator thermostat and housing, water pump, fan, fan torus, vernatherm, surge tank, oil cooler, hoses, and temperature gauges.

l. *Vehicle accessories*—accessory items that include fareboxes, destination signs, radios, and wheelchair lifts.

m. *Tires*—vehicle system that includes hubs, bearings, seals, wheels, and tires.

n. *Fuel and lubricants*—includes the cost of fuel (diesel or gasoline) and lubricants consumed by a subfleet during a particular fiscal year.

Site-Specific Criteria

In planning its capital investment strategy for revenue vehicles, each public agency is influenced by many local factors. The factors that were anticipated to have a measurable impact on cost-effective capital investments and included in this study are the following:

1. *Climate.* The climate in which a vehicle operates was expected to have a significant impact on the frequency of all four major repair categories (i.e., engine, drivetrain, body, and frame) and, hence, on operating and maintenance costs. Hot summer climates may reduce engine life due to hot running temperatures, and areas using salt in winters may experience reduced body and frame life. In addition, individual vehicle subsystem costs were expected to be impacted by climate, particularly the air conditioning, heating and cooling subsystems.

2. *Fleet Composition.* Public agencies are required to have many different types of buses in their fleet to satisfy different service requirements. These may include 30-ft to 35-ft buses for circulator service, 40-ft standard coaches for local line-haul as well as express service, and 55-ft to 60-ft articulated buses for heavily patronized local and express routes. With competitive bidding procedures in place throughout the country, an agency may also have buses from several manufacturers in each type. Each has unique maintenance requirements that must be considered in capital investment planning.

3. *Fleet Age.* As vehicles accumulate service miles/hours, their maintenance requirements may increase. If so, more operating revenues must be devoted to older buses in order to maintain their availability and reliability through aggressive preventive maintenance programs and replacement/repair of worn or failed components.

4. *Operating Speed.* The average operating speed in revenue service was used as the determining factor to learn if buses operating over routes with low average speeds require more maintenance than those with higher speeds.

5. *Accident Frequency.* The frequency of accidents, often caused by local operating conditions (e.g., street width, traffic congestion, terrain), was expected to impact body and frame life, and hence operating costs. Local accident frequency may impact the decision to repair body and frame subsystems versus replacing the entire vehicle.

6. *Roadcalls.* The roadcall frequency, limited to mechanical failures only, can significantly impact local operating cost. Further, as fleets age and become less reliable in service, operators may consider the replacement/rehabilitation option to improve reliability and reduce costs.

7. *Unit Cost Rates.* Individual operators have unique cost characteristics to consider based on their regional economy, local labor agreements, and supplier arrangements. When comparing costs within a given transit system (i.e., between subfleets) it is appropriate to focus on absolute expense figures. However, when comparing cost characteristics between transit agencies it is important to compare relative costs. Therefore, unit cost data (e.g., average labor rates, fringe benefits, overhead, consumable and nonconsumable cost rates) were needed to compare the relative impact (e.g., proportion change) of age, mileage, and other factors on operating cost efficiency. This reliance on both absolute and relative cost factors ensured the most usable and relevant results from the study.

Data Collection Guide

A well-structured data collection guide was considered mandatory for this study involving quantitative data analysis to ensure consistency in data collection. The guide was structured to capture both quantitative information, such as frequency and cost estimates for selected jobs and agency descriptive information, as well as quantitative information that was needed to interpret the results of analysis. The data collection guide, which is presented in Appendix E, was organized into six sections:

1. *General Agency Information.* General information that described the selected agency and its operating characteristics included annual mileage operated, revenue service mileage, revenue service hours, peak scheduled vehicle requirement, active bus fleet, spare buses, accident rate, miles between mechanical failures, winter climate, and summer climate.

2. *Maintenance Cost Data.* Maintenance cost data were requested on both an aggregate and unit cost level. Aggregate costs included direct labor, fringe benefits, maintenance administration, consumable supplies, and nonconsumable supplies expense. Unit costs included hourly labor rates by mechanic position.

3. *Bus Fleet Profile.* This element requested a description of the operator's fleet composition. Subfleet information included year built, manufacturer, model, total number of vehicles, engine type, transmission, and remarks on rebuild status.

4. *Bus Subfleet Cost per Mile.* This section of the data collection guide was designed to glean data on the total operating and maintenance cost per vehicle-mile over a 10-year period. During the study it was discovered that historical costs at a subfleet level are relatively scarce.

5. *Bus Fleet Operating Information.* This area of the guide requested subfleet deployment information (i.e., fleet size, miles, hours, and costs) and major rebuild frequencies and costs (i.e., engine assembly, transmission, major body refurbishment, and major frame rehabilitation). This information was requested by division for multifacility operators.

6. *Operating and Maintenance Cost.* The final section of the data collection guide was designed to capture operating cost information by subfleet by vehicle subsystem and cost area (e.g., brake repairs). For multifacility agencies, these data were requested by operating division.

Data Collection Procedure

Actual data collected using the guide was handled by visits to each agency by a member of the study team. Well in advance of a visit, the data collection guide was mailed to each selected agency and discussed by telephone. Each agency was asked to compile as much information as possible before the visit so that the time on site could be devoted to understanding the information and to making key field observations that would be useful in interpreting data during the analysis. It was very important to capture the agency's maintenance philosophy and understand its maintenance reporting system.

Analytical Approach

The statistical and financial techniques for compiling and evaluating capital investment implications on bus operating and maintenance costs were comprised of three primary elements: (1) a series of statistical applications to compare the range of subfleet operating and maintenance costs (i.e., absolute and relative) as determined in the data collection activity; (2) procedures for evaluating the factors which account for, or contribute to, major variances in the operating and maintenance cost of a vehicle over its service life; and (3) a technique for evaluating repair/replace/rehabilitate decisions for transit revenue vehicles in terms of operating and maintenance costs coupled with capital investment needs.

Compare Analysis of Costs. Based on the specific subfleet operating and maintenance cost information provided by the ten subject agencies, the study team conducted a comparative analysis of subsystem, subfleet and total cost per mile. The comparative analysis was designed to identify the range of variables and results reported by the subject agencies. In addition to absolute values, the comparison included more aggregate values (e.g., the proportion of expenditures by vehicle subsystem). The primary tools of comparison were the mean and standard deviation (using $n-1$ weighting to account for the limited sample size) for all variables. This step was intended to describe what was reported by operators in a comparative manner.

1. *Mean.* The average (e.g., mean) value of all primary cost parameters collected at the agencies was determined by adding like values across all subject agencies and dividing the sum by the number of agencies responding. The formula (Eq. 1) for calculating the mean value is:

$$\text{Mean}_{pj} = \left(\sum_{a=1}^{n} \text{Value}_{pa}\right) \bigg/ n \qquad (1)$$

where: p = cost parameter; a = observation (e.g., subfleet or agency); n = number of observations in test; and j = vehicle type (e.g., subfleet).

The mean value provided a norm or expected value for each parameter in the analysis.

2. *Standard Deviation.* The standard deviation of cost parameters provided a normalized range of experience at the subject transit agencies using the mean value as a point of reference and $n-1$ weighting to account for the constrained sample size. The standard deviation is a commonly used statistical formula and is shown in Eq. 2.

$$\text{Standard Deviation}_{pj} = \sqrt{\sum_{a=1}^{n} \frac{(\text{Value}_{pa} - \text{Mean}_{pj})^2}{n-1}} \qquad (2)$$

where: p = cost parameter; a = observation (e.g., subfleet or agency); n = number of observation in test; and j = vehicle type (e.g., subfleet).

The standard deviation provided an indication of the normalized range of the actual values for parameters influencing operating and maintenance cost characteristics. This is not to say that all data points will fall within $\pm$ one standard deviation, but rather that 68.26 percent of transit agencies are expected to fall within that range specified. It also served to identify those areas which required more detailed analysis due to high variability.

Evaluate Impact of Independent Factors. The scope and scale of analysis in this activity was a function of the results of the comparative analysis. While the comparative analysis sought to reveal what happened in terms of operating and maintenance costs, the evaluation of independent factors strived to explain why cost relationships occurred. This evaluation attempted to quantify the impact of vehicle age, cumulative mileage, deployment, and local operating conditions on vehicle longevity and cost. This analysis was conducted both within and between transit systems. The analysis employed a powerful, comprehensive statistical computer program to perform complex calculations. The types of statistical analysis used in identifying causal factors and in quantifying relationships included: ANOVA (unbalanced design), regression analysis, life-cycle fitting, cross correlation, chi-square, factor analysis, and Spearman rank correlation coefficient.

1. *ANOVA (Unbalanced Design).* Analysis of variance (ANOVA) techniques are useful for a set of statistical problems where the impact of one or more nonmetric variables on a single dependent variable is being analyzed. The ANOVA for Unbalanced Designs procedure was employed to analyze the effect of one or more qualitative factors (e.g., climate) on a single response variable (e.g., engine life) when the number of observations are not equal at all combinations of the factor levels. Unlike hypothetical applications, empirical studies often contain an unequal number of observations per factor. In this study, operators that submitted incomplete data, or a single data element that was questionable and thus eliminated, did not adversely impact variance analysis by employing this technique.

2. *Regression Analysis.* Regression analysis summarizes data and quantifies the nature and strength of the relationship among cost variables. A simple regression analysis was used to fit a model relating one dependent variable (e.g., cost for body repair) to one independent variable (e.g., subfleet type) by minimizing the sum of squares of the residuals for the fitted line. It is applicable to linear, multiplicative, exponential and reciprocal models or relationships. A multiple regression provides the same capability but allows analysis of the impact of one or more independent variables (e.g., accident frequency, subfleet, climate and unit cost) on a single dependent variable (e.g., cost for body repair). The regression analysis visually showed the fit between variables, and conducted an analysis of variance.

3. *Life-Cycle Fitting.* The life-cycle fitting analysis estimated the trend in a set of time series data (e.g., subfleet cost per mile by vehicle age or cumulative mileage). The procedure was based on the function $Z = \exp(a + b/t)$, which fit an s-shaped curve to the time points (or cumulative mileage points). The model coefficients were obtained using least squares, after taking the natural logarithms of Z. This procedure was used to profile vehicle life-cycle costs by subfleet.

4. *Cross Correlation.* The cross-correlation function estimates the correlation between one time series at a specified time and a second time series for the same variable recognizing the time lag. It was expected to be useful in comparing similar subfleets or different ages when limited historical data were available. The technique was used to determine whether or not the two data periods are comparable and, if correlated, whether one led to another (e.g., whether higher cumulative mileage led to higher operating and maintenance costs).

5. *Chi-Square.* The procedure for the chi-square goodness-of-fit statistic calculates a chi-square that compares observed to expected frequencies. Chi-square is defined as the sum of observed minus expected frequencies squared, each divided by the expected value. In this study, it was used to examine the implications and significance of age, mileage, and local conditions on operating and maintenance costs.

6. *Factor Analysis.* The factor analysis procedure extracts principal components from a correlation matrix. Factor weights were scaled so that their sum of squares was equal to the associated eigenvalue and was thus related to the total variance explained by the factor.

The procedure also calculates estimated communalities for each variable using the squared multiple correlation between that variable and all other variables. For certain mathematical models, the communalities calculate what proportion of the variability of each variable is shared with the other variables in the data. In this study, factor analysis was used to explain the variation in cost accounted for by local unit cost factors, subfleet, vehicle age and use, and other factors among the diverse operators.

7. *Spearman Rank Correlation Coefficient.* The Spearman rank correlation coefficient procedure uses the ranks of the data rather than the actual data values. First, each variable is ranked separately. Then, the differences between the ranks of paired observations are calculated to measure the disagreement between the pairs. The squared disagreements over all pairs are summed, and a relative measure of disagreement is calculated. The coefficient is scaled to fall between -1 (perfect disagreement) and $+1$ (perfect agreement).

The Spearman rank correlation coefficient procedure is equivalent to ranking each variable separately and calculating the usual correlation coefficient on the ranks. It was used to define the relative importance of independent variables on life-cycle costs. The results were used to help simplify the capital investment analysis methodology by eliminating factors that only nominally contribute to the overall variance in costs, thereby simplifying the procedure for use by transit operators while maintaining a high level of accuracy.

Capital Investment Evaluation Methodology. The final step in the analytical approach was to prepare and document a realistic and practical methodology for evaluating capital investments from an operating cost perspective. The methodology developed must have broad applicability, yet be sensitive to local operating conditions and fleet composition. The objective of the methodology is to provide capital investment decision-makers with clear, usable information as to the capital and operating cost trade-offs between continued operation of an existing vehicle, replacement with a new vehicle, and rehabilitation of the existing vehicle. While the final structure of the methodology was dependent on the results of the statistical evaluation, the methodology was designed to incorporate four features:

1. *Capital and Operating Costs.* The methodology employs a net present value analysis that discounts the future stream of capital and operating expenditures to allow whole life cost comparisons. The technique incorporates features of annualized equivalent costing to allow equitable comparison of vehicle investment strategies when useful vehicle life varies between options (e.g., replace at 12 years, versus rebuild at 7 years).

2. *Actual Default Relationships.* The study produced data representing the actual experience of a variety of transit operators. This information and actual numeric relationships, included as default parameters, allow an agency to utilize the numbers developed in this study, or internal numbers if available in applying the methodology.

3. *Wide Applicability.* The methodology must be uncomplicated both in terms of ease of understanding and requirements to apply the methodology.

4. *Sample Applications.* The methodology is demonstrated for a medium-sized agency. The sample application illustrates the breadth and depth of the analytic techniques.

ORGANIZATION OF THE REPORT

This report has been prepared to document the approach, findings, conclusions, and applications of the project results. This chapter has presented an overview of the research objectives and approach. The remainder of the report is organized as follows. Chapter Two reviews the findings of the literature search to identify prior efforts on capital investments other than bus replacement and research activity on bus replacement schedules, life-cycle cost analysis, and bus purchasing guidelines. The results of the survey of transit agencies on actual and planned bus retirement programs are presented. The transit bus operating and maintenance cost findings are reviewed and the causal factors of differences between agencies are discussed.

Chapter Three presents the bus replacement model, including algebraic solutions, developed as a result of the research and discusses its use. Chapter Four discusses the conclusions of the research and areas where future investigation is warranted.

Appendix A presents a hypothetical demonstration of the methodology for a medium-sized agency—the case study is representative of real conditions. Appendix B presents the titles of the literature found for cost-effective capital investments other than bus replacements. Appendix C provides the titles of the literature found on bus replacement strategies. Appendix D contains the data collection guides that were used to survey current bus replacement practices of transit agencies. Appendix E provides the collection forms used to glean disaggregate operating and maintenance cost information from the subject agencies. The final appendix (F) provides the detailed results of the survey of current bus replacement practices.

CHAPTER TWO

FINDINGS

This chapter presents the study findings in four primary areas (1) non-bus capital investments to reduce operating costs, (2) bus investment strategies to reduce operating costs, (3) bus replacement practices in the transit industry, and (4) detailed operating and maintenance cost characteristics relative to vehicle age. The findings were developed based on a balanced investigation of prior research and documentation, a broad-based survey of 88 transit systems, and a detailed analysis of operating and maintenance costs at 11 systems.

CAPITAL INVESTMENTS OTHER THAN BUS REPLACEMENT

Overall, industry literature reports that non-vehicle replacement investment strategies aimed at cost reduction or revenue enhancement focus on four primary investment types: fixed facilities, vehicle enhancement equipment, maintenance diagnostic equipment, and information systems. Each of these investment types is characterized by different capital requirements and different levels of return. Specific literature references are included in Appendix B.

Fixed Facilities

Fixed-facility investments include the design and development of major facilities (e.g., maintenance shops, servicing facilities, administrative buildings), upgrade or rehabilitation of such facilities, design and development of passenger facilities (e.g., bus stops, transfer stations), installation of cost-effective equipment (e.g., high pressure bus washers), and installation of energy saving equipment (e.g., solar generators, heat curtains). Investments in fixed facilities are frequently the most expensive of cost-effective investment opportunities and, correspondingly, offer some of the highest returns in operating cost reduction. This is not to suggest that all fixed facility investments result in operating cost savings, but rather that through application of private sector value engineering techniques, cost improvements can be planned, designed, and implemented.

A common fixed-facility investment is reconstruction or new construction of a maintenance facility. This is an expensive and time-consuming endeavor, and the degree of operating cost reduction is largely a function of facility location, design, and capacity before and after the new facility is completed. Because many operators are replacing trolley and bus barns built more than 40 years ago, there is a high potential for realizing substantial operating cost reductions. Several operators have documented their approach and results (e.g., Bridgeport; Washington, D.C.; New Jersey Transit) and reported potential operating cost savings of between $3 million and $11 million annually.

Significant cost reductions can also be captured through enhancements of existing facilities at a lower investment cost and somewhat lower savings than facility replacement. One successful area of investment in cold weather climates has been in the area of heating cost containment. Some operators have implemented solar energy systems (e.g., Denver RTD) to reduce heating budgets, and others have installed heat curtains to contain warm air in exposed areas.

Other capital investments occur on the street and are designed to better serve patrons (e.g., bus stop shelters and transfer facilities). While these investments result in a moderate increase in costs in many cases, the cost may be more than off-set by an increase in ridership and, hence, revenue. The magnitude of potential revenue benefits is unclear from the literature.

Vehicle Enhancement Equipment

Another capital investment strategy applied by some transit operators entails upgrading vehicle components and equipment to realize operating cost savings. The federal government generally views a procurement of new vehicle components/equipment totalling at least 5 percent of the vehicle's investment cost as a capital procurement. In recent years, significant attention has been focused on engineered vehicle reliability and efficiency improvements. Key examples include the following:

1. Communication systems such as two-way radios, which have helped several systems in reducing service delays and responding to roadcalls. Some properties have reported ridership increases and operator cost reductions as a result.
2. Cost effective components such as air starters (which reduce electrical system maintenance costs and improve performance in hot and cold weather), rotary compressors (which appear less costly to repair than reciprocating compressors), brake retarders (which are intended to reduce brake wear, but experience is widely varied as to cost savings or cost increases resulting from their use), and fuel efficient transmissions (which could offer a substantial savings for high mileage bus operators). In many cases the actual magnitude of cost savings from improved component reliability is unclear, although less frequent and less costly repairs certainly result in cost reductions.
3. Air conditioning improvements such as evaporative coolers and roof-mounted A/C units have proven cost-effective improvements. Evaporative coolers are effective in semi-arid western regions and increase passenger comfort at a cost well below conventional mechanical air conditioning. Substantial documentation is also available on the benefits of roof-mounted air conditioning units.
4. Electric buses, which are more common abroad than in the United States, are believed to have lower energy cost than combustion engine vehicles. However, the capital cost of electric buses is quite high and life-cycle costs are not yet well defined.

Overall, capital investments in improved vehicle costs are relatively inexpensive and show potential for good savings results. Because this is a relatively new area of technology and management interest, cost savings potential has not been fully explored on many items.

Maintenance Diagnostic Equipment

Maintenance diagnostic equipment is intended to reduce maintenance trouble-shooting time by defining a problem, reduce premature replacement by indicating component or subsystem condition, and better define maintenance program needs. The two most common types of bus maintenance diagnostic equipment are brake test equipment and dynamometers. Brake test equipment is generally designed to evaluate the condition of the bonded brake lining and is intended to avoid early brake replacement and denote brake problems before an in-service failure occurs—both of which reduce operating costs. Dynamometers and engine analyzers are designed to evaluate the operating condition and compression factors for combustion engines. Dynamometers come in bench and chassis models. The first is primarily used to test rebuilt engines and transmissions before installation, and the latter is designed to evaluate engines in-frame. The relative usefulness of dynamometers in transit has varied from agencies reporting the equipment to be of nominal value to agencies reporting substantial usefulness and cost savings.

Another recent development in bus maintenance equipment is an electrical system tester. Referred to as an "electronic footprint", this analyzer is attached to the electric system wiring and conducts a detailed evaluation of all bus electrical systems. While potential cost savings are high, the capital investment may be exorbitant because each vehicle type must have a different analyzing program (i.e., electronic signatures vary substantially by component, subsystem, and vehicle).

Information Systems

The timely availability of better vehicle maintenance information can result in quantifiable cost savings through reduction in clerical workloads and better decisions on component life cycles. The SCRTD in Los Angeles estimates that it saves $1,000,000 annually as a result of its new management information system. Information systems can facilitate management of almost any part of a vehicle maintenance program (e.g., work order processing, work scheduling, parts and inventory control, and maintenance program planning). Other information systems, such as service run cutting and scheduling programs, can reduce driver costs of revenue service. In many other cases it is difficult to identify a specific cost reduction arising from better information, although improvements in effectiveness appear closely related.

Another area of information-related improvements is in automatic vehicle location and/or monitoring (AVL/M) systems. These systems monitor bus movement, and sometimes vehicle performance, which can result in reduced service delays. Many systems are expensive, and little data are available of actual operating cost reductions. Development of a multi-user system (e.g., transit, solid waste removal, police) offers the opportunity of reduced capital cost through shared investment while retaining operational improvements.

PAST AND CURRENT RESEARCH ON BUS REPLACEMENTS

A second literature was conducted to assess transit bus replacement schedules, life-cycle cost analysis, and bus purchasing guidelines. The results of the investigation are discussed below, and Appendix C presents the literature titles for reports found in the search.

Bus Replacement Schedules

There are several published and unpublished research documents which suggest that the post-World War II transit industry was undercapitalized and the 12-year federal replacement funding program sought to remedy this deficiency through an infusion of federal capital dollars. Conversely, one unpublished dissertation attempts to prove the hypothesis that the UMTA capital grant program would foster over-capitalization in rolling stock, premature bus replacement, and other economic inefficiencies. Articles espousing both viewpoints examine capital and operating costs as well as increased passenger attraction due to new equipment to justify a particular capital investment program. The documents are dated in the late 1960's and early 1970's, making their results of limited usefulness in today's equipment and technological environment. More to the point, the documents are speculative in nature—they address what is expected to occur under different capital programs, not what did occur.

Apart from local funding constraints much of the research suggests that operators replace one-twelfth of their fleet annually. Several reasons are discussed promoting this strategy:

1. Federal funding policies make capital dollars available for revenue vehicle replacement after 12 years of service (or 500,000 cumulative vehicle-miles).
2. Local capital dollars may be easier to allocate in equal annual amounts and this strategy facilitates better long-term planning for bus replacement.
3. Major maintenance work appears easier to schedule and conduct when vehicle ages are equally dispersed between 1 and 12 years. This is particularly true with regard to scheduling and conducting powertrain overhauls.

While many of the advantages to equally distributed bus procurements are clear, there is also a significant potential for realizing a disadvantage in terms of fleet mix. Federal procurement regulations revolve around a "low bid" philosophy, which requires contract awards to be made to the lowest responsive bidder. This practice can result in procurement of a wide variety of fleet types (i.e., theoretically, a different bidder could be awarded the contract each year). To the degree that different bus types do not have interchangeable subsystems and components, an increased burden is placed on operating cost in terms of parts stocking, training and equipment requirements. This can be addressed to some extent by using a life-cycle costing technique to low bid determination.

Another vehicle replacement scheduling policy prevalent in the documentation is a staggered vehicle procurement policy that endeavors to purchase larger blocks of vehicles every 3 to 5 years. The primary driving forces behind this strategy are to capture economies of scale, reduce paperwork required for annual procurements, and gain leverage in ordering deviations from standard designs through larger procurements. A disadvantage occurs with regard to maintenance planning, control, and cost. Generally, large numbers of vehicles incur failures simultaneously as vehicles age and maintenance departments may experience poor operating performance and/or high overtime costs to keep the fleets running.

In Fiscal Year 1982, the Pennsylvania Department of Transportation realized the benefits of both annual incremental replacements and bulk procurements by consolidating statewide bus purchase needs for 13 urbanized transit authorities and three smaller transit systems into a single project. The project resulted in a procurement of 1,000 advanced design buses over a 3-year period. Along with economy of scale, the project produced consistent, staggered delivery schedules; cut paperwork and time associated with federal approval of 16 individual capital grant applications; gave operators greater leverage in ordering vehicle modifications; and provided more leverage in warranty control due to the size of the procurement.

Several research documents also present a combination of bus replacement and rehabilitation as an effective fleet management strategy. The literature stresses that not all vehicles are candidates for rehabilitation or remanufacture due to structural degradation, but rebuilding some vehicles can substitute for replacement at a cost savings. An important consideration in making a rehabilitation decision is vehicle availability. Rehabilitation must be carefully scheduled to ensure that peak requirements will be met with the remaining fleet (i.e., while undergoing rehabilitation a vehicle is unavailable for service). Because of vehicle requirements, most rehabilitation programs in the literature are staged so that a small number of vehicles are rehabilitated every 3 to 6 months.

Life-Cycle Costing

Life-cycle costing (LCC) is a method of estimating the total lifetime cost of acquiring, operating, and maintaining a product. There are two common approaches to life-cycle costing—net present value (NPV) and annual equivalent cost (AEC). The net present value cost of a transit bus is defined as its capital, initial, or acquisition cost (i.e., or rehabilitation cost if appropriate) plus the present value of a lifetime of operating and maintenance costs. This produces a single dollar amount which represents the total expenditure expected on the vehicle over its useful life, assuming the capital outlay is made immediately, and future operating and maintenance costs are discounted into present-day dollars. The NPV approach is useful for comparing investments with exactly the same useful life.

Another common approach to life-cycle costing is termed "annual equivalent cost", which spreads the capital investment cost over the vehicle's useful life and adds annual operating and maintenance costs. This technique is most appropriate when comparing vehicles with different economic life spans (e.g., replacement versus rehabilitation). The AEC approach assumes that only a portion of the capital expenditure is consumed each year and, hence, spreads the capital cost and interest over the useful life of the vehicle in equal annual amounts. The current annual operating and maintenance cost is added to this figure to identify AEC in current dollar terms.

The AEC methodology more closely reflects the transit funding environment than does the NPV. The NPV methodology determines how much money you need in hand today to cover the vehicle's entire life of capital and operating cost, assuming you can invest operating and maintenance costs for future years and earn interest to be applied to those expenditures. The AEC methodology spreads the capital cost of a vehicle over its useful life, accounting for the time value of money (e.g., similar to an interprise fund or sinking fund), which reflects the consumption or depreciation of a vehicle's value over time. The operating and maintenance cost is expressed in annual, constant dollar terms—reflecting that these revenues are earned in the year expended.

Life-cycle costing can be used in determining the lowest responsive bid in a vehicle procurement based on the Surface Transportation Assistance Act of 1978. In fact, life-cycle costing was mandatory in a vehicle bid for a single year, but was made optional after several difficulties were experienced in applying LCC in transit.

There is a substantial amount of published and unpublished literature on life-cycle costing as it applies to transit bus procurement. Life-cycle costing techniques vary substantially between operators, with some opting for simple cost comparisons between two or three high cost components (e.g., fuel efficiency, engine life, and parts requirements) to very complex comparisons of life-cycle, work needs, and materials. All of the literature reviewed by the research team focused on comparing vehicles during the procurement phase. No research was uncovered which addressed the use of LCC techniques in determining cost-effective replacement or rehabilitation times, which is the focus of this research effort.

The greatest area of concern in LCC is how cost estimates are prepared for each vehicle type. Most of the literature notes that in almost every case operators need to rely on manufacturer's cost data as at least some of the vehicles proposed are frequently not operating in the existing fleet. So, even though the operator's LCC technique for evaluating whole life vehicle costs is consistent between manufacturers, the method used by manufacturers to provide cost information could vary widely. These differences have resulted, on occasion, in significantly divergent cost estimates on essentially the same vehicle. Much of the literature presents alternative suggestions toward avoiding these problems. Many different specific approaches to estimating LCC in the procurement phase are discussed in the literature. The scope of each method is focused on addressing the procurement cost concerns, data availability, and analytic capabilities of individual operators. No single technique appears "best" for all situations in either a theoretical or empirical framework.

Bus Purchasing Guidelines

Federal funding policy in the area of bus replacement is restricted by the application of minimum standards for fleet replacement and rehabilitation, and for contracting procedures. In view of the federal contribution of up to 80 percent of total capital investment in fleet replacement, federal regulations in this regard are of vital importance to transit operators.

Federal Funding Policy for Bus Replacement

Initially, federal funding policy regarding bus replacement, outlined in the Urban Mass Transportation Act of 1964, as amended, was based on vehicle life expectancy (a 12-year vehicle replacement cycle) and funding availability. Since that time, vehicle sophistication has been enhanced dramatically because of technological factors, and a vehicle's useful life and associated costs have changed radically. While some operators, usually those with low mileage systems, are operating 24-year old buses without problems (for example, the University Transit System in Davis, California), others have difficulty keeping 8-year old vehicles on the streets.

In response to the changing environment, in October 1985, UMTA revised its guidelines to include a minimum cumulative mileage limit of 500,000 miles. Consequently, current UMTA policy is to fund vehicle replacements on the basis of a vehicle age of 12 years or 500,000 cumulative vehicle-miles, whichever occurs first. UMTA is, however, willing to entertain exceptions to these minimum standards. In interviews with UMTA personnel, it was indicated that exceptions, while rare, are treated on a case-by-case basis; and are favorably considered for reasons such as exceptionally rough terrain, harsh climate, and fire damage. Unless an exception is granted, capital replacement subsidies are reduced if a bus is retired before it has reached the normal life threshold.

Federal Funding Policy for Bus Rehabilitation

UMTA guidelines governing federal assistance for the rehabilitation and purchase of transit rolling stock include two provisions that are relevant to operator's deliberations regarding bus replacement versus rehabilitation. The first is the allowable cost of rehabilitation, which is defined in terms of the comparative value of a new vehicle as shown in Eq. 3:

$$\text{Allowable cost} = \frac{\text{Purchase Price}}{12} * \text{Years of Extended Life} \quad (3)$$

Thus, for example, if the current market price of a new bus is \$130,000 and the operator is expecting an additional six years from a rehabilitated vehicle, the allowable unit cost for the rehabilitation would be \$65,000. The UMTA rehabilitation funding policy states that a rebuild must extend the life of a bus by more than 5 years to qualify for funding.

The second provision is the cost borne by the transit system for rehabilitation or replacement. The new federal guidelines define a sliding scale for the federal match, based on vehicle age at the time of replacement or rehabilitation. The full 80 percent match is provided only if the vehicle has reached the end of its normal service life (i.e., 12 years or 500,000 miles for standard 40-ft coaches). The match is prorated for younger vehicles, based on the ratio of age to the normal service life. The replacement or rehabilitation of a 6-year old bus (the minimum age), for example, would receive a 40 percent federal match.

These guidelines are important because they define a maximum unit cost for rehabilitation which UMTA will fund and the rate at which the rehabilitation or replacement cost will be met by UMTA. It is this latter impact of the funding guidelines which most directly affects the replace versus rehabilitate decision.

Federal Funding Policy for Contracting Instruments

Among the contracting methods available for bus procurement are:

1. Competitive sealed bids, wherein sealed bids are publicly solicited and a firm-fixed-price contract (lump sum or unit price) is awarded to the responsive bidder whose bid is lowest in price.
2. Competitive negotiation, where proposals are requested from a number of sources through a Request for Proposal process. This contracting instrument is used if competitive sealed bids are not appropriate.
3. Noncompetitive negotiation, where a proposal is solicited from one source only, or after solicitation from a number of sources, competition is determined inadequate. This contracting instrument should be used only in special circumstances, such as the availability of an item from one source only.
4. Competitive bid with option for future purchase of further items at a fixed price, where the operator contracts to purchase a given number of vehicles immediately at a fixed price (or price plus escalator), with the option of purchasing a given number of vehicles by a future date at a given price (or price plus escalator).
5. Additional innovative procurement methods may be used with the approval of UMTA.

In general, in the interests of free competition, UMTA prefers that the competitive sealed bid be used. In particular, if the competitive bid-future option instrument is used, UMTA prefers that the length of time for which options are in effect be relatively short (less than a year). Life-cycle costing is an alternative to the low bid process. It was mandatory for one year, in FY 1983–84, but was made optional thereafter because of the difficulty in identifying and quantifying specific costs.

SURVEY OF CURRENT BUS REPLACEMENT PRACTICES

A survey of a broad cross section of U.S. transit agencies was conducted to determine the bus replacement and rehabilitation practices currently in place. The transit agencies surveyed included a wide range of operator fleet sizes and geographic locations to ensure that survey results are representative of bus replacement practices nationwide. The survey focused on identifying factors considered important in making replacement and rehabilitation decisions and to contrast them with the factors actually used by transit operators to schedule future fleet capital investment.

The survey also assessed the evolving sophistication of the fleet management effort at transit systems by obtaining information on planned investments in fixed facilities, vehicle enhancement equipment, and maintenance diagnostic equipment. Additional information on vehicle procurement policies and vehicle quality assurance programs was also requested. The final element of the survey instrument included a roster of actual bus retirements and rehabilitations over the 1980 to 1985 timeframe and those planned for the 1986 to 1990 timeframe.

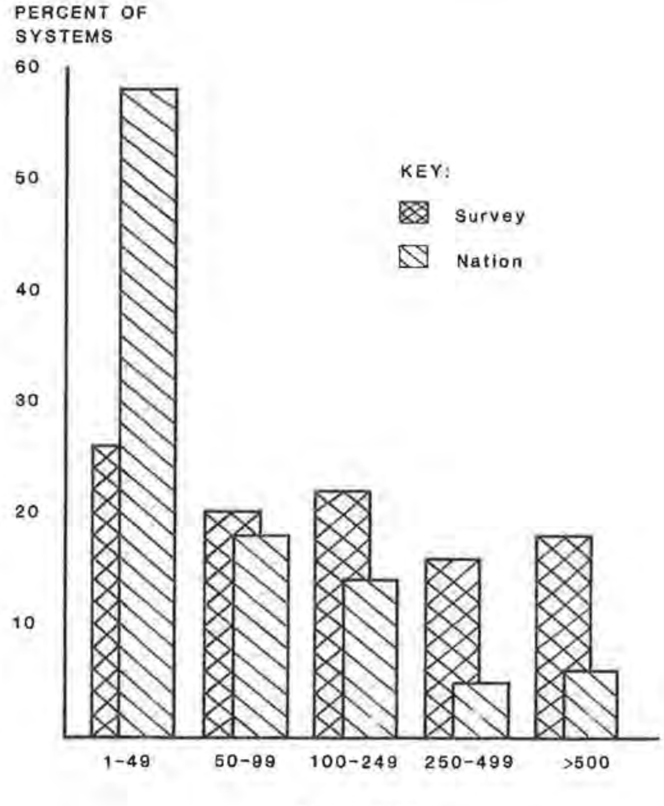

Figure 2. Fleet distribution of survey respondents.

Survey Distribution and Response

The survey was sent to 160 transit agencies across the nation with the emphasis placed on systems with fleets in excess of 50 buses, because these operators would more likely need to address the capital replacement issues that are the focus of this study. Eighty-eight responses were received from the survey. The responding transit operators represent almost 20 percent of the transit operators in the United States and operate a total of 27,842 buses (which comprise approximately one-half of the active transit buses in service in the country). The high response rate is attributed to the simplicity of design of the survey instrument and conciseness of the overview. Figure 2 shows the fleet size distribution for the survey respondents as contrasted with all U.S. transit agencies. Responses were received from operators in 34 states.

Survey Findings

The survey explored the factors affecting replacement and rehabilitation decisions. Factors examined included age, mileage, hours, fund availability, life-cycle costs, and major system failures. The survey results showed less diversity in capital programming and fleet maintenance practices than expected by the research team. The detailed results of the survey are provided in Appendix F.

Basis for Actual Fleet Capital Investment Decisions

Consistent with the literature search, the major conclusion resulting from the survey is that when federal and local funds are available transit operators base capital replacement decisions on the simple criterion of bus age. Ninety-two percent of the responding systems rank this single factor as either the primary or secondary consideration in the vehicle replacement decision. Cumulative mileage and major system failures, while receiving significant consideration in the replacement decision, are of less importance than the age of a vehicle.

The rehabilitation decision is influenced by the same factors as the replacement decision, but fewer agencies consider rehabilitation as a viable option. In fact, half of the transit operators surveyed do not rehabilitate buses. This reflects the influence of the UMTA guidelines, which only consider full funding for rehabilitation when a bus is at the end of minimum normal service life (e.g., 12 years old or 500,000 cumulative vehicle-miles). Further, bus rehabilitation must be justified relative to the purchase of a new bus. The survey results reflect the fact that for many operators there is no compelling reason to consider bus rehabilitation under federal funding guidelines.

Basis for Planned Fleet Capital Investment Decisions

The survey results for planned fleet investments again reflect the pragmatic influence of UMTA financial assistance. The availability of federal funds is cited by 96 percent of respondents as the primary or secondary consideration when scheduling fleet replacements. UMTA guidelines are the dominant consideration when scheduling replacements. Concerns such as uniform fleet replacement, economies of scale, and economies of financing are only of minor importance, with less than 10 percent of transit agencies giving these factors primary consideration.

As UMTA funds and guidelines influence plans for fleet replacement, the lack of federal funds is the major consideration on whether to plan for bus rehabilitation. For reasons previously cited, however, most transit systems do not consider bus rehabilitation as a viable option when compared with the purchase of a new vehicle.

Other Capital Investments

One of the hypotheses considered in the survey is that transit operators are taking advantage of increasingly sophisticated capital equipment as part of their fleet maintenance programs. The questionnaire explored this in three areas: fixed facilities, vehicle enhancement equipment, and maintenance diagnostic equipment. Results in the latter two categories indicate that agencies are investing in such equipment to maintain vehicles, again supporting the literature search results addressed previously.

The survey results show that two-thirds of the transit systems have no plans for a new maintenance facility over the next 5 years. Half of the remaining systems have budget approval for a new facility. Similar results for new central shops and maintenance facility rehabilitation suggest that most transit agencies have adequate fixed facilities to meet their near-term needs.

The survey results suggest that increased emphasis is being placed on supporting capital investments in the maintenance areas. Almost one-half of the transit systems are in the process of acquiring air starters, while over one-third are acquiring brake retarders. These same proportions hold for maintenance diagnostic equipment. Approximately one-third of the operators surveyed are in the process of acquiring brake test equipment, dynamometers and/or electrical system testers.

Vehicle Procurement Process

Transit systems are becoming increasingly sophisticated in their procurement evaluation processes, as shown by consideration given to price offsets and life-cycle costing. While 90 percent of transit operators use the low bid criterion for the purchase of revenue vehicles, approximately one-half include evaluation for price offsets and life-cycle costing as primary and secondary considerations in the procurement process. Competitive negotiations receive less consideration.

Almost every transit agency provides for in-plant quality assurance inspection of new and rehabilitated vehicles. Almost two-thirds of the agencies rely on staff inspectors solely for this inspection. The remainder use consultants or a combination of staff and consultants to conduct the inspection.

Fleet Replacement Practices

The final component of the survey included a review of actual and planned bus retirements and rehabilitations. Information was requested for actual fleet replacements for the past 6 years (1980–1985) and for planned replacements for the coming 5 years (1986–1990).

Actual Replacement and Rehabilitation

It was reported that 5,116 vehicles or 18 percent of the existing fleet of the transit systems responding to the survey were replaced during the 1980–1985 timeframe. The actual replacement and rehabilitation decisions demonstrate the different duty cycles that are in existence at different transit systems.

Large transit systems with more than 1,000 buses in their fleets replace their buses at an earlier age and with less cumulative vehicle-miles than other agencies. Figure 3 presents the actual fleet retirements reported by the agencies. The median retirement age for the large agency buses is 11 years with over 34 percent being replaced in 10 years or less. The medium-size systems, with between 250 and 1,000 buses, and the small agencies, with less than 250 buses, have a median retirement age of 17 years and 14 years, respectively. Interestingly, the small systems operate over 16 percent of their buses for more than 20 years, while their medium-size counterparts keep over 12 percent of their vehicles in service for a similar time period.

Figure 4 presents a similar picture for retirement mileage. The median mileage at replacement for the large transit agencies was 350,000 cumulative vehicle-miles, while the medium and small agencies reported a median retirement mileage of 500,000 miles and 450,000 miles, respectively. Only the small and medium-size agencies reported results for previously retired buses. The results show that the rehabilitation decision is made sooner than the replacement decision. The median age at the time of rehabilitation was 13 years (1 to 4 years prior to retirement). The median mileage of the buses of the small agencies was 250,000 cumulative vehicle-miles and 450,000 miles for the medium-size systems at rehabilitation.

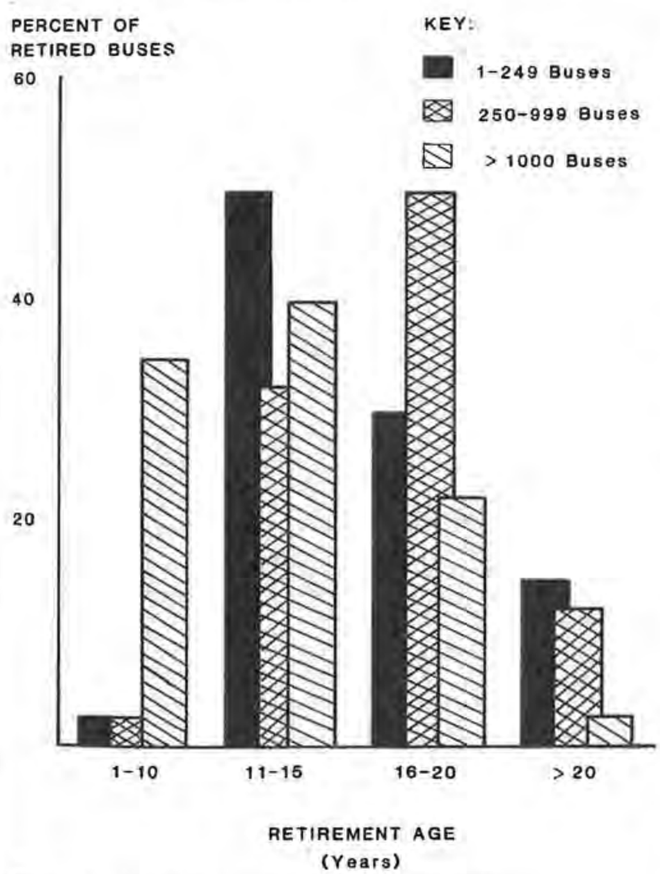

Figure 3. Actual fleet retirement age 1980–1985.

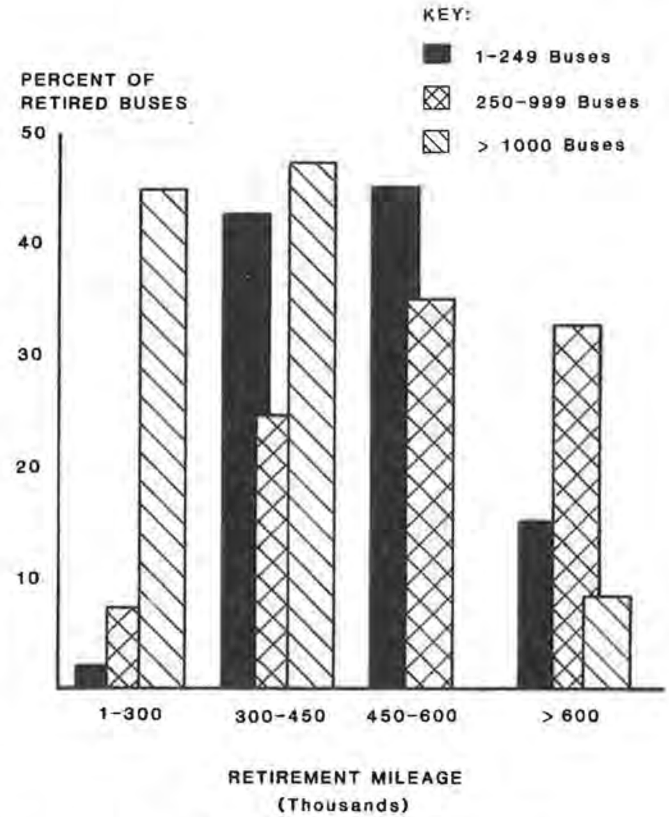

Figure 4. Actual fleet retirement mileage 1980–1985.

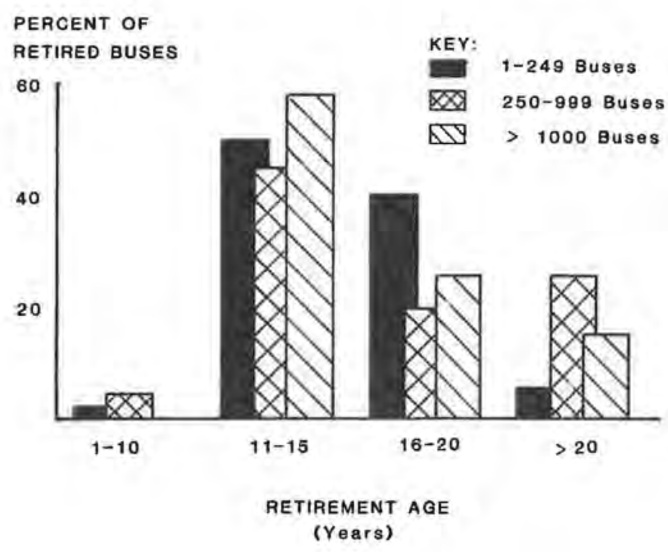

Figure 5. Planned fleet retirement age 1986–1990.

Planned Replacement and Rehabilitation

The survey results shown in Figure 5 and Figure 6 for planned bus retirement for the next 5 years include 7,890 buses or 28 percent of the active fleet for the operators surveyed. This corresponds to an average bus life of approximately 16 years, which

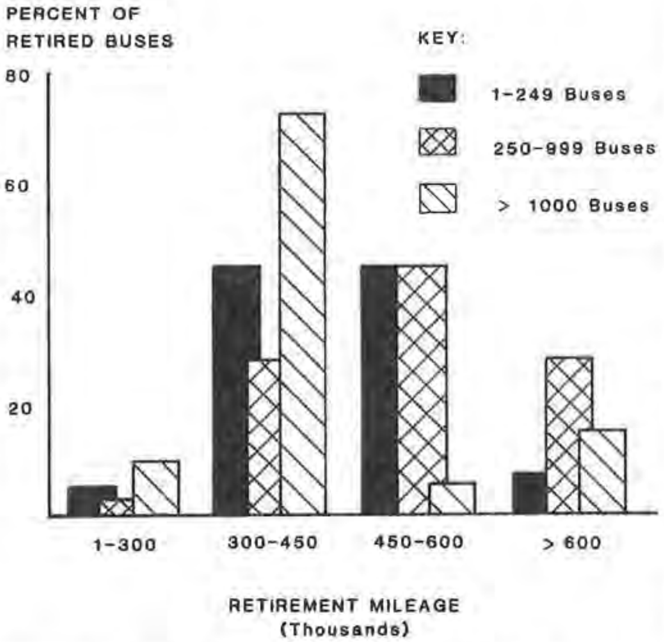

Figure 6. Planned fleet retirement mileage 1986–1990.

is greater than the 12 years accepted by UMTA. While past practice indicates a significant difference between bus retirement practice for large, medium and small transit operators, future plans show that this gap is expected to dissipate. The survey shows that largely due to anticipated funding constraints, transit operators are planning to use vehicles for more service years before retirement.

SURVEY OF OPERATING AND MAINTENANCE COSTS

An essential part of the research entailed the collection and analysis of detailed transit operating and maintenance cost data. As discussed in Chapter One, the research team used a disaggregate data collection guide (shown in Appendix E) to glean detailed life-cycle cost information from transit operators. Because of the nature of the data required, only 11 transit operators were able to provide most of the data elements needed for the research. Some of the operators were able to provide cost data by individual operating divisions which, in a practical sense, operate as separate cost and production centers. This brought the number of observations up to 26 individual bus maintenance locations. Although this is not a large sample, great care was taken to ensure that the participating operators represent the vast array of operating characteristics and fleet compositions found in the industry.

Data Availability

It was determined that most operators participating in the study had only recently implemented automated maintenance cost reporting systems (e.g., within the prior 1 to 3 years). This additional performance tracking capability contributed significantly to the quality of maintenance cost data. However, because formal cost monitoring at a detailed level is a new capability, historical subfleet cost data were not available at any participating operator. Thus, the research was not able to build a life-cycle cost profile for any single fleet type at any operator, Rather, data were collected for similar vehicles of different ages at different operators to help explain cost variances.

All of the operators contacted during the detailed cost collection effort demonstrated a keen interest in bus operating and maintenance costs relative to a vehicle's useful life. Most operators indicated that they are just beginning, or will begin in the next 2 years, to evaluate the usefulness of this information in managing the capital assets of the agency. The timing of this particular study supports these efforts.

Bus Subsystem Costs

Vehicle operating and maintenance costs were examined by individual vehicle subsystem defined in Chapter One to identify major cost components and the impact of vehicle age on these components.

Distribution of Cost by Subsystem

As described in Chapter One, the research team collected information from each participating operator concerning each one of the 14 different categories (subsystems) of operating and maintenance cost by vehicle fleet. The subsystem cost as a proportion of the total annual operating and maintenance costs typically exhibited a wide range across the 11 operators and 160 vehicle fleets reviewed, as shown in Figure 7. There are many reasons for the deviation. One is related to how work is reported. Some operators record all running repair conducted during inspection procedure as inspection work; others allocate the repair to subsystems. Another relates to the age of a particular fleet. Because fleets were defined as all vehicles within a single operator of the same make, model, and year, and only 1 or 2 years of data were available, if the observed years happened to occur during a time when major subsystem repairs (e.g., engine rebuild) occurred, the mix of costs would reflect a higher proportion of costs for that subsystem than other fleets. Another example of this would be new fleets under warranty, where fuel, servicing, and inspection would command higher cost proportions than many fleets with subsystem repair and rebuild costs. Different operating environments also impact specific subsystems (e.g., speed may impact brake costs; climate may impact heating, air conditioning, and cooling costs; and accident rates may impact body costs). Maintenance philosophies on acceptable appearance levels and performance levels will also impact the proportion of expenses allocated to subsystems. As defined in the study, 160 fleets were examined. It appears that most variances are represented, and the means provide reasonable points of reference for average fleets. The subsystem costs are:

1. *Fuel and Lubricants Costs.* Typically a transit operator's single largest operating and maintenance expense item accounted for 29 percent of the total, on average, with a standard deviation of 11 percent.
2. *Servicing Costs.* The annual costs associated with carrying

out such works as cleaning, sweeping, and fueling vehicles typically represented 11 percent of total operating and maintenance costs for those agencies reporting, with a standard deviation of 6 percent. Vehicle appearance policies significantly impact the proportion of costs devoted to this subsystem.

3. *Inspection Costs.* The annual costs of conducting scheduled vehicle inspections and associated preventive maintenance averaged 10 percent of total costs, with a standard deviation of 4 percent. It should be recognized that transit operators have differing inspection philosophies. Some make most needed repairs as part of the inspection, while others complete the inspection and schedule repairs to be completed at a later date.

4. *Body Repairs Costs.* The annual costs associated with maintaining a vehicle's body exhibited a wide range across the operators reviewed. The average was approximately 9 percent of total operating and maintenance cost with a standard deviation of 6 percent. Differing bus appearance policies, accident rates, and climate all contribute to the variance cost.

5. *Engine Repair Costs and Fuel.* The annual cost of maintaining, operating, and repairing vehicle engines typically represent 9 percent of total costs, with a standard deviation of 5 percent. The phase of an engine's life cycle has a major impact on its overall operating cost.

6. *Brake Costs.* Comprised of all cost for running repairs and reline work on bus brakes on average account for 8 percent of total costs, with a standard deviation of 2 percent. Operating speeds, brake lining materials, and passenger loads were cited as significant causes of variances.

7. *Air Conditioning, Heating, and Ventilation Costs.* The costs associated with ensuring that transit passengers enjoy comfortable air temperatures on their rides typically accounted for 7 percent of total annual operating costs, with a standard deviation of 2 percent.

8. *Electrical Costs.* The annual costs of ensuring that a vehicle's electrical subsystems are adequately maintained typically accounted for 5 percent of total costs, with a standard deviation of 3 percent.

9. *Drivetrain Costs.* The annual costs associated with maintaining and repairing the transmission and differential typically accounted for 5 percent of the total, with a standard deviation of 2 percent.

10. *Suspension Costs.* On average, suspension repair costs represented 5 percent of the total, with a standard deviation of 2 percent.

11. *Tire Costs.* The annual expenditures for repair and maintenance of vehicle tires and wheels accounted for 4 percent of total costs on average, with a standard deviation of 2 percent. Some of the operators noted that the contract costs for tires was not included in their information system, nor was it distributed by subfleet.

12. *Accessories Costs.* Maintenance and repair of fareboxes, wheelchair lifts, and destination signs represented on average 3 percent of total annual costs, with a standard deviation of 1 percent across the operators and vehicle fleets.

13. *Air System Costs.* Costs of repairs, including compressor, air pipe, valves and controls, averaged approximately 3 percent of total costs, with a standard deviation of 2 percent.

14. *Cooling Costs.* Maintaining the radiator, water pump, fan and engine temperature controls averaged 2 percent of total operating and maintenance costs for the operators reviewed. The standard deviation was 1 percent.

These cost proportions are summarized in Table 1. The focus

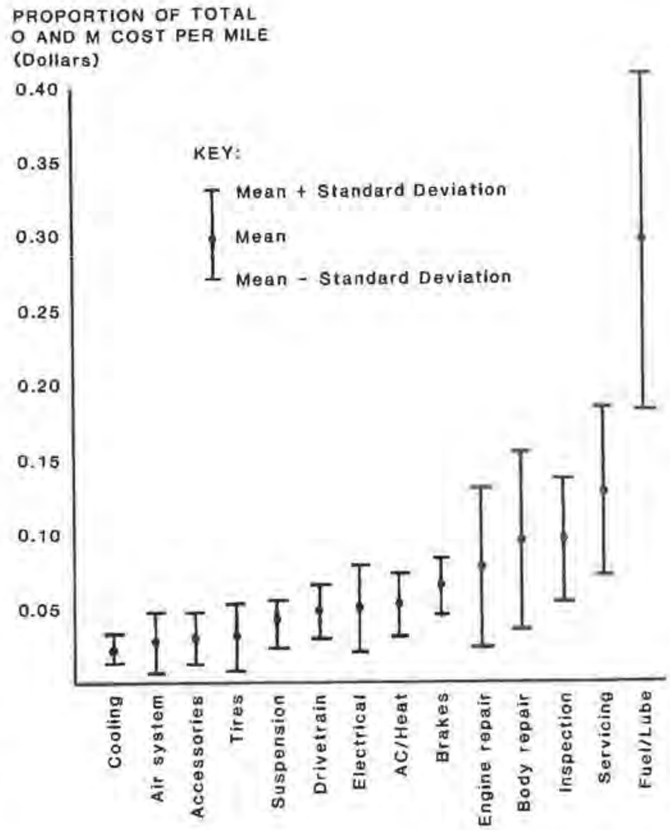

Figure 7. Distribution of subsystem operation and maintenance costs.

Table 1. Annual operating and maintenance cost of subsystems.

Subsystem Costs	Mean Proportion of Total Costs
Fuel and Lubricants	29%
Servicing	11%
Inspection	9%
Body Repair	9%
Engine Repair	8%
Brakes	8%
Air Conditioning and Heating	7%
Electrical	6%
Drivetrain	5%
Suspension	5%
Tires	4%
Accessories	3%
Air System	3%
Cooling	2%

of this study was on the higher cost category items (e.g., drivetrain, engine, and body).

Relationship of Cost to Vehicle Age

Having identified the cost categories and amounts which comprise total annual operating and maintenance expenditures, the research team subsequently reviewed the distribution of each individual cost category across the 160-vehicle fleets studied, in relation to vehicle age. For the purpose of this research study, vehicle age is measured in terms of both years and cumulative miles.

It is important to note that none of the operators reviewed could provide a detailed year-by-year outline of operating and maintenance expenses over the entire life of a fleet (e.g., 12 years). Instead, all operators provided the research team with 1 or 2 years of detailed cost data by vehicle fleet and subsystem (i.e., cost category). Consequently, there was typically a substantial amount of data for similar vehicle types (i.e., those with the same manufacturer) of different ages. Because of operator resource constraints, this analysis was limited to the available data used to assess the impact of vehicle age, in terms of both years and cumulative miles, on total annual operating and maintenance costs, and on each individual subsystem cost.

The research team focused on identifying the degree to which costs are influenced by age. It is recognized that many other factors also influence costs (e.g., differences in vehicle specifications even within the same basic make and model, differences in vehicle appearance and performance standards, and differences in operating environments), but the purpose of the analysis was to determine the impact of different replacement practices on costs.

To allow a reasonable analysis of the impact of age on costs, the research team removed the impact of wage differentials by determining the mean wage rate across all participating operators and dividing this amount by the wage rate reported by each respective operator. The resulting ratio was multiplied by the labor proportion of total operating and maintenance costs for that operator (which assumes that labor rates are subject to a higher degree of variability than parts and materials), and this ratio was then applied to the actual cost per mile to normalize for wage differences. This provides an equitable basis of comparison of cost differences. The model also rounds cost figures to the nearest penny, which reduces the deviation of lowest cost figures and rounds very low dollar amounts to zero.

The research team also attempted to define the degree to which other factors influence costs (e.g., climate, speed) using matrix and multiple correlation analyses. Even when using up to seven intuitive causal factors, the analyses failed to reach a cumulative correlation of 0.50 for any vehicle subsystem cost. This was not an expected study result, and the study team was unable to conclusively ascertain the reasons for disparate costs in light of a failure to define significant correlated factors. The results did produce further queries as to the validity of the data, and while some operators offered revised data for outlyers, the correlation results did not improve. The newness of the information systems, coupled with the fact that most users of the systems noted that the capture of labor hours was more frequently used at a disaggregate level than were costs, suggests that inaccuracies may be more likely to occur at a disaggregate basis. It is still believed, by the operators involved and the research team, that the data are resonably accurate at the more aggregate level needed to address the basic issue of age in this study.

Because of the insignificant correlations between subsystem costs and apparent causal factors uncovered in this analysis, the material presented in this report focuses on the relationship of age and cost. The correlation between subsystem costs and other characteristics is not presented because no conclusions could be drawn based on the analyses, even when multiple factors are considered simultaneously. Inclusion of such extemporaneous material would convolute the results of the analysis at hand, while offering little or no additional insight to vehicle cost tendencies.

As a reminder a perfect association of two variables (i.e., variables change in direct relation to one another) is signified by a correlation coefficient of 1.0. Statistically independent variables are signified by a coefficient of 0.0. A perfect inverse correlation of two variables (i.e., variables change in direct relation to one another, but in opposite directions) is denoted by a coefficient of -1.0. It is important to note that the correlation coefficient is r and not R-squared. The correlation coefficient is determined based on the mathematical formula of the line shown in the graphics presented for each cost and age relationship. The lines are determined by fitting a model relating the dependent variable (i.e., cost) to the independent variable (i.e., age) by minimizing the sum of the squares of the residuals for the fitted line. One of four models was selected, based on the highest correlation achieved—linear, miltiplicative, exponential, or reciprocal.

In the multiplicative and exponential models, the dependent variable (i.e., cost) is first transformed by taking its natural logarithms. Then, the model parameters are estimated. In the reciprocal model, the reciprocal of the dependent variable (i.e., cost) is used. Therefore, a model with a positive slope can produce a negative correlation coefficient. The actual formulas for each model are not presented for two reasons. First, the mathematical formulas are likely to be of limited value to most users of this document. Second, the low correlations suggest that it would be inappropriate to use the models in a predictive manner.

Vehicle Age

As noted earlier, vehicle age can be measured in two ways—in terms of cumulative miles since manufacture, and the number of years since manufacture. Both are valid measures of vehicle age, each representing the wear and exposure experienced by a vehicle. As would be expected there is a high correlation (approximately 87 percent) between vehicle age in years and cumulative miles on the vehicle, as shown in Figure 8. A variation was noted in the annual mileage per vehicle accumulated by the 160-vehicle fleets reviewed for this research study. It was determined that the average annual vehicle mileage across the 160-vehicle fleets is just over 30,000 miles with a standard deviation of almost 11,000 miles.

Vehicle Age in Years

As shown in Figure 9, there is a low correlation (20 percent) between years since manufacture and total annual operations and maintenance costs per mile. While the mean cost per mile

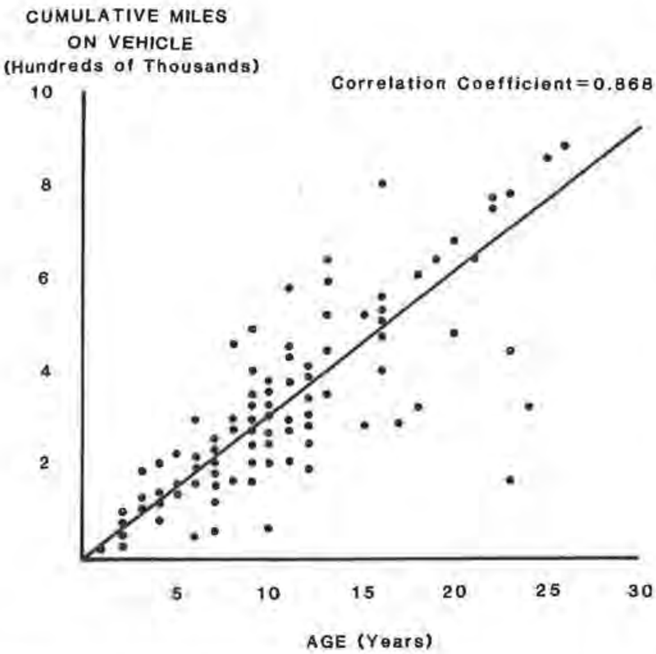

Figure 8. Relationship of cumulative miles on vehicle to age of vehicle.

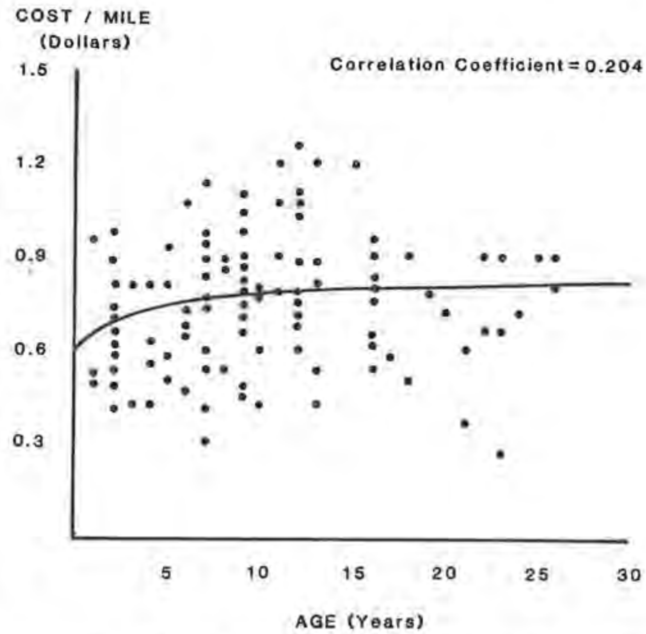

Figure 9. Relationship of total annual operations and maintenance cost per mile to vehicle age.

across the 160-vehicle fleets reviewed is $0.77, the standard deviation is $0.22.

Vehicle Age in Cumulative Miles

There is a slightly higher correlation between total operating and maintenance costs and cumulative miles (26 percent, as shown in Figure 10) than between total costs and years since manufacture (20 percent). Consequently, cumulative miles is used as the measure of vehicle age against which annual costs by vehicle subsystem (e.g., drivetrain, engine repair) are compared.

The relatively low correlations between cumulative miles and total costs per mile and between years and total costs indicate that vehicle age (by either measure) is not the primary factor in explaining total annual operating and maintenance costs per mile. The next step is to determine whether age impacts individual subsystem costs.

Fuel and Lubricants Costs

Representing, on average, 29 percent of total annual operations and maintenance expenditures per vehicle-mile, fuel and lubricant costs are typically an operator's single largest vehicle operating expense item (exclusive of driver wages). As shown in Figure 11, it does not appear that this cost item is significantly impacted by vehicle age in terms of cumulative miles. The correlation between the two parameters is 30 percent. It is more likely that fuel and lubricant costs are related to speed, engine and transmission efficiency, and vehicle size, more than age. While the observed average in this cost category was $0.22, the standard deviation was $0.05. It is important to note that correlations between cost and speed, hours of operation, vehicle type, transmission type, and engine type were analyzed, but even the cumulative correlation for all of these variables was less than 0.10.

The downward slope of fuel and lubricant cost relative to cumulative vehicle-miles can be misinterpreted. While the data

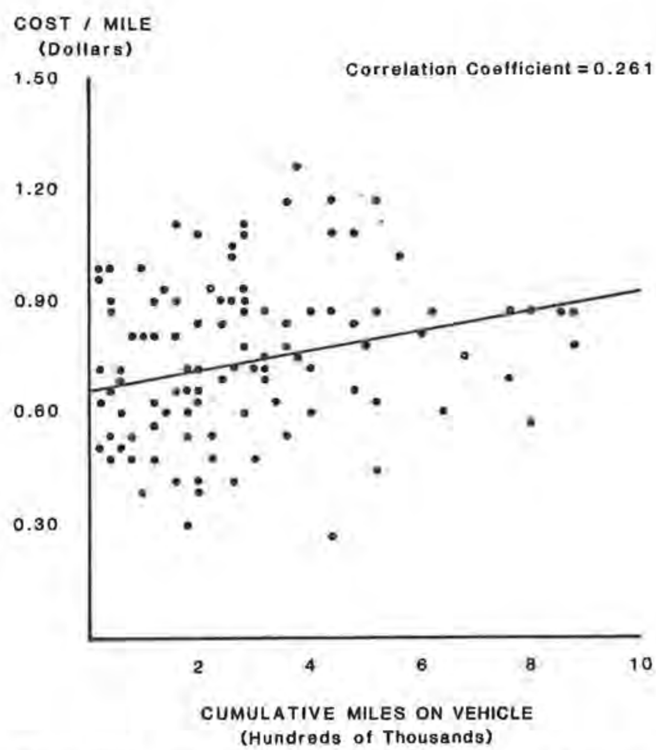

Figure 10. Relationship of total annual operations and maintenance cost per mile to cumulative miles on vehicle.

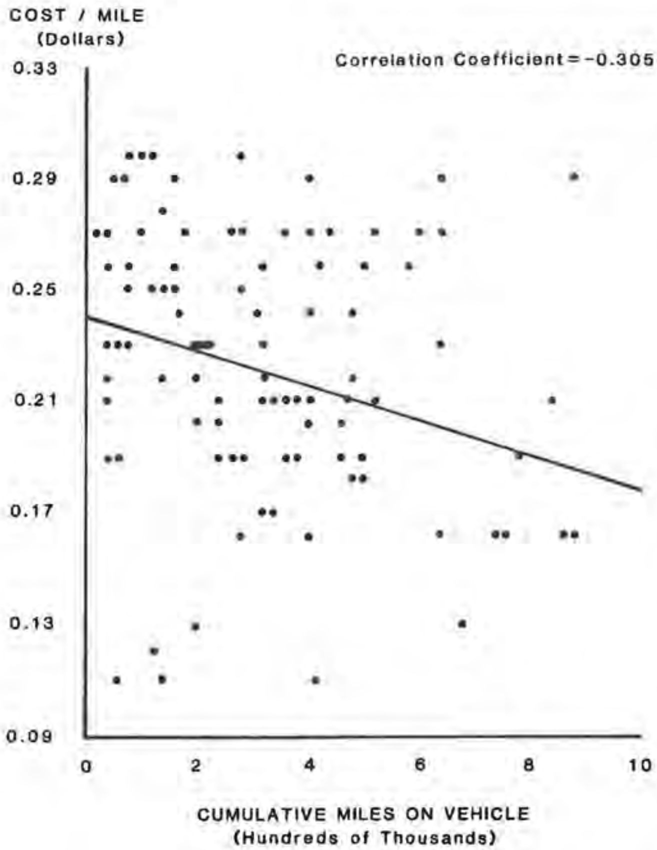

Figure 11. Relationship of annual fuel and lubricant costs per mile to cumulative miles on vehicle.

indicate that older vehicles (i.e., buses with greater cumulative miles) consume less fuel, it should not be assumed that fuel costs drop as a vehicle ages. One should recall that the vehicles represented at different mileage levels are different buses. The higher mileage vehicles are old new look buses. They are lighter than today's buses (safety and compartmentalization requirements were more lenient), have smaller engines, and do not generally have emission control devices that reduce fuel efficiency.

Vehicle Servicing Costs

Annual vehicle servicing costs per mile are, on average, the second largest vehicle operating and maintenance expense item (11 percent of total). Servicing costs were $0.01 per mile on the average, with a standard deviation of $0.05. The analysis showed that there is a 22 percent correlation between this cost item and vehicle age in cumulative miles, as shown in Figure 12. From a conceptual standpoint vehicle age in cumulative miles has no impact on annual servicing costs. This is because all vehicles are treated essentially the same for a given operator in terms of cleaning, fueling, and fare vault pulling. Intuitively, it would appear that vehicle size, vehicle appearance policy, or facility layout may have a more significant impact than age. The research team only had data on vehicle size and found the correlation coefficient between that variable and cost to be less than 0.03.

Vehicle Inspection Costs

As shown in Figure 13, vehicle inspection costs are $0.08 per vehicle-mile on the average (or approximately 9 percent of total

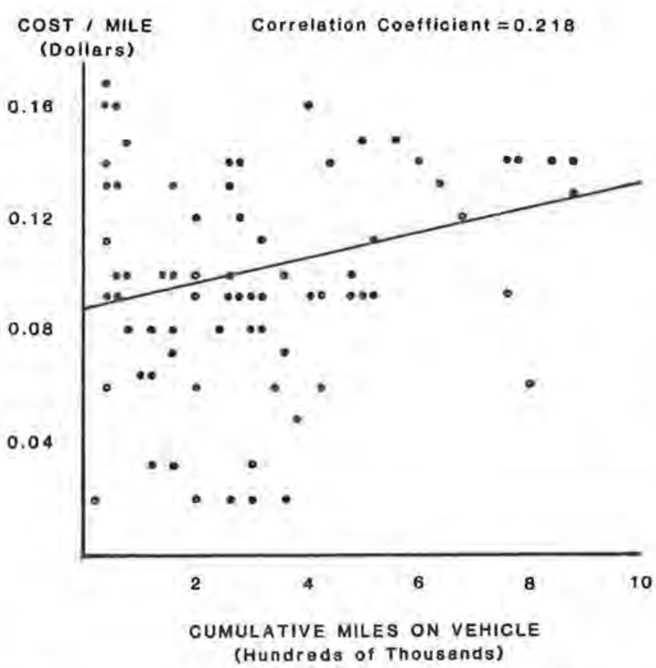

Figure 12. Relationship of annual service costs per mile to cumulative miles on vehicle.

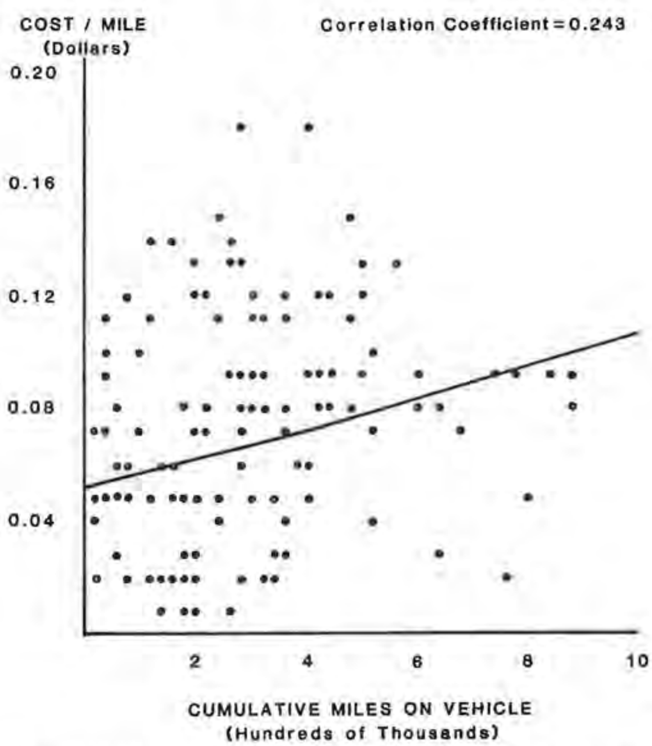

Figure 13. Relationship of annual inspection costs per mile to cumulative miles on vehicle.

operating and maintenance expenditures). The standard deviation is \$0.04 per mile. As inspection procedures are primarily based on internal agency programs and policies, it does not appear that vehicle age in cumulative miles, logically, has a major impact on this expense item. There is a 24 percent correlation between inspection costs and cumulative vehicle-miles observed for the purposes of this study.

Body Repair Costs

Annual body repair costs represent 9 percent of total operating and maintenance costs per vehicle-mile, on average (i.e., \$0.08 per mile, as shown in Figure 14). While the standard deviation is high (\$0.06 per mile), it does appear reasonable to expect a high correlation between body repair costs and vehicle age in terms of cumulative miles. This is because vehicle age is a proxy for factors such as exposure to climate and accidents, as well as wear from use—all of which can necessitate repair to a vehicle's body, upholstery, and glass. The analysis, in fact, showed the correlation between body repair costs and vehicle age in cumulative miles to be 39 percent. Additional factors were considered in a correlation matrix analysis (i.e., climate, accident rate, and vehicle type), but the aggregate correlation coefficient was only five points higher than cumulative miles alone.

Engine Repair

Annual engine repair costs are \$0.06 per vehicle-mile on average, as shown in Figure 15, or approximately 7 percent of total annual operating and maintenance expenditures, with a standard deviation of \$0.03 per mile. The relatively high correlation found between this expense item and vehicle age in cumulative miles (27 percent) makes intuitive sense, based on the fact that engine repair costs are related to wear and use of the engine. Other factors, including engine type, speed, and hours of operation, were evaluated with little additional variability attributed to independent variables.

Brake Costs

Annual brake costs per mile represent 8 percent of total operating and maintenance costs per mile, or \$0.05 per mile, as shown in Figure 16. As expected, there is a low correlation (16 percent) between this expense item and vehicle age in cumulative miles. Routinely brakes are repaired and relined on a relatively frequent basis. A correlation matrix was developed to analyze the impacts of speed, vehicle type and terrain, but less than three points were added from these explanatory variables.

Air Conditioning and Heating Costs

Annual air conditioning, heating and ventilation costs represent approximately seven percent of total operating and maintenance expenditures. As shown in Figure 17, the average for this expense item over the 160-vehicle fleets reviewed was \$0.04 per mile, with a standard deviation of over \$0.02 per mile. As expected, the correlation of 6 percent found between air conditioning and heating costs and cumulative miles per vehicle is quite low, given that these costs are primarily driven by climate

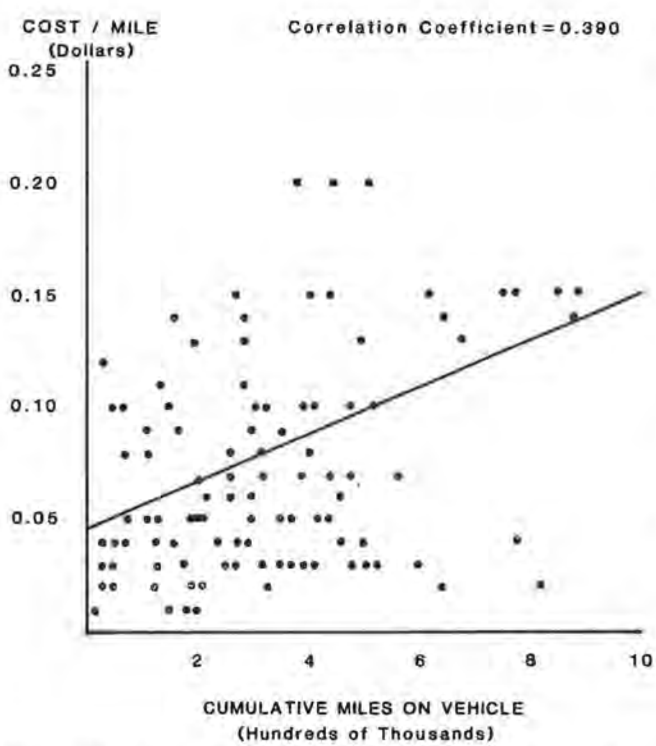

Figure 14. Relationship of annual body repair costs per mile to cumulative miles on vehicle.

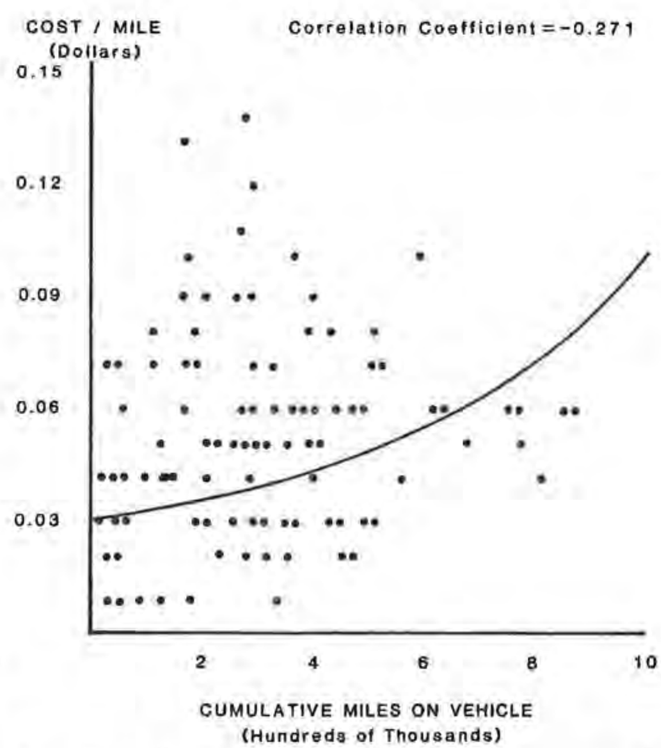

Figure 15. Relationship of annual engine repair costs per mile to cumulative miles on vehicle.

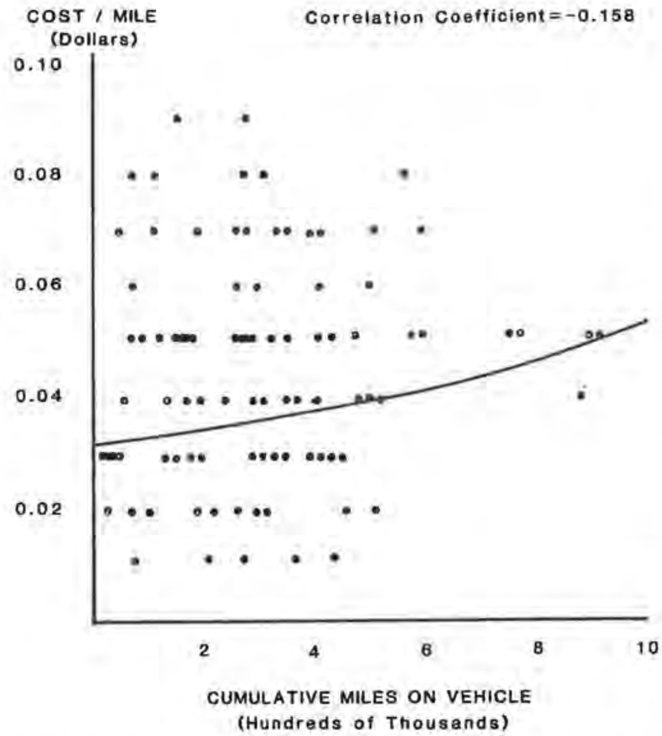

Figure 16. Relationship of annual brake costs per mile to cumulative miles on vehicle.

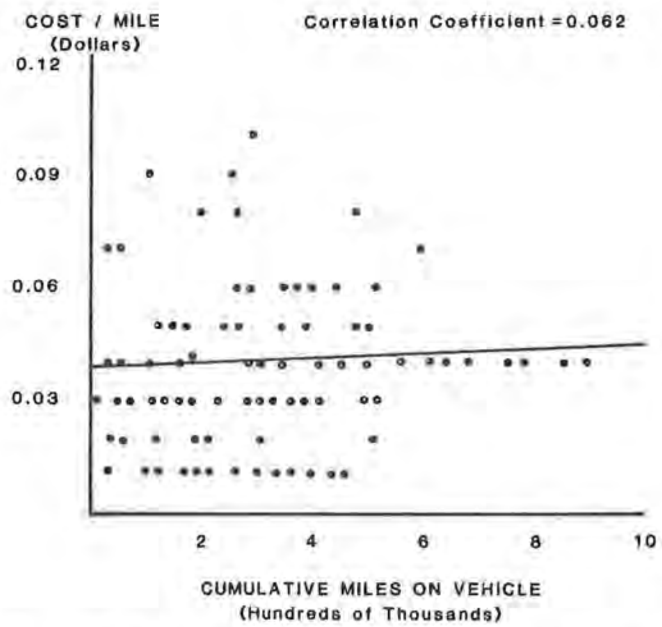

Figure 17. Relationship of annual air conditioning and heating costs per mile to cumulative miles on vehicle.

rather than vehicle age. This was verified in the correlation analysis of cost and climate, which produced a correlation coefficient of 0.27. When cumulative mileage impacts were applied after the impacts of climate were removed, the coefficient for mileage dropped from 0.06 to 0.01.

Electrical Costs

Representing, on the average, 5 percent of total operating and maintenance expenditures, the annual mean expenditure on a vehicle's electrical system is $0.04 per mile with a standard deviation of $0.02 per mile, as shown in Figure 18. The low correlation found between this expense item and vehicle age in terms of miles is based on the fact that electrical costs appear to be more a function of factors such as vehicle size and type. A correlation matrix including vehicle model, manufacturer, and climate added on additional 0.04 to the coefficient.

Drivetrain Costs

Annual drivetrain costs per mile, accounting for approximately 5 percent of total operating and maintenance costs (or $0.04 per mile, as shown in Figure 19), show a stronger correlation with vehicle age in terms of cumulative miles (27 percent). As with engine repair costs, this result is as expected, given that cumulative miles on a vehicle is a primary determinant of drivetrain maintenance and repair requirements. Factors including speed, transmission type and terrain were considered, but contributed little to the coefficient (i.e., 0.07)

Suspension Costs

As shown in Figure 20, there is no significant correlation between suspension costs per mile and vehicle age in terms of cumulative miles. Suspension costs typically account for approximately 4 percent of total operating and maintenance costs, or $0.03 per mile, with a standard deviation of approximately $0.02 per mile across the 160-vehicle fleets reviewed.

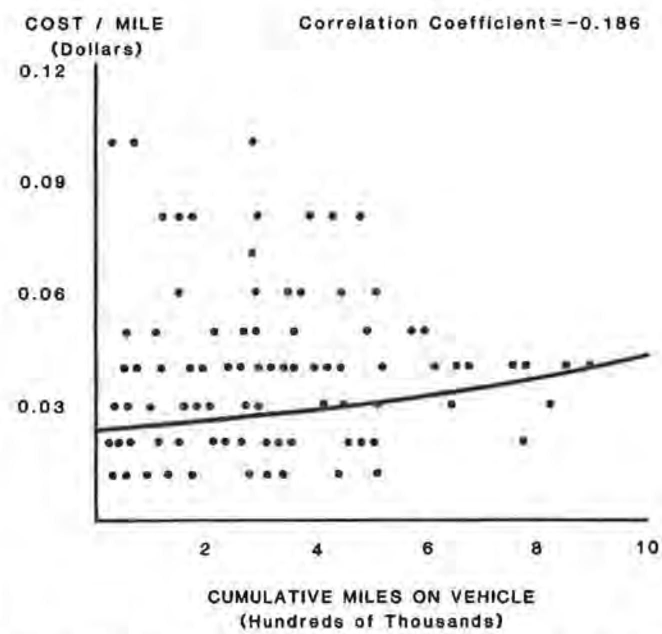

Figure 18. Relationship of annual electrical costs per mile to cumulative miles on vehicle.

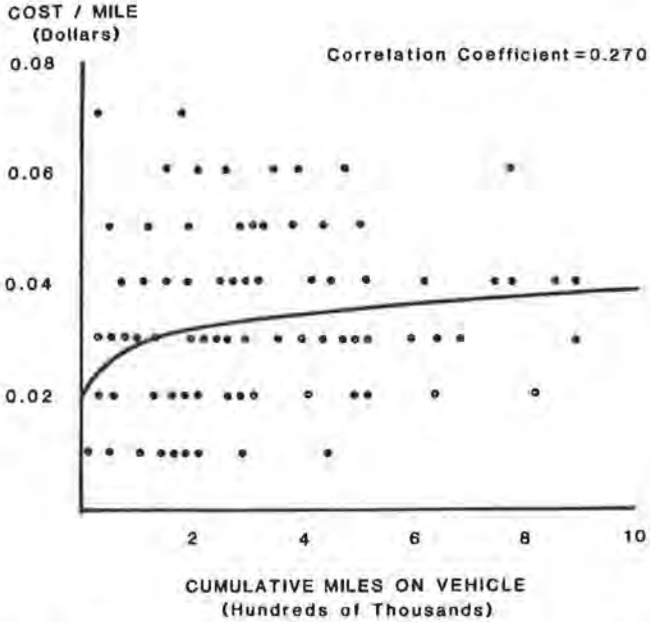

Figure 19. Relationship of annual drive train costs per mile to cumulative miles on vehicle.

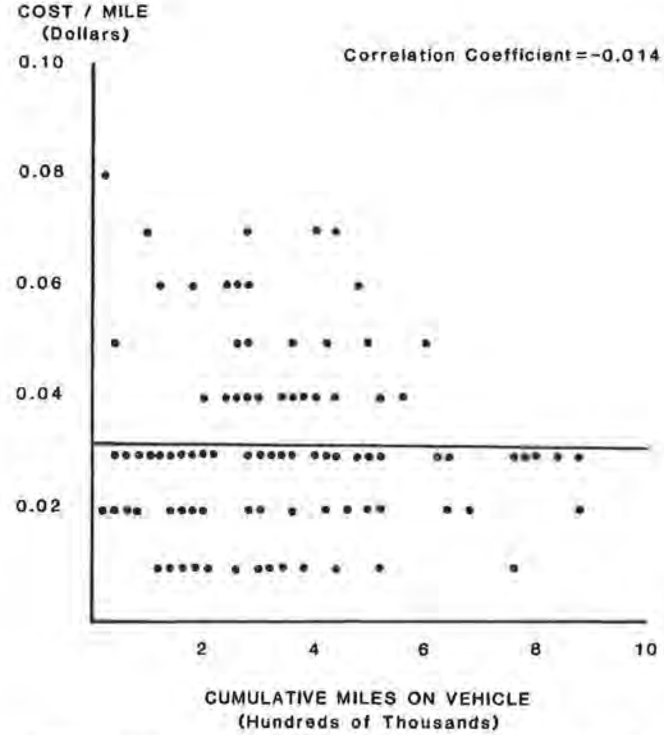

Figure 20. Relationship of annual suspension costs per mile to cumulative miles on vehicle.

Wheel and Tire Costs

This expense, on the average, represents approximately 4 percent of the total annual operating and maintenance costs per mile. The mean wheel and tire costs observed across the 160-vehicle fleets is \$0.02 per vehicle-mile, with a standard deviation of almost \$0.02 per mile. Thus, while there is a high correlation between tire costs per mile and vehicle age in terms of cumulative miles (48 percent, as shown in Figure 21), the standard deviation is extraordinarily high. Consequently, there may be some relationship between annual tire costs and cumulative miles on a vehicle, but it is more likely that these costs are impacted by contractual agreements with suppliers and internal operator policy. In fact, a number of operators indicated that the contract cost for tires was not captured by the maintenance management information system. Because of the high standard deviation, the research team cannot draw a reasonable relationship between this cost item and vehicle age. Because tire and wheel cost comprise only 2 percent of total vehicle operations and maintenance costs, it is not deemed as a principal focus of investigation.

Air System Costs

While air system costs exhibit a high correlation with vehicle age in terms of miles (42 percent, as shown in Figure 22), this expense item represents an average of just 2 percent of total annual operating and maintenance expenditures, or \$0.02 per mile. Because of the low total expense, this item is not expected to be a major focus of the study.

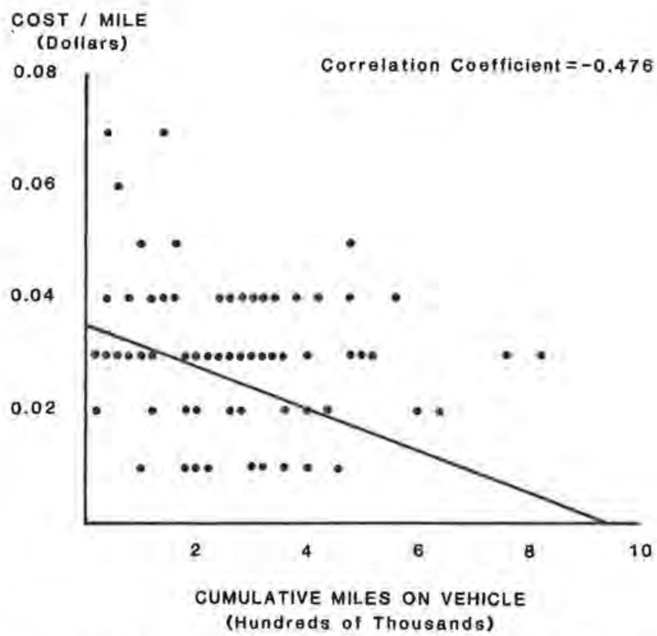

Figure 21. Relationship of annual tire costs per mile to cumulative miles on vehicle.

Cooling Costs

Annual cooling costs per mile account for less than 2 percent of total operating and maintenance expenses (or \$0.08 per mile),

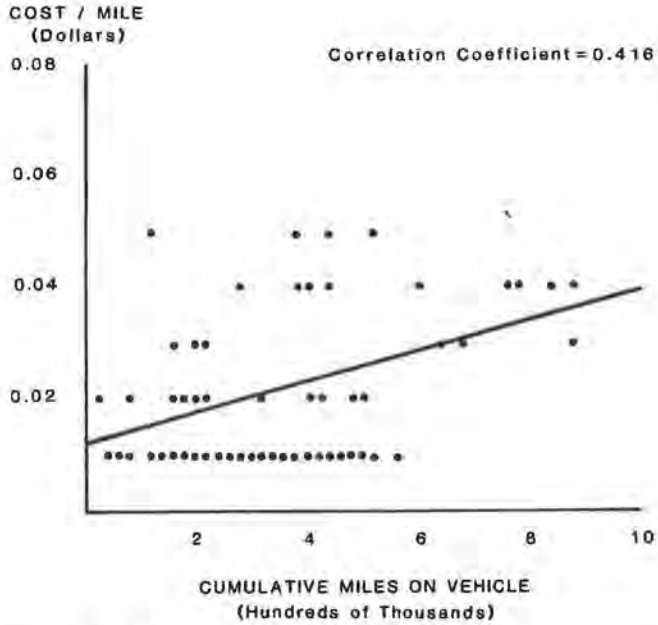

Figure 22. Relationship of annual air system costs per mile to cumulative miles on vehicle.

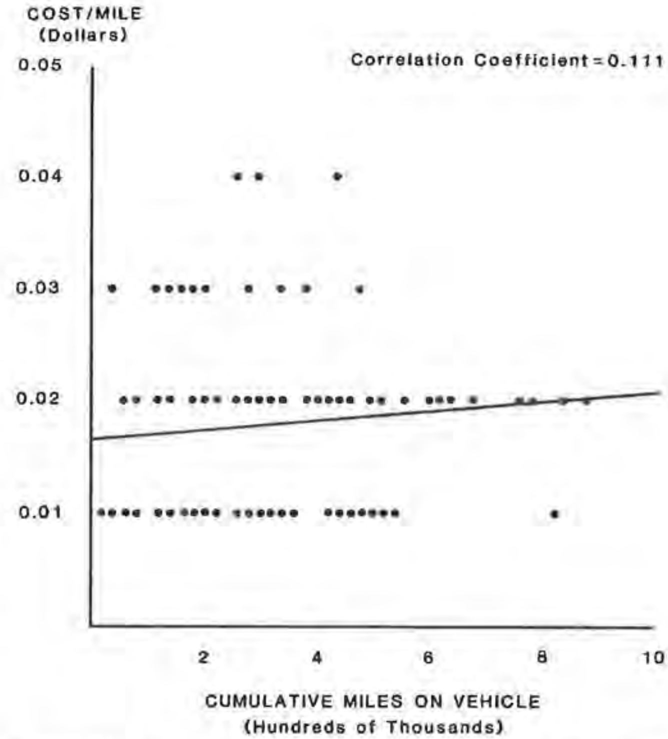

Figure 23. Relationship of annual cooling costs per mile to cumulative miles on vehicle.

on average. As shown in Figure 23, there is low correlation (11 percent) between this expense item and vehicle age in cumulative miles. When coupled with local climate, the aggregate coefficient is 0.22. However, the correlation with cumulative miles did not improve when assessed by individual climate area.

Cost Variances Related to Age

Based on the results of the subsystem analysis, most subsystem operating and maintenance costs do not appear to be significantly correlated to vehicle age. Three subsystem cost categories that account for at least 5 percent of total vehicle operating and maintenance costs have a correlation with age of at least 27 percent and are logically impacted by vehicle age. These three are body, engine, and transmission repair. Three other cost areas accounted for at least 5 percent of expenses, but do not have a logical relationship with vehicle age (e.g., fuel and lubricants, servicing, and inspections).

Each of these three vehicle subsystems are characterized by routine running repair costs and periodic major repair and rehabilitation costs. The latter category of expenditure is most closely related to age, in either years or cumulative vehicle-miles. For example, a major engine rebuild expense may occur every 250,000 miles or 8 years.

The body subsystem can be divided into two separate major repair activities, frame rehabilitation and body/upholstery/glass repair. Each represents a major work activity and can be analyzed separately in terms of cost and frequency.

This section of the report reviews both the cost and frequency of activities and the factors contributing to this experience.

Cost Profiles

The research team developed profiles of the variation of annual operations and maintenance costs with vehicle age (in terms of years since manufacture and cumulative miles on vehicle) for each of five vehicle types—AMG, Flxible, GMC, MAN, and RTS. These were the most common vehicle types among the 160-vehicle fleets reviewed, each case having nine or more observations in the information analyzed.

The profile of annual operating and maintenance costs versus vehicle age in years was developed on the basis of the average total annual costs per vehicle for the fourteen subsystem costs discussed in the previous section (e.g., fuel and lubricants, engine repair, air conditioning, and heating). Although the data indicate a moderate growth in costs for older vehicles, a flat cost is shown here to better demonstrate the impact of major repair activities. The basic cost of operating and maintaining the fourteen subsystems is compared to the specific cost and frequency of the four major rebuild activities (frame, body, transmission, and engine) for each vehicle type. The profile of operating and maintenance cost with respect to cumulative vehicle-miles was developed on a dollars per mile basis, by 50,000-mile segment.

The vehicle cost profiles were developed by determining the mean total vehicle operations and maintenance cost by vehicle type and adding to this amount the cost of rebuilds or major repairs when they occur. As noted in the prior section, most vehicle operations and maintenance costs do not appear to be significantly related to vehicle age (although most experience somewhat higher costs for older vehicles), excepting for major subsystem repair. The research team developed cost profiles using constant dollars (i.e., FY'85 dollars) to allow an easy review of vehicle cost by age.

AMG Cost Profile

As shown in Figure 24, the annual mean base cost of operating and maintaining an AMG vehicle is more than $28,000 for the participating agencies (i.e., based on 19 observations). Transmission rebuilds typically occur three times over an AMG's lifetime—at 5, 10, and 15 years (if the vehicle is not yet retired at 15 years). A transmission rebuild on average costs about $2,350. Engine and frame rebuilds occur simultaneously at 8 years, with costs of $5,400 and $2,580, respectively. A body rebuild, coinciding with a transmission rebuild, occurs in the tenth year, at an average cost of $6,150.

Another way to view costs against vehicle age is using cumulative miles (by 50,000-mile segment) and shows a similar jagged profile in Figure 25. Costs per mile are greatest in the 250,000 to 300,000 mile segment (at $0.79 per mile), compared to the base costs of $0.62 per mile. This represents a 30 percent increase in cost due to transmission and a body rebuild that occurs in that mileage segment.

Flxible Cost Profile

On the basis of 39 Flxible fleets observed, the cost profile with vehicle age in years, shown in Figure 26, illustrates a cost change in operating and maintenance costs over the life of the vehicle. The annual base cost is $29,900, with transmission rebuilds occurring at 4-year intervals (at a cost of $2,040), body and engine rebuilds occurring at 8 years (at costs of $5,040 and $4,480, respectively), and a frame rebuild occurring at 9 years (costing $7,275 on average). Consequently, the highest annual cost occurs in year eight ($41,440), exceeding the base cost by 39 percent.

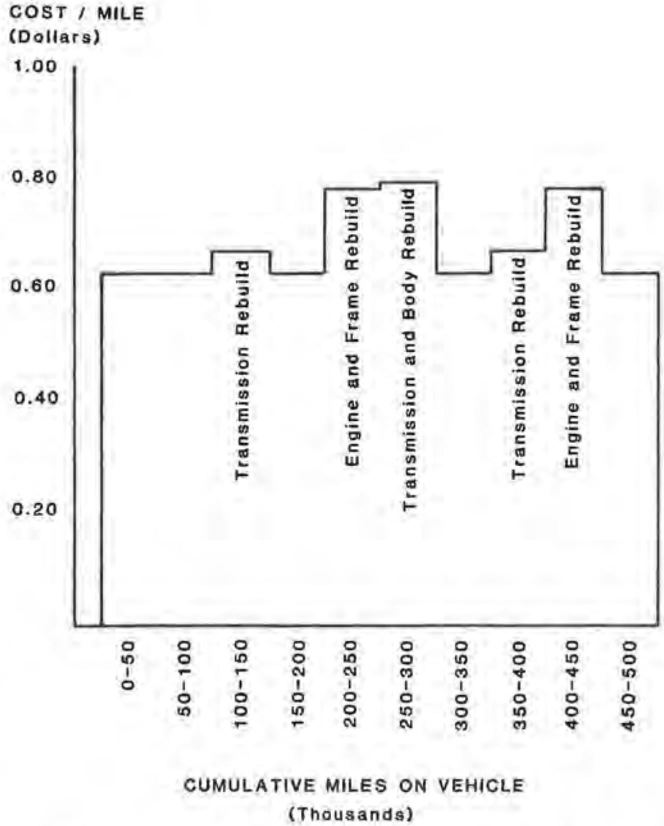

Figure 25. Average operations and maintenance costs per mile by cumulative miles on AMG vehicle.

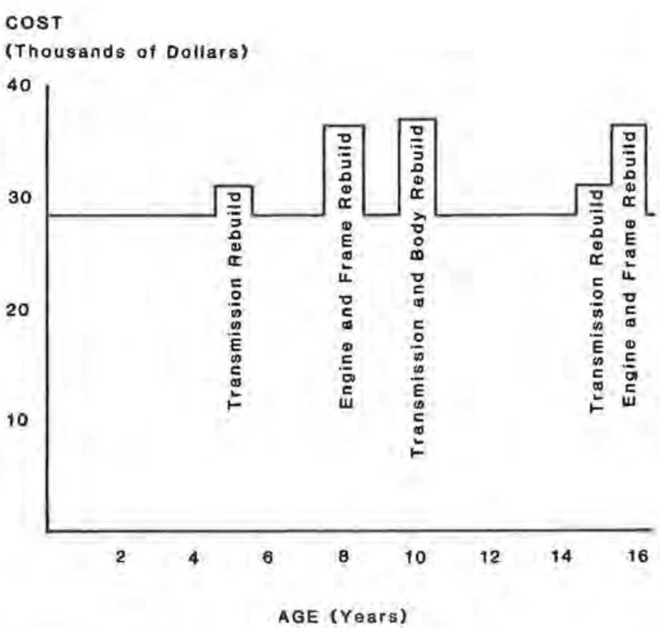

Figure 24. Relationship of annual operations and maintenance expenditures to age of AMG vehicle.

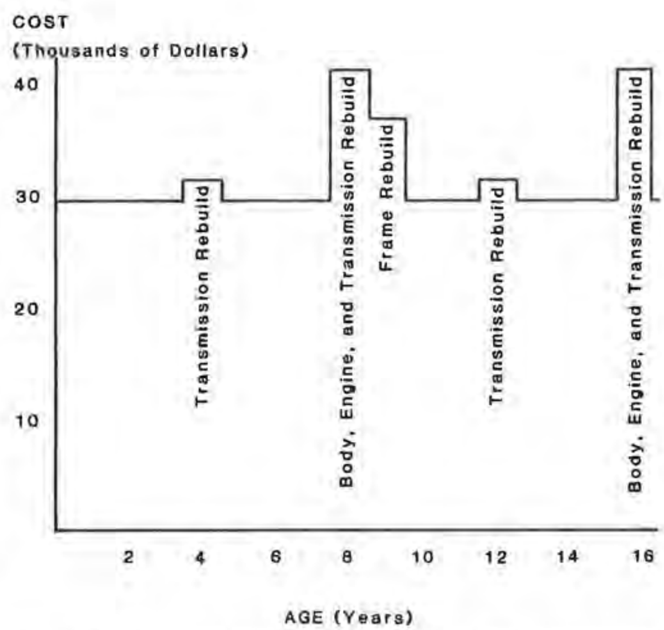

Figure 26. Relationship of annual operations and maintenance expenditures to age of Flxible vehicle.

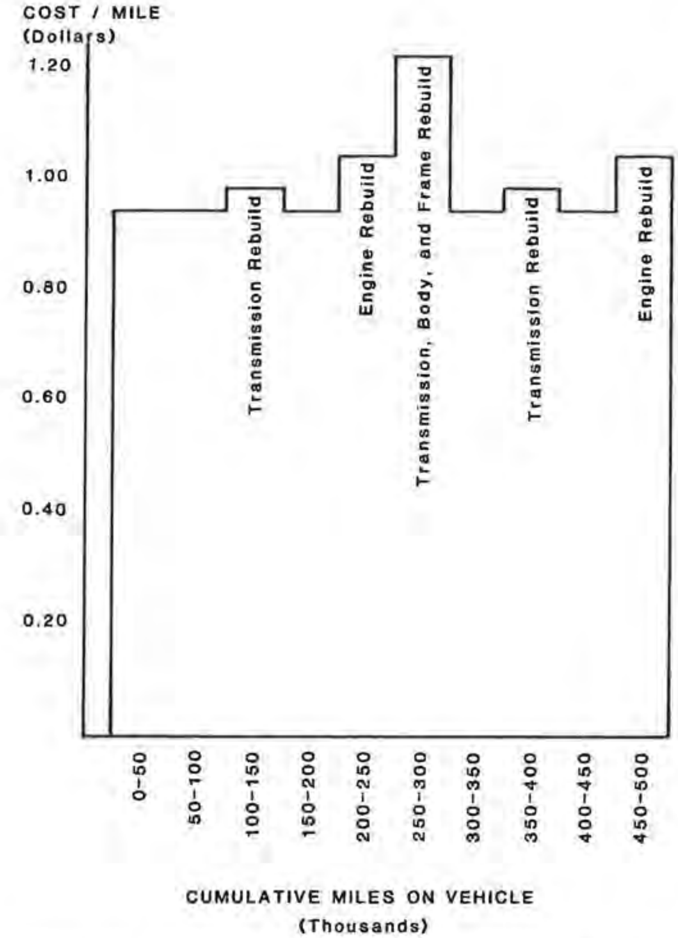

Figure 27. Average operations and maintenance costs per mile by cumulative miles on Flxible Vehicle.

As shown in Figure 27, the $1.22 per mile experienced in the 250,000 to 300,000 cumulative miles segment exceeds the base operating and maintenance cost mile of $0.94 by 30 percent. A body, frame, and transmission rebuild occurs in this 50,000-mile segment.

GMC Cost Profile

Forty-nine observations were available for GMC vehicles. As shown in Figure 28, the average base operating and maintenance cost per vehicle among the operators reporting was lower (at $22,560) than for either the AMG or the Flxible. The deviation from the base cost was also lower for this vehicle type. A total of $31,890 was the highest annual figure observed for the GMC, in the ninth year, when frame and body rebuilds occur at average costs of $4,500 and $4,800, respectively. Transmission rebuilds occur at 4-year intervals on average for this vehicle type, at a cost of $1,750, and an engine rebuild costing $5,230 occurs at year 8.

The maximum cost per mile for GMC vehicles ($0.92) occurs in the 250,000 to 300,000 miles segment when transmission, body, and frame rebuilds occur as shown in Figure 29. This is 31 percent above the base cost of $0.70 per mile.

MAN Cost Profile

The average annual base cost per vehicle reported for the nine MAN fleets observed is $18,700, the lowest of the five fleets reviewed. In the case of the MAN, however, both transmission rebuilds and engine rebuilds occur with greater frequency than for the other vehicle types, at 3-year intervals and 6-year intervals, respectively, as shown in Figure 30. The cost of transmission rebuild is $2,560 on average, and that of an engine rebuild is $5,420. Conversely, body and frame rebuilds tend to last a couple of years longer on MAN's than on the other vehicles—each being needed at 12 years rather than at 9 or 10 years. A body rebuild on a MAN costs $6,270 on average. Observations for frame rebuild were not available from the reporting agencies. However, based on the vehicle types, a frame rebuild is estimated to cost $5,875.

In year 12, thus, a rebuild is carried out on each of the four major subsystems—frame, body, engine, and transmission—at a combined cost of $20,120. Total costs in the twelfth year (if not retired) are $38,820, which is 108 percent higher than the base cost of $18,700.

As shown in Figure 31, the 250,000 to 300,000 miles segment is again the highest cost segment (at $0.98 per mile) because of a frame and body rebuild. This exceeds the base cost of $0.74 per mile by 32 percent. MAN vehicles have the lowest annual average mileage per vehicle of the five fleet types reviewed of the agencies examined—approximately 25,000 miles per year.

RTS Cost Profile

The average annual base operating and maintenance cost per vehicle for the 17 RTS fleets reviewed was $23,260, as shown in Figure 32. Subsystem rebuild activity tended to occur rela-

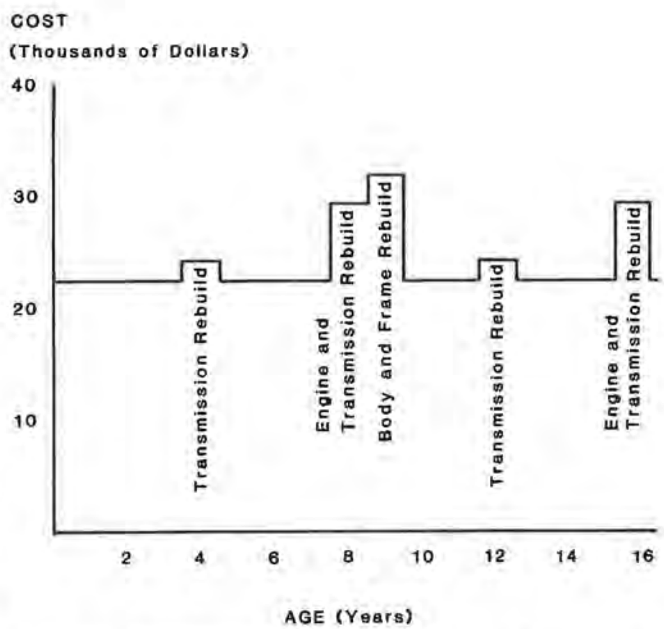

Figure 28. Relationship of annual operations and maintenance expenditures to age of GMC Vehicle.

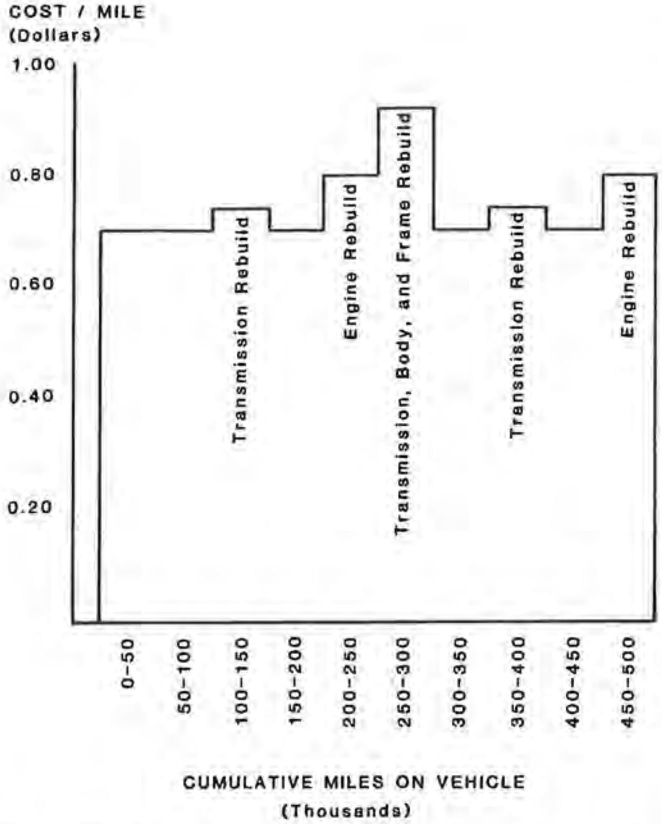

Figure 29. Average operations and maintenance costs per mile by cumulative miles on GMC vehicle.

tively frequently for this vehicle type with transmission rebuilds occurring every 3 years on average, engine rebuilds every 6 years, and body and frame rebuilds every 8 years. The costs of the rebuild activities are, however, commensurately lower than other fleets. A transmission rebuild costs \$2,140, on average, and engine rebuild costs \$4,610, and body and frame rebuilds cost \$6,200 and \$2,600, respectively. The highest annual total cost occurs in the eighth year (\$32,060) when frame and body rebuilds occur. This is 38 percent higher than the average annual base cost of \$23,600.

As shown in Figure 33, the average base cost per mile over a 50,000-cumulative mile segment is \$0.66. The highest cost per mile occurs in the 250,000 to 300,000 miles segment because of transmission, body, and frame rebuilds. The \$0.88 per mile figure is a third higher than the base cost per mile of \$0.66.

Causal Factors

In addition to determining the average cost and frequency of each of the four subsystem rebuild activities (engine, transmission, body, and frame), the research team attempted to determine additional individual factors which drive these items. This analysis was conducted by regressing the subsystem cost or frequency (as the dependent variable) against a number of independent variables, such as vehicle type, vehicle age, average speed, and climate. The analysis was conducted on the aggregate,

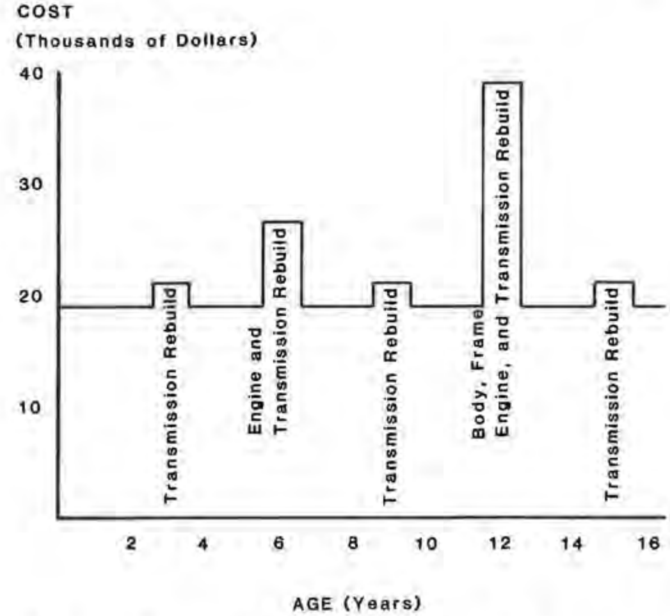

Figure 30. Relationship of annual operations and maintenance expenditures to age of MAN vehicle.

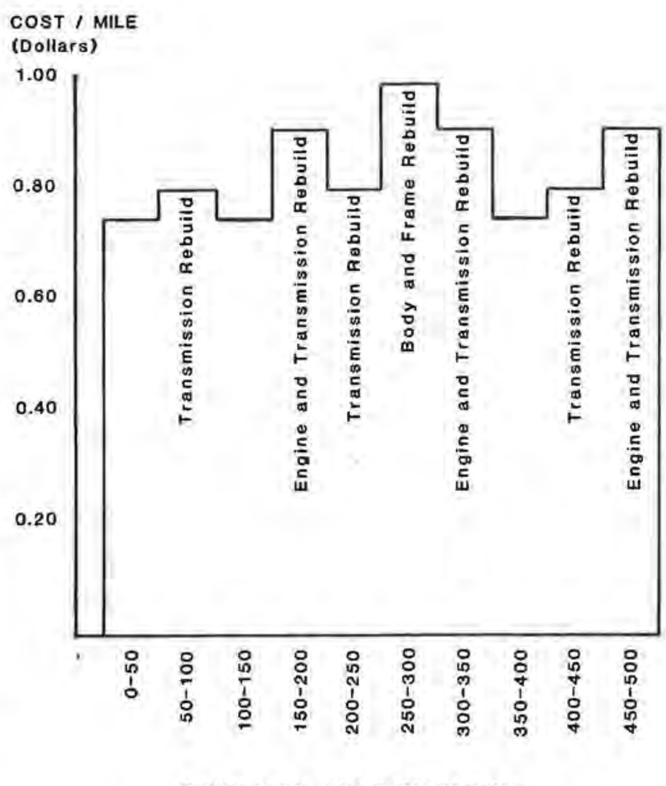

Figure 31. Average operations and maintenance costs per mile by cumulative miles on MAN vehicle.

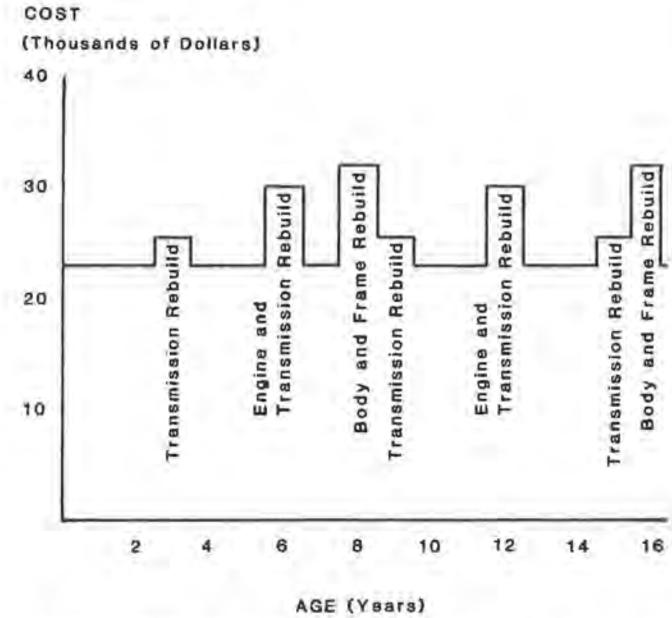

Figure 32. Relationship of annual operations and maintenance expenditures to age of RTS vehicle.

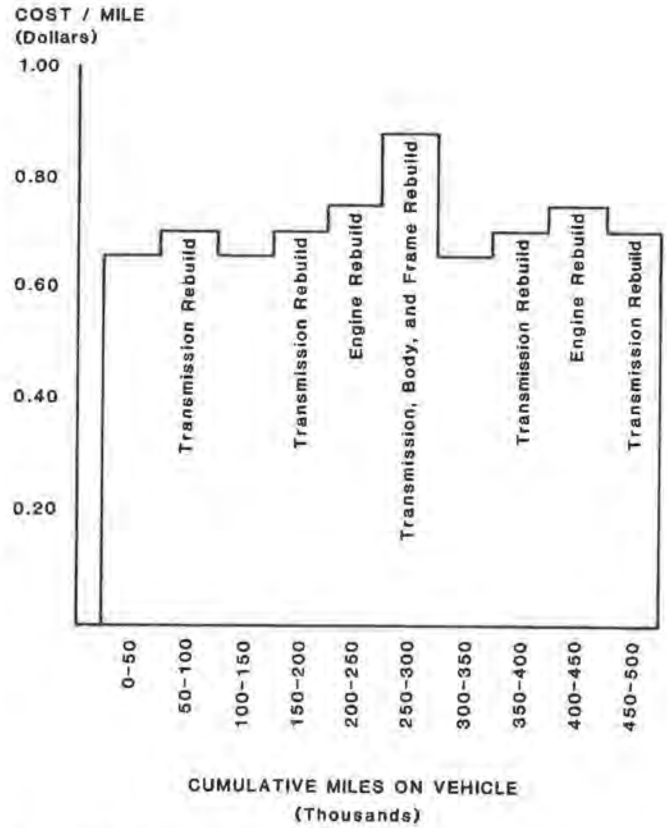

Figure 33. Average operations and maintenance costs per mile by cumulative miles on RTS vehicle.

across all vehicle fleets. It is reasonable to expect that the external or operational factors driving subsystem cost and frequency are the same for the five primary vehicle types reviewed (AMG, Flxible, GMC, MAN, and RTS).

Engine Rebuild

The interval between engine rebuilds varies between 152,000 cumulative miles for the MAN and 238,000 miles for the GMC for the operators reporting in this study. The cost per engine rebuild varies between $4,611 for the RTS to $5,420 for the MAN. The correlation between the frequency and cost of an engine rebuild (measured across all vehicle fleets observed) is relatively low at 20 percent.

Factors that were found to be significant in explaining the cost of an engine rebuild (selected on the basis of the variable's statistical t-statistic) include average speed, type of vehicle, and type of engine. Annual hours of operation were found not to be significant. The highest observed R-squared value in the regression analysis (when all the significant independent variables were included) was 0.43.

In the case of engine rebuild frequency, vehicle age in terms of both years and cumulative miles was significant. In addition, type of vehicle and type of engine were found to be significant, whereas average speed was not. When all the significant variables were included, the R-squared value for the regression was 0.22.

In the course of the study, the research team was informed by several operators that engine rebuilds are carried out on the basis of experience and interval policy rather than on a failure basis. The practice tends to conceal the impact of operating conditions on engine wear. The operators reviewed are just beginning to use their sophisticated information systems to determine a more cost-effective rebuild cycle.

Transmission Rebuild

Transmission rebuild costs vary on average from $1,750 for the GMC to $2,560 for the MAN within the study group. The interval between transmission rebuilds varies from 80,400 miles for the MAN to 127,300 miles for the Flxible. The correlation between cost and frequency across all the vehicle fleets was found to be low (22 percent). The major factors explaining the cost of a transmission rebuild, from the multiple regression analysis, are average speed, mechanic rate, type of vehicle, and type of transmission. When all these variables were used in a regression, the R-squared value was 0.61.

The frequency of transmission rebuilds depended primarily on type of transmission and type of vehicle, but the resulting R-squared value was lower, at 0.26. As for engine rebuilds, operators make their transmission rebuild decisions primarily on the basis of experience, rather than on a failure basis.

Body Rebuild

Body rebuild costs are typically the most expensive of the four subsystem rebuild costs considered in this research study. Body rebuilds cost, on average, between $4,820 (for a GMC) and $6,270 (for a MAN), and they occurred at between 253,000 miles (for a Flxible) and 288,000 miles (for a MAN). There is a significant correlation of 44 percent between the cost of a body rebuild and the frequency of a rebuild. An R-squared value of 0.55 was found when body rebuild costs were regressed against body rebuild frequency in miles and climate. It is also anticipated that type of vehicle is a significant driver of body rebuild cost, but because of data difficulties this could not be tested.

An additional explanatory variable found to be significant in explaining body rebuild frequency was vehicle length. When this variable was regressed against frequency, in combination with climate, the resulting R-squared value was 0.33. The accident rate and the age were found to be insignificant in explaining frequency.

From the research team's extensive discussions with transit operator personnel, it was found that body rebuild decisions are very heavily influenced by agency policy, regarding vehicle's appearance. Some of the operators repair small dents and scratches as they occur. Others conduct a major body repair after a specified lapsed time period (e.g., 5 years). This time period is often a policy decision.

Frame Rebuild

A frame rebuild costs between $2,580 (for an AMG) and $7,275 (for a Flxible) on average and occurs at approximately 250,000 miles. There is a low correlation between the cost and frequency of a frame rebuild (12 percent). This indicates that a frame rebuild costs about the same amount regardless of the cumulative miles.

The accident rate was found to be highly significant in explaining the frequency of frame rebuilds. A regression of frequency against accident rate alone yielded an R-squared of 37 percent. As for frame rebuild cost, the hypothesis that climate and vehicle type are significant in explaining frequency could not be tested because of the lack of relevant data, although the research team believes them to be related.

Several operators were unable to provide detailed data of frame rebuild costs and frequency. From conversations with participating operators, it is probable that factors such as passenger loads, roadway condition, and the structural design of the vehicle have an impact on the cost and frquency of a frame rebuild. The research team was unable to collect this information, and cannot confirm or refute these beliefs.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

REDUCTION OF OPERATING COST THROUGH BUS INVESTMENT

As demonstrated in Chapter Two, all bus operating and maintenance costs are not constant over a vehicle's useful life. Further, capital investment decisions can be made in a manner to reduce both operating cost expenditures and whole life costs (i.e., sum of capital and operating cost expenditures).

The data provided by transit operators participating in this research effort indicated differences in the running repair, preventive and routine maintenance costs of vehicle types of different ages, but did not attribute the majority of these differences to vehicle age in statistical correlations. However, major subsystem rebuild costs do change significantly with age (e.g., engine, transmission, body and frame). This is illustrated in Figure 34 for the engine subsystem alone. The example is based on the mean costs and frequencies reported by the participating operators, and uses a 12-year replacement cycle. As shown, a vehicle's capital cost can be distributed equally over its useful life ($17,907 per year, or $135,000 total), and annual vehicle operating and maintenance cost can be assumed to remain constant for the purposes of this illustration (expressed in current dollars as $27,200 per bus per year). An engine rebuild is required in years 5 and 10, at a cost of $5,400 in current dollars. This results in a 12 percent increase in operating costs in years 5 and 10 due to engine rebuild needs alone.

Another way to view the engine rebuild cost is as a bus investment. That is, rebuilding an engine provides additional reliable service from a bus for another 5 years. Therefore, the cost of rebuilding can logically be distributed amongst those 5 years when the value of the rebuild is consumed (shown in Figure 35). Although the engine rebuild provides another 5 years of useful life in the example, the bus is retired 3 years after the second rebuild, thus requiring that expense to be distributed over only 3 years.

If an operator wanted to gain the full value of the second engine rebuild, the bus would have to remain in service another 2 years, as shown in Figure 36. This effectively reduces the annual operating and maintenance cost over the final years of the vehicle's useful life.

In practice, this concept is more complex. This research has determined that the major repair and rebuild activities change over a vehicle's useful life for engine, transmission, body and frame subsystems. Further, each activity has a different expense and a different frequency as illustrated in Figure 37. The illustration is based on one participating operator's experience:

- Capital cost is $135,000, or $17,907 per year.
- Basic vehicle operating cost is $17,600 per year.
- Transmissions are rebuilt in 5 years, cost $2,250.
- Engines are rebuilt at 8 years, costing $5,404.
- Bodies are refurbished at 10 years, costing $6,153.

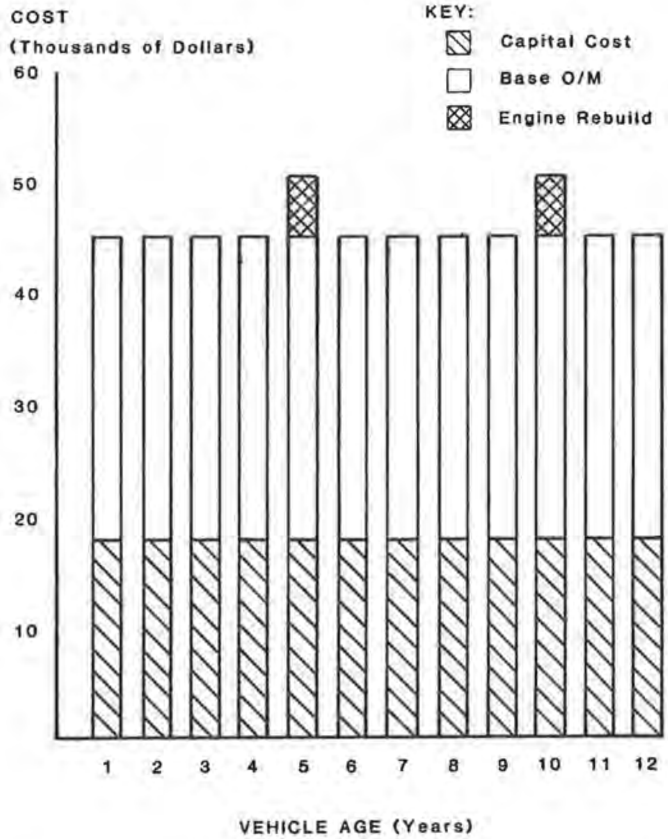

Figure 34. Typical sequence of engine rebuild activity over 12-year time frame in relation to annual operations and maintenance costs.

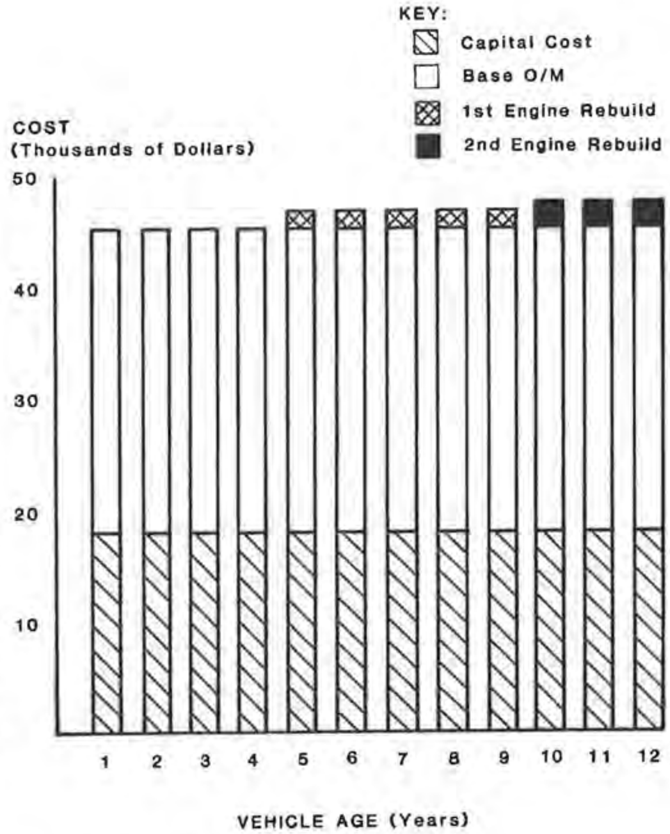

Figure 35. Cost of engine rebuild activity distributed over useful life of vehicle for 12-year retirement.

- Frames are rehabilitated at 8 years, costing $2,577.

Thus, in year 10 operating costs rise 48 percent above the base, with other increases of 45 percent in year 8 and 13 percent in year 5.

As with the earlier example, these expenditures can be allocated over several years as they provide value beyond the year of initial expenditure. Figure 38 allocates expenditures over a 12-year horizon, and indicates a rising operations and maintenance expense in the latter years. The vehicle's scheduled retirement results in an imbalance between the planned frequency of major repairs and the actual value derived in its final years:

- Planned engine life is 8 years; actual consumed is 4 years.
- Planned body life is 10 years; actual consumed is 3 years.
- Planned frame life is 8 years; actual consumed is 4 years.

If an operator wants to realize more of the benefit paid for through rebuilds, the vehicle's retirement could be delayed until 16 years of age. The cost of major repairs is then allocated over a longer base, hence decreasing the annual operating and capital cost shown in Figure 39. This smoothes out the cost increases, but adds another transmission rebuild in year 15, which is 1 year before retirement.

Knowing that the vehicle is about to be retired, the operator could decide not to conduct the transmission rebuild, as shown in Figure 40. This effectively reduces operating costs, but may introduce some additional vehicle reliability risk. Operators

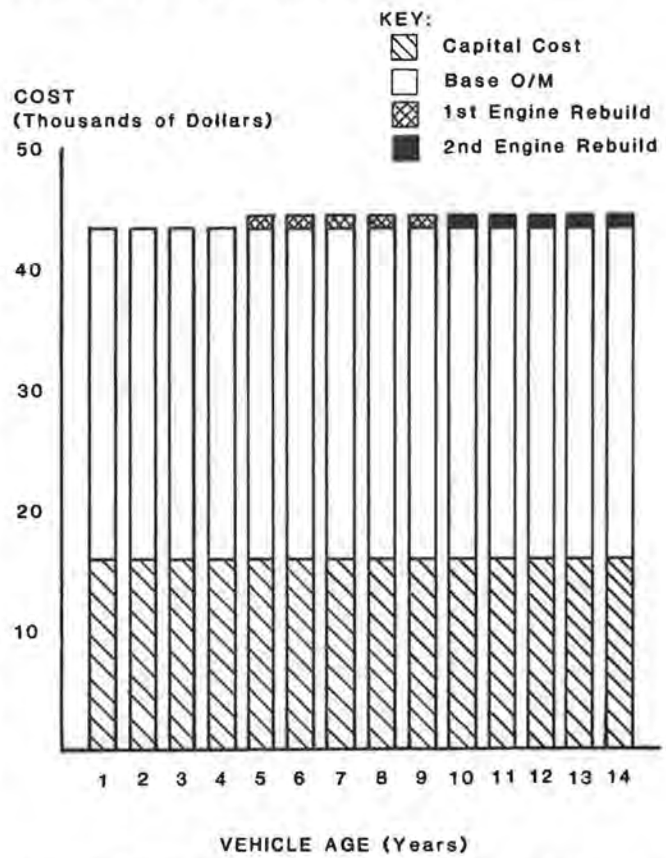

Figure 36. Costs of engine rebuild activity distributed over useful life of vehicle to realize lowest operating cost.

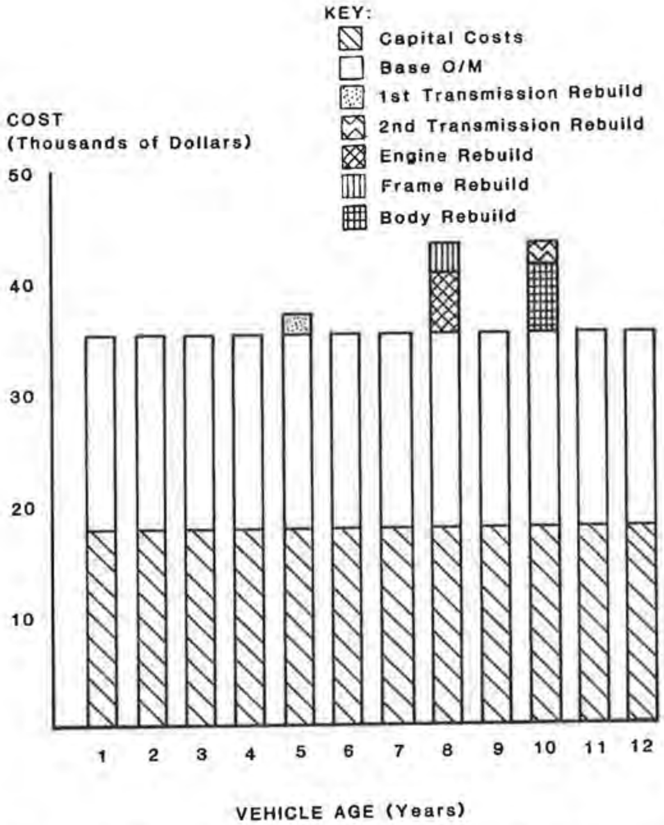

Figure 37. Typical sequence of subsystem rebuild activity over 12-year time frame in relation to annual operations and maintenance costs.

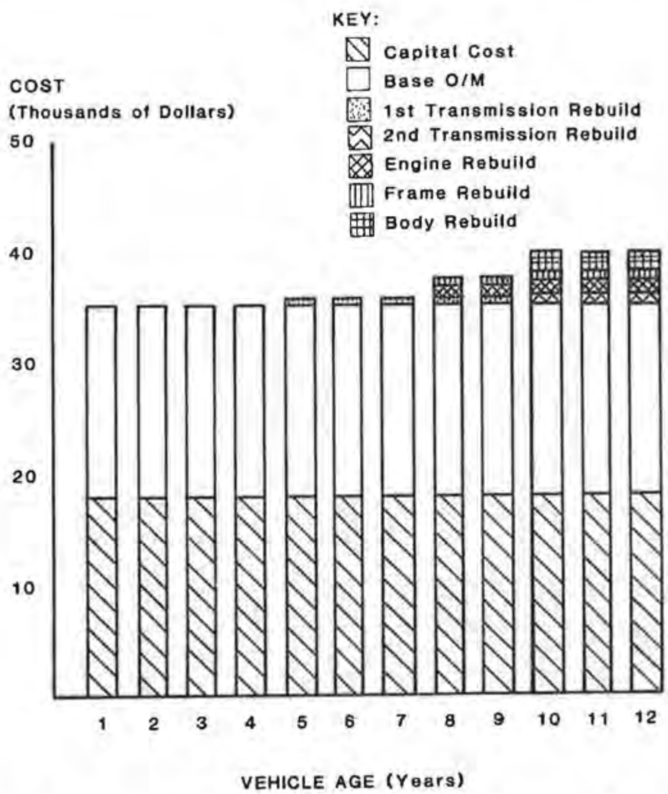

Figure 38. Costs of subsystem rebuild activity distributed over 12-year useful life of vehicle.

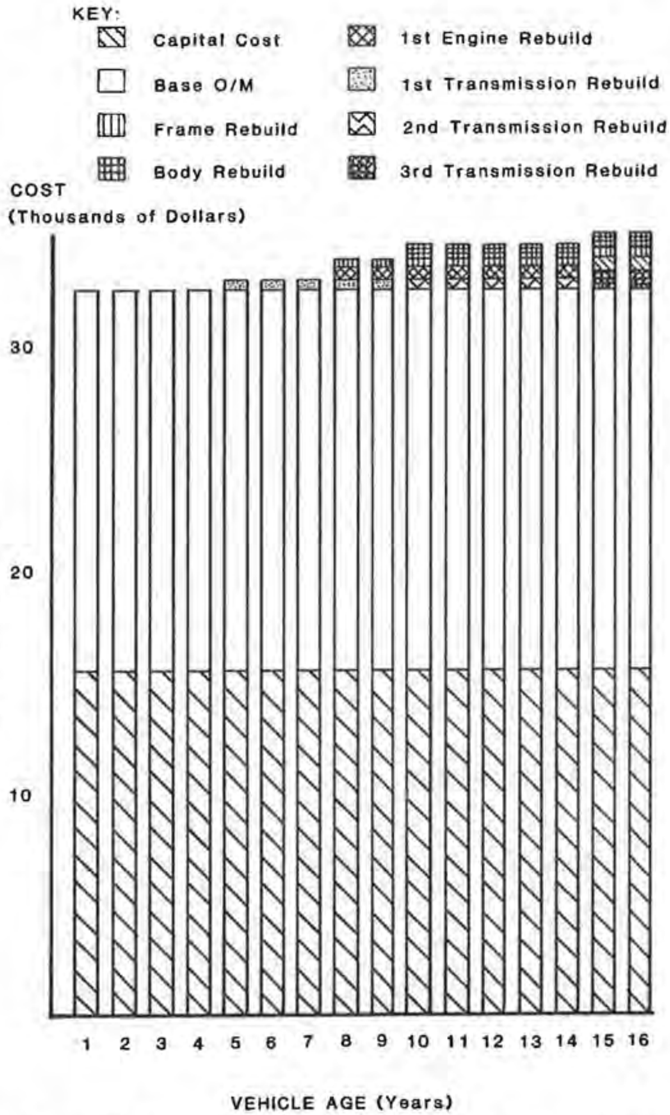

Figure 39. Costs of subsystem rebuild activity distributed over 16-year useful life of vehicle.

would have to make such a decision considering both costs and reliability.

The concept of "getting value for money" is the driving force behind the capital investment decision methodology presented herein. In reducing operating costs, one must leverage major repair expenditures to gain maximum benefit.

BUS INVESTMENT DECISION METHODOLOGY

Given that bus investment decisions have an impact on operating costs and that transit funding is becoming increasingly constrained, transit managers need a simple methodology for incorporating operating cost considerations in making vehicle-replacement decisions. The research team has developed a straightforward capital analysis methodology in support of managers faced with this need.

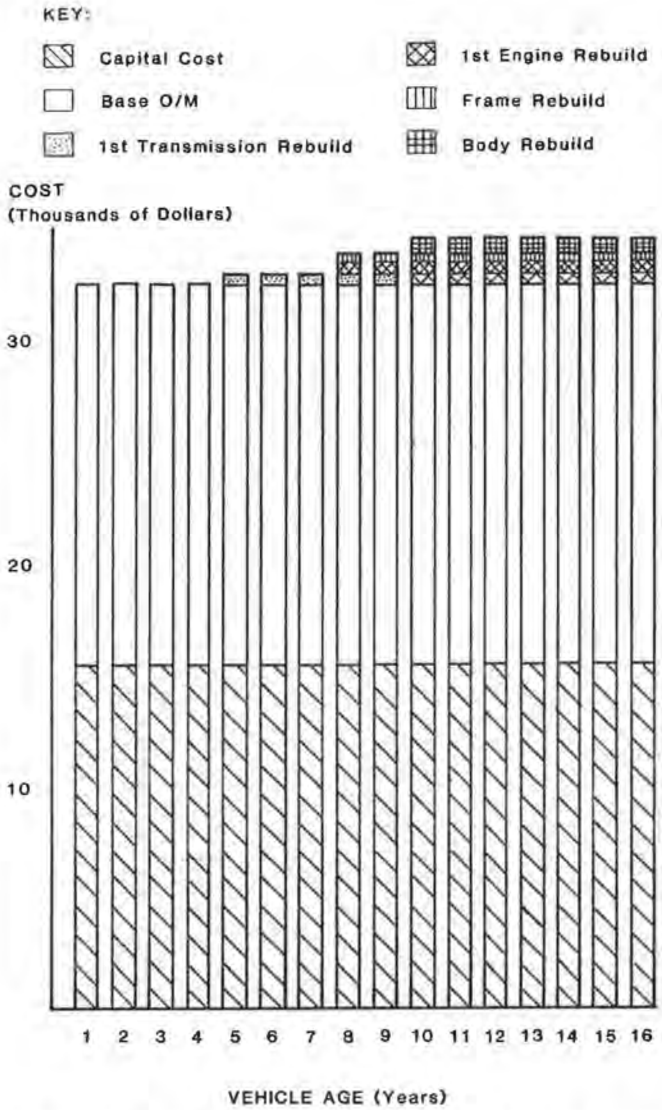

Figure 40. Costs of subsystem rebuild activity distributed over useful life of vehicle to realize lowest operating cost.

The methodology analyzes both operating and capital costs, as both have been shown to be closely related. The methodology uses an "annualized equivalent cost" (AEC) approach to combine capital and operating costs equitably. The AEC approach distributes, on an amortization basis, capital costs over a vehicle's useful life and adds annual operating and maintenance expense (in constant dollar terms) to this figure. This varies from a "net present value" (NPV) approach which takes the total initial capital cost and adds the present value of the future stream of operating and maintenance costs to it. The primary reason for selecting the AEC approach to life-cycle costing is that it allows a fair comparison of investments with different life spans. The NPV approach, conversely, is limited to investments with equal useful lives. Other reasons, as discussed earlier in this document, relate to the nature of transit funding and ease of comprehension.

Data Requirements

The capital investment methodology requires information which the research team found to be generally available throughout the industry. Data availability was considered as a primary criterion to ensure broad applicability of the methodology. Specific data requirements are given in Table 2. A few items warrant additional explanation:

1. *Fleet Type.* The methodology can be applied by individual subfleet or across all fleets.
2. *Interest or Discount Rate.* For purposes of simplicity it is suggested that operators use the yield on long-term U.S. Treasury bonds or state tax exempt revenue bonds. This information is available in the financial section of most newspapers.
3. *Proportion of Vehicles Eligible for Rebuild.* Because of exposure and wear, not all vehicles can be rehabilitated. This item should specify the proportion of vehicles which could be rebuilt effectively (e.g., 0.75).
4. *Useful or Economic Life.* This refers to the service or active life of a bus.
5. *Basic Vehicle Operations and Maintenance Costs.* These include the cost of fuel and lubricants, vehicle servicing, and all maintenance costs excluding the cost of engine and transmission rebuild, major body refurbishment, and major frame rehabilitation. This item should reflect the average cost of the vehicle over its useful life in constant dollar terms.
6. *Miles Between Subsystem Rebuild.* This item includes this agency's actual experience with major subsystem repair, whether

Table 2. Data items required for analysis.

1. Fleet Type
2. Number of Active Buses in Fleet
3. Annual Miles per Vehicle
4. Interest or Discount Rate
5. Current Spare Ratio
6. Minimum Acceptable Space Ratio
7. Proportion of Vehicles Eligible for Rebuild
8. Capital Cost New
9. Useful or Economic Life (New)
10. Rebuild/Remanufacture Cost
11. Additional Useful Life from Rebuild
12. Basic Vehicle Operations and Maintenance Cost per Mile
13. Average Cost of Engine Rebuild
14. Average Miles Between Engine Rebuilds
15. Average Cost of Engine Rebuild per 1,000 miles (13 ÷ 14)
16. Average Cost of Transmission Rebuild
17. Average Miles Between Transmission Rebuilds
18. Average Cost of Transmission Rebuild per 1,000 miles (16 ÷ 17)
19. Average Cost of Major Body Refurbishment
20. Average Miles Between Body Refurbishment
21. Average Cost of Body Refurbishment per 1,000 miles (19 ÷ 20)
22. Average Cost of Major Frame Rehabilitation
23. Average Miles Between Frame Rehabilitation
24. Average Cost of Frame Rehabilitation per 1,000 miles (22 ÷ 23)
25. Average Total Cost of Rebuilds per 1,000 miles (sum 15,18,21 and 24)

rebuild is driven by a policy mileage, a failure basis, or some other means. The number to be used is actual average miles between subsystem rebuilds.

Analysis of Current Bus Replacement Cycle

The suggested methodology for evaluating current bus replacement practices relative to potential cost savings is comprised of 14 uncomplicated steps. The only tools required to conduct the analysis are the data elements discussed above and a calculator or adding machine. If desired, the calculations could be conducted long-hand or be placed on a simple microcomputer spreadsheet. When conducted manually, one application of the methodology requires less than 30 min time—an effective investment given the 12-plus year life of a bus.

Step 1—Determine Annual Capital Cost per Vehicle

The first step is to determine the annualized capital cost of a bus in the subject fleet. This is a function of the initial purchase price, the expected useful life and the long-term interest rate. As part of the AEC approach, the total purchase price is amortized over the vehicle's useful life (i.e., similar to a mortgage determination). The capital cost is incurred in a single year, but the expenditure is deemed an investment with value (both capital price and imputed interest) consumed annually over its useful life. An amortization table, and the determining formula, is presented in Table 3. The interest rate for the numbers shown in the table is 8 percent compounded annually.

The mathematical formula for calculating the annualized equivalent cost is shown in Eq. 4. The amortization factor is based on the long-term interest of discount rate and the years of useful bus life.

$$\text{Initial Purchase Price} * \text{Amortization Factor} \quad (4)$$

It is important to note that the salvage or residual value of a transit bus is not considered in this calculation. This is because industry experience indicates that the bus resale market is low and the net impact on current costs is nominal. For example, suppose a bus bought today at $135,000 has a resale value of $1,000 at the end of 12 years and assuming an 8 percent discount rate, this would be worth $397 today. Applying this to the AEC of the initial purchase price results in a cost savings of $52 per annum compared to a base cost of $17,914, or a cost reduction of two-tenths of 1 percent. In the interest of simplicity, and because it does not have a significant impact, this step is excluded from the methodology.

Step 2—Calculate Basic Annual Vehicle Operating and Maintenance Cost

The annual basic operations and maintenance (O/M) costs can be determined in one of two ways. The first method is to assume that the O/M cost incurred in the first year of the vehicle's life (likely to be known by the transit operator) is the same (in constant dollars) as that incurred in each year of the vehicle's life. The second method is to assume that the vehicle becomes more expensive to operate and maintain as it accumulates mileage (i.e., ages), even in constant dollar terms. The study results indicate that the second method (i.e., cost growth) is probably more reasonable, albeit the low correlation between cost and age and the low total cost growth (i.e., cost growth ranged from $0.025 per mile to $0.037 per mile after each 100,000 miles of operation) makes the first option (i.e., no real cost growth) an acceptable and easier application.

Table 3. Amortization factors for annualizing investment cost.

YEARS OF USEFUL LIFE	AMORTIZATION FACTOR
1	1.0800
2	0.5608
3	0.3880
4	0.3019
5	0.2505
6	0.2163
7	0.1921
8	0.1740
9	0.1601
10	0.1490
11	0.1401
12	0.1327
13	0.1265
14	0.1213
15	0.1168
16	0.1130
17	0.1096
18	0.1067
19	0.1041
20	0.1019
21	0.0998
22	0.0980
23	0.0964
24	0.0950
25	0.0937

Note: Formula for calculating amortization factors is:
$(1/(1-(1-\text{interest rate})^{-\text{years}})) + \text{interest rate}$

Option 1—Constant O/M Cost. The basic annual operating and maintenance cost, excluding major rebuilds, under this option is calculated as shown in Eq. 5.

$$\text{Initial Year O/M Cost per Mile} * \text{Annual Miles per Vehicle} \quad (5)$$

This value is to be expressed in current dollars. It is not amortized, discounted, or inflated because the revenues are generally expended in the year they are earned, and the inherent value of the expense is also consumed in a short time frame.

Option 2—Escalating O/M Cost. The second method is to take an increase in O/M costs over the life of the vehicle into account. This involves applying an equation which includes parameters for the base cost and the useful life of the vehicle. The analysis conducted earlier indicated that O/M costs tend to increase with cumulative miles. While the life-cycle costs were not available for any vehicle subfleet from any of the

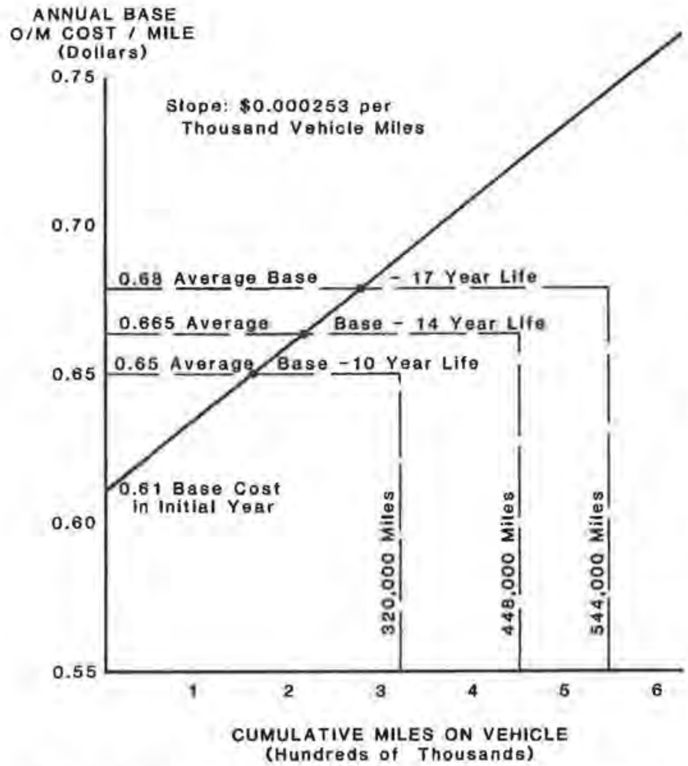

Figure 41. Numerical example of variation in annual average base operations and maintenance costs with useful life of vehicle.

responding agencies, it was shown that for all of the subfleets the O/M costs increased between $0.00025 and $0.00037 per mile per 1,000 cumulative miles. Thus, to determine the annual base O/M cost at any point in a vehicle's life Eq. 6 is used.

$$\text{Cost/Mile} = \text{Base O/M Cost/Mile} + \$0.000253\ (\text{Cumulative miles in thousands}) \quad (6)$$

Under this option, the base O/M costs will increase with each succeeding year in a vehicle's life.

To use this escalating cost option in the methodology as simply as possible, an average annual base O/M cost is calculated over the life of the vehicle in constant dollar terms. The longer a vehicle's useful life, the higher its average annual base O/M costs will be, as shown in the hypothetical example in Figure 41.

To determine the average annual base O/M cost over a given useful vehicle life, using the growth equation above, first calculate the base O/M cost per mile in the final year of the vehicle's life as shown in Eq. 7.

$$\text{Final Year O/M Cost per Mile} = \text{Initial Year O/M Cost per Mile} + (\$0.000253)(\text{Cumulative miles in thousands}) \quad (7)$$

The average of the initial year and final year O/M cost per mile is then calculated.

As an alternative to the two options outlined previously, the operator may use any annual base O/M cost that is deemed appropriate based on local experience and judgment.

Step 3—Determine Major Repair and Rebuild Costs

Major repair and rebuild of vehicle subsystems change directly with vehicle age, and as such are calculated separately. This step is comprised of two minor calculations:

a. Calculate total major repair or rebuild costs using Eq. 8.

$$\sum_{j}^{n=4} (\text{Average Cost of Rebuild}_j) * (\text{Cumulative Miles/Miles Between Subsystem Rebuild}_j) \quad (8)$$

where j = subsystem type (i.e., engine, transmission, body, and frame). It is important to note that the result of cumulative miles divided by miles between subsystem rebuild must be rounded down to the nearest whole number in all cases.

b. Determine annualized major repair or rebuild cost using Eq. 9.

$$\text{Total Major Rebuild Cost} \div \text{Useful Life} \quad (9)$$

Step 4—Determine Current AEC Bus Cost

By using the results of Step 1, Step 2, and Step 3(b), the AEC cost is determined in Eq. 10 for the fleet as follows:

$$(\text{Annual Capital Cost} + \text{Basic O/M Cost} + \text{Major Rebuild Cost}) * \text{Number of Buses in Active Fleet} \quad (10)$$

This cost will serve as the basis for comparison with other capital investment strategies, which are analyzed in Steps 5 through 13. Note that the value used for basic O/M cost will be different depending on which option is used in Step 2.

Step 5—Determine Residual Useful Miles of Subsystems Rebuilt

As demonstrated in this report, some expected useful life generally remains in some vehicle subsystems upon retirement. It is important to quantify the anticipated miles of life remaining in the four major subsystems upon vehicle retirement. This is determined using the number of rebuilds conducted over the vehicle's life (i.e., the number calculated in Step 3(b) as cumulative miles divided by miles between subsystem rebuilds, and rounded down to the nearest whole number), the miles between subsystem rebuild (data items), and the cumulative vehicle miles at retirement (Step 3, a). Each subsystem is calculated separately using Eqs. 11, 12, 13, and 14.

a. Determine engine miles remaining.

$$((\text{Number of Rebuilds Completed} + 1)(\text{Miles Between Engine Rebuilds})) - \text{Cumulative Vehicle Miles} \quad (11)$$

b. Determine transmission miles remaining.

$$((\text{Number of Rebuilds Completed} + 1) * (\text{Miles Between Transmission Rebuilds})) - \text{Cumulative Vehicle Miles} \quad (12)$$

c. Determine body miles remaining.

((Number of Refurbishments Completed + 1) * (Miles Between Body Refurbishment)) − Cumulative Vehicle Miles (13)

d. Determine frame miles remaining.

((Number of Rehabilitations Completed + 1) * (Miles Between Frame Rehabilitation)) Cumulative Vehicle Miles (14)

Step 6—Determine Life Consumed of Latest Rebuilds

Several transit operators throughout the United States have determined that they can save money by retiring vehicles early (i.e., shortening vehicle's economic or useful life). This step together with others presented on the following pages, allows the operator to take a life reduction option into account. These steps in the methodology are based on the premise that significant operating cost savings could be made (particularly in the rebuild and refurbishing work—engine, transmission, body, and frame) by terminating a vehicle's life *before* the last rebuild/refurbishing work is conducted. The technique used closely mirrors the estimation of life extension presented in Step 5, and initially involves calculating the life consumed (in miles) of the last system rebuild work using Eq. 15.

Subsystem Life Consumed = Average Miles between Subsystem Rebuild − Subsystem Residual Miles (15)

The calculation is done for each of the four subsystems—engine, transmission, body, and frame.

Step 7—Determine Residual Bus Life in Years

The primary focus of the methodology is to determine how to best use bus investments to reduce transit costs. This step is designed to determine the remaining useful bus life at the point of retirement based on current practice. Because remaining useful life varies by subsystem and rebuild costs also vary by subsystem, the formula optimizes remaining useful bus life based on the lowest operating cost item. The calculation uses the residual subsystem miles (determined in Step 5) and the rebuild cost per 1,000 miles of each subsystem required in the data elements. The mathematical formula is provided in Eq. 16.

$$\left[\sum_{j}^{n=4} (\text{Residual Miles}_j) * (\text{Rebuild Cost per 1,000 miles}_j/\text{Total Cost of Rebuilds per 1,000 miles})\right] / \text{Annual Miles per Active Vehicle} \quad (16)$$

where j = vehicle subsystem (i.e., engine, transmission, body, and frame).

Step 8—Determine Potential Reduction in Useful Bus Life (in Years)

This step parallels Step 7 by allowing the determination of a potential reduction of a vehicle's life. The means used is to weight (based on subsystem rebuild cost) the miles consumed to the end of the vehicle's useful life in the latest rebuild/refurbishment in each of the four subsystem categories. The mathematical formula follows:

$$\left[\sum_{j}^{n=4} (\text{Miles Consumed}_j) * (\text{Rebuild Cost per 1,000 miles}_j/\text{Total Cost of Rebuilds per 1,000 miles})\right] / \text{Annual Miles per Active Vehicle} \quad (17)$$

where j = vehicle subsystem (i.e., engine, transmission, body, and frame).

Step 9—Determine New Vehicle Useful Life

This is conducted in two simple steps, using the residual bus life calculated in Step 6 and the initial useful life in the data base. Separate calculations are carried out for the life extension and life reduction scenarios.

a. Calculate new vehicle life in years using Eqs. 18 or 19.

Initial Useful Life + Residual Bus Life (for Life Extension) (18)

Initial or Useful Life − Reduction (for Life Reduction) (19)

b. Calculate new cumulative miles using the figure calculated in Eq. 20.

New Vehicle Life * Annual Miles per Vehicle (20)

The result will obviously be different for the life extension and life reduction scenarios.

Step 10—Determine New Amortized Cost per Vehicle

Similar to Step 1, this is calculated as:

Purchase Price New * Amortization Factor (21)

Since the amortization factor differs based on the useful life of the vehicle, this step will yield two values, one for life extension and one for life reduction. Use the new vehicle useful life developed in Step 9 to determine the amortization factor.

Step 11—Determine Annual Vehicle Operating and Maintenance Cost

As noted in Step 2, there are two basic assumptions that one can make concerning the behavior of annual basic operations and maintenance costs over time. The first (Option 1) is to assume that the O/M costs incurred in the initial year of the vehicle's life remain constant over the entire vehicle life, irrespective of length. The second (Option 2) is to assume that annual O/M costs increase with a vehicle's age.

If the user of this methodology assumes the former (i.e.,constant O/M costs), then the figure used here is that calculated in Step 2—using Eq. 5. If the user assumes escalating O/M costs with age (Option 2), the new annual average base

O/M cost values must be calculated—one for the extended life and one for the reduced life. As discussed earlier, average annual O/M costs will always be greater with increased useful life.

The process for calculating average annual base O/M costs for the new useful life is, first, determine the annual base O/M cost in the final year of the vehicle's new useful life using Eq. 7 and, then, average the initial year's and final year's O/M cost.

Step 12—Determine New Annualized Major Repair Costs

Because the useful life of the vehicle has been changed, the number of major repair/rebuild events may likewise have changed. The calculation relies on the new cumulative miles determined in Step 9 and on two data items (miles between rebuilds and average cost per rebuild). The mathematical equation is:

$$\left[\sum_{j}^{n=4} (\text{New Cumulative Miles/Miles Between Subsystem Rebuilds}_j) * (\text{Average Cost per Subsystem Rebuild}_j)\right] / \text{New Useful Life in Years} \quad (22)$$

where j = vehicle subsystem (i.e., engine, transmission, body, and frame). As was the case earlier, this quotient must be rounded off to a whole number. Whether to round up or down must be determined based on agency experience. Rounding down means that the miles between subsystem rebuilds are increased and rounding up means that miles between subsystem rebuilds are decreased. If available information does not suggest a potential direction, the research team suggest the following:

- Round engine and transmission down if the residual proportion is 0.20 or less. Round it up at 0.21.
- Round body and frame down if the residual proportion is 0.50 or less. Round it up at 0.51.

The difference reflects the fact that vehicles may not run if engines and transmissions are not properly maintained. Body and frame subsystems generally offer greater operating flexibility. While they may not look as nice, the bus will still operate with a longer rebuild cycle. This step must be carried out twice—once under the life extension scenario and once under the life reduction scenario.

Step 13—Determine New AEC Cost

Using the results of Steps 10, 11, and 12, determine the AEC cost for the new capital replacement strategy as follows:

$$(\text{New Annual Capital Cost} + \text{Basic O\&M Cost} + \text{New Major Rebuild Cost}) * \text{Number of Buses in Active Fleet} \quad (23)$$

Again, this step must be carried out for both life extension and life reduction scenarios. In addition, the number for basic O/M costs will change, depending on whether the user assumes constant O/M costs or escalating costs.

Step 14—Determine Expected Change in AEC Cost

The purpose of this step is to determine the magnitude of the expected change in cost given a change in the bus capital replacement strategy. The calculation is:

$$\text{New AEC} - \text{Initial AEC} \quad (24)$$

Two values are determined, one for life extension and one for life reduction. A negative result indicates a cost savings and a positive result indicates a higher cost. Consequently, the cost effects of lengthening or reducing a vehicle's life can be compared to retiring a vehicle at the end of its initial life.

Analysis of Replace Versus Bus Rebuild

The findings in Chapter Two indicate that most operators do not include bus rebuild or remanufacture in their vehicle investment programs. UMTA does provide capital funding for qualifying bus remanufacture projects. While still not a widespread practice, the availability of federal capital funds has resulted in an increase in the number of bus rebuilds conducted. With the continued sense of industry austerity impacting capital investments as well as operating programs, it is likely that bus rehabilitation will continue to be an issue. Because the annualized equivalent cost (AEC) technique allows equitable comparison of whole life costs for investments with different life spans, it is an appropriate approach for analyzing the rebuild versus replace decision as well.

In making such a comparison, the operator could examine the current capital program and the suggested vehicle retirement program, both from the analysis above and the AEC of a bus rebuild. The evaluation requires application of five straightforward steps. The numbers used here for base O/M costs should be consistent with those used in the earlier part of the analysis (i.e., either Option 1: Constant O/M costs, irrespective of vehicle life; or Option 2: Escalating costs with age assumed).

Step 1—Determine Annual Capital Cost Per Vehicle

As was the case above, the first step is to determine the annual equivalent capital cost for each investment option.

a. Initial annual capital cost is the result from Step 1 in the analysis of bus replacement (above).

b. Suggested (new) annual capital cost is the result from Step 10 in the analysis of bus replacement (above).

c. Bus rebuild annual capital cost is calculated using Eq. 25.

$$\text{Purchase Price Bus Rebuild} * \text{Amortization Factor} \quad (25)$$

Amortization factors can be derived from Table 3 based on the years of expected useful life from time of the rebuild forward.

Step 2—Determine Annual O/M Cost Per Vehicle

As discussed in Chapter Two, there was insufficient information available to identify vehicle operating and maintenance cost differences between new and rehabilitated buses (excluding major repair to engines, transmission, body, and frame). This is because there were too few observations for rehabilitated bus costs. The cost data used here should reflect the operator's specific experience.

a. Initial annual O/M cost is the result from Step 2 in the analysis of bus replacement (above).

b. Suggested (new) annual O/M cost is the result from Step 11 in the analysis of bus replacement (above).

c. Bus rebuild annual O/M cost is calculated as:

O/M Cost per Mile * Annual Miles per Vehicle (26)

The value is to be expressed in current dollars. Again, use the same option (i.e., constant or escalating costs) as was used earlier.

Step 3—Determine Major Subsystem Repair Costs

None of the operators reviewed in this study conduct any major subsystem repairs on rebuilt buses. Most operators consider a rebuilt bus to have a useful lifespan of 5 to 8 years, hence falling short of subsystem rebuild cycles.

a. Initial major subsystem repair cost is the result from Step 3(b) in the analysis of bus replacement (above).

b. Suggested (new) major subsystem repair cost is the result from Step 12 in the analysis of bus replacement (above).

c. Bus rebuild major subsystem repair cost for most operators this amount will be zero. If an operator does rebuild major subsystems (e.g., engine, transmission, body, and frame) after several years of use in a rebuilt bus, these costs can be calculated using the formulas in Step 3 of the analysis of bus replacement (above).

Step 4—Determine Expected Change in AEC Cost

The purpose of this step is to compare the annualized equivalent costs for each investment option and to identify any potential cost savings from rebuilding or remanufacturing buses.

a. Initial replacement strategy versus bus rebuild is determined as follows. Sum the results of Steps 1(a), 2(a), and 3(a) to determine the AEC for the current replacement program. Sum the results of Steps 1(c), 2(c), and 3(c) to determine the AEC for the rebuild program. Calculate the change in cost due to a bus rebuild program using Eq. 27.

(Bus Rebuild AEC − Initial AEC) *
Number of Vehicles in Fleet (27)

A negative number indicates a cost reduction and a positive number is a cost increase.

b. Suggested replacement strategy versus bus rebuild is determined as follows. Sum the results of Steps 1(b), 2(b), and 3(b) to determine the AEC for the suggested replacement strategy. Calculate the change in cost due to a bus rebuild program using Eq. 28.

(Bus Rebuild AEC − Suggested AEC) *
Number of Buses in Fleet (28)

A negative number indicates a cost reduction due to rebuilding buses and a positive number indicates a cost increase.

Step 5—Number of Vehicles to be Rebuilt

It is important to note that there are constraints to rebuilding buses that are different from replacement considerations. First, not all vehicles can be rebuilt because of physical conditions and deterioration. Second, vehicles have to be out of service for 3 to 6 months while being remanufactured. If rebuilding buses results in a cost savings above, two additional calculations should be conducted, as follows.

a. *Vehicles eligible for rebuild:* Because of physical deterioration, some proportion of vehicles cannot effectively be remanufactured. The number of vehicles available for rebuilding should be calculated as shown in Eq. 29.

Proportion of Buses Eligible * Number in Fleet (29)

b. *Spare ratio limitation:* If a particular fleet is to undergo remanufacture, other vehicles will have to assume their workload while the rebuilding occurs. To determine the number of spare buses available to cover rebuilds, complete Eq. 30.

(Systemwide Spare Ratio − Minimum Acceptable Spare
Ratio) * Systemwide Number of Active Vehicles (30)

c. Total buses available for rebuild which can be rebuilt at any one time is the value of Step 5(a), up to the value of 5(b). For purposes of illustration, an example application of the methodology is included in Appendix A.

ASSESSMENT OF LIMITATIONS

This research project encompassed an extensive literature search, a broad-based transit survey, and a detailed analysis of bus operations and maintenance costs at 11 transit agencies with 26 separate operating divisions. The resulting bus replacement/remanufacture investment decision methodology is applicable to any transit agency for the purposes of evaluating operating and capital cost savings opportunities through bus investment. While the entire analysis was guided by sound research principles and the results are conservatively stated, there are some limitations inherent in the bus replacement evaluation methodology. The users of the report should be cognizant of the potential limitations, as discussed in the following sections.

Constrained Sample Site

The detailed bus operating and maintenance cost analysis presented in Chapter Two was based on an investigation of disaggregate diesel bus costs at 11 transit agencies. This field was somewhat expanded because the analysis was conducted on an operating division level, as divisions frequently act as independent maintenance and operating centers. Twenty-six separate divisions were analyzed in the study. Although the participating entities were not randomly selected, every reasonable effort was made to achieve a representative cross section of public transit agencies for vehicle operating and maintenance cost analysis purposes. The 11 selected agencies are evenly distributed geographically, by fleet size and by climatic conditions. Even so, the sample had two absolute constraints: (1) each agency had to be able to provide the disaggregate cost data required; (2) each agency had to be willing to spend the time required to provide the data.

While the researchers do not believe that these constraints invalidate the results presented in Chapter Two, there is no numeric data to confirm or refute cost comparability with those agencies not capturing detailed bus cost data. It is important to note that this would not impact the validity of the methodology presented in this chapter, as operators are to use their own data and not default parameters based on other operators. The data elements required to apply the methodology are minimal, and in the researchers' experience, widely available.

Data Availability

Data availability was a concern, even in the survey group. Historical information on disaggregate bus operating and maintenance cost was not available from any operator surveyed. Therefore, the research team was unable to establish a vehicle cost profile based on actual costs by vehicle type by subsystem and repair activity over a vehicle's entire life span. Rather, similar vehicles (i.e., make) were compared of different ages. It is important to note that the vehicles compared over time are similar—not the same period. Vehicle specifications and even model numbers vary within a given manufacturer, which do not impact costs. Further, disaggregrate cost information was gleaned from management information systems. The costs have not been subjected to fiscal audit, nor have any of the study participants used the systems heavily in financial planning decisions. The disaggregrate data are more often used for work assignment planning, although most agencies indicated that they planned to use the cost monitoring capability in the future.

There may be, therefore, some inaccuracies in the data reported. It is important to note that there is, at present, no standard for cost accounting in maintenance management information systems. While all operators indicated that some allocation of costs was done, this varied from fringe benefits to full administration costs. Labor and parts costs were reported several ways, using averages, actual, or highest cost parameters. Further, work categories are not consistently defined. This is believed to have contributed to the wide cost variations and low correlation with causal factors found in the study.

Although this induces some limitations on costs reported in Chapter Two, the analytic results suggest that the available data were adequate to support the findings which are developed on a more aggregrate basis. Because of the historical data limits, the research team evaluated buses of different ages over a 2-year period (holding other factors constant) to identify variances related to age. In one way, this may produce better results than examining a single fleet's performance over 12 or 15 years as inflationary factors are constant. However, because of data availability concerns, default parameters are not a result of this study. Further, specific guidance on operating and maintenance cost growth relative to age cannot be provided.

Dedicated Funds

Because capital and operating funds frequently are not interchangeable in the transit industry, it may not always be desirable to optimize annual equivalent costs in whole life terms. For example, an operator may find that it has more flexibility in capital costs than in operating budgets.

The methodology accommodates operating and capital costs separately, combining them at the very end of the analysis. Therefore, to optimize on any part of the whole life costs, one should compare annualized operating and capital costs separately. Although this is not the ideal economic solution, in the emperical world these situations do exist and, therefore, it is important to allow separate analysis of cost types.

Impact of Operating Characteristics

The two primary reasons that the research team did not suggest default values in the methodology are that the data required are widely available and that the data analyzed could not be well correlated with unique operating conditions. Availability of needed data and inconsistencies of reporting were discussed earlier. Chapter Two discussed the results of analyzing correlations of independent variables such as climate, terrain, speed, and accidents with subsystem rebuild frequencies and cost. One additional reason that there was relatively little relationship between local operating characteristics and subsystem rebuild practices is that few of the operators are running the vehicles to failure. Most of the transit agencies reviewed are conducting rebuilds on a policy basis based on their overall past experience. This may also explain why subsystem rebuild frequencies were highly consistent between operators for the same fleet type.

The investigation also determined that many transit agencies are beginning to experiment with different subsystem rebuild policies to identify a more cost-effective approach for their unique operating conditions. Therefore, in the next several years the industry should gain a wealth of new information on this subject. The methodology proposed for capital investment analysis will accommodate all changes in this area.

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Transit systems do not routinely consider operating and maintenance cost reduction as the driving factor in bus replacement decisions. Federal and local funding availability and age in years are the most frequent determinants in a vehicle investment decision. Maintenance management information systems, however, are rapidly increasing the amount of useful information available on vehicle operating and maintenance costs. Transit operators are beginning to expand the use of this information to make better investment decisions.

This research effort was intended to produce specific guidelines and default parameters to assist transit operators in making vehicle replacement decisions to reduce overall expenditures. While the study successfully produced a rational methodology for cost reduction through vehicle replacement planning, it did not produce reasonable default parameters that can be applied by all operators. The reason for this is that sufficient data were not available from any operator on any subfleet to prudently assess the specific cost impacts induced by local operating conditions and vehicle aging.

The ability to capture and report vehicle operating and maintenance costs by subsystem is a recent advancement in transit industry. Even the forerunners of the transit maintenance management information age have only had the necessary reporting systems in place for 2 to 3 years. The ability to track manhours expended by vehicle subsystems has been in place for a longer period, and is used routinely by maintenance managers in work planning. The tracking of costs, however, has not been a primary focus of the recent past even for those operators with the capability.

In this research effort, the data sources for detailed maintenance task and the subsystem cost for subsystems were designed for use by maintenance managers. None of the systems has ever been subjected to the rigors of a financial audit, and there is no standard for reporting. Operators vary in definition and application of labor rates (high, average, and actual were used at different operators), materials costs (first-in-last-out, last-in-first-out, current market values and allocated costs were used at different agencies), and allocation of overhead (fully allocated to partially allocated burdens). In addition to reporting differences, the lack of use of cost data allows greater opportunity for reporting or even algorythmic errors. The research team in cross checking reported data uncovered a number of inconsistencies and worked with agencies to resolve errors. Undiscovered errors may still reside in the final study data base.

The next result of the data conditions, as demonstrated in Chapter Two, is a set of cost data which show some aggregate trends, but which cannot be reasonably correlated with causal factors (e.g., local operating conditions, vehicle age). The limitations of using only 1 or 2 years of data to develop a 12-year to 24-year profile of vehicle cost trends are insurmountable. The research team suggests that the issue of default parameters be revisited in about 3 years when data availability will better support this important task.

While specific cost parameters reflecting vehicle type, local operating conditions, and aging were not developed, clear aggregate trends were reached from the research effort. First, operating maintenance costs are higher for similar vehicles with higher cumulative miles and more years of use. The cost growth trend referred to is in constant dollar terms (i.e., it does not include the impact of inflation). The increase in operating and maintenance cost is not consistent between vehicle subsystems and on aggregate was found to be between $0.025 per mile and $0.037 per mile for each 100,000 cumulative miles operated.

Second, the most significant cost changes, and most readily identifiable, were major repair and rebuild costs of four vehicle subsystems—engine, transmission, body, and frame. This is expected because of the fact that these activities were infrequent, directly related to age or exposure, and are expensive. None of the operators participating in this study, in either the broad-based survey or in the detailed data group, optimize replacements based on these maintenance investments. The methodology proposed helps operators judge when replacement should occur to glean the maximum benefit out of dollar investments in maintaining vehicle. The transit operators involved in this study have remarked that the methodology is logical and will result in cost savings.

It is also concluded that a broad array of non-bus capital investments can be used to reduce operating expenditures. Suggested research projects are outlined for future consideration.

Use of Capital Investment to Reduce Operating Costs

A broad-based survey of U.S. transit agencies conducted by the research team shows that transit operators do not routinely consider operating cost reductions in making capital investment decisions. The majority of operators contacted cited federal and local funding availability as the primary factors used in making bus investment decisions. Consequently, UMTA's 12-year vehicle replacement cycle guideline has been adopted as policy by many of the transit agencies reviewed. Operators with a longer replacement cycle often cited local funding constraints as the primary determinant. The impact of capital investment strategies on operating cost is, however, a secondary consideration for some operators. Actual vehicle failures and reliability ranked relatively low on the list of considerations.

Local and federal funding availability has been found to have a varying impact on replacement cycles, depending on an agency's size. Large agencies, for example, tend to replace their vehicles more frequently (after 11 years and 350,000 miles, on average) than either medium-sized agencies (after 17 years and 500,000 miles) and small agencies (after 14 years and 450,000 cumulative vehicle-miles).

Data Availability

Many of the transit operators participating in the narrow-based survey have only recently gained a wealth of detailed operating and maintenance information through the implementation of automated cost reporting systems. The "information technology" age has come to transit only within the last few years. Because of this, some data concerns are inherent in this study.

Because of the advent of increased data availability, the participating agencies were able to provide the research team with extensive operating and maintenance cost data for 1 or 2 years at the vehicle fleet and subfleet levels. Most participating operators have substantial data on maintenance activities, component failures, and their associated frequency and cost. Even though substantial detailed data were provided, much of this is suspect at a dissagregrate level. There are no standards for reporting detailed maintenance cost in the industry, and although, the research team made every effort to promote consistency, many gaps persist. Further, cost information was gleaned from maintenance management information systems, which were not subjected to the rigors of financial reporting systems in terms of checks and balances and rules on accurate portrayal of cost. The resulting data are imperfect and subject to doubt at disaggregrate levels.

As information availability on vehicle maintenance and operations activities is a recent development, transit managers are just beginning to use the information to make decisions concerning policy in these areas. Increased use of the data may result in more consistent and accurate reporting. The reduced availability of operating and capital funds for transit, a direct result of increased stringency in government spending, serves as a catalyst for encouraging operators to use this information to reduce cost. As the industry becomes acclimated to these increased analytic capabilities, it is anticipated that improved capital and operations decision-making will lead to greater cost efficiency. Although this study does provide a solid approach to identifying cost-effective replacement strategies, it does not provide default parameters guiding bus replacement. Because of the data limitations discussed, supporting data will not be available for 2 to 3 years hence.

Vehicle Age Impact on Operating Cost

Vehicle operations costs can be divided into two broad categories, basic operating and maintenance costs and major repair and rebuild activities. Basic operating and maintenance costs include running repair and preventive and routine vehicle maintenance. While the research team was able to obtain only 1 or 2 years of data for these items from the operators, information for several different fleet types and vehicles ages was available. Based on the data obtained, the research team did not find evidence of a strong correlation between basic operations and maintenance costs and vehicle age—whether measured in terms of years or cumulative vehicle-miles. However, the data did indicate an overall growth in the cost per mile in aggregate terms, even if not correlated well with age. A strong correlation was, however, found between the four major rebuild activities reviewed (frame rebuild, transmission rebuild, body rebuild, and engine rebuild) and vehicle age. These four activities are relatively high cost items and are performed infrequently based on the wear and exposure of a vehicle. Because of the magnitude of these events, transit operators usually plan them in advance with most operators having a routine policy for dictating the thresholds (in terms of a fixed number of cumulative miles or years since manufacture) at which they occur.

As the four major rebuild activities are typically planned in advance, they are compatible with the capital planning process. The methodology presented in this research report is intended to assist the nation's diverse transit operators in taking these costs, as well as the capital costs associated with purchasing and rehabilitating vehicles and routine operating and maintenance costs, into account by developing a unified approach to reducing agency costs.

Life-Cycle Costing

Given that some of the major operating cost items (namely the subsystem rebuilds) vary with vehicle age, a life-cycle costing (or whole life costing) approach is the most appropriate way to evaluate capital investment decisions. Life-cycle costing incorporates the capital value of the investment as well as the operating and maintenance cost stream over the useful life of the vehicle, thus allowing a transit operator to evaluate the type, timing, and magnitude of costs in a rational manner.

The financial methodology outlined in this research report is one method of analyzing the problem. The technique allows operating costs to be taken into account when making capital investment decisions and vice versa. Thus, the magnitude and timing of subsystem rebuild work can change the time at which a vehicle is retired and, conversely, the retirement age of a vehicle has an impact on the subsystem rebuild work to be completed and operating costs. The AEC approach is the most responsive to needs of this problem, as it allows equitable comparison of vehicles with differing economic life.

Non-Vehicle Capital Investments

Initially, the research team conducted a comprehensive literature review of cost-effective transit capital investment techniques other than those involving bus replacement or rehabilitation. Industry literature clearly demonstrates that there are four primary types of non-vehicle replacement investment strategies that can lead to operating cost reductions or revenue enhancements. These strategies are in the areas of fixed facilities, vehicle enhancement equipment, maintenance diagnostic equipment, and information systems. Each of these investment strategies is characterized by unique capital requirements and levels of return.

Fixed facility investments include the design and construction of major facilities such as maintenance shops and administration buildings. This category of non-vehicle investment also includes the rehabilitation and upgrade of such facilities, and the installation of costly items such as high pressure bus washers and energy saving equipment (e.g., heat curtains). These investments can provide cost savings commensurate with the level of investment required.

A second category of non-vehicle transit capital investment involves upgrading vehicle components and equipment to realize operating cost savings (i.e., by using vehicle enhancement equipment). Examples of such items include two-way radio systems, brake retarders, and air starters. These have been noted to reduce operating costs moderately.

Maintenance diagnostic equipment, a third form of non-vehicle capital investment, allows a more rapid identification of mechanical problems and a better definition of maintenance program needs. Examples of such equipment for buses include dynamometers and brake test equipment. Experience has been mixed with these investments.

The fourth category of non-vehicle investment is information systems. The increased availability of vehicle maintenance information can lead to substantial cost savings through more informed decision-making concerning component life cycles and reduced clerical costs. Information systems that are increasingly being used in the vehicle maintenance area include work scheduling systems and inventory control systems. The literature did not present adequate documentation on actual cost savings resulting from these investments.

SUGGESTED RESEARCH

Because maintenance cost information systems are currently being expanded, and limited experience is available to provide historical remanufactured bus operating and maintenance cost, the research team suggests that for the immediate future research focus on non-vehicle capital investments. Several years from now, when an historical base of detailed vehicle operating and maintenance costs is available, it will be advantageous to revisit the vehicle replacement issue. Several research candidates which focus on reducing operating cost deficits follow.

Transit Vehicle Enhancement Equipment

Transit agencies are being subjected to increased pressures from a number of institutional and market forces. Continuing escalation of labor and materials costs and decreasing external funding are presenting stiff challenges to transit managers. In climate of increased financial austerity, the effectiveness with which transit managers allocate their scarce resources becomes increasingly important.

In addition to financial pressures to become more efficient, transit maintenance managers are operating in an environment of escalating vehicle sophistication. Vehicle components and subsystems are becoming increasingly difficult to maintain and repair because of increased legal, operating, and passenger requirements which require advanced technology. Increased sophistication has, in many instances, resulted in decreased inservice performance. It has also placed extensive burdens on the training and quality control programs of many transit maintenance departments.

Recent technological advances in the area of transit vehicle enhancement equipment (upgrading vehicle components, equipment, and subsystems) have made this a promising area in which substantial operating cost savings can be realized at little cost to agency. Many of the cost savings stem from greater equipment reliability and longer life cycles. Some examples of effective investments in revenue vehicle enhancement equipment include:

- Cost effective components, such as air starters (which reduce electrical system maintenance costs and improve performance in hot cold weather), rotary compressors (which appear less costly to repair than reciprocating compressors), brake retarders (which are intended to reduce brake wear, but experience is widely varied from their use), and fuel efficient transmissions (which could offer a substantial savings from high mileage bus operators). In many cases the actual magnitude of cost savings from improved component reliability is unclear, although less frequent and less costly repairs certainly result in cost reductions.
- Air conditioning improvements, such as evaporative coolers and roof-mounted air conditioning units, have proven cost-effective investments. Evaporative coolers are most effective in semi-arid western regions and increase passenger comfort at a cost well below conventional mechanical air conditioning. Substantial documentation is also available on the benefits of roof-mounted air conditioning units.
- Communications systems, such as two-way radios, have helped several systems in reducing service delays and responding to roadcalls. Some agencies have reported ridership increases and operator cost reductions as a result.
- Electric buses, which are more common abroad than in the United States, are believed to have lower energy costs than combustion engine vehicles. However, the capital cost of electric buses is quite high and life-cycle costs are not yet well defined.
- Vehicle accessories, such as electronic destination signs (which in many cases have been less expensive to maintain than manual scroll signs), electronic registering fareboxes (which generally cost more to repair than mechanical boxes but capture more revenue through improved security), and low maintenance wheelchair lifts. Cost savings/revenue enhancement opportunities are high and installation is relatively easy.

Overall, capital investments in improved vehicle equipment are relatively inexpensive and show potential for good savings results. Because this is a relatively new area of technology and management interest, cost savings potential has not been fully explored on many items. At the same time, transit operators are seeking means for engineering improvements in vehicle reliability and cost in response to the need to become more cost efficient. Operators need assistance in identifying high opportunity improvements to revenue vehicle maintenance operating costs and effectiveness. This research project would address this need by identifying specific, cost-effective investments in revenue vehicle enhancement equipment and associated costs and benefits.

Objective of Research

The overall objective of this suggested research would be to identify and quantify the costs and benefits associated with the use of vehicle enhancement equipment and provide transit operators with guidelines for implementing cost-effective improvements. The following tasks are suggested to attain the project objectives:

1. Identify the field of available transit revenue vehicle equipment enhancements and subsystem improvements. This should include a literature review, as well as telephone interviews because many improvements are not yet documented in industry literature.
2. Identify transit operators who have installed and implemented each category of equipment either on a test basis or fleet-wide. Compile a list of operators willing to participate in the research and attempt to get four to eight operators in each improvement category.
3. Develop procedures for gathering data from both manufacturers and operators (e.g., site visits, data collection guides), and for conducting information interviews.

4. Develop procedures for analyzing the data to be collected. Analysis should isolate the specific costs of equipment, including purchase cost, installation, training, routine or preventive maintenance, repair, rebuild, and useful life. These costs are to be compared using net present value of capital and operating costs to the life-cycle costs of existing equipment.

Additional costs and revenues stemming from reliability improvements (e.g., reduction of inservice breakdowns), revenue enhancement through improved ridership, revenue security, and so forth, are to be included. The analysis should follow a case study structure and include comprehensive cost information.

5. Collect data from operators, and manufacturers as appropriate, through written surveys and interviews. Analyze data to determine costs and benefits of vehicle enhancement equipment by type. The study should present the analysis in a case study framework which recognizes the impact of local operating conditions on the cost savings (e.g., fleet mix, miles operated, climate, and so on). The cost savings methodology should be expressed in annual and life-cycle costing terms, and both successes and failures should be included.

6. Develop an equipment investment analysis procedure for transit operators which will help operators in defining costs and savings of alternative vehicle equipment enhancements. The methodology should facilitate definition of a break-even point and return on investment from equipment changes. The life-cycle costing technique should recognize that many operators require a short payback period for this type of investment.

7. The report of the research should include two specific results: (a) a "Value for Money Handbook", which includes detailed case studies on the results of vehicle enhancement equipment investments; and (b) a methodology for analyzing the potential benefit of alternate investments vehicle equipment, recognizing differences in operating environments.

Maintenance Diagnostic Equipment

There is widespread concern with increasing transit operating deficits. To counteract this trend, UMTA has been exploring ways to institutionalize private sector arrangements in the provision of transit services. The recent UMTA Private Enterprise policy statement makes it clear that transit agencies must adopt a private sector management and investment policy to compete in the public/private sector marketplace.

Typically over 20 percent of bus operating costs is for maintenance which can amount to greater than 40 percent of discretionary expenditures for bus operations. In an effort to improve maintenance productivity many public transit agencies are making major purchases for maintenance diagnostic equipment (e.g., brake test equipment, dynamometers, and electrical system testers). These expenditures can amount to upwards of $1,000 per bus. It is unclear whether these expenditures are cost effective in improving performance or are exacerbating the long-term cost-containment strategy. It is also unclear as to why some operators report great success using new diagnostic equipment, while others find the equipment of little real benefit.

Objective of Research

The objective of this project is to compare and contrast public and private investment criteria and experience with various maintenance diagnostic equipment. The attainment of this objective will be accomplished in the following tasks.

1. Identify major public and private fleet operators which have made major investments in maintenance diagnostic equipment. Identify the specific type of equipment purchased and the nature of its use (e.g., bench, floor or chassis dynamometer use for checking rebuilds alone or all vehicles).

2. Review the rationale that was used to justify these investments and analyze the experience to date. Focus on cost impacts by comparing before and after costs for training, troubleshooting, and repair on specific vehicle subsystems.

3. Compare and contrast the experience of public and private operators, identify constraints and opportunities for public investment, and present rationale to guide public investment decision-making. The rationale should include life-cycle cost measurement and guidelines for using equipment to its fullest advantage.

Bus Maintenance Facility Layouts

Continuing escalation of labor and materials costs and decreasing support funding are presenting stiff challenges to transit managers. During a 5-year period ending recently, transit maintenance costs increased at a rate far exceeding transportation and administrative costs. Recent research on maintenance manpower planning indicated that as much as 25 percent of maintenance may be lost to movement of buses to and from repair areas due to insufficient bus parking space. "Picking a bus from the stack" is a familiar expression to transit bus mechanics.

On the average, transit agencies spend 21 percent of their maintenance manpower on the servicing and cleaning of buses. Staffs devoted to this critical function vary widely among agencies with crew sizes dictated by the time required to take a bus through the servicing cycle. The bus parking arrangement and its relationship to the service facilities impact the time requirements. Two transit agencies have adopted a unique "fuel-in-place" concept where each bus is fueled and serviced in its overnight parking location, doing away with the need for a separate service facility. The elimination of the time to move each bus to the service lane and back to parking results in reduced service crew sizes.

Even though operating assistance may decline, there are expectations that some level of capital funding will be available. This suggested research project will focus on determining the cost of providing adequate bus parking space and efficient layouts to reduce manpower cost.

Objective of Research

The overall objective of this research is to develop a method for evaluating the capital investments necessary to provide efficient bus parking servicing arrangements and to measure improvements in operating efficiency to reduce or control operating costs. The following tasks are suggested to attain the project objectives:

1. Identify different bus parking practices currently used by transit agencies. Identify different methods for cleaning and servicing of buses.

2. Identify site-specific criteria; e.g., stack parking, diagonal

parking, travel distance from parking area to service island, number of servicing locations in a single cycle, direction of bus circulation, and area construction costs.

3. Develop procedures for gathering data; e.g., site visits, data collection guides.

4. Develop procedures for analyzing data, establishing comparisons, and evaluating cost/benefits. These must account for site-specific factors, and should include life-cycle costs due to the nature of the investment.

5. Develop methodology for identifying representative agencies for data collection.

6. Collect data from agencies and perform analysis. Include impacts of local site-specific characteristics.

7. Develop methodology to permit transit agencies to understand the impact of different methods of parking and servicing of buses on maintenance operating costs and the capital costs that would be expected to realize savings.

Bus Cost Parameters

This study developed a methodology for evaluating bus replacement strategies but was unable to provide default parameters for use by operators in assessing costs trade-offs. The primary reason for this was the lack historical cost data by subfleet and vehicle subsystem. Maintenance management information systems have only recently provided the data capture capability needed to analyze detailed cost impacts of aging and vehicle wear. The purpose of this proposed research effort is to gather historical cost data at a detailed level to provide operators with specific parameters for evaluating changes in vehicle operating and maintenance costs over its useful life. Transit operators could then use the specific cost characteristics to develop vehicle replacement strategies that reduce overall operating and maintenance costs.

Objective of Research

The objective of this project is to prepare an aging profile of which cost characteristics are by subfleet and vehicle subsystems. The attainment of the objective will be accomplished in the following tasks:

1. Select ten transit operators with appropriate data capture and reporting capabilities, and who will participate in the study (the ten included in the current NCTRP research project would be appropriate). Requests that these operators report information to the NCTRP over 5 years. As at least 2 years are available now (i.e., one more year than included in the current study), this will involve an additional 3 years of reporting.

2. Prepare a detailed data collection and reporting guide for use by participating operators. It should glean data on subfleet composition, local operating conditions, aggregate operating and maintenance costs, disaggregate costs by subsystem (separately for labor and materials), rebuild costs and frequencies for fleet purchased new and rehabilitated fleet. The guide should also capture any changes to the information system or reporting structure over the 5 years. Finally, documentation of the methodology and principals guiding cost reporting should be detailed (e.g., basis for labor costs, overhead allocations, and materials costs).

3. Collect the data over a 5-year period. The guide should be forwarded to the participating operators as soon as possible. Transit operators generally retain detailed data for 1 or 2 years only (18 months is frequently cited). While some operators store older data on tape, others purge it all together. Also, information system changes occur periodically and may impact data consistency. It is essential to collect this data annually, and store it for analysis.

4. Review and analyze the data. After 5 years of data are compiled, the research team should analyze the data and identify the degree to which local operating conditions, vehicle subfleets, and age impact costs. The 5 years of data by subsystem can be normalized for each subfleet by statistically factoring out the impact of local operating conditions. Then, a 5-year cost profile can be developed for each observation on a normalized basis. When all observations are combined the research team can develop a reasonable profile for similar vehicles over its useful life.

5. Prepare guidelines for using the study results at local operators, addressing fleet mix, local operating characteristics, and vehicle aging costs. The guidelines should be comprehensive and easy to use.

APPENDIX A
EXAMPLE OF MODEL APPLICATION TO A TRANSIT OPERATOR

INTRODUCTION

A step-by-step application of the financial methodology developed in Chapter 3 is outlined here. As bus investment decisions have an impact on operating costs and because transit funding is becoming increasingly constrained, transit managers need a simple methodology for incorporating operating cost considerations in making vehicle replacement decisions. The straight-forward capital analysis methodology illustrated here is comprised of eighteen simple steps. The only tools required to conduct the analysis are a calculator and minimal data availability. The methodology requires information which, typically is readily available at transit agencies, as discussed in the main body of the text.

The methodology analyzes both operating and capital costs, as both have been shown to be closely related. The technique used to combine capital and operating costs is the "annualized equivalent cost" (AEC) technique. The AEC approach distributes, on an amortization basis, capital costs over a vehicle's useful life and adds annual operating and maintenance expense to this figure. The AEC approach to life cycle costing allows a fair comparison of investments with different life spans.

As required by the original research scope, the methodology has broad-based application, allowing the same procedures to be applied to transit agencies throughout the nation, irrespective of factors such as size, fleet composition, and geographic location.

In this Appendix, the model is applied to a fictitious transit authority -- Anytown Transit (a medium-sized operator). The methodology could be applied equally successfully under a variety of operating conditions.

Medium-Sized Transit Operator: Anytown Transit

Anytown Transit is located in the midwestern U.S. The agency owns and operates a number of vehicle fleets, including 200 buses of Fleet Type 2. Data elements necessary for the application of the model to this fleet are outlined in Table A-1. The model is applied as follows:

- Step 1: Amortized Capital Cost per Vehicle

  Capital Cost (New): $135,000
  Useful Life (New): 14 years
  Amortization Factor for 14 years: 0.1213 (from Table 3)
  Amortized Capital Cost = (135,000) (0.1213)
  = $16,376 per vehicle per year

- Step 2: Calculate Annual Operating and Maintenance Cost

  a. Cumulative Vehicle Miles
  = (Average Annual Miles) (Useful life)
  = (32,000) (14) = 448,000 miles per vehicle

TABLE A-1
DATA ITEMS REQUIRED FOR ANALYSIS
MEDIUM-SIZED OPERATOR: ANYTOWN TRANSIT

1.	Fleet Type	Fleet Type 2
2.	Number of Active Buses in Fleet	200
3.	Annual Miles per Vehicle	32,000
4.	Interest or Discount Rate	8%
5.	Current Spare Ratio	17%
6.	Minimum Acceptable Spare Ratio	14%
7.	Proportion of Vehicles Eligible for Rebuild	75%
8.	Capital Cost New	$135,000
9.	Useful or Economic Life (New)	14 years
10.	Rebuild/Remanufacture Cost	$80,000
11.	Additional Useful Life from Rebuild	6 years
12.	Basic Vehicle Operations and Maintenance Cost per Mile	$0.61/mile
13.	Average Cost of Engine Rebuild	$5,200
14.	Average Miles Between Engine Rebuilds	200,000 miles
15.	Average Cost of Engine Rebuild per 1,000 miles (13 ÷ 14)	$26.00
16.	Average Cost of Transmission Rebuild	$2,150
17.	Average Miles Between Transmission Rebuilds	120,000 miles
18.	Average Cost of Transmission Rebuild per 1,000 miles (16 ÷ 17)	$17.92
19.	Average Cost of Major Body Refurbishment	$6,000
20.	Average Miles Between Body Refurbishment	260,000 miles
21.	Average Cost of Body Refurbishment per 1,000 miles (19 ÷ 20)	$23.08
22.	Average Cost of Major Frame Rehabilitation	$5,700
23.	Average Miles Between Frame Rehabilitation	260,000 miles
24.	Average Cost of Frame Rehabilitation per 1,000 miles (22 ÷ 23)	$21.92
25.	Average Total Cost of Rebuilds per 1,000 miles (sum 15, 18, 21, and 24)	$88.92

b. Calculate O/M Cost

User has the option of applying the initial base O/M cost across the life of the vehicle (assumes flat cost), applying the cost growth equation to the initial cost to get an annual average O/M cost over the life of the vehicle (escalating cost), or using any other figure deemed appropriate.

Option 1 (Flat Cost)

Applying the $0.61/mile initial cost across the 14 year useful life gives annual base O/M cost of:

(0.61) (32,000) = $19,520

Option 2 (Escalating Cost)

Applying the cost growth equation to base cost:
Annual O/M Cost in first year = \$0.61/mile
Annual O/M Cost in last year of useful life (year 14)
= 0.61 + (0.000253) (Cumulative Miles in thousands)
= (0.61) + (0.000253) (448)
= \$0.72/mile

Average O/M costs over life of vehicle
= (0.61 + 0.72)/2
= \$0.665/mile

Average annual O/M cost over 14 year useful life of vehicle
= (32,000) (0.665)
= \$21,280

- Step 3: Determine Major Repair/Rebuild Costs

a. Engine Rebuild Cost
= (Average Engine Rebuild Cost) (Cumulative Miles/Engine Rebuild Miles) where cumulative miles/engine rebuild miles is rounded down to the nearest whole number.
= (5,200) (448,000/200,000)
= (5,200) (2) = \$10,400

b. Transmission Rebuild Cost
= (Average Transmission Rebuild Cost) (Cumulative Miles/Transmission Rebuild Miles) where cumulative miles/transmission rebuild miles is rounded down to the nearest whole number.
= (2,150) (448,000/120,000)
= (2,150) (3) = \$6,450

c. Body Rebuild Cost
= (Average Body Rebuild Cost) (Cumulative Miles/Body Rebuild Miles) where cumulative miles/body rebuild miles is rounded down to the nearest whole number.
= (6,000) (448,000/260,000)
= (6,000) (1) = \$6,000

d. Frame Rebuild Cost
= (Average Frame Rebuild Cost) (Cumulative Miles/Frame Rebuild Miles) where cumulative miles/frame rebuild miles is rounded down to the nearest whole number.
= (5,700) (448,000/260,000)
= (5,700) (1) = \$5,700

e. Annualized Major Repair Cost
= (Engine Rebuild Cost + Transmission Rebuild Cost + Body Rebuild Cost + Frame Rebuild Cost)/(Useful life)
= (10,400 + 6,450 + 6,000 + 5,700)/14
= \$2,039 per vehicle per year

- Step 4: Determine Current AEC Bus Cost

Option 1 (Flat Cost):

AEC= (Amortized Capital Costs + Annual O/M Costs + Major Repair Costs) (Number of Buses)
= (16,376 + 19,520 + 2,030) (200)
= \$7,587,000

Option 2 (Escalating Cost):

AEC= (Amortized Capital Costs + Annual O/M Costs + Major Repair Costs) (Number of Buses)
= (16,376 + 21,280 + 2,039) (200)
= \$7,939,000 for fleet

- Step 5: Determine Residual Life of Rebuilds in Miles

a. Engine
Residual Life = (Number of Rebuilds + 1) (Engine Rebuild Miles) - (Cumulative Miles)
= (2+1) (200,000) - (448,000)
= 152,000 miles

b. Transmission
Residual Life = (Number of Rebuilds +1) (Transmission Rebuild Miles) - (Cumulative Miles)
= (3 + 1) (120,000) - (448,000)
= 32,000 miles

c. Body
Residual Life = (Number of Rebuilds + 1) (Body Rebuild Miles) -(Cumulative Miles)
= (1+1) (260,000) - (448,000)
= 72,000 miles

d. Frame
Residual Life = (Number of Rebuilds + 1) (Frame Rebuild Miles) - (Cumulative Miles)
= (1+1) (260,000) - (448,000)
= 72,000 miles

- Step 6: Determine Life Consumed of Latest Rebuilds in Miles

a. Engine
Life Consumed = Engine Rebuild Miles - Engine Residual Miles
= 200,000 - 152,000
= 48,000 miles

b. Transmission
Life Consumed = Transmission Rebuild Miles - Transmission Residual Miles
= 120,000 - 32,000
= 88,000 miles

c. Body
Life Consumed = Body Rebuild Miles - Body Residual Miles
= 260,000 - 72,000
= 188,000 miles

d. Frame
Life Consumed = Frame Rebuild Miles - Frame Residual Miles
= 260,000 - 72,000
= 188,000 miles

- Step 7: Determine Residual Bus Life

Residual Bus Life = (Engine Residual Miles) (Engine Rebuild Cost/Total Rebuild Cost per 1,000 miles) + (Transmission Residual Miles) (Transmission Rebuild Cost/Total Rebuild Cost per 1,000 miles) + (Body Residual Miles) (Body Rebuild Cost/Total Rebuild Cost per 1,000 miles) + (Frame Residual Miles) (Frame Rebuild Cost/Total Rebuild Cost per 1,000 miles) ÷ (Annual miles per vehicle)
= (152,000) (26.00/88.92) + (32,000) (17.92/88.92)
+ (72,000) (23.08/88.92) + (72,000) (21.92/88.92) ÷ (32,000)
= 2.73
Rounded to 3 years

- Step 8: Determine Potential Reduction in Useful Vehicle Life

Potential Life Reduction = (Engine Miles Consumed) (Engine Rebuild Costs/Total Rebuild Cost per 1,000 miles) + (Transmission Miles Consumed) (Transmission Rebuild Cost/Total Rebuild Cost per 1,000 miles) + (Body Miles Consumed) (Body Rebuild Cost/Total Rebuild Cost per 1,000 miles) + (Frame Miles Consumed) (Frame Rebuild Cost/Total Rebuild Cost per 1,000 miles) ÷ (Annual miles per year)
= (48,000) (26.00/88.92) + (88,000) (17.92/88.92) + (188,000) (23.08/88.92) + (188,000) (21.92/88.92) ÷ (32,000)
= 3.97
Rounded to 4 years

- Step 9: Determine New Useful Vehicle Life

a. Life Extension:
New Vehicle Useful Life
= Initial Useful life + Residual Life
= 14 + 3 = 17 years

New Cumulative Vehicle Miles
= (New Useful Life) (Annual Vehicle Miles)
= (17) (32,000)
= 544,000 miles

b. Life Reduction:
New Vehicle Useful Life
= Initial Useful Life - Reduction
= 14 - 4
= 10 years

New Cumulative Vehicle Miles
= (New Useful Life) (Annual Vehicle Miles)
= (10) (32,000)
= 320,000 miles

- Step 10: Determine New Amortization Cost

a. Life Extension:
New Amortization Cost
= (Capital Cost) (Amortization Factor for New Useful Life)
= (135,000) (0.1096 from Table 3)
= $14,796/year

b. Life Reduction:
New Amortization Cost
= (Capital Cost) (Amortization Factor for New Useful Life)
= (135,000) (0.1490 from Table 3)
= $20,115/year

- Step 11: Calculate Annual Operating and Maintenance Costs

Option 1 (Flat Cost): Use annual average O/M costs, assuming flat cost per mile, determined in Step 2: $0.615/mile or $19,520 per year in this example.

Option 2 (Escalating Cost): Calculate revised annual average O/M cost based on the new vehicle life by applying cost growth equation. The revised annual O/M cost will be different for the life extension and life reduction examples.

a. Life Extension:
Annual O/M Cost in first year = $0.61/mile
Annual O/M Cost in last year of useful life (year 17)
= 0.61 + (0.000253) (Cumulative Miles in thousands)
= 0.61 + (0.000253) (544)
= $0.748/mile

Average over new life of vehicle
= (0.61 + 0.748)/2
= $0.68/mile

Average annual O/M Cost over 17 year useful life of vehicle
= (32,000) (0.68)
= $21,760

b. Life Reduction:
Annual O/M Cost in first year = $0.61/mile
Annual O/M Cost in last year of useful life (year 10)
= 0.61 + (0.000253) (Cumulative Miles in thousands)
= 0.61 + (0.000253) (320)
= $0.69/mile

Average over new life of vehicle
= (0.61 + 0.69)/2
= $0.65/mile

Average annual O/M Cost over 10 year useful life of vehicle
= (32,000) (0.65)
= $20,800

- Step 12: Determine Major Repair and Rebuild Costs (same for both options)

a. Life Extension:

Engine

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) - 1
= (544,000/200,000) - 1
= 1.72
Round to 2

2) Cost = (Number) (Average Cost of Rebuild)
= (2) (5,200)
= $10,400

Transmission

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) - 1
= (544,000/120,000) -1
= 3.53
Round to 4

2) Cost = (Number) (Average Cost of Rebuild)
= (4) (2,150)
= $8,600

Body

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) -1
= (544,000/260,000) - 1
= 1.09
Round to 1

2) Cost = (Number) (Average Cost of Rebuild)
= (1) (6,000)
= $6,000

Frame

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) -1
= (544,000/260,000) - 1
= 1.09
Round to 1

2) Cost = (Number) (Average Cost of Rebuild)
= (1) (5,700)
= $5,700

Annualized Repair Cost
= (Engine + Transmission + Body + Frame)/(New Useful Life)
= (10,400 + 8,600 + 6,000 + 5,700)/17
= $1,806 per vehicle per year

b. Life Reduction:

Engine

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) - 1
= (320,000/200,000) - 1
= 0.6
Round to 1

2) Cost = (Number) (Average Cost of Rebuild)
= (1) (5,200)
= $5,200

Transmission

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) - 1
= (320,000/120,000) -1
= 1.66
Round to 2

2) Cost = (Number) (Average Cost of Rebuild)
= (2) (2,150)
= $4,300

Body

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) -1
= (320,000/260,000) - 1
= 0.23
Round to 0

2) Cost = $0

Frame

1) Number of Rebuilds
= (New Cumulative Miles/Miles Between Rebuilds) -1
= (320,000/260,000) - 1
= 0.23
Round to 0

2) Cost = $0

Annualized Repair Cost
= (Engine + Transmission + Body + Frame)/(New Useful Life)
= (5,200 + 4,300 + 0 + 0)/10
= $950 per vehicle per year

- Step 13: Determine New AEC Vehicle Costs

Option 1: (Flat Cost) Base O/M Cost derived over original useful life of vehicle is also applied to revised vehicle lives (as calculated in Step 2).

a. Life Extension:
AEC = (Amortized Capital Cost + O/M Cost + Major Repair Cost) (Number of Buses)
Amortized Capital Cost = $14,796 (from Step 10)
Annual Base O/M Cost = $19,520 (from Step 2)
Major Repair Cost = $1,806
AEC = (14,796 + 19,520 + 1,806) (200)
= $7,244,400

b. Life Reduction:
Amortized Capital Cost = $20,115 (from Step 10)
Annual Base O/M Cost = $19,520
Major Repair Cost = $950 (from Step 12)
AEC = (20,115 + 19,520 + 950) (200)
= $8,117,000

Option 2 (Escalating Cost): Annual average base O/M Cost does vary with length of useful life (as calculated in Step 11).

a. Life Extension:
AEC = (Amortized Capital Cost + O/M Cost + Major Repair Cost) (Number of buses)
Amortized Capital Cost = $14,796 (from Step 10)
Annual Base O/M Cost = $21,760 (from Step 11)
Major Repair Cost = $1,806
AEC = (14,796 + 21,760 + 1,806) (200)
= $7,672,400

b. Life Reduction:
Amortized Capital Cost = $20,115 (from Step 10)
Annual Base O/M Cost = $20,800 (from Step 11)
Major Repair cost = $950 (from Step 12)
AEC = (20,115 + 20,800 + 950) (200)
= $8,373,000

- Step 14: Determine Potential Change in Cost

Option 1 (Flat Cost): Use base O/M Cost calculated in Step 2.

a. Life Extension:
Cost Change = Extended Life AEC - Initial AEC
= 7,244,400 - 7,587,000 (from Steps 13 and 4, respectively)
= $(342,600)

b. Life Reduction:
Cost Change - Reduced Life AEC - Initial AEC
= 8,117,000 - 7,587,000 (from Steps 13 and 4, respectively)
= $530,000

Option 2 (Escalating Cost): Use base O/M Cost calculated in Step 11.

a. Life Extension:
Cost Change = Extended Life AEC - Initial AEC
= 7,672,400 - 7,939,000 (from Steps 13 and 4, respectively)
= $(266,600)

b. Life Reduction:
Cost change = Reduced Life AEC - Initial AEC
= 8,373,000 - 7,939,000 (From Steps 13 and 4, respectively)
= $434,000

Thus, under Option 1, there is a potential savings of $342,600 per year allowing the 200 vehicles to remain in useful service for three extra years (i.e., for 17 years in total). Under Option 2, the equivalent savings is $266,600.

Life extension is the least expensive alternative of the three reviewed. Under Option 2 (escalating O/M cost), life reduction yields annual savings in operating costs of $2,254 per vehicle over the current useful life scenario (i.e., 14 years), and $2,461 per vehicle per year saving over the extended life scenario. This is equivalent to $450,800 and $492,200 per year, respectively, over the entire fleet. The operating cost savings due to the life reduction, are however, more than offset by the additional annual capital costs -- $5,319 per year more than the extended life scenario (i.e., $1,063,800 for the entire fleet) and $3,739 per year more than the current useful life scenario (i.e., $747,800 for the entire fleet).

In order to determine whether replacing vehicles is cheaper than rebuilding them for the least expensive alternative (i.e., life extension) under the Option 1 scenario (i.e., constant O/M costs), follow this sequence of steps:

- Step 15: Amortize Capital Cost of Vehicles

a. Replacement Option
Capital Cost (New): $135,000
Useful Life: 17 years
Amortization Factor for 17 years: 0.1096 (from Table 3)
Amortization Costs = (0.1096) (135,000)
= $14,796 for vehicle per year

b. Rebuild Option:
Cost: $80,000
Life Extension: 6 years
Amortization Factor for 6 years: 0.2163 (from Table 3)

Amortization Cost = (0.2163) (80,000)
= $17,304 per vehicle per year

- Step 16: Determine Annual Operating and Maintenance Costs

  a. Replacement Option
  O/M Cost = $19,520 per vehicle per year (from Step 2)

  b. Rebuild Option
  O/M Cost = $19,520 per vehicle per year (from Step 2)

- Step 17: Determine Major Repair Costs
  (Minimum of Step 3 or Step 12)

  a. Replacement Option
  Major Repair Costs = $1,806 per vehicle per year (from Step 12)

  b. Rebuild Option:
  None

- Step 18: Calculate and Compare AEC Values

  a. Replacement Option
  AEC = $244,800 (from Step 13)

  b. Rebuild Option
  AEC = (Amortized Capital Cost + Annual O/M Cost)
  (Number of Vehicles)
  = (17,304 + 19,500) (200)
  = $7,364,800

  c. Potential Cost Savings due to Rebuilding Vehicles
  Savings = Replacement AEC - Rebuild AEC
  = 7,244,400 - 7,364,800
  = $120,400

It is thus cheaper to replace rather than rebuild vehicles, in this case.

- Step 19: Determine Number of Vehicles to be Rebuilt

  Not applicable

APPENDIX B
LITERATURE TITLES FOR COST EFFECTIVE CAPITAL INVESTMENTS OTHER THAN BUS REPLACEMENTS

Fixed Facility Investments

- "SEPTA CAPITAL IMPROVEMENT STRATEGY-BUS FLEET REPLACEMENT AND BUS MAINTENANCE FACILITY RENOVATIONS", Southeastern Pennsylvania Transportation Authority, 202B PSFS Building, 12 South 12th Street, Philadelphia, Pennsylvania 19107, September 1981.

- "VALUE ENGINEERING (GBTD)", Mitchell, S., Greater Bridgeport Transit District, 525 Water Street, Bridgeport, Connecticut 06604.

- "VALUE ENGINEERING", Manoukian, P., Washington Metropolitan Area Transit Authority, 600 5th Street NW, Washington, D.C. 20001.

- "SOUTHERN DIVISION MAINTENANCE FACILITIES MASTER PLAN FOR N.J. TRANSIT BUS OPERATIONS, INC. REVISED EDITION", Daniel, Mann, Johnson and Mendenhall, 1709 New York Avenue NW, Washington, D.C. 20006; New Jersey Transit, P.O. Box 10009, McCarter Highway and Market Streets, Newark, New Jersey 07101; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, April 1984.

- "VALUE ENGINEERING FOR BUS MAINTENANCE FACILITIES", Urban Mass Transportation Administration, Office of Technical Assistance, 400 7th Street SW, Washington, D.C. 20590.

- "TRANSPORTATION SYSTEMS MANAGEMENT. PINE BLUFF, ARKANSAS", Southeast Arkansas Regional Planning Commission, P.O. Box 8298, Pine Bluff, Arkansas 71611; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, 1984.

- "TRAFFIC CONTROL AT BUS TERMINALS BASED ON AUTOMATIC BUS IDENTIFICATION", Lazic, D.M.; Jovanovic, T.D., Elektrotehniska Zveza Slovenije Titova 50 Ljubljana Slovenia Yugoslavia, October 1982.

- "SPECING BUS WASHERS", Bobit Publishing Company, Metro, Vol. 81, No. 11, February 1985.

- "CITY OF EL PASO PUBLIC TRANSIT ADMINISTRATION ENERGY CONTINGENCY PLAN", City of El Paso, Texas, Public Transit Administration, El Paso, Texas, October 1980.

Vehicle Enhancement Equipment

- "TWO-WAY RADIO COMMUNICATION MASS TRANSPORTATION DEMONSTRATION PROJECT", New York City Transit Authority, 370 Jay Street, Brooklyn, New York 11201.

- "QUEENS VILLAGE RADIO-DATA-LOCATOR SYSTEM", Dornfield, S., Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, Piscataway, New Jersey 08854.

- "ENCODER/DECODER DESIGN FOR AUTOMATIC IDENTIFICATION AND AUDIO MONITORING OF AUTOMATED TRANSIT SYSTEMS", Nessim, S.M.; Mitry, S.A., Toledo University, Toledo, Ohio 42606, 1980 Conference Paper.

- "THE USE OF RADIO COMMUNICATIONS IN RURAL TRANSPORTATION", Baksa, E.J.; Wegmann, F.J.; Chatterjee, A., Tennessee University, Knoxville Transportation Center, Knoxville, Tennessee 37916, 1980.

- "SINGLE CABLE COMMUNICATIONS TECHNOLOGY FOR RAIL-TRANSIT SYSTEMS", Cassara, F.A., Polytechnic Institute of New York, 333 Jay Street, Brooklyn, New York 11201.

- "AIR STARTERS FOR TRANSIT BUSES", Yu, C.; McCurdy, N., Transportation Systems Center Operations Assistance Division, 55 Broadway, Cambridge, Massachusetts 02142; Erdoel and Kohle Erdgas Petrochemie, Ernst-Mey-Strasse 8, D-7022 Leinfelder, West Germany.

- UMTA TECHNICAL ASSISTANCE PROGRAM

  UMTA, as part of its Technical Assistance Program has conducted several studies on cost effective vehicle subsystems and components, including:

  - Reliability Evaluation of V-730 Transmission, Project MA-06-0120, Transportation Systems Center, May 1982.
  - Updated Reliability Evaluation of V-730 Transmission, Project MA-06-120, Transportation Systems Center, July 1983.
  - Evaluation of Retarders for Transit Buses, Project MI-06-0025, Michigan DOT, June 1983.
  - Tests of Improved Components and Subsystems on AMG and RTS Buses, Project CA-06-1064, SCRTD, July 1984.
  - Bus Transmission and Brake Retarder Evaluation, Project PA-06-0082, SEPTA, February 1985.
  - Rotary Screw Air Conditioning Compressor Evaluation, Project DC-06-0469, WMATA, November 1984.
  - Rotary Screw Air Conditioning System Evaluation, Project MA-06-0120, TSC/Garrett AiResearch, January 1983.

- "EVAPORATIVE COOLERS FOR TRANSIT BUSES, VOLUME I - - DESIGN, DEVELOPMENT, TESTING AND EVALUATION", Butz, J.R.; Mattil, J.F.; Marquez, J., Regional Transportation District, 1600 Blake Street, Denver, Colorado 80202; Urban Mass Transportation Administration, 400 7th Street, SW, Washington, D.C. 20590.

- "ROOF-MOUNTED AIR CONDITIONING", Gambaccini, M., Central New York Regional Transportation Authority, One Centro Center, 200 Cortland Avenue, Drawer 820, Syracuse, New York 13205.

- "TRANSIT BUS TIRE SURVEY", American Public Transit Association, 1225 Connecticut Avenue NW, Washington, D.C. 20036; Chicago Transit Authority, Merchandise Mart Plaza, P.O. Box 3555, Chicago, Illinois 60654.

- "PRESENT TECHNOLOGY AND DEVELOPMENT POSSIBILITIES FOR ELECTRIC VEHICLES. FINAL REPORT", Olsson, C.; Ristborg, H., Statens Vattenfallsverk, Vaellingby, Sweden, March 1980.

- "PILOT STUDY: ELECTRIFICATION OF THE ADELAIDE BUS SYSTEM", South Australia Department of Transport, Victoria Square, Adelaide, South Australia, Australia, 1982.

- "INDUCTIVE COUPLING ALTERNATIVE ANALYSIS", Nasick, M., Massachusetts Bay Transportation Authority, 50 High Street, Boston, Massachusetts 02110.

- "PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON TRAFFIC CONTROL SYSTEMS HELD AT BERKELEY, CALIFORNIA ON AUGUST 6-9, 1979. VOLUME 2B: CONTROL EQUIPMENT", University of California Berkeley; Institute of Transportation Studies, 109 McLaughlin Hall, Berkeley, California 94720; Federal Highway Administration, 400 7th Street SW, Washington, D.C. 20590.

- "LT TURNS TO HIGH-TECH TO FIGHT TRAFFIC CONGESTION", Goldsack, P.J.; Carter, C. Carroll, Mass Transit, Vol. 11, No. 8, August 1984, pp. 12-13.

- "VEHICLE DETECTORS", Stewart, P.M., Australian Road Research Board, Australian Road Research Board Conference Proc., Vol. 12, No. 4.

- "A NOTE ON THE ENERGY EFFICIENCY OF VARIOUS MEANS OF TRANSPORT", Gunnarsson, S.O.; Persson, B., Printerhall Limited, Traffic Engineering and Control, Vol. 17, No. 10, October 1976.

- "STUDY OF FLYWHEEL ENERGY STORAGE - - VOLUME 1, EXECUTIVE SUMMARY; VOLUME 2, SYSTEMS ANALYSIS; VOLUME 3, SYSTEM MECHANIZATION; VOLUME 4, LIFE-CYCLE COSTS; VOLUME 5, VEHICLE TESTS", Lawson, L.J.; Smith, A.K.; Davis, G.D., AiResearch Manufacturing Company, 2525 West 190th Street, Torrance, California 90509, September 1977.

- "A STUDY OF FLYWHEEL ENERGY STORAGE FOR URBAN TRANSIT VEHICLES, PHASE I", General Electric Corporate Research & Development, Schenectady, New York, September 1977.

- "MAN-MADE POLYMERS - - THE FIRE SAFETY ISSUE REACHES FLASHPOINT", Hodges, P.D., Automotive Industries International, Automotive Industries, Vol. 159, No. 12, December 1979.

- "TRANSIT SECURITY GUIDELINES MANUAL", American Public Transit Association Technical and Research Services Department, Washington, D.C. 20036; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590; Transit Development Corporation, Incorporated, 1730 M Street NW, Washington, D.C. 20036, February 1977.

- "ELECTROMECHANICAL TRANSIT SECURITY EQUIPMENT", Berry, C.R.; Stuart, D.G., Barton-Aschman Associates, Incorporated, 820 Davis Street, Evanston, Illinois 60204, November 1982.

- "THE SYNCHRONOUS MOVING-CELL CONTROL PHILOSOPHY FOR AUTOMATED TRANSPORTATION SYSTEMS", Rumsey, A.F.; Powner, E.T., Gordon and Breach Science Publishers, Incorporated, Transportation Planning and Technology, Vol. 2, No. 3, 1974, pp. 157-164.

- "COORDINATION AND CONTROL OF PARATRANSIT SERVICES", Wilson, N.H.M., Transportation Research Board, Transportation Research Board Special Report N164, 1976; pp. 174-182.

- "LEA TRANSIT COMPENDIUM (LTC)", Lea (ND) Transportation Research Corporation, 123 Green Street, Huntsville, Alabama 35801, 1977.

- "BUS CONTROL: A REVIEW OF PRESENT KNOWLEDGE", Finnamore, A.J.; Jackson, R.L., Leeds University, England, Operational Research Unit, Centre for Computer Studies, Leeds LS2 9JT West Yorkshire, England, July 1977.

- "AUTOMATION AND CONTROL IN TRANSPORT. 2ND REVISED EDITION", Barwell, F.T., Pergamon Press Limited, Headington Hill Hall, Oxford OX3 OBW England.

- "AUTOMATIC PASSENGER COUNTERS AND BUS LOCATION", Friedman, T., METRO/Seattle, 821 Second Avenue, Exchange Building, Seattle, Washington 98104.

Maintenance Diagnostic Equipment

- "DEVELOPMENT OF TRANSIT COACH BONDED BRAKE LINING TEST EQUIPMENT AND TEST PROCEDURES - - PROGRESS REPORT", Simeone, L.F., Transportation Systems Center Research and Special Programs Administration, Cambridge, Massachusetts 02142; Urban Mass Transportation Administration, Office of Technical Assistance, 400 7th Street SW, Washington, D.C. 20590, January 1984.

- "VEHICLE DESIGN, ACCEPTANCE TESTING, AND MAINTENANCE SUPPORT SERVICES: RESOURCE PAPER", Buckel, H.H., Transportation Research Board, Transportation Research Board Special Report N198, 1983.

- UMTA TECHNICAL ASSISTANCE PROGRAM

  The UMTA Technical Assistance Program has conducted several studies related to bus maintenance diagnostic equipment. While abstracts are not available for these projects, three recent studies include:

  - Engine Testing Program for Standard Size Buses, Project MI-06-0037, Michigan DOT/UMTA, October 1982 - October 1984.
  - Maintenance Equipment Study, Project MD-06-0101, AMAF Industries/UMTA, September 1983 - October 1984.
  - Automatic Bus Diagnostics Evaluation Methodology, Project MD-06-0101, MAXIMA Corporation, September 1983 - June 1984.

Information Systems

- "COMPUTERIZED CUSTOMER INFORMATION SYSTEM - - PART OF SCRTD'S TRANSMIS PROJECT", Simpson, A.U., Friendship Publications, Incorporated, Bus Ride, Vol. 20, No. 8, January 1985.

- "A VITAL PHASE OF TRANSIT EVOLUTION: MANAGEMENT INFORMATION SYSTEMS", Knautz, D.D., Transportation Research Board Special Report N187, 1980.

- "AN INFORMATION SYSTEMS MANUAL FOR HUMAN SERVICE TRANSPORTATION", United Services Agency, 111 North Pennsylvania Boulevard, Wilkes Barre, Pennsylvania 18701, May 1982.

- "INFORMATION AND CONTROL SYSTEMS FOR PARATRANSIT SERVICES", Wilson, N.H.M.; Colvin, N.J., Transportation Research Board, Transportation Research Board Special Report N184, 1979.

- "JAPAN: WHERE COMPUTERS AND TRANSIT WORK TOGETHER", Tomlinson, D.; Carter, C. Carroll, Mass Transit, Vol. 11, No. 8, August 1984.

- "AUTOMATIC VEHICLE LOCATION - - AN OVERVIEW", Riter, S.; McCoy, J., Institute of Electrical and Electronics Engineers, IEEE Transactions on Vehicular Technology, Vol. 26, No. 1, February 1977.

- "MONITOR - - AN AUTOMATIC BUS LOCATION AND COMMUNICATION SYSTEM FOR CHICAGO", Wiksten, C.L.; Brown, C.P., Institute of Electrical and Electronics Engineers, IEEE Vehicular Technology Society Conference Proc., September 1980 Proceeding.

- "AUTOMATIC VEHICLE LOCATION. A SURVEY OF METHODS WITH SPECIAL INTEREST TO DEAD RECKONING", Vanter, C., Chalmers University of Technology, Sweden, Fack S-402, 20 Goeteborg 5, Sweden, 1978 Monograph.

- "THE FEASIBILITY OF APPLYING THE ACTIVE TVTIME SYSTEM TO AUTOMATIC VEHICLE LOCATION", Howe, D.A., National Bureau of Standards, Boulder, Colorado, 1974.

- "EXPERIMENTS IN BUS SERVICE CONTROL USING AN INTERACTIVE MODEL OF A TYPICAL BUS ROUTE", Jackson, R.L.; Stone, D., Newcastle-Upon-Tyne University, England, Department of Civil Engineering, Claremont Tower, NE1 7RU Newcastle-Upon-Tyne, Northumberland, England, 1975 Proceeding.

- "MEASUREMENT OF THE PERFORMANCE OF BUS SERVICES", Gault, H.E.; Doherty, P.G., Newcastle-Upon-Tyne University, England, Transport Operations Research Group, Newcastle NE1 7RU, Tyne and Wear, England, February 1979, Technical Report.

- "DETAILED DESIGN FOR A MIS FOR THE SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT", Ludwick, J.S., Jr., Mitre Corporation, 1820 Dolley Madison Boulevard, McLean, Virginia 22102 MTR-80W84; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, October 1980.

- "AUTOMATIC VEHICLE MONITORING SYSTEMS", Scales, W.C., Mitre Corporation, P.O. Box 208, Bedford, Massachusetts 01730 UMTA-VA-06-0027; Urban Mass Transportation Administration, 1612 K Street NW, Washington, D.C. 20006.
- "A STUDY OF THE COSTS AND BENEFITS ASSOCIATED WITH AVM", Reed, H.D.; Roos, M.; Wolfe, M.; DiGregorio, R., Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142. DOT-TSC-UMTA-77-5 MA-06-0041.
- "EXPERIMENTS ON FOUR DIFFERENT TECHNIQUES FOR AUTOMATICALLY LOCATING LAND VEHICLES: A SUMMARY OF RESULTS", Blood, B.E.; Kliem, B.W.A., Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142. DOT-TSC-UMTA-77-28 MA-06-0041, June 1977.
- "A COMPREHENSIVE FIELD TEST AND EVALUATION OF AN ELECTRONIC SIGNPOST AVM SYSTEM. VOLUME I. TEST RESULTS", Gruver, G.W., Hoffman Information Identification, Inc., Fort Worth, Texas; Transportation Systems Center, Cambridge, Massachusetts; Urban Mass Transportation Administration, Washington, D.C.
- "REPORT ON PHASE I TESTS OF FAIRCHILD AUTOMATIC VEHICLE MONITORING (AVM) SYSTEM", Pokorny, A.J.; Briefel, H., Fairchild Space and Electronic Company, 20301 Century Boulevard, Germantown, Maryland 20767. DOT-TSC-UMTA-77-35 FR-77-32, August 1977.
- "OVERVIEW OF AUTOMATIC VEHICLE MONITORING SYSTEMS", Mitre Corporation, Westgate Research Park, McLean, Virginia 22101, National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151, August 1973.
- "U.S. DEPARTMENT OF TRANSPORTATION'S AUTOMATIC VEHICLE MONITORING PROGRAM", Symes, D.J., Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, New York 10017.
- "AUTOMATIC VEHICLE MONITORING: A LIFE SAVER", Carter, D.A., Institute of Electrical and Electronics Engineering Service Center, 445 Hoes Lane, Piscataway, New Jersey 08854, 1980 Conference Paper.
- "AUTOMATIC VEHICLE MONITORING - - PAST, PRESENT AND FUTURE", Symes, D.J., Institute of Electrical and Electronics Engineers Inc., 445 Hoes Lane, Piscataway, New Jersey 08854; Society of Automotive Engineers, Incorporated, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.
- "CUTTING COSTS IN PUBLIC TRANSPORT. THIRTEENTH ANNUAL SYMPOSIUM, UNIVERSITY OF NEWCASTLE-UPON-TYNE, MARCH 30 - APRIL 1, 1982", Webster, F.V.; Hibbs, J.; Cochrane, R.L.D.; Heubeck, W.W.; Collins, B.M.; Trennery, S.G.; Harrison, M.; Tebb, R.G.P.; Jones, T.M.; Niemann, K., Newcastle-Upon-Tyne University, England, Claremont Road, Newcastle NE1 7RU, Tyne and Wear, England.
- "THE IMPACT OF ELECTRONICS ON THE PRODUCTIVITY OF PUBLIC TRANSIT SYSTEMS", Tyson, H. B.; Kowalski, T.W., Institute of Electrical and Electronics Engineers Inc., 445 Hoes Lane, Piscataway, New Jersey 08854; Society of Automotive Engineers, Incorporated, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096, 1980.

- "LOW-COST AVM (AUTOMATIC VEHICLE MONITORING) THROUGH MULTI-USER COST SHARING", Gruver, G.W., Institute of Electrical & Electronics Engineers Inc., 445 Hoes Lane, Piscataway, New Jersey 08854; Society of Automotive Engineers, Incorporated, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.
- "QUEENS VILLAGE: A QUANTUM JUMP IN BUS CONTROL/COMMUNICATIONS (NEW YORK CITY)", Dornfield, S., Institute of Electrical & Electronics Engineers Inc., 445 Hoes Lane, Piscataway, New Jersey 08854; Society of Automotive Engineers, Incorporated, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.
- "RESEARCH PROBLEMS IN TRANSPORTATION COMMUNICATIONS", Transportation Research Board, Transportation Research Circular N254, February 1983.
- "NICE: DEVELOPMENT OF THE VIDEOBUS AND CIBUS SYSTEMS", Artaud-Macari, J., International Union of Public Transport, UITP Revue, Vol. 32, No. 1, 1983, pp. 43-46.
- "A SOCIOECONOMIC IMPACT ASSESSMENT OF THE LOS ANGELES AUTOMATIC VEHICLE MONITORING (AVM) DEMONSTRATION", Daetz, D.; Bebendorf, M., SYSTAN, Incorporated, 343 Second Street, P.O. Box U, Los Altos, California 94022; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, October 1982 Final Report.
- "ERIC COMPUTERIZED RIDER INFORMATION SYSTEM DEMONSTRATION", Parody, T.E., Charles River Associates, Incorporated, 200 Clarendon Street, John Hancock Tower, Boston, Massachusetts 02116.
- "AUTOMATIC VEHICLE MONITORING: EFFECTIVE TECHNIQUE FOR TRANSIT SYSTEM MANAGEMENT AND CONTROL", Lyles, R.W.; Lanman, M.H., III, Transportation Research Board, Transportation Research Record N854, 1982, pp. 30-37.
- "FIELD TESTING OF A PULSE TRILATERATION AUTOMATIC VEHICLE MONITORING SYSTEM IN PHILADELPHIA", O'Connor, J.F.; Riccio, A.H., Hazeltine Corporation, Greenlawn, New York 11740; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590.
- "BENEFIT-COST ANALYSIS OF INTEGRATED PARATRANSIT SYSTEMS. VOLUME 5: THE IMPACTS OF TECHNOLOGICAL INNOVATION", Flusberg, M.; Menhard, H.R.; Walker, J.; Sobel, K., Multisystems, Incorporated, 1050 Massachusetts Avenue, Cambridge, Massachusetts 02138; Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142, September 1979, Final Report.
- "FEDERAL TRANSIT SUBSIDIES", Hilton, G.W., American Enterprise Institute for Public Policy, 1150 17th Street NW, Washington, D.C.
- "APPLICABILITY OF DIGITAL DATA COMMUNICATION FEATURES IN PUBLIC TRANSIT SYSTEMS: TECHNOLOGY ASSESSMENT", Datta, T.K.; Bowman, B.L.; Cynecki, M.J., Wayne State University Department of Civil Engineering, 5475 Woodward Avenue, Detroit, Michigan 48202; Highway Safety Research Institute, Huron Parkway and Baxter Road, Ann Arbor, Michigan 48105; Michigan State Highway Commission, Highways Building, P.O. Box 30050, Lansing, Michigan 48909.

- "APPLICABILITY OF DIGITAL DATA COMMUNICATION FEATURES IN PUBLIC TRANSIT SYSTEMS: EXECUTIVE SUMMARY", Datta, T.K.; Bowman, B.L.; Cynecki, M.J., Wayne State University Department of Civil Engineering, 5475 Woodward Avenue, Detroit, Michigan 48202; Highway Safety Research Institute, Huron Parkway and Baxter Road, Ann Arbor, Michigan 48105; Michigan State Highway Commission, Highways Building, P.O. Box 30050, Lansing, Michigan 48909.

- "EVALUATION OF PASSENGER COUNTER SYSTEMS FOR AN AVM EXPERIMENT. VOLUME II: TEST DATA", Balaram, A.; Gruver, G.; Thomas, H., Gould Information Identification, Incorporated, Fort Worth, Texas UMTA-MA-06-0041; Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142; Urban Mass Transportation Administration, 400 7th Street, SW Washington, D.C. 20590.

- "EVALUATION OF PASSENGER COUNTER SYSTEM FOR AN AVM EXPERIMENT. VOLUME I: TECHNICAL REPORT", Gould Information Identification, Incorporated, Fort Worth, Texas UMTA-MA-06-0041; Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590.

- "VIBRATION TESTS ON TRANSIT BUSES", Anderson, J.; Thomas, H., Gould Information Identification, Incorporated, 9011 John W. Carpenter Freeway, Dallas, Texas 75247 UMTA-MA-06-0041; Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, March 1979, Final Report.

- "PHILADELPHIA FIELD TESTS OF AN OVERLAPPING SIGNPOST AVM SYSTEM DURING THE MULTI-USER AVM PROGRAM", Gruver, G.W., Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, New York 10017, 1978, pp. 543-548.

- "NATIONAL AUTOMATIC POSITION INDICATOR SYSTEM (NAPIS)", Shibata, T.; Aiki, T., Matsushita Electrical Company, Limited, National Technical Report, Vol. 23, No. 5, October 1977, pp. 706-716.

- "LORAN AUTOMATIC VEHICLE MONITORING SYSTEM, PHASE I. VOLUME II. APPENDICES", Stapleton, R.; Chambers, F., Teledyne Systems Company, 19601 Nordhoff Street, Northridge, California 91324; Transportation Systems Center, 55 Broadway, Cambridge, Massachusetts 02142, August 1977, Final Report.

- "A COMPREHENSIVE FIELD TEST AND EVALUATION OF AN ELECTRONIC SIGNPOST AVM SYSTEM. VOLUME II. APPENDIX", Gruver, G.W., Hoffman Information Identification, Inc., Fort Worth, Texas; Transportation Systems Center, Cambridge, Massachusetts; Urban Mass Transportation Administration, Washington, D.C., August 1977.

- "EFFECT OF AUTOMATIC VEHICLE MONITORING ERROR ON TRANSIT SCHEDULE ADHERENCE MONITORING", Bruce, P.; Ludwick, J.S.: Swetnam, G.F., Jr., Transportation Research Board, Transportation Research Record N626, 1977; pp. 1-6.

- "THE SHAPE OF THINGS TO COME", Sansom, J.H.; Ennor, P.D., Newcastle-Upon-Tyne University, England, Claremont Tower, NE1 7RU, Newcastle-Upon-Tyne, Northumberland, England, 1974 Proceeding, pp. 77-89.

- "SCHEDULE CONTROL AND MANAGEMENT INFORMATION SYSTEM STUDY", International Business Machines Corporation, 18100 Frederick Pike, Gaithersburg, Maryland 20760, UMTA-IT-09-0040; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590; Chicago Transit Authority, Merchandise Mart Plaza, P.O. Box 3555, Chicago, Illinois 60654.

- "TELECOMMUNICATION AND TRANSPORTATION", Kodis, T.D., American Society for Information Science, American Society for Information Science, Bulletin, Vol. 2, No. 1, June 1975.

- "USE OF DATA PROCESSING IN TAXICAB CONTROL", Davidson, J., Highway Research Board Special Reports, N136, 1973; pp. 99-101.

APPENDIX C
LITERATURE TITLES FOR RESEARCH ON BUS REPLACEMENTS

Life-Cycle Costing Techniques

- "SMALL TRANSIT VEHICLES: HOW TO BUY, OPERATE, AND MAINTAIN THEM", Boghani, A.B.; Palmer, D.W.; Gott, P.G.; Nayak, P.R., Transportation Research Board, NCTRP Report 11, January 1985.

- "THE CHANGING FACE OF TRANSIT PROCUREMENT", Metro Vol. 81, No. 2, March 1985.

- "LIFE-CYCLE PROCUREMENT TECHNIQUES. TRANSIT PROPERTY BUS PROCUREMENTS", Bailey, B.; Graves, M.; Szten, E., Technology Applications, Incorporated, 5201 Leesburg Pike, Suite 1000, Falls Church, Virginia 22041; Urban Mass Transportation Administration, 400 7th Street SW, Washington D.C. 20590, December 1984, Final Report.

- "LIFE-CYCLE COSTING (LCC) INFORMATION AND EVALUATION STUDY", Graves, M., Technology Applications, Incorporated, 501 Leesburg Pike, Suite 1000, Falls Church, Virginia 22041.

- "LIFE-CYCLE COSTING FOR PROCUREMENT OF SMALL BUSES", Winslow, R.; Morrow, B.; Carbone, R.; Cross, E., Gill Associates, Inc., Washington, D.C.; Urban Mass Transportation Administration, Washington D.C.; Naval Underwater Systems Center, Newport, Rhode Island, August 1980.

- "USE OF LIFE-CYCLE COSTING FOR TRANSIT EQUIPMENT PROCUREMENT", Winslow, R.H., Gill Associates, Inc., under contract to U.S. Department of Navy, Naval Underwater Systems Center, November 1980.

- "UNITED STATES TRANSIT BUS DEMAND", Hieghtchew, R.E., Jr., Highway Users Federation for Safety and Mobility; Transportation Development Division, 1776 Massachusetts Avenue NW, Washington, D.C. 20036, Technical Memo No. 12, June 1975.

- "LIFE-CYCLE COST PROCUREMENT PROCEDURES FOR ADVANCED-DESIGN BUSES (DEVELOPMENT AND TEST APPLICATION)", Kain, B.R.; Marks, G.J.; Hall, F.M., Advance Management Systems, Incorporated, 1526 Connecticut Avenue NW, Washington, D.C. 20036; UMTA-VA-06-0045, Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, Final Report, May 30, 1980.

- "LIFE-CYCLE COST EVALUATION METHODS", American Public Transit Association, 1225 Connecticut Avenue NW, Washington, D.C. 20036, August 1982.

Techniques Other Than Life-Cycle Costing For Bus Replacement

- "THE ECONOMIC COSTS OF THE URBAN MASS TRANSPORTATION CAPITAL GRANT PROGRAM", Tye, W.B., Harvard University Library, Cambridge, Massachusetts 02138, 1969 Dissertation, not published.

- "FIVE-YEAR MODERNIZATION PLAN", Transportation Research Board Unpublished Report N28, May 1982, Final Report.

- "PENNSYLVANIA'S POOLED PURCHASE OF BUSES TO START A TREND", Cupper, D.; Carter, C. Carroll, Mass Transit, Vol. 9, No. 3, March 1982.

- "BUS REPLACEMENT POLICY", Hopper, P.G.; McCallum, W.M., New South Wales Ministry of Transport, Australia, 117 Macquarie Street, Sydney, New South Wales, Australia 0307-7683, 1979 Conference Paper.

- "EVALUATION OF ALTERNATIVE SERVICE IMPROVEMENTS (TWIN CITIES, MINNESOTA) - INTERIM REPORT #6", Simpson & Curtin, July 1969.

- "ECONOMICS OF TRANSIT BUS REPLACEMENT", Metropolitan, Vol. 67, No. 6, November 1971.

- "NATIONAL BUS REPLACEMENT PROGRAM", Metropolitan, Vol. 69, No. 5, September 1973.

Organization Specific Approaches To Bus Replacement

- "SYSTEM PRESERVATION NEEDS", Shafran, I., American Society of Civil Engineers; Journal of Transportation Engineering, Vol. 110, No. 3, May 1984.

- "VEHICLE PURCHASE POLICY - GREATER MANCHESTER TRANSPORT", Cochrane, R.L.D.; Tyson, W.J., Leeds University, England; Operational Research Unit, Center for Computer Studies, Leeds LS2 9JT, West Yorkshire, England, July 1980.

- "SEPTA CAPITAL IMPROVEMENT STRATEGY - BUS FLEET REPLACEMENT & BUS MAINTENANCE FACILITY RENOVATIONS", Southeastern Pennsylvania Transportation Authority, 2028 PSFS Building, 12 South 12th Street, Philadelphia, Pennsylvania 19107, September 1981.

- "TRANSIT EQUIPMENT: INTERIM REPORT 5-A APPENDIX", Simpson & Curtin, April 1971.

- "NEW JERSEY BUS FLEET MAINTENANCE SYSTEMS AND FACILITIES STUDY", New Jersey Department of Transportation, 1035 Parkway Avenue, Trenton, New Jersey 08625; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590; Tri-State Regional Planning Commission, One World Trade Center, 56 South, New York, New York 10048, Final report, April 1980.

Bus Replacement: General

- "THE BUS REBUILDING INDUSTRY GROWS UP", Baehr, G.T.; Carter, C. Carroll, Mass Transit, Vol. 9, No. 12, December 1982.

- "REPORT OF THE SUBCOMMITTEE ON OVERSIGHT AND REVIEW OF THE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION, U.S. HOUSE OF REPRESENTATIVES, ON THE URBAN MASS TRANSPORTATION ADMINISTRATION'S TECHNOLOGY DEVELOPMENT AND EQUIPMENT PROCUREMENT PROGRAMS (BUS AND RAIL ROLLING STOCK)" DO WE KNOW WHAT WE'RE TRYING TO DO?", United States House of Representatives Committee on Public Works and Transportation, 96th Congress, Washington, D.C. 20515, March 1980.

- "SURVEY AND ANALYSIS OF BUS REHABILITATION IN THE MASS TRANSPORTATION INDUSTRY", Balzer, B.B.; Savage, A.E.; Stark, R.C., ATE Management and Service Company, Incorporated, 1911 North Fort Myer Drive, Suite 306, Arlington; Virginia 22209; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590, November 1980, Final Report.
- "BUS REHABILITATION GUIDELINES", Bridgman, M.S.; Sveinsson, H.; Balzer, B.B.; and Fowler, B.W., Batelle Columbus Laboratories and ATE Management and Service Company, Inc., February 1983.
- "THE BIG BEND BUS", Hebert, R.; Demoro H.W.; Carter, C. Carroll, Mass Transit, Vol. 6, No. 12, December 1979.
- "ECONOMIC COMPARISON OF NEW BUSES VERSUS REHABILITATED BUSES", Bridgman, M.S.; Sveinsson, H.; and King, R.D., Batelle Columbus Laboratories, February 1983.
- "KEEP OLD BUSES ON THE ROAD", American City and County, Buttenheim Publishing Corporation, Berkshire Common, Pittsfield, Massachusetts 01201, November 1979.
- "COMPETITION RESHAPING FUTURE FOR U.S. RAIL/BUS INDUSTRY", Young, D., Chicago Tribune, Mass Transit, Carter, C. Carroll, 337 National Press Building, Washington, D.C. 20045, November 1982.
- "ESTABLISHING A CYCLE BUS REPLACEMENT", Cullinan, Thomas J., New York State Department of Transportation.
- "SMALL VEHICLE PROCUREMENT WORKSHOP", Public Technology, Incorporated, Technical Assistance Briefs.
- "UMTA SMALL TRANSIT VEHICLE PROCUREMENT", Workshop Proceedings, Indianapolis, Indiana, November 15-16, 1983, Dumke, James, Editor, U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge, Massachusetts 02142.
- "THE ECONOMICS OF BUS REHABILITATION", McLeod, Douglas, S., Transportation Research Record, No. 887, 1982.
- "FEASIBILITY STUDY FOR TRANSIT VEHICLE REHABILITATION CENTER", Florida Department of Transportation, Environmental Science & Engineering and ATE Services, Inc., 1980.

Other Related Abstracts

- "THE LOS ANGELES DOUBLE DECK BUS DEMONSTRATION PROJECT: AN EVALUATION", McCall, C.B.J.; Simkowitz, B.J., CACI, Incorporated, 12011 San Vicente Boulevard, Los Angeles, California 90049; Urban Mass Transportation Administration, 400 7th Street SW, Washington, D.C. 20590.
- "THE POTENTIAL FOR HIGH CAPACITY BUSES IN CANADA", Department of Transport, Canada; Queen Street, Place de Ville, Ottawa, Ontario, Canada; De Leuw Cather, Canada, Limited; 133 Wynford Drive, Don Mills, Ontario M3C 1K1, Canada, March 1979.

- "PRICING INVESTMENT DECISIONS AND SUBSIDIES IN TRANSPORT", Morgan, E.V., Manchester University, England, Department of Economics, Manchester, England, September 1974.
- "CONTROLLING RISING OPERATING DEFICIT THROUGH CAPITAL INVESTMENTS", Bell, Dean P. and Amedee, George P., New Orleans Regional Transit Authority.
- "MICROCOMPUTER TOOLS FOR TRANSIT CAPITAL BUDGETING", Dooley, T.D., Transportation Systems Center, Research and Special Programs Administration, Cambridge, Massachusetts 02142, April 1982.

APPENDIX D
DATA COLLECTION GUIDE FOR SURVEY OF
CURRENT BUS REPLACEMENT PRACTICES

AGENCY: ______________________________

For the first four questions please circle the number that corresponds to the level of consideration given to each item and comment on other significant factors influencing the investment or purchasing decision.

1 - Primary consideration
2 - Secondary consideration
3 - Minor consideration
4 - No consideration

1. What is the basis for revenue vehicle capital investment decisions (e.g., rehabilitation, replacement)? Please circle the number corresponding to the level of consideration.

	Replace	Rehabilitate
• Age in years	1 2 3 4	1 2 3 4
• Cumulative mileage	1 2 3 4	1 2 3 4
• Cumulative hours	1 2 3 4	1 2 3 4
• Local fund availability	1 2 3 4	1 2 3 4
• Federal fund availability	1 2 3 4	1 2 3 4
• Life cycle costs	1 2 3 4	1 2 3 4
• Major system failures	1 2 3 4	1 2 3 4
• Other	1 2 3 4	1 2 3 4

Please comment if other considerations affect your investment decisions.

2. What is the basis for scheduling replacement investment decisions for revenue vehicles? Please circle the number corresponding to the level of consideration.

	Consideration
• Planned per UMTA guidelines	1 2 3 4
• One-twelfth of fleet each year	1 2 3 4
• Bulk procurements for economies of scale	1 2 3 4
• Bulk procurements for economies of financing	1 2 3 4
• Local fund availability	1 2 3 4
• Federal fund availability	1 2 3 4
• Other	1 2 3 4

Please comment if other considerations affect the scheduling of your investments.

3. What is the basis for scheduling bus rehabilitation investment decisions for revenue vehicles? Please circle the number corresponding to the level of consideration.

	Consideration
• UMTA guidelines	1 2 3 4
• Major system failure	1 2 3 4
• Proportion of fleet each year	1 2 3 4
• Life cycle cost analysis	1 2 3 4
• Lack of federal funds for new buses	1 2 3 4
• Lack of local funds for new buses	1 2 3 4
• Other	1 2 3 4

Please comment if other considerations affect the scheduling of your investments.

4. What procurement guidelines are used for the purchase of revenue vehicles? Please circle the number corresponding to the level of consideration.

	Consideration
• Low bid	1 2 3 4
• Evaluation for price offsets	1 2 3 4
• Life cycle costing determination	1 2 3 4
• Competitive negotiations	1 2 3 4

5. What is the source of the local share for capital investments? Are these funds dedicated to transit?

____

____

6. The following have been identified as having potential for reducing bus operating costs. Are major capital investments planned in the next five years in the following areas? Please circle the number corresponding to the level of commitment to the investment.

	No Plans			Budget Approved
Fixed Facilities				
New Maintenance Facility	1	2	3	4
New Central Shops	1	2	3	4
Rehabilitation of Maintenance Facilities	1	2	3	4
Vehicle Enhancement Equipment				
Brake retarders	1	2	3	4
Air Starters	1	2	3	4
Others - Please Specify ____________	1	2	3	4
____________	1	2	3	4
Maintenance Diagnostic Equipment				
Brake test equipment	1	2	3	4
Dynamometers	1	2	3	4
Electrical system tester	1	2	3	4
Others - Please Specify ____________	1	2	3	4
____________	1	2	3	4

7. Does your agency provide for in-plant quality assurance inspection of vehicles, both new and/or rehabilitated? If so, who performs the inspections? Please circle the appropriate response.

Inspection required	Yes	No
Agency staff inspectors	Yes	No
Consultant staff inspectors	Yes	No
Combination of agency/consultant	Yes	No

8. Could you provide a copy of your latest Transportation Improvement Plan (TIP) which shows your bus replacement plans? If so, please return with this completed questionnaire.

9. Please complete the attached replacement/rehabilitation schedules if possible. We would appreciate copies of any staff or consultant studies that have addressed the replacement rehabilitation decisions for revenue vehicles and any worksheets or criteria that may be used to evaluate the life cycle cost bids for new revenue vehicles.

EXPLANATION OF TERMS

Year Built - Calendar Year in which bus was manufactured.

Manufacturer - Name of manufacturer which produced the bus fleet. The name abbreviatons are as follows:

AMG	AM General Corporation
BIA	Bus Industries of America, Inc.
BLUE	Blue Bird Body Company
CARP	Carpenter Body Works, Inc.
C&E	Coach and Equipment Manufacturing Corporation
CHAN	Chance Manufacturing Company
CHRY	Chrysler Corporation
COLL	Collins Industries, Inc.
CROW	Crown Coach Corporation
EAGL	Eagle International, Inc.
FLTP	Flxette Division, LTP, Inc.
FLX	Flxible
FLY	Flyer Industries, Ltd.
GILL	Gillig Corporaton
GMC	GMC Truck and Coach Division, General Motors Corporation
GMCC	Diesel Division, General Motors of Canada
GRUM	Grumman
MAN	M.A.N. Truck and Bus Corporation
M-B	Mercedes-Benz A.G.
MCI	Motor Coach Industries, Inc.
MINI	Minibus, Inc.
NCC	National Coach Corporation
NEOP	Neoplan USA Corporation
SCAN	Saab-Scania
TC	Twin Coach

THOM Thomas Built Buses, Inc.
TMC Transportation Manufacturing Corporation
TRAN Transcoach
VOLVO Volvo of America Corporation
WAYNE Wayne Corporation

Model - Manufacturer's model designation.

Length - Exterior overall length.

Owned and Leased - Number of buses owned and leased by the agency.

Active Service - Number of buses maintained for regular scheduled service including spares.

Major Rehabilitation - Major rebuilding of a bus to continue its useful service life. Usually includes complete power plant rebuild, transmission overhaul, body and interior refurbishment, complete repainting of bus and major refurbishment of bus undercarriage system including repair of frame.

BUS REPLACEMENT/REHABILITATION SCHEDULE

AGENCY: ____________________

	Year Built	Manufacturer	Model	Length	Number Owned and Leased	Number to be Replaced/Rehabilitated E.A.C.M.*/E.A.C.M. 1986	1987	1988	1989	1990	Remarks
1.						/	/	/	/	/	
2.						/	/	/	/	/	
3.						/	/	/	/	/	
4.						/	/	/	/	/	
5.						/	/	/	/	/	
6.						/	/	/	/	/	
7.						/	/	/	/	/	
8.						/	/	/	/	/	
9.						/	/	/	/	/	
10.						/	/	/	/	/	
11.						/	/	/	/	/	
12.						/	/	/	/	/	

Note: 1. E.A.C.M.* - Estimated average cumulative mileage (thousands) at time of replacement or rehabilitation.

2. If any of the active buses have had a prior year major rehabilitation, please note the number and year of rehabilitation in the Remarks column. What was the average cumulative mileage at the time of rehabilitation?

PRIOR YEAR BUS RETIREMENTS

AGENCY: ____________________

	Year Built	Manufac-turer	Model	Length	Number Replaced/Average Cumulative Mileage (thousands) 1980	1981	1982	1983	1984	1985	Remarks
1.					/	/	/	/	/	/	
2.					/	/	/	/	/	/	
3.					/	/	/	/	/	/	
4.					/	/	/	/	/	/	
5.					/	/	/	/	/	/	
6.					/	/	/	/	/	/	
7.					/	/	/	/	/	/	
8.					/	/	/	/	/	/	
9.					/	/	/	/	/	/	
10.					/	/	/	/	/	/	
11.					/	/	/	/	/	/	
12.					/	/	/	/	/	/	
13.					/	/	/	/	/	/	
14.					/	/	/	/	/	/	
15.					/	/	/	/	/	/	

APPENDIX E

DATA COLLECTION GUIDE FOR TRANSIT BUS OPERATING AND MAINTENANCE COSTS

Purpose:

This Data Collection Guide has been prepared to assist in the compilation of data needs in order to develop methods to guide transit managers in determining the optimal bus fleet replacement schedule for different operating environments. Optimal fleet replacement is intended to result in reduced operating costs to transit systems. The intent is to gather as much detailed information as possible on the life cycle costs of different types of buses and to identify the primary causal factors for operating and maintenance expenses.

Most of the data collection forms are specific; however, if the specific data requested is not available from your organization, please indicate this and provide as much data as possible. It is recognized that much of the data is available at agencies in different reports and in a variety of formats. If you can address the requested data items, but not in the format enclosed, please provide the data in your current format. Copies of existing reports can be provided to minimize the time needed to assemble the information, while still fulfilling the study requirements.

The Data Collection Guide has been organized in six sections:

- General Agency Information
- Maintenance Cost Data
- Bus Fleet Profile
- Bus Fleet Life Cycle Cost
- Bus Fleet Operating Information
- Operating and Maintenance Cost by Subfleet and Subsystem

General Agency Information

This section is intended to provide information that describes each agency's service characteristics. During on-site visits, study team members will attempt to gain an insight of the operations and local conditions to better understand the data provided in the other sections.

Maintenance Cost Data

This information will be used to normalize data from a number of different agencies in all areas of the country. It is required to make meaningful comparisons.

Bus Fleet Profile - Active Fleet

Most agencies maintain a bus fleet inventory that provides this basic information. A copy of that inventory should be provided if it contains the needed data. This form will be sent to each agency with the fleet inventory information contained in the 1985 edition of Transit Passenger Vehicle Fleet Inventory published by APTA.

Bus Fleet Life Cycle Cost - By Bus Subfleet

The research team would like to have as much historical data as possible in order to determine the effect of age and mileage on the cost of operating and maintaining transit buses.

Bus Fleet Operating Information

The information requested on this form is extremely important. In addition to the cost of routine running repair, servicing, cleaning and inspecting of buses, four major repair items have been identified as being significant in terms of costs that must be considered in the decision on when a bus should be replaced or rehabilitated. These are the rebuilding of the power plant, rebuild of the drive train (transmission), major refurbishment and repainting of a bus and the major rehabilitation of the bus frame and under carriage. The frequency of these events are expected to vary by type of bus and the usage. Local conditions (i.e., stop and go traffic, salt on streets in winter) will also be a factor.

Transit agencies with more than one operating garage are requested to provide fleet information for each facility since earlier studies reported that service characteristics may be considerably different at each.

Operating and Maintenance Cost by Subfleet and Subsystem/Cost Area

The information from this form will enable the study team to determine the subsystem cost variance for the different bus types and to identify potential areas of concern.

ALTERNATIVE BUS REPLACEMENT STRATEGIES

AGENCY: ______________________

GENERAL AGENCY INFORMATION

1. Annual mileage operated, total miles ____________
2. Revenue service mileage, miles per year ____________
3. Revenue service hours, hours per year ____________
4. Peak schedule requirement, maximum scheduled ____________
5. Active bus fleet, total available for service ____________
6. Spare buses, number ____________
7. Accident rate, accidents per million miles ____________
8. Road calls, miles between incidents ____________
9. Winter climate ____________
10. Summer climate ____________

MAINTENANCE COST DATA

1. Reporting period, year ending ____________
2. Direct labor, annual dollars ____________
3. Fringe benefit expense, annual dollars ____________
4. Maintenance administration expense, annual dollars ____________
5. Consumable supplies, annual dollars
   - Fuel ____________
   - Oil ____________
   - Coolant ____________
   - Other ____________
6. Nonconsumable supplies
   - Parts and Materials ____________
   - Tires ____________
   - Other ____________
7. Mechanic hourly labor rates
   - Level ____________
   - Level ____________
   - Level ____________
   - Level ____________

BUS FLEET PROFILE - ACTIVE FLEET

	Year Built	Manufac-turer	Model	Total Number	Length	Engine Type	Trans-mission	Remarks
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								

Note: If any of the buses listed above have undergone a major rehabilitation to extend the useful life, please include the number and year of rehabilitation in the Remarks column. Include the average cumulative mileage of buses at time of rehabilitation.

BUS SUBFLEET LIFE CYCLE COST

AGENCY: ____________________

	Year Built	Manufac- turer	Model	COST PER MILE 1985	1984	1983	1982	1981	1980	1979	1978	1977	1976
1.													
2.													
3.													
4.													
5.													
6.													
7.													
8.													
9.													
10.													
11.													
12.													

BUS FLEET - OPERATING INFORMATION

AGENCY: ____________________

Reporting Period: ____________________

Subfleet	1	2	3	4	5	6	7
Year							
Manufacturer							
Number of buses							
Annual Mileage							
Annual Service Hours							
Annual Operating and Maintenance Cost							
ENGINE ASSEMBLY							
Average Mileage At Rebuild							
Average Cost of Rebuild							
TRANSMISSION							
Average Mileage at Rebuild							
Average Cost of Rebuild							
MAJOR BODY REFURBISHMENT							
Average Mileage at Refurbishment							
Average Cost of Body Refurbishment							
MAJOR FRAME REHABILITATION							
Average Mileage at Rehabilitation							
Average Cost of Rehabilitation							

NOTE: For agencies with more than one operating garage, please provide this information for each facility.

OPERATING AND MAINTENANCE COST
BY SUBFLEET AND SUBSYSTEM/COST AREA

AGENCY: ______________________

For Year Ending: __________________

DOLLARS PER YEAR (Thousands)

Subfleet	1	2	3	4	5	6	7	8
Year								
Manufacturer								
Service/cleaning								
Inspections								
Body repairs								
Engine repairs								
Brake repairs								
Electrical repairs								
Air system								
AC/heating								
Drivetrain								
Suspension/steering								
Cooling								
Accessories								
Tires								
Fuel/lubricants								

NOTE: For agencies with more than one operating garage, please provide this information for each facility.

APPENDIX F
SURVEY RESULTS OF CURRENT BUS REPLACEMENT PRACTICES

NOTE: In the Tables for questions 1, 2 and 3 the results are presented as follows:

Row % Excluding No Consideration
Total Count
Column %

1. What is the basis for revenue vehicle capital investment decisions (e.g., rehabilitation, replacement)?

Replacement	CONSIDERATION: Primary #	Primary %	Secondary #	Secondary %	Minor #	Minor %	No #
Age in Years	65	74.7 22.5	15	17.2 9.6	7	8 6.7	1
Cumulative Mileage	39	49.4 13.5	29	36.7 18.6	11	13.9 10.6	9
Cumulative Hours	13	13.3 4.5	10	22.7 6.4	17	64 16.3	48
Local Fund Availability	46	56.8 15.9	24	29.6 15.4	11	13.6 10.6	7
Federal Fund Availability	57	69.5 19.7	19	23.2 12.2	6	7.3 5.8	6
Life Cycle Costs	16	23.5 5.5	25	36.8 16	27	39.7 26	20
Major System Failures	30	38.5 10.4	28	35.9 17.9	20	25.6 19.2	10
Other	10	47.6 3.5	6	28.6 3.8	5	23.8 4.8	67

Question #1 (Continued)

Rehabilitation	Primary #	Primary %	Secondary #	Secondary %	Minor #	Minor %	No #
Age in Years	33	58.9 19.6	16	28.6 15.4	7	12.5 4.2	32
Cumulative Mileage	27	49.1 16.1	18	32.7 17.3	10	18.2 6	33
Cumulative Hours	9	29 5.4	7	22.6 6.7	15	48.4 8.9	57
Local Fund Availability	25	45.5 14.9	17	30.9 16.3	13	23.6 7.7	33
Federal Fund Availability	27	50.9 16.1	18	34 17.3	8	15.1 4.8	34
Life Cycle Costs	11	24.4 6.5	15	33.3 14.4	19	42.2 11.3	43
Major System Failures	27	54 16.1	11	22 10.6	12	24 7.1	38
Other	9	69.2 5.4	2	15.4 1.9	2	15.4 1.2	74

(CONSIDERATION: Primary, Secondary, Minor, No)

2. What is the basis for scheduling replacement investment decisions for revenue vehicles?

	Primary #	Primary %	Secondary #	Secondary %	Minor #	Minor %	No #
UMTA Guidelines	54	68.4 25.7	15	19 14.7	10	12.7 11.1	8
One-twelfth of Fleet per Year	6	18.2 2.9	9	27.3 8.8	18	54.5 20	54
Economies of Scale	12	20 5.7	21	25 20.6	27	45 30	27
Economies of Financing	9	19.1 4.3	16	34 15.7	22	46.8 24.4	40
Local Fund Availability	50	61.7 23.8	23	28.4 22.5	8	9.9 8.9	5
Federal Fund Availability	64	78 30.5	15	18.3 14.7	3	3.7 3.3	5
Other	15	75 7.1	3	15 2.9	2	10 2.2	66

(CONSIDERATION: Primary, Secondary, Minor, No)

3. What is the basis for scheduling bus rehabilitation investment decisions for revenue vehicles?

	CONSIDERATION						
	Primary		Secondary		Minor		No
	#	%	#	%	#	%	#
UMTA Guidelines	29	47.5 19.3	17	27.9 17	15	24.6 18.5	26
Major System Failure	28	46.7 18.7	17	28.3 17	15	25 18.5	27
Proportion of Fleet Each Year	8	25 5.3	15	46.9 15	9	28.1 11.1	55
Life Cycle Cost Analysis	14	27.5 9.3	17	33.3 17	20	39.2 24.7	36
Lack of Local Funds	26	45.6 17.3	20	35.1 20	11	19.3 13.6	30
Lack of Federal Funds	33	60 22	14	25.5 14	8	14.5 9.9	32
Other	12	80 8	0	0 0	3	20 3.7	72

4. What procurement guidelines are used for the purchase of revenue vehicles?

	CONSIDERATION			
	Primary	Secondary	Minor	No
Low Bid	58	24	2	4
Evaluation for Price Offsets	10	29	12	37
Life Cycle Costing	28	21	12	27
Competitive Negotiations	21	8	13	45

5. The following have been identified as having potential for reducing bus operating costs. Are major capital investments planned in the next five years in the following areas?

	No Plans			Budget Approved
Fixed Facilities				
New Maintenance Facility	58	3	12	15
New Central Shops	74	4	1	9
Rehabilitation of Maintenance Facility	52	7	8	21
Vehicle Enhancement Equipment				
Brake Retarders	57	11	7	13
Air Starters	46	12	14	16
Other Equipment	66	2	2	18
Maintenance Diagnostic Equipment				
Brake Test Equipment	59	9	9	11
Dynamometers	50	10	6	22
Electrical System Tester	51	13	10	14

6. Does your agency provide for in-plant quality assurance inspection of vehicles, both new and/or rehabilitated? If so, who performs the inspection?

	Number
Inspection Required	83
Agency Staff Inspectors	57
Consultant Staff Inspectors	27
Combination of Agency/Consultant	30

TABLE F-I
ACTUAL RETIREMENT PRACTICES

	FLEET < 250 #	FLEET < 250 %	FLEET ≥ 250 and < 1000 #	FLEET ≥ 250 and < 1000 %	FLEET ≥ 1000 #	FLEET ≥ 1000 %	TOTAL #	TOTAL %
Age at Retirement								
8 Years or Less	18	2.9	64	2	357	26	439	8.6
9 Years	0	0	9	.3	5	.4	14	3
10 Years	0	0	7	.2	107	7.8	114	2.2
11 Years	13	2.1	2	.1	351	25.6	366	7.2
12 Years	19	3.1	61	1.9	83	6	163	3.2
13 Years	79	12.9	192	6.1	57	4.2	328	6.4
14 Years	164	26.8	276	8.8	1	.1	441	8.6
15 Years	29	4.7	520	16.6	74	5.4	623	12.2
16 Years	100	16.3	193	6.2	48	3.5	341	6.7
17 Years	40	6.5	158	5	118	8.6	316	6.2
18 Years	24	3.9	193	6.2	71	5.2	288	5.6
19 Years	10	1.6	804	25.7	53	3.9	867	16.9
20 Years	16	2.6	268	8.6	18	1.3	302	5.9
Greater than 20 Years	100	16.3	384	12.3	30	2.2	514	10
TOTAL	612		3131		1373		5116	

TABLE F-I (Continued)

	FLEET < 250 #	FLEET < 250 %	FLEET ≥ 250 and < 1000 #	FLEET ≥ 250 and < 1000 %	FLEET ≥ 1000 #	FLEET ≥ 1000 %	TOTAL #	TOTAL %
Age at Retirement								
250,000 or Less	0	0	16	.9	0	0	16	.6
250 to 300,000	6	1.2	89	5.1	267	45	362	12.6
300 to 350,000	9	1.8	280	15.9	176	29.7	465	16.2
350 to 400,000	4	.8	76	4.3	79	13.3	159	5.6
400 to 450,000	197	38.6	91	5.2	24	4	312	10.9
450 to 500,000	89	17.4	243	13.8	0	0	332	11.6
500 to 550,000	67	13.1	255	14.5	0	0	322	11.2
550 to 600,000	66	12.9	123	7	0	0	189	6.6
600 to 650,000	20	3.9	136	7.7	47	7.9	203	7.1
650 to 700,000	5	1	89	5.1	0	0	94	3.3
700 to 750,000	17	3.3	64	3.6	0	0	81	2.8
More Than 750,000	31	6.1	297	16.9	0	0	328	11.5
TOTAL	511		1759		593			2363

TABLE F-2
ACTUAL REHABILITATION PRACTICES

	FLEET<250		FLEET ≥ 250 and < 1000		FLEET ≥ 1000		TOTAL	
	#	%	#	%	#	%	#	%
Age at Retirement								
8 Years or Less	20	16.4	0	0	0	0	20	10.9
9 Years	0	0	0	0	0	0	0	0
10 Years	0	0	0	0	0	0	0	0
11 Years	2	1.6	0	0	0	0	2	1.1
12 Years	20	6.4	0	0	0	0	20	10.9
13 Years	30	24.6	36	58.1	0	0	66	35.9
14 Years	37	30.3	7	11.3	0	0	44	23.9
15 Years	0	0	0	0	0	0	0	0
16 Years	10	8.2	4	6.5	0	0	14	7.6
17 Years	1	.8	11	17.7	0	0	12	6.5
18 Years	1	.8	3	4.8	0	0	4	2.2
19 Years	0	0	0	0	0	0	0	7.6
20 Years	0	0	1	1.6	0	0	1	.5
More than 20 Years	1	.8	0	0	0	0	1	1.5
TOTAL	122		62		0		186	

TABLE F-2 (Continued)

	FLEET<250		FLEET ≥ 250 and < 1000		FLEET ≥ 1000		TOTAL	
	#	%	#	%	#	%	#	%
Age at Rehabilitation								
250,000 or Less	20	62.5	0	0	0	0	20	21.3
250 to 300,000	0	0	0		0	0	0	1.1
300 to 350,000	1	3.1	0	0	0	0	1	1.1
350 to 400,000	10	31.2	0	0	0	0	10	10.6
400 to 450,000	1	3.1	0	0	0	0	1	1.1
450 to 500,000	0	0	43	69.4	0	0	43	45.7
500 to 550,000	0	0	0	0	0	0	0	0
550 to 600,000	0	0	5	8.1	0	0	5	5.3
600 to 650,000	0	0	0	0	0	0	0	0
650 to 700,000	0	0	0	0	0	0	0	0
700 to 750,000	0	0	3	4.8	0	0	3	3.2
More Than 750,000	0	0	11	17.7	0	0	11	11.7
TOTAL	32		62		0		94	

TABLE F-3
PLANNED RETIREMENT PRACTICES

	FLEET < 250 #	FLEET < 250 %	FLEET ≥ 250 and < 1000 #	FLEET ≥ 250 and < 1000 %	FLEET ≥ 1000 #	FLEET ≥ 1000 %	TOTAL #	TOTAL %
Age at Retirement								
8 Years or Less	21	1.2	37	1.1	0	0	58	.7
9 Years	0	0	4	.1	0	0	4	.1
10 Years	16	.9	88	2.6	0	0	104	1.3
11 Years	57	3.2	443	13.3	0	0	500	6.3
12 Years	246	13.7	582	17.5	415	15	1243	15.8
13 Years	290	16.1	241	7.3	417	15.1	948	12
14 Years	229	12.8	158	4.8	371	13.4	758	9.6
15 Years	92	5.1	112	3.4	422	15.2	626	7.9
16 Years	94	5.2	186	5.6	255	9.2	535	6.8
17 Years	82	4.6	128	3.9	259	9.4	469	5.9
18 Years	24	1.3	103	3.1	49	1.8	176	2.2
19 Years	9	.5	113	3.4	57	2.1	179	2.3
20 Years	537	29.9	187	5.6	126	4.5	850	10.8
Greater Than 20 Years	99	5.5	942	28.3	399	14.4	1440	18.3
TOTAL	1796		3324		2770		7890	

TABLE F-3 (Continued)

	FLEET < 250 #	FLEET < 250 %	FLEET ≥ 250 and < 1000 #	FLEET ≥ 250 and < 1000 %	FLEET ≥ 1000 #	FLEET ≥ 1000 %	TOTAL #	TOTAL %
Age at Retirement								
250,000 OR LESS	16	1.9	0	0	0	0	16	.3
250 to 300,000	28	3.3	46	2.4	200	10	274	5.8
300 to 350,000	56	6.6	331	17.5	200	10	587	12.4
350 to 400,000	175	20.5	160	8.5	675	33.9	1010	21.3
400 to 450,000	152	17.8	22	1.2	518	26	692	14.6
450 to 500,000	209	24.5	232	12.3	96	4.8	537	11.3
500 to 550,000	77	9	276	14.6	0	0	353	7.4
550 to 600,000	91	10.7	333	17.6	15	.8	439	9.3
600 to 650,000	40	4.7	169	8.9	105	5.3	314	6.6
650 to 700,000	5	.6	157	8.3	87	4.4	249	5.3
700 to 750,000	0	0	0	0	3	.2	3	.1
More Than 750,000	5	.6	167	8.8	94	4.7	266	5.6
TOTAL	854		1893		1993		4740	

TABLE F-4
PLANNED REHABILITATION PRACTICES

	FLEET < 250		FLEET ≥ 250 and < 1000		FLEET ≥ 1000		TOTAL	
	#	%	#	%	#	%	#	%
Age at Rehabilitation								
8 Years or Less	0	0	78	21.8	0	21.8	78	10.1
9 Years	0	0	0	0	0	0	0	0
10 Years	0	0	2	.6	0	.6	2	.3
11 Years	0	0	88	24.6	0	24.6	88	11.4
12 Years	3	7.1	50	14	0	0	53	6.9
13 Years	3	7.1	50	14	0	0	53	6.9
14 Years	3	7.1	0	0	0	0	3	.4
15 Years	0	0	0	0	93	25.1	93	12.1
16 Years	0	0	0	0	0	0	0	0
17 Years	4	9.5	0	0	0	0	4	.5
18 Years	6	14.3	9	2.5	0	2.5	15	1.9
19 Years	0	0	28	7.8	57	15.4	85	11
20 Years	0	0	52	14.6	157	42.3	209	27.1
More Than 20 Years	23	54.8	0	0	64	17.3	87	11.3
TOTAL	42		357		371		770	

TABLE F-4 (Continued)

	FLEET < 250		FLEET ≥ 250 and < 1000		FLEET ≥ 1000		TOTAL	
	#	%	#	%	#	%	#	%
Age at Rehabilitation								
250,000 or Less	0	0	0	0	183	49.3	183	32
250 to 300,000	3	27.3	0	0	0	0	3	1.1
300 to 350,000	3	27.3	3	1.6	0	1.6	5	1.1
350 to 400,000	5	45.5	0	0	93	25.1	98	17.2
400 to 450,000	0	0	0	0	0	0	0	0
450 to 500,000	0	0	50	26.5	95	25.6	145	25.4
500 to 550,000	0	0	56	29.6	0	0	56	9.8
550 to 600,000	0	0	0	0	0	0	0	0
600 to 650,000	0	0	0	0	0	0	0	0
650 to 700,000	0	0	80	42.3	0	0	80	14
700 to 750,000	0	0	0	0	0	0	0	0
More Than 750,000	0	0	0	0	0	0	0	0
TOTAL	11		189		371		571	