NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 17

Impacts of Standardized vs. Nonstandardized Bus Fleets

TRANSPORTATION RESEARCH BOARD
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Impacts of Standardized vs. Nonstandardized Bus Fleets

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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 in 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 Research 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

This report will be of interest to transit agency staffs concerned with the procurement and maintenance of transit buses. The report provides agencies with two uncomplicated methods to estimate and evaluate the costs and benefits of standardized versus nonstandardized bus fleets in their procurement programs. One of the two methods can be used to answer the question, "What is the likely cost impact of fleet standardization versus nonstandardization of full size coaches?" The second method addresses the question of, "How can the cost impacts determined in the first method be used in competitive procurement decisions?" The methods can be applied to each fleet bid in a given procurement and the results can be compared to ascertain which bid would result in the lowest total cost fleet. Prior to use in a new procurement, transit agencies can apply the methods to their last procurement as a test and calibration for future use. In summary the methods presented were found to be simple, repeatable and appear accurate.

Most transit systems operate buses produced by several manufacturers of differing vehicle configurations with varying requirements for maintenance procedures and personnel training. Maintenance managers have long contended that mixed fleets are more costly to maintain and operate and they have attempted to achieve some standardization by specifying common components regardless of the vehicle supplier. Recognizing that the transit industry is in a period of fiscal austerity, a study to explore the cost impacts of standardized versus nonstandardized bus fleets was deemed essential to the development of prudent bus procurement practices.

Under NCTRP Project 35-1, "Impacts of Standardized vs. Nonstandardized Bus Fleets," research was undertaken by Fleet Maintenance Consultants, Inc., with Booz Allen & Hamilton, Inc., as subcontractor, with the objective of developing a methodology for estimating the costs and benefits of standardized vs. nonstandardized fleets of 35 and 40 foot transit coaches.

To accomplish the objectives, the research agency first surveyed recent bus procurements by a large cross section of transit agencies. Respondents to the survey operate over half of the transit buses in the United States. The survey focused on identifying cost of training, capital, parts inventory, and operations resulting from the introduction of new buses into their fleets. In addition the researchers surveyed 22 transit agencies that could provide detailed operating and maintenance costs at the subsystem level for each bus subfleet. These agencies were a representative cross section of transit agencies in terms of fleet size, composition, and usage.

Based on the results of the surveys, a series of statistical applications was made to compare the range of operating and maintenance costs for each subsystem for buses produced by different manufacturers of varying vehicle configurations, and to account for variances. The analysis formed the basis for an uncomplicated method for use by transit managers to estimate and evaluate the costs and benefits of standardized versus nonstandardized bus fleets in their procurement programs. The methodology requires only minimal data input and is easy to apply. Only a pocket calculator is required, but the method is appropriate for a computer spreadsheet application. The report contains the necessary forms and presents two worked-out examples. Use of the methodology should help transit agencies achieve more cost-effective transit bus procurements.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCTRP Project 35-1 by Fleet Maintenance Consultants, Inc., and Booz Allen & Hamilton, Inc. Richard W. Drake, Senior Associate of Fleet Maintenance Consultants, Inc., and Douglas W. Carter, Senior Associate of Booz Allen & Hamilton, Inc., served as co-principal investigators with Mr. Drake having overall management responsibility for the successful completion of the Project. Mr. John Schiavone 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. Emry Robinson, an Associate with Booz Allen & Hamilton, provided valuable assistance in the data analysis.

Without the cooperation of the many transit agencies who provided survey information, 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. The agencies that contributed detailed operating and maintenance cost data for their bus fleets are acknowledged: Sun Tran of Albuquerque, Ann Arbor Transportation Authority, Central Ohio Transit Authority (Columbus), Citibus (Lubbock), Chicago Transit Authority, Culver City Municipal Transit (California), Fort Worth Transportation Agency, Iowa City Transit, Metro Regional Transit Authority (Akron), Metropolitan Transit Authority of Harris County (Houston), North San Diego County Transit District, Norwalk Transit (California), Regional Public Transportation Authority (Phoenix), Pierce Transit (Tacoma), Public Transit Authority (El Paso), Regional Transportation District (Denver), Riverside Transit Authority, Suburban Mobility Authority (Detroit), Torrance Municipal Bus Lines (California), Tri-County Metropolitan Transportation District (Portland), Washington Metropolitan Area Transit Authority, and Wichita Transit Authority.

IMPACTS OF STANDARDIZED VS. NONSTANDARDIZED BUS FLEETS

SUMMARY

Federal and local procurement policies have historically sought to maximize competition among manufacturers during the procurement of transit buses. The result of these policies has been highly mixed bus fleets at almost all transit agencies across the country. Transit managers and staff have long contended that the introduction of different vehicle types into their fleets results in increased operating costs. The need for greater austerity at federal, state, and local government levels also impacts transit operators. They are becoming more concerned about the long term impact of operating costs of new buses.

A comprehensive search of the literature found few reports on studies of the costs of fleet mix, thus underscoring the need for this study. The issue is addressed tangentially through discussions of estimated impacts of life cycle costing. The literature does contain statements that bus operators are using procurement specification procedures to improve standardization of their rolling stock. This study addresses the issue of fleet mix for 35-ft and 40-ft buses only. Smaller buses and articulated buses are excluded.

A broad cross section of U.S. transit agencies was surveyed to solicit recent industry experience with the introduction of new 35-ft and 40-ft buses into existing fleets in recent years. Respondents to the survey operate approximately 53 percent of these transit bus types in the country. The broad-based survey collected information on the initial capital, labor, and parts costs that were incurred with the introduction of new buses and examined the extent of similarity of the new vehicles compared to the existing fleet. The survey found that only 37 percent of the bus procurements necessitated additional capital investment for new tools, diagnostic equipment or facility modifications. Of these only 10 percent had a major impact. Seventy-eight percent reported a decrease or only a slight increase in inventory costs. Twenty-two percent reported significant increases in inventory costs as a result of new buses. Training requirements varied significantly based on the similarity with existing buses. Overall training requirements were 100 percent higher for vehicles not represented in the current fleet.

A second, detailed cost survey was conducted with those operators who indicated they could provide detailed information to assist with quantifying operating and capital cost impacts of diversity with respect to fleet composition. The degree of fleet standardization was assessed in terms of bus model/make, as well as several vehicle subsystems and maintenance activities. A total of 22 transit agencies provided the detailed data. These agencies are a representative cross section of transit agencies across the country. The detailed cost survey data was analyzed using several statistical analytical techniques to ascertain fleet mix implications. The analysis normalized costs across operators to facilitate meaningful analysis, evaluated the range of cost experience for each similar vehicle type grouping, and assessed fleet mix as a causal factor contributing to cost differences.

This research effort found that operating and capital costs generally do increase with increases in fleet diversification; however, the cost increase is relatively small. The

ongoing vehicle maintenance costs increase about 3 percent, with each distinct 35-ft and 40-ft vehicle type added to the fleet. Parts inventory also increases with the introduction of a nonstandard vehicle, but this is generally a temporary condition over the first year of operation. When capital costs are incurred, they are usually relatively minor and relate to specialized tools and diagnostic equipment.

A practical methodology was developed for use by transit managers for evaluating the impact of the introduction of a standard or nonstandard vehicle into the existing bus fleet. The methodology also provides for the inclusion of initial capital costs and labor (training) costs in the decision process. The method has broad applicability and is sensitive to local conditions and fleet composition. This analysis can be particularly valuable when bid prices encompass a narrow range.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

Public procurement policies have historically sought to maximize competition among prospective vendors, particularly for the purchase of transit buses. As a result, many transit agencies operate bus fleets of vehicles produced by several different manufacturers of differing vehicle configurations. Each may require some degree of separate parts inventory, different maintenance procedures, and special training for maintenance and operations personnel. The competitive demands for scarce operating and capital dollars require a sound investment strategy. Given the number of domestic and foreign manufacturers of transit buses, the cost trade-off between standardized bus fleets or subfleets must be considered.

For the purposes of this study, the term standardization is intended to mean a bus subfleet that has identical or similar major components regardless of manufacturer. The real test of whether or not a new bus is standard or nonstandard is if its introduction requires additional costs for parts inventory, maintenance, or operation. The scope of the research is limited to 35-ft and 40-ft transit coaches. A subfleet is a grouping of standardized vehicles within a transit agency's total fleet.

Federal procurement guidelines have recognized the need to address both operating and capital cost implications of a vehicle procurement through life cycle or whole life cost comparison techniques. Transit systems have responded to the increasingly complex rolling stock marketplace by becoming more sophisticated in their procurement evaluation processes. In a recent research project conducted for the National Cooperative Transit Research and Development Program, approximately one-half of the respondents to an industry-wide survey (more than 20 percent of the nation's transit systems responded, representing more than 50 percent of the active transit vehicles in service today) indicated that operating costs offsets or life cycle costing are used in evaluating vehicle procurements. However, transit systems are often stymied by a lack of reliable operating cost data for several vehicles in a specific procurement. Many transit agencies have had to rely on operating cost data provided by the vendor on new vehicle types or new vehicle subsystems, which may or may not reflect the operator's actual experience down the road.

This research effort (NCTRP Project 35-1) provides reasonable and accurate data concerning actual operating and capital cost differences experienced in a variety of operating cost environments as the result of different degrees of nonstandardization. The objective of the project is to develop a methodology for evaluating the cost implications of fleet mix in vehicle procurement decisions.

RESEARCH APPROACH

The approach to the study was to use public transit bus maintenance and operations cost databases that were developed in prior research projects for the National Cooperative Transit Research and Development Program and to supplement them with information gathered from broad-based surveys of recent transit bus procurement experience. The approach was to develop a tool for use by transit managers that is realistic in that it takes into consideration those factors that can significantly influence operating costs and provide a method for evaluating the factors based on the agency's specific fleet characteristics. It is pragmatic in that it recognizes the limited resources of most public bus operators. Because estimating life cycle costs can be a complex process involving many considerations, a sophisticated computerized planning model is not in the best interests of the transit community at large. The study approach is to develop a straightforward, nonautomated analysis model that is applicable to all bus agencies, regardless of size, but can be automated, if so desired.

The approach is accurate in that the methodology includes actual data and adjustment factors to reflect individual fleet characteristics. The data were investigated and tested to ensure reliability and integrity. The study was carried out in six tasks, as follows:

1. Conduct a search of the current literature on bus procurement methodology and fleet mix cost implications.
2. Identify cost factors associated with operating standardized versus nonstandardized bus fleets.
3. Develop a preliminary methodology to guide data collection efforts.
4. Conduct a broad-based survey of transit agencies to access fleet mix implications and cost factors. This survey also provided the opportunity to identify those transit agencies that have the capability and willingness to provide detailed operating and cost data on their bus fleets.
5. Compile detailed operating and maintenance cost data at the subsystem level for different bus types from a representative cross section of transit agencies.
6. Refine and verify the methodology for estimating and evaluating costs of standardization and nonstandardization through the analysis of detailed operating cost data.

Survey of Past Research on Costs of Fleet Mix

A survey of industry literature was conducted to access the costs of fleet mix, or nonstandardization of transit buses. 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 database 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 was supplemented by data gleaned from several other industry data sources, including: the Urban Mass Transportation Administration (UMTA) Transit Research Information Center (TRIC), UMTA Abstracts, and The National Transportation Information Service.

Identification of Cost Factors

The research team called upon its experience gained in two earlier NCTRP projects in identifying the cost factors anticipated to be impacted by fleet mix. These sources are: (1) the database developed in 1984 by Drake and Carter (*1*) for the NCTRP maintenance manpower planning study, (2) the database developed in 1986 by Drake, Carter and Gaudette (*2*) for the NCTRP alternative bus replacement strategies project, and (3) survey data collected from operators willing to participate in this project.

The 1984 database contains subfleet, vehicle subsystem, maintenance work tasks (more than 2,000 individual activities), cost structure, and operating characteristics data from 15 transit agencies with a total of 80 subfleets. Subfleet size ranges from 15 vehicles to 450 standard buses at a single operator. The data are quite reliable with explanatory variables accounting for more than 90 percent of the differences in labor requirements to perform similar subsystem tasks at dissimilar agencies.

The 1986 database provides detailed fleet composition and cost data by vehicle subsystem and fleet type, and operating characteristics data for 11 transit operators, with 160 individual operating subfleets. The proportion of costs by subsystem and differences between subfleet costs were statistically explained by different operating characteristics, but the actual dollar differences were not adequately explained, even considering relative cost of living, maintenance employee wage and benefit rates, and accounting structure differences. The data have demonstrated a strong correlation of cost relationships among operators (e.g., cost of overhaul of one transmission type compared to another). Additional survey data were collected from operators willing to participate in this project to further define cost factors.

The cost factors that were preliminarily identified to be impacted by the purchase of new buses were grouped into four categories:

1. *Personnel training:* Costs associated with training personnel to operate and maintain new buses may range from essentially none for buses exactly alike those in the existing fleet to major efforts to familiarize operators with a completely new bus. The maintenance work force may require training in diagnostics, general repairs, or major overhaul of totally different engines and transmissions.
2. *Capital costs:* One time costs may be required to modify facilities to accommodate new buses (e.g., vehicle lifts to accommodate a heavier vehicle) or to purchase new diagnostic equipment.
3. *Parts inventory:* The introduction of a new major component into the fleet may require additional spare parts. A completely new make of bus may require an increase in the inventory of body parts (e.g., body panels, doors, glass).
4. *Operating and maintenance costs:* A new bus type may be more or less economical in the use of fuel. The time needed to clean the interior of buses may differ because of the type of seats (e.g., cantilevered vs. pedestal); however, it is expected that the most significant differences may be in the maintenance-related cost areas. Prior studies indicated that the vehicle systems or components that may contribute the most to cost variances between vehicle types are engine, transmissions, electrical, brakes, suspension/air, heating/ventilation/air conditioning, and wheelchair lifts.

Because these costs can vary considerably, depending on the degree of standardization of new vehicles versus existing vehicles, these cost factors were investigated in terms of compatibility and similarity:

1. *Exactly alike existing vehicle:* Same model from the same manufacturer with similar accessory equipment.
2. *Mostly alike:* Buses from same manufacturer with minor changes from prior models.
3. *Partially compatible:* Buses from different manufacturer but with similar components (e.g., engine, drivetrain, AC systems).
4. *Not similar:* A completely new vehicle.

Design a Preliminary Methodology

The purpose of this task was to present a preliminary methodology (i.e., straw man) for estimating and evaluating the costs and benefits of procuring standardized versus nonstandardized fleets. The preliminary methodology was a conceptual approach to comparative cost analysis, which would be modified, calibrated, and tested using data collected in later tasks. The methodology was designed to address two distinct questions: (1) What is the likely cost impact of fleet standardization versus nonstandardization for full sized coaches? (2) How can this information be used in competitive procurement decisions?

The first question was addressed using a straightforward method of cost comparison which presents the one-time and ongoing stream of cost differences as a single cost figure (excluding vehicle price). This represents a dollar value which can be added to, or subtracted from, the vehicle price. It is a conceptually simple approach, focusing on only the most significant cost differences.

Initial investments include the staff training costs related to the introduction of a new fleet type, and the initial cost of new supporting equipment and facility modifications. Staff training generally includes three employee groups: operators, service attendants, and mechanics; however, the number of employees to be trained on a new vehicle type may not reflect the size of the procurement (e.g., all drivers may require training even though the new type may comprise only a small percentage of the total fleet).

Capital costs may include new lifts required because of increased vehicle weight, new diagnostic equipment (e.g., electronic analysis equipment), vehicle cleaning equipment, and special tools. Capital investment may also be required in the form of bus washer modifications (e.g., due to roof-mounted AC units), pit and bay configuration modifications (e.g., due to midship versus rear exhaust) and other capital costs. These are likely to occur in relatively few fleet mix situations, since very significant vehicle changes are required to trigger these investments.

The net change in operating cost over the life of a vehicle fleet is another important consideration where vehicle changes are significant. These costs can be estimated as the product of the current operating and maintenance cost per vehicle-mile, a cost adjustment factor reflecting the relative increase (or decrease) over the current bus fleet, the annual vehicle-miles traveled and the useful life of the vehicle in question.

This method is straightforward and addresses bus fleet standardization in terms of the specific agency's current and possible future fleet mix. Thus, the approach effectively addresses situations where an agency is moving toward fewer bus types or a wider mix of vehicle types. The cost estimated by this technique reflects the net change in total cost (e.g., capital and operating) attributable to fleet mix issues over the useful life of a vehicle fleet.

The second question of how to use this information in evaluating vehicle bids can also use the methodology, described above, to adjust bid prices to reflect lifetime operating and capital cost changes resulting from fleet mix issues. This second approach addresses annual equivalent costs, which many operators currently use in procurement efforts. It begins by determining the one time investment related to the procurement (e.g., purchase price, other capital investments required, initial training costs) and amortizing this amount over the useful life of the vehicle fleet. This amount is added to the manual operating cost of the fleet to determine total annual equivalent cost.

The appropriate cost adjustment factors by fleet type and subsystem configuration will be determined through data collection and analysis tasks in the study. The product of the agency's current cost per mile and cumulative adjustment factor is then multiplied by the annual miles that the new fleet is expected to operate. This value is then added to the annualized initial investment cost to estimate total fleet cost. This analysis is applied to each fleet bid in the procurement and the results are compared to ascertain the lowest total cost fleet.

The two methods represent conceptual frameworks for approaching the study problem statement in a logical and supportable manner. The methods will be calibrated and tested during the course of data analysis and evaluation. This reflects the two methods of cost comparison routinely conducted in the transit industry: total useful life cost and average annual equivalent cost.

Survey Industry for Fleet Mix Implications and Cost Factors

To discern the current practice in assessing fleet mix implications, the cost factors deemed significant by transit industry professionals, and the needs of the industry to effectively address the issue, a survey of a broad cross section of the U.S. transit agencies was designed to ensure that it was representative of the range of agency sizes and geographic locations. The survey addressed vehicle procurements within the past 4 years for 35-ft and 40-ft transit buses.

Agency Selection

The 1988 Transit Passenger Vehicle Fleet Inventory published by the American Public Transit Association was used as the primary source document to prepare a mailing list for the survey. Other transit agencies not included in the inventory report, but known by the study team, were included. Agencies were selected that operate 35-ft and 40-ft transit coaches and had added new vehicles to their fleets in recent years. A total of 174 agencies were selected that included all fleet sizes and geographical regions of the country.

Survey Instrument to Solicit Industry Experience

The survey instrument was designed to be short and concise in order to require minimal effort by each agency and obtain responses from as many as possible. The survey instrument is provided in Appendix B.

For each procurement of 35- and 40-ft heavy-duty transit coaches placed in service in the prior 4 years, each agency was asked to provide the manufacturer and model of the vehicle, the year of purchase, and the number of vehicles. For each vehicle fleet procured, the agency was asked to denote the degree of difference from the existing fleet types (e.g., exactly like existing buses, minor differences, significant differences, or completely new) for each of the following factors: (1) manufacturer, (2) model, (3) engine, (4) transmission, (5) electrical, (6) brakes, (7) suspension, (8) seats, (9) heating and air conditioning, (10) destination signs, and (11) wheelchair lifts. Comments on other possible differences were solicited (e.g., air starter or brake retarders) as well as on the performance of post-procurement analysis of any fleets.

Training costs associated with each new procurement were sought. Actual or estimated number of manhours per employee required for training was requested in each of the following areas: (1) operator training/familiarization; (2) cleaner/servicer training; and (3) mechanic training (system familiarization, general repair and diagnostics, component rebuild training).

The impact of new buses on capital expenditures was addressed by asking each agency to rate each procurement (e.g., no cost impact, minor impact, major impact) in each of the following areas: (1) bus washing equipment, (2) interior cleaning equipment, (3) vehicle lifts, (4) engine exhaust systems, (5) diagnostic equipment, (6) special tools/equipment, (7) additional parts storage space, and (8) fluid distribution systems (e.g., new ATF dispenser).

Each agency was asked if actual or estimated costs could be provided in the areas that were significantly impacted. Agencies that gave a positive reply were contacted for the detailed information.

An evaluation of the change in spare parts inventory was requested in terms of a decrease, no increase, minor increase, or significant increase for each of the following subsystems: (1) engine, (2) transmission, (3) electrical, (4) brakes, (5) suspension, (6) heating and air conditioning, (7) destination signs, (8) wheelchair lift, and (9) body.

The survey instrument also asked if the agency could provide actual or estimated parts costs of each, or any, of the subsystems, as well as the dollar value and number of line items in the inventory before and after receipt of the new buses. These questions identified the agencies for later follow-up contacts to obtain the information.

Changes in costs associated with operating and maintaining new buses compared with other buses in the existing fleet were queried. The comparison for each procurement was requested in the same terms as the inventory cost changes but with the following breakdown:

1. Fuel consumption.
2. Cleaning/servicing time.
3. Preventive maintenance time.
4. Repair time (engine, transmission, electrical, brakes, cooling, suspension/air, heating/air conditioning, destination signs, and wheelchair lifts).
5. Repair parts (engine, transmission, electrical, brakes, cooling, suspension/air, heating/air conditioning, body, tires, destination signs, and wheelchair lifts).

Each agency was also asked if its vehicle maintenance information system could report the cost in each of these areas for each vehicle type in the fleet. This question was extremely important to the ultimate success of the study. It helped to identify the agencies that could provide the detailed data needed to refine and calibrate the methodology.

Data Collection and Tabulation

The survey instrument was mailed to each of the 174 transit agencies. In cover letter with the survey package, a target date was given and each agency's cooperation was requested. Immediately following the target date, telephone calls were placed to each agency failing to respond in order to solicit their cooperation. Information received from the agencies was sorted and tabulated. The size of the sample results in a representative summary of perceived and actual fleet diversification impacts.

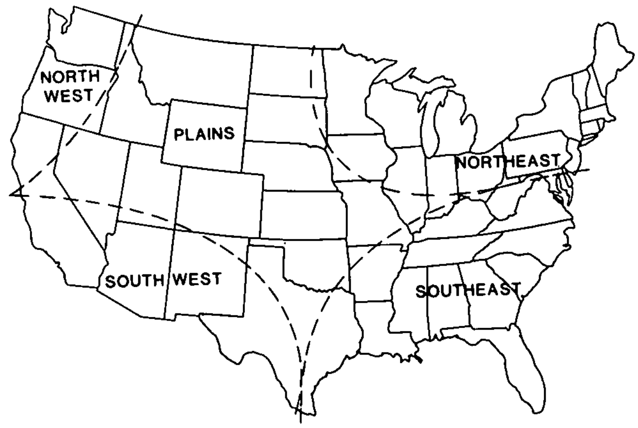

Figure 1. Geographical regions defined for study purposes.

Compilation of Detailed Operating and Maintenance Data

The goal of this study is to develop a universal tool to evaluate the impacts of standardized versus nonstandardized bus fleets. 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 data availability, fleet size, and geographic location.

1. *Data availability:* A most important criterion in selecting an agency was the availability of the required data on operating and maintenance costs by type of vehicle and by vehicle subsystem. It was not expected that each agency could provide all of the data on every item. Willingness of transit agencies to devote the necessary staff resources to compile the data was an important consideration. During the initial broad-based survey, each agency was asked if its maintenance information system could produce the disaggregate data and if they were willing to provide it.

2. *Fleet size:* The purpose of the study was to produce a methodology that could be used by all transit operators. Bus agencies were grouped into the following five size categories: less than 49 buses, 50 to 99 buses, 100 to 249 buses, 250 to 500 buses, and greater than 500 buses.

3. *Geographic location:* To ensure a representative cross section of bus agencies, the country was divided into five major regions. Figure 1 shows the different areas. The 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.

The 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.

The 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.

The 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.

The Plains 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.

Participating Agencies

From the initial survey, responses were received from 31 agencies that indicated the capability and willingness to provide the detailed data. During the process it was found that nine of the agencies could not compile the information from their management information systems. A total of 22 operators provided all or most of the requested data element.

Participants in the Northeast region were Ann Arbor Transit Authority, Central Ohio Transit Authority, Chicago Transit Authority, Metro Regional Transit Authority (Akron), and Suburban Mobility Authority (Detroit).

Three participants, from the Southeast region, were Fort Worth Transportation Authority, Metropolitan Transit Authority of Harris County (Houston), and Washington Metropolitan Area Transit Authority.

Transit operators that participated in the Southwest region included Sun Tran of Albuquerque, Citibus (Lubbock), Culver City Municipal Bus Lines, North San Diego County Transit, Norwalk Transit, Regional Public Transportation Authority (Phoenix), Public Transit Authority of El Paso, Riverside Transit Authority, and Torrance Municipal Bus Lines. Northwest region participating agencies were Pierce Transit (Tacoma) and Tri-County Metropolitan Transportation Agency (Portland). Plains region operators were Iowa City Transit, Regional Transportation District (Denver), and Wichita Transit Authority.

Collection of Detailed Data

A well-structured data collection guide was considered mandatory for this study involving quantitative data analysis to ensure consistency in data collection and compatibility with the other databases from prior studies. The guide was structured to capture the quantitative information, agency fleet descriptions, and general agency information.

1. *Bus fleet profile:* This information described the agency's current bus fleet and its overall use. The importance of bus model numbers and proper description of major components was emphasized. For each subfleet the following information was requested: manufacturer, model, year built, number in the fleet, average annual mileage, engine model, transmission model, retarder model, air conditioning type, brake system (i.e., S-cam, wedge), suspension system type, farebox model, destination sign type, and wheelchair lift model.

2. *General information:* Two items of general information were requested. The average mechanic rate that was used to determine the reported maintenance costs was required in order to normalize the costs for the different operators during the analysis. Secondly, the cost for cleaning and servicing the bus fleet was to be reported as a lump sum for the prior year. The earlier studies had found that these costs were maintained as a separate line item in maintenance cost reports and could not be related to specific subfleet.

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. For the purposes of this analysis, 14 vehicle subsystems, or cost areas, were used. Labor costs and parts costs were requested separately.

a. Inspection—the performance of preventive maintenance and safety checks on vehicles by 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 may be 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 18,000 mile, 36,000 mile, and 72,000 mile inspections, each becoming more comprehensive as the interval increases.
b. 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.
c. 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, and oil filters.
d. Braking system—vehicle system used to stop the vehicle. Brake components include drums, shoes, lining, seals, spiders, cams, and slack adjustors.
e. Electrical system—vehicle system that includes generator/alternator, regulator, battery, starter, lighting system, control switches, solenoids, horn, wiring, and cabling.
f. Air system—vehicle system that includes compressor, air pipe and tubing, control cylinders, shift cylinders, 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.
g. Air conditioning/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; the vehicle system that provides heat and ventilation to the interior;

and the heating units, blowers and blower motors, water modulation valve, and heater related cables and wiring.

h. Drivetrain—vehicle system consisting of transmission, driveline, and differential.
i. Suspension system—vehicle system that includes bellows, leveling valves, shock absorbers, radius bars, lateral bars, and stabilizer. Most operators include steering wheel, steering column, steering box, drag links, tie rods, tie rod ends, and power steering pump.
j. Cooling system—vehicle system that includes radiator thermostat and housing, water pump, fan, fan torus, vernatherm, surge tank, oil cooler, hoses, and temperature gauges.
k. Farebox—component used to collect fares from passengers. Types range from simple direct deposit into vault devices to sophisticated electronic devices for registering not only fares but types of passengers.
l. Destination signs—component used to provide information to passengers related to route and destination of specific buses.
m. Wheelchair lifts—components, which normally mount in either the front or rear stepwell, which are deployed to lift a wheelchair and occupant to the bus floor level.
n. Tires—in addition to the tires (normally provided through a lease arrangement with a manufacturer), some operators include repair costs associated with hubs, wheel bearings, and seals.
o. Fuel usage—the fuel consumption of each subfleet was requested in average miles per gallon. No labor costs were requested for this cost element because they are normally included in the cleaning and servicing cost category.

4. *Subfleet rebuild costs:* Four subsystems or major components were identified as those most likely to show cost variance between subfleets. These were power plant, transmission brakes, and differential. The cost of rebuild and the average mileage at rebuild were requested. Many agencies do not include major component rebuild (e.g., engine) in their reported operating and maintenance costs. Because these activities are infrequent and costly, they are usually included in capital cost reporting. Information of other rebuild costs considered significant by each operator was requested.

5. *Capital costs:* The initial broad-based survey asked agencies to indicate if new procurements impacted capital costs. Those that responded that they could provide the detailed costs were asked to provide the data in this survey.

6. *Parts inventory cost increases:* The change in parts inventory costs was requested for engine, transmission, electrical, brakes, suspension system, heating/air conditioning, destination signs, and wheelchair lifts.

Data Collection Procedure

Funds available for this study did not allow for visits to each of the participating agencies; therefore, the study team maintained close contact with each by telephone. The data collection guide was mailed to each agency and an immediate follow-up was made to respond to questions. Because there is no commonly accepted definition of each subsystem within the transit industry, the study team provided guidance, whenever possible, in an attempt to obtain comparable data. Additionally, it was very important to understand each agency's maintenance philosophy and cost reporting practices.

Analytical Approach

The analytical approach used in this report was designed to identify the costs associated with bus fleet diversity (i.e., nonstandardization). It is a widely recognized fact that different bus makes, models, and manufacturers have different capital and operating costs. It is further recognized that the myriad of operating environments, vehicle utilization practices, labor agreements, and maintenance policies and practices further exacerbate differences in vehicle capital and operating costs. It is not the intent of this analysis to assess and evaluate the causes and effects of these significant cost issues. This research effort focuses solely on the potential contribution of fleet mix to overall capital and operating costs.

Stated simply, this project assesses the impact of fleet diversification on initial investment costs and ongoing maintenance costs. The analysis strives to address two questions: Is the cost of introducing new buses into a fleet impacted by the similarity or differences of the new vehicles compared to existing 35- and 40-ft vehicles? Are ongoing maintenance costs of any vehicle impacted by the similarity or differences to other vehicles in the fleet?

The analysis does not address why bus type A has a different capital or operating cost from bus type B. It does attempt to determine if the cost of bus type A changes if bus type B and C are introduced into the same fleet. This concept is extremely important when reviewing the cost analysis. The research team did not strive to determine whether or not one bus type has a different cost from another, or why this may occur. The sole cost relationship analyzed and validated is cost impacts resulting from fleet diversification.

In support of this approach, several statistical and analytical techniques were applied to ascertain fleet mix cost implications. The analysis proceeded in three phases: (1) normalize costs across operators to facilitate meaningful analysis, (2) evaluate the range of cost experience for each similar vehicle-type grouping, and (3) assess fleet mix as a causal factor contributing to cost differences and quantify its impact.

Normalize Costs Across Operators

Significant efforts were made to ensure that costs are as comparable as possible to ensure valid statistical and cost analysis. As noted previously, the study team worked closely with each participant to define cost categories and report total labor and materials cost related to vehicle maintenance and operations. The research team did not attempt to justify or validate cost differences between vehicle types, but focused solely on diversification impacts on cost.

The labor costs include direct wages. They exclude fringe benefits and direct and indirect overhead. It should be noted that some maintenance information systems used average mechanic wage rates to determine costs, and others used employee specific wages. These differences do not impact data quality for the purposes of this study, as they should average out over an entire year. Several maintenance information systems recorded loaded labor rates (i.e., direct wages plus direct variable benefits) and used these in tracking costs. The reported costs were reduced by the specific variable benefit rate applicable to those operators. Labor costs were normalized using average mechanic wage rates for the purposes of this analysis. All operator mechanic wage rates were averaged, then each operator's labor cost was adjusted by multiplying the labor cost by the unweighted mean wage rate divided by that operator's wage rate. These normalized labor costs are more suited for analysis of fleet mix impacts because labor rate differences are eradicated.

Materials cost includes all vehicle parts and materials and excludes any overhead or parts handling costs. The study team analyzed several approaches to adjusting these values for regional differences (e.g., local area consumer price indexes versus national indexes, labor wage rates, operator size), but could not find a reasonable relationship between any of these factors and parts cost per mile. The materials cost used in the analysis is the specific cost reported by each operator without adjustment.

Analysis of Cost Range

Using the normalized labor cost and actual materials cost, the study team assessed the range of costs for similar vehicle fleets. First, all 22 operator subfleets were grouped into similar vehicle-type categories (e.g., identical or mostly identical vehicles). Cost analysis was conducted by subfleet, vehicle subsystem, and overall cost per mile. Similar analysis was conducted on the training, parts inventory, and capital cost impacts reported in both the first and second survey instruments. The primary tools for examining the range of reported costs are mean and standard deviation (using $n-1$ weighting to account for the limited sample size) for all variables.

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 mean value provided a norm or expected value for each parameter in the analysis. The formula (Eq. 1) for calculating the mean value is:

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

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 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 actual values for parameters influencing operating and maintenance cost characteristics. This is not to say that all data points will fall within ± 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 follow-up with specific agencies to understand high variability.

Causal Factor Analysis of Fleet Mix

The final phase of analysis involved an assessment of the impact of fleet diversification or standardization on new fleet introduction costs and ongoing maintenance costs. Fleet standardization was identified as an independent variable, and costs (e.g., capital, training, subsystem, subfleet, parts) as a dependent variable; and several statistical techniques were applied to ascertain the degree to which costs are impacted by fleet mix and the extent of that impact. All statistical analyses were conducted on a microcomputer using a powerful statistical package. Primary statistical analyses used include regression analysis, chi-square, factor analysis, and coefficient of correlation squared (r-squared).

Regression analysis summarized data and quantified the nature and strength of the relationship among cost variables and fleet mix. A simple regression analysis was used to fit a model relating one dependent variable (e.g., engine operating cost by a subfleet) to one independent variable (e.g., number of distinct fleet types) 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 on a single dependent variable. The regression analysis visually showed the fit between variables, and conducted an analysis of variance.

The procedure for the chi-square goodness-of-fit statistic calculates a chi-square that compares observed to expected frequencies for a given relationship. 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 the number of vehicle types in a fleet on operating and maintenance costs of each subfleet and subsystem.

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 wage rate, fleet mix, subfleet type, and mileage among the diverse operators.

The final statistical technique used in the analysis is r-squared, or the coefficient of correlation squared. This technique mathematically describes the changes in a dependent variable (e.g., subfleet and subsystem cost) correlating with a change in the independent variable (i.e., extent of fleet standardization). This analysis determines the extent to which differences in the dependent variable (i.e., costs) are a function of variability in the independent variable (i.e., fleet standardization). The r-squared is expressed in percentage terms as used in this project. A value of 100 percent indicates that all of the variability in the dependent variable (i.e., cost) is mathematically attributable to the change in the independent variable (i.e., fleet mix). This would imply a perfect correlation. A value of zero percent would indicate that none of the difference in the dependent variable (i.e., cost) is mathematically attributable to the change in the independent variable (i.e., fleet standardization). The mathematical formula is:

$$r^2 = \left(\frac{\frac{1}{N} \sum (x - \bar{x})(y - \bar{y})}{\sigma_x \sigma_y} \right)^2 \tag{3}$$

where $\bar{x}$ = arithmetic mean of x variable; $\bar{y}$ = arithmetic mean of $\bar{y}$ variable; σ = standard deviation; and N = number of observations

Refine the Methodology for Estimating Costs of Standardized and Nonstandardized Bus Fleets

The final step in the analytical approach was to refine the methodology for evaluating the cost impacts of standardized and nonstandardized bus fleets. The methodology developed must have broad applicability, yet be sensitive to local fleet composition. The objective of the methodology is to provide decision-makers with clear, usable information as to the capital and operating cost trade-offs if a new vehicle is introduced into the bus fleet. While the final structure of the methodology was dependent on the results of the statistical evaluation, the methodology was designed to incorporate three features:

1. *Capital and operating costs:* The methodology includes an analysis of initial capital investment costs, initial operating cost investments (e.g., training), and ongoing operating costs. One-time costs are amortized over the life of a vehicle and ongoing costs normalized to facilitate comparison of these different cost categories.
2. *Actual default relationships:* The study produced data representing the actual experience of a variety of transit operators. This information and actual numeric relationships are included as default parameters allowing an agency to utilize the numbers developed in this study, or internal numbers if available in applying the methodology. The operating cost per mile by subfleet is not a default value, but the cost increase per additional diverse fleet is. The costs reported by subfleet are those reported by agencies for the purposes of this study and cannot be assumed to reflect general experience without further verification.
3. *Wide applicability:* The methodology must be uncomplicated both in terms of ease of understanding and requirements to apply the methodology.

ORGANIZATION OF THE REPORT

This report documents the technical approach, findings, conclusions, and applications of the project results. Chapter One 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 research activity on cost of bus fleet mix and life cycle costing. The results of the survey of transit agencies on recent experience on bus procurements are presented. The transit bus operating and maintenance cost findings are reviewed and fleet standardization is investigated as a causal factor of cost differences. Chapter Three presents the methodology for estimating the cost of operating a mixed bus fleet, 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.

The Reference section presents a listing of the references that have been cited within the text of the report. Appendix A presents the titles of the literature found for costs of fleet mix and life cycle costing. Appendix B contains the survey instrument that was used to survey recent bus procurement experience of transit agencies. Appendix C provides the collection forms used to glean disaggregrate operating and maintenance cost information from the participating agencies. Appendix D provides a demonstration of the methodology for a hypothetical agency. A blank worksheet is also provided as an aid to analysis efforts.

CHAPTER TWO

FINDINGS

BASIS OF FINDINGS

This chapter presents the study findings in three major areas: (1) summary of the results of a literature search on the costs of fleet mix and life cycle costing, (2) recent experience of the transit industry with fleet mix implications of bus procurements, and (3) detailed operating and maintenance cost characteristics relative to impacts of standardized and nonstandardized bus fleets. The findings were developed based on a balanced investigation of prior research and documentation, a broad-based survey of 66 transit systems with recent bus procurements, and a detailed analysis of operating costs of 22 transit agencies.

PAST AND CURRENT RESEARCH

As anticipated, few reports have studied the costs of fleet mix, thus underscoring the importance of this study. Articles do tangentially address the fleet mix issue through discussing estimated impacts on life cycle costing; however, no quantifiable estimates of its effects were found in this literature search. The literature does contain statements that bus operators are using specification procedures to improve standardization of their rolling stock.

Additionally, it is mentioned that cost pressures on transit bus operators are forcing them to demand better reliability and lower maintenance costs. In response, it is believed that there may be a demonstrable need for more guidance on cost reduction implications in the design phases (e.g., brake retarders, air compressors).

Life cycle costing, on the other hand, has been studied extensively. Much of the industry literature focuses on developing and refining guidelines for using life cycle costing procedures. It also underscores the fact that transit systems generally lack the information, resources, and technical expertise to evaluate life cycle costs effectively.

Lack of consistent life cycle costing guidelines is thought to be most acute in the small bus arena. These buses (ranging from van conversions to 30-ft heavy duty small buses) are highly diverse in both capital costs and technology. The uses of these vehicles are also highly diverse, spanning the range from large transit fleets in major urban areas to small rural operators, and including fixed-route, demand-responsive, shuttle, and other services. Few guidelines exist with which transit providers, seeking to purchase or replace small buses, can make objective decisions concerning the best type to be procured. The only published documentation found in the literature search was a study by Boghani, et al. (*3*).

A popular theme in life cycle costing relates to the fact that bus manufacturers often use varying methodologies in developing life cycle costs, resulting in different cost estimates for the same vehicle. Some of these cost variances are due to inconsistent treatment of operating and maintenance costs, physical and performance characteristics, and the costs of nonstandardization.

Literature does exist which examines the use of life cycle costing techniques to evaluate bus rehabilitation versus replacement, addressing the fleet mix question in terms of new versus old buses, and providing some guidelines and potential pitfalls on the subject.

BROAD-BASED SURVEY FOR FLEET MIX IMPLICATIONS AND COST FACTORS

Survey Distribution and Response

A broad cross section of U.S. transit agencies was surveyed to determine recent industry experience with the introduction of new buses into existing fleets. The transit agencies surveyed included a wide range of operator fleet sizes and geographical locations to ensure that survey results are representative of the industry.

The broad-based survey was sent to 174 transit agencies across the nation which had vehicle procurement activity in the previous 5 years. Sixty-six responses were received from the survey covering 150 different fleet procurements which varied from one vehicle to over 400. The responding transit agencies operate a total of 24,030 35-ft and 40-ft transit buses which were the focus of this study. This represents over 53 percent of these bus types operating in the United States in 1989 as reported by the American Public Transit Association (*4*). Responses were received from operators in 34 states.

The high rate of response is attributed to the simplicity of the survey instrument and the conciseness of the questions. Figure 2 shows the fleet size distribution for the survey respondents as contrasted with all transit operators which have 35- and 40-ft transit buses in their fleets. Small transit agencies make up a smaller percentage of the respondents than their portion of the nationwide transit population. This is explained by the fact that the survey request was for information about bus procurements in the past 4 years. The smaller operators purchase buses less frequently than the larger agencies which, in general, attempt to replace a portion of their fleet every year or two. Table 1 presents the distribution of vehicle and subsystem similarity to existing fleets of the respondents. The numbers in the table are the percentage of the reporting agencies in each category.

The broad-based survey focused on collecting available information on those initial capital, labor, and parts costs that were incurred as a result of introduction of each new subfleet into the respective transit operator's revenue fleet. This survey examined the extent of similarity of new vehicles to the existing bus fleet, and the cost of introducing these new vehicles in service. The survey instrument also gleaned operator expectations regarding ongoing cost categories that might be impacted by nonstandard vehicles and each operator's ability and willingness to provide detailed, ongoing cost information that was the subject of the second study survey. Survey responses were verified and clarified through telephone contact to ensure reliable results. These results are discussed in the following sections by cost category.

Capital Costs Necessitated by the Procurement of New Vehicles

The introduction of new vehicles into a bus fleet could necessitate the expenditure of additional capital to maintain and service the new fleet. The vehicles could require new tools, additional diagnostic equipment, more parts storage space, different vehicle lifts (e.g., weight maximums), new interior cleaning equipment, different fluid distribution systems (e.g., new automatic transmission fluid, engine oil), or bus washing facility modifications (e.g., height restrictions). The initial survey queried operators as to whether or not the purchase of new buses caused the expenditure of capital dollars (for items other than the vehicles), and if so, on what items.

Overall, it was found that a minority of bus procurements necessitated additional capital investment. Only 37 percent of the respondents identified capital cost impacts related to the introduction of new buses into the fleet. Of these impacts, 27 percent were minor and 10 percent were major.

Special tools and diagnostic equipment were the most commonly cited capital costs, with 72 and 58 percent of the procurements, respectively, requiring some additional expenditure of capital. Conversely, bus washing and fluid distribution equipment costs were the least impacted, with approximately 8 percent of the new vehicle procurements requiring minor additional capital expenditure, and only 1 percent incurring a significant cost.

Figure 3 summarizes the initial survey results on capital cost impacts. A second survey on detailed costs, discussed later in this chapter, focuses on quantifying the magnitude of these capital cost impacts.

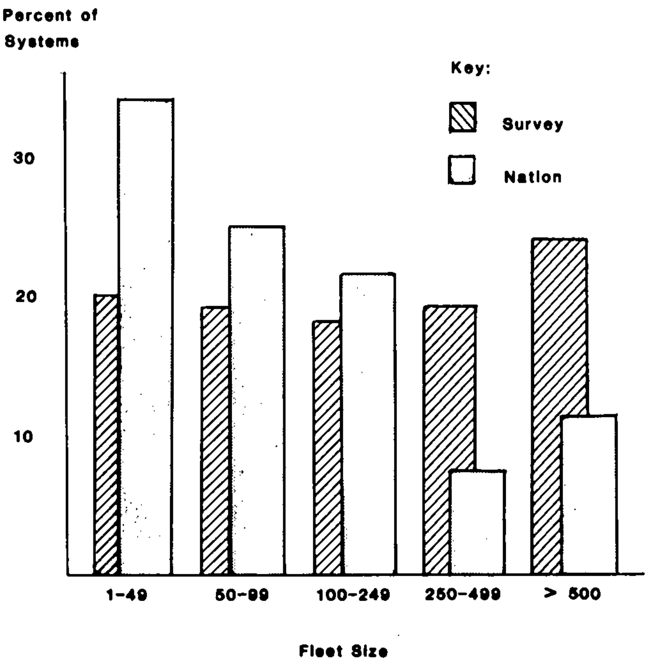

Figure 2. Fleet size distribution of survey respondents.

Table 1. Similarity of new vehicles purchased to those already present in survey respondent fleets.

	Percent Exactly Like Existing Buses	Percent With Minor Differences	Percent With Significant Differences	Percent Completely New
Manufacturer	39.7	7.4	10.3	42.6
Model	22.3	19.4	17.3	41.0
Engine	25.4	31.2	19.6	23.9
Transmission	28.3	16.7	21.7	33.3
Electrical	22.0	34.8	24.1	19.1
Brake	28.9	40.8	19.0	11.3
Suspension	29.4	36.4	22.4	11.9
Seats	64.0	19.9	6.6	9.6
HVAC	30.0	28.5	18.5	23.1
Destination Signs	38.3	25.5	15.6	20.6
Wheelchair Lifts	39.2	15.5	6.2	39.2

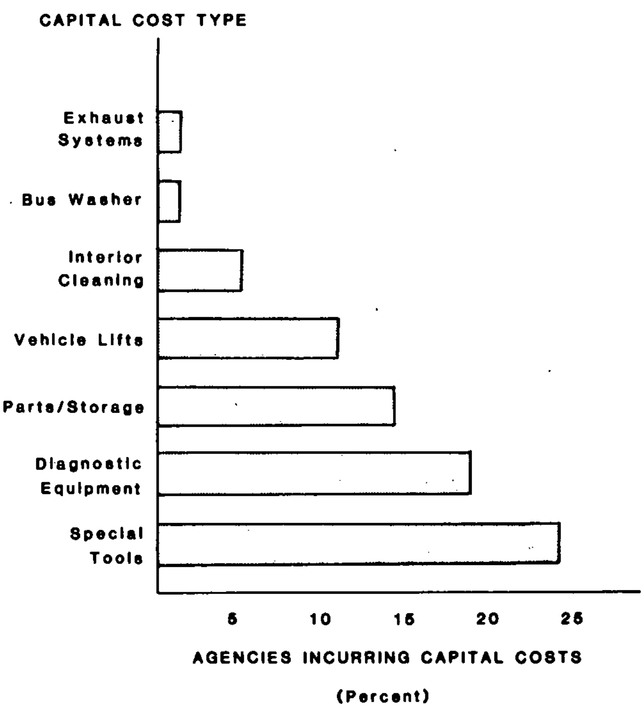

Figure 3. Percent of surveyed agencies incurring nonvehicular capital costs as a result of introducing new vehicle types into the existing fleet.

Parts Inventory Increases Related to New Vehicle Procurements

The introduction of a new vehicle type into a fleet may require a real increase in the parts and materials inventory maintained by an agency. Some minimum amount of parts is required to maintain vehicles in a timely manner, and if parts are not interchangeable among vehicles, the size and cost of the inventory may increase. This does not necessarily mean that parts consumption will increase, but the number of materials on hand may be greater than that necessary if all buses used the same parts. The broad-based survey elicited information on parts inventory impacts of new bus procurements. For each vehicle subsystem, respondents were asked whether their inventory of spare parts—as measured by average parts inventory cost per vehicle—decreased, increased, or remained stable. Summary results showed that less than 4 percent of the operators reported inventory cost decreases, 74 percent of the respondents indicated no, or only slight, increases in inventory costs; and 22 percent of the respondents reported significant increases in inventory costs.

Table 2 shows that the cost impacts were relatively evenly distributed across vehicle subsystems. Significant transmission parts cost increases were reported most frequently (over 26 percent), and brake increases were reported least frequently (at 17 percent). The detailed cost survey, discussed later in this chapter, quantifies the extent of cost impact.

Fully 70 percent of the broad-based survey respondents indicated that they routinely order a spare parts package as an element of the vehicle procurement. This allows operators to capitalize (at a lower local funding match) some initial operating costs of a new vehicle. As a point of information, the study team polled vehicle manufacturers to determine the recommended spare parts package in vehicle procurements, the results of which are given in Table 3. These results were compared with the recent procurements of six agencies and were found to be very consistent with actual experience.

Table 2. Percent of surveyed agencies reporting costs associated with expanded parts inventory resulting from the introduction of a new vehicle into the fleet.

	Percent With Decrease	Percent With No Increase	Percent With Minor Increase	Percent With Significant Increase
Engine	4.23	27.46	47.89	20.42
Transmission	4.23	26.06	43.66	26.06
Electrical	3.52	40.14	35.21	21.13
Brake	6.34	39.44	37.32	16.90
Suspension	2.82	43.66	31.69	21.83
HVAC	2.88	35.25	38.85	23.02
Destination Signs	2.84	45.39	34.75	17.02
Wheelchair Lifts	2.91	34.95	34.95	27.18
Body	3.60	35.97	34.53	25.90

Table 3. Fleet mix impacts on standard spare parts package included in vehicle procurements.

Similarity to Existing Buses	Range of Increase (Dollars per Bus)
No differences	Base for Comparison
Minor differences	150-175
New manufacturer with similar major subsystems (i.e., engine, transmission, air conditioning)	1,375-1,590
New manufacturer with similar engine but new transmission	1,645-2,245
New manufacturer with new engine and transmission	2,700-3,400

Training Labor Costs

Vehicle procurements are likely to result in, at least, some training or familiarization costs. Staff, which may receive training on the new vehicle, include drivers, service attendants, and mechanics. Mechanic training falls into several categories, and not every mechanic will receive all types of training. These categories include system familiarization, general repair and diagnostics, and component rebuild training. The broad-based survey requested the actual number of hours of training required per person by labor category and mechanic activity for each of the 150 procurements reported.

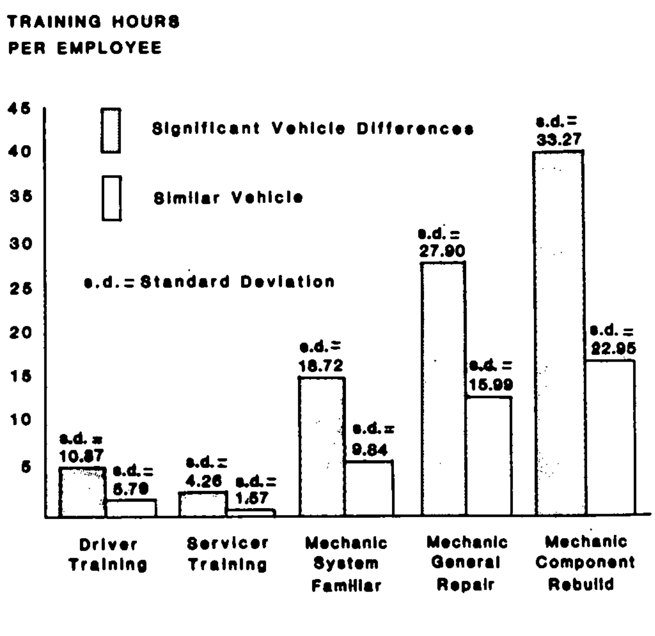

Figure 4. Training time impacts—average training hours per employee by class resulting from new vehicle procurements.

The training requirements varied significantly, based on the degree of vehicular similarity with existing fleets. Where new vehicles varied significantly from the agency's existing fleet, most agencies reported additional training requirements for each employee class. Overall, training requirements were 100 percent higher for vehicles not represented in the current fleet than they were for vehicles similar to those already owned, as shown in Figure 4.

Eighty-two percent of respondents reported significant driver training impacts. Seventy-five percent reported significant cleaner/servicer training impacts. Seventy-nine percent reported significant mechanic training impacts related to system familiarization; seventy-nine percent reported significant mechanic training impacts related to general repair/diagnostic efforts. And sixty-seven percent reported significant mechanic training impacts related to component rebuild training.

Transit bus drivers generally received some training or familiarization for every new vehicle procurement. Usually, all drivers received training on the new fleet. When new vehicles are assigned to a single division or garage, sometimes driver training was limited to the employees assigned to that garage. More frequently, all drivers still received minimal familiarization training on that vehicle. Actual training hours vary according to the new vehicle's similarity to the existing fleet. Driver training usually varied between ½ hour and 4 hours, with a mean of 1.5 hours, in cases where the new vehicle closely resembled those in the existing fleet. Driver training increased to between 4 and 24 hours, with a mean of 5.5 hours, in cases where new vehicles were substantially different from existing fleets. Local policy differences accounted for the significant range experienced when new vehicle types are introduced into the fleet.

Service attendants do not always receive training on a new vehicle, particularly if their areas of responsibility do not change (e.g., fluids replacement, interior cleaning, exterior cleaning). As a rule of thumb, if service attendants also serve a vehicle hostling function (i.e., shuttling vehicles within the yard), they received at least 1 hour of training with the bus drivers, even if the new vehicles are represented in the existing fleet. Training requirements for similar vehicles usually varied between no training and 1 hour, with a mean of 30 min. Service attendants received between 2 and 16 hours for nonstandard vehicles, with a mean of 2.5 hours.

Mechanic training is disaggregated by type of maintenance activity or function (e.g., system familiarization, general repair and diagnostics, and component rebuild). At small transit agencies, where every mechanic is involved in each of these activities, every mechanic receives each category of training. As transit agencies increase in size, segregation of maintenance responsibilities usually occurs, and only those mechanics involved in each activity participate in relevant training.

Mechanic system familiarization is generally provided to all mechanics expected to work on a new vehicle. When new vehicles are similar to those currently in the fleet, mechanics received between 4 and 16 hours of training, with a mean of 5.5 hours per employee. When nonstandard vehicles were introduced into the fleet, average training was 15 hours per employee, generally ranging from 4 hours to 80 hours. Again, local policy accounted for the vast range of training time incurred. Some operators indicated that new vehicle training served a primary mechanic training function, while others indicated that this activity provided supplemental training only.

Mechanic general repair training is provided for mechanics responsible for running repair and preventive maintenance of the new vehicle. Average training time for similar vehicles was about 13 hours per employee, generally ranging between 8 hours and 36 hours. Nonstandard vehicles resulted in an average general repair training time of 28 hours per mechanic, with a range from 16 hours to 184 hours.

Mechanic component rebuild training hours for similar vehicles averaged 16 hours per mechanic, ranging from 4 hours to 64 hours. Nonstandard vehicles resulted in a mean of 40 hours, with a range of 8 hours to 124 hours per mechanic.

SURVEY ON DETAILED COST IMPACTS

Subsequent to the broad-based survey, a follow-up survey was sent to those operators who indicated that they could provide additional information to assist with quantifying operating and capital cost impacts. This detailed cost survey collected information on fleet composition, labor rates, parts cost, mileage, capital cost, and operating cost by subfleet and vehicle subsystem. These data were carefully verified and analyzed to enhance the overall study results, especially in the area of assessing operating cost impacts of fleet standardization issues. This survey collected detailed information on all 35-ft and 40-ft bus types at each operator. Twenty-two operators provided most or all of the data requested, representing 97 subfleets.

The detailed cost survey analysis focused on quantifying cost impacts of diversity with respect to fleet composition. The degree of fleet standardization was assessed in terms of bus model/make, as well as several vehicle subsystems and maintenance activities. These subsystems include engine, transmission, body, brake, air system, air conditioning and heating, suspension and steering, cooling, farebox, destination signs, wheelchair lifts and tires. The maintenance activities for which data were collected separate from the subsystem information include cleaning and servicing and inspection.

The detailed cost survey was designed to glean additional quantitative data on initial costs of introducing a new vehicle to a bus fleet, and to collect data regarding ongoing operations costs of mixed fleets. The data request was structured to help determine answers to two questions: Is the cost of introducing new buses into a fleet impacted by the similarity or differences of the new vehicles compared to existing vehicles for 35-ft and 40-ft buses? (2) Are ongoing maintenance costs of any vehicle impacted by the similarity or differences of other vehicles in the fleet?

Therefore, the analysis recognizes that different vehicles and vehicle configurations are associated with different costs, but does not attempt to analyze, verify, or explain these differences beyond the impact of fleet diversity, Simply stated, the analysis determines if operating costs for a specific subfleet are influenced by the presence of other vehicle types in the same fleet. It does not attempt to determine the impact of operating speeds, climate, use, passenger loads, maintenance policies, or other such factors on operating or capital costs. One cannot assume that the subfleet cost per mile reported for the purposes of this study is universal or can otherwise be applied to another operator without further analysis.

Statistical Analysis

Survey data were analyzed using several statistical and analytical techniques to ascertain fleet-mix cost implications. The analysis proceeded in three phases: (1) normalize costs across operators to facilitate meaningful analysis, (2) evaluate the range of cost experience for each similar vehicle-type grouping, and (3) assess fleet mix as a causal factor contributing to cost differences and quantify its impact.

Labor costs were normalized across operators to eliminate direct wage benefits and variable benefits influences on cost figures reported. The average mechanic direct wage rate for operators included in the study was $11.42. All operator labor costs were adjusted to reflect this normalized wage rate, as discussed in Chapter One. This significantly improved the statistical validity of the data, because the mechanic wage rates reported varied from a high of $38.75 for one agency, which included fringe benefits, to $8.15 for an agency reporting only direct wages. Statistical analysis of materials expenses revealed no closely correlated adjustment factor; therefore, these costs were not adjusted.

Operating and capital costs were examined in terms of means and standard deviations to ascertain the range and average costs that might be related to fleet diversity. Operating costs were examined in terms of labor and parts cost per mile of operation. In the case of operating costs, mileage differences accounted for 88.3 percent of the difference in reported normalized costs by operator (i.e., the r-squared for operating costs and mileage is 88.3 percent). This result closely reflects the findings of prior industry research conducted by Drake and Carter (*1*) and Drake et al. (*2*). Therefore, the analysis of fleet standardization impacts is conducted on data already adjusted to remove impacts of varying labor rates and miles of operation.

Capital costs did not correlate with vehicle-miles traveled. These costs did demonstrate some correlation with fleet size (i.e., 42 percent of the variation in expenditures correlates with differences in the size of the procurement). As this explanatory variable had a relatively low mathematical correlation, capital costs are examined both in total and per vehicle in the new fleet.

The normalized costs were also examined in statistical terms—simple and multiple regression, chi-square, correlation (r-squared), t-statistic, and factor analyses—and other evaluations were conducted to determine if there was a mathematical correlation between fleet diversity and cost, and to quantify that relationship. The findings and conclusions of that analysis are discussed below.

Fleet Standardization Ongoing Operating Cost Implications

Ongoing operating and maintenance costs were analyzed in terms of labor cost, parts cost, and total cost for bus fleets and for vehicle subsystems. Labor and parts cost are examined separately as the study team found higher variability in the way parts costs are reported, as compared to labor cost. Some operators expense parts when they are received; others, when they are forwarded to a division or yard; and still others, when they are installed on a vehicle. Further, some operators report parts cost on a last-in first-out (LIFO) accounting basis, resulting in a higher cost than those using first-in first-out (FIFO) or average cost accounting basis. Finally, parts consumption is not necessarily at a constant level over a vehicle's life. Major subsystem rebuilds, increases or decreases in the inventory size, and international exchange rates can all significantly influence costs for a particular subfleet in any given year. The study team worked with operators to fairly report costs to support analysis, but the extent of variability is still a consideration in interpreting results.

The primary analysis is at the bus subfleet level, with vehicle subsystems evaluated to ascertain the likely impact of individual vehicle subsystem standardization on cost. It is important to note that the bus type analysis is believed to be more accurate and useful than the vehicle subsystems analysis. The likelihood of transit maintenance information recording differences is higher at the vehicle subsystem level than at the subfleet level, giving disaggregate results higher variability than is experienced at the total subfleet cost level. This belief is borne out by the statistical analysis where cost impact confidence levels are consistently better at the subfleet level than for any vehicle subsystem. The subsystem analysis was initially deemed important because a new vehicle procurement may impact the standardization of a single subsystem rather than the entire vehicle. The results of the analysis suggest that, with the exception of engines, subsystem impacts are either hidden by reporting differences, nonexistent, or too erratic to forecast, reliably, impacts from fleet diversity.

Table 4. Average maintenance cost per mile by subfleet type.

Subfleet Type	Number of Observations	Labor	Parts	Total
Flxible (Pre-870)	7	$0.069	$0.057	$0.126
Flxible 870	4	0.087	0.137	0.224
Flxible Metro	14	0.076	0.063	0.139
Gillig	7	0.070	0.135	0.205
GMC (Pre-RTS)	15	0.113	0.127	0.240
GMC RTS	27	0.075	0.111	0.186
All Buses	97	$0.085	$0.113	$0.198

Finally, it is important to note that the cost analysis was conducted for subsystem types and subfleets with at least five observations in the database. Cost analysis was not conducted on several subsystem types because of insufficient data points, including D2566, VTB-903, L-10, and DS-11 engines; ZF500, MT740 and D-863 transmissions; and Cubic Western Data fareboxes. The cost analysis on the remaining subfleets and subsystems counted these excluded elements as another point of disparity, even though detailed cost analysis was not conducted on those specific elements. Each level of analysis is discussed below.

Bus Cost Analysis

Average bus cost per mile is $0.198 across the subfleets examined, as noted in Table 4. The 35-ft and 40-ft subfleets included in this study are pre-870 Flxibles, Flxible 870's, Flxible Metro's, Gillig's, pre-RTS GMC's and GMC RTS's. Insufficient data were provided on other fleets for inclusion in this study. Table 4 presents the mean costs by type of vehicle as reported for this study, which range from $0.126 per mile to $0.240 per mile. These numbers should not be widely used, for purposes other than the fleet-mix analysis herein, without further investigation. The average fleet in the survey is comprised of four distinct subfleets, with a range of a single subfleet to eight subfleets.

Regression analysis of per mile bus costs against each transit operator's fleet mix reveals that costs for every vehicle type increase modestly with the number of distinct vehicle types operating in the fleet. The analysis (see Table 5) indicates that labor cost per mile increase by $0.006 per additional vehicle type added to the fleet (at the normalized labor rate of $11.42), and parts costs increase by $0.001 per mile per additional vehicle type in the fleet. Figure 5 illustrates this relationship. The cost of every bus increases with each diverse subfleet included in the total active fleet. The t-test indicates that there is a 90 percent confidence level that the labor cost increase is mathematically valid, and a 60 percent confidence level for the parts-cost increase exists (note that parts cost demonstrated higher variability and, hence, lower predictability). In spite of the high confidence levels related to fleet diversity and cost, the correlation factor (r-squared) indicates that less than 2 percent of the variability in labor cost reported by operators is due to fleet diversity and less than 1 percent of the variability in parts cost is related to fleet diversity.

Note also that the mean cost per mile for labor and parts varies considerably by vehicle type with nearly a 100 percent

Table 5. Mathematical relationships of the number of diverse vehicle types in fleet to maintenance cost per mile.

	R-Squared of Fleet Diversity to Cost	T-Test of Fleet Diversity to Cost	Slope (Cost per Mile Change per Diverse Fleet Added)
Labor Cost Impacts			
All Buses	1.87	90%	$0.006
Flx Pre-870	9.90	75%	0.014
Flx 870	3.07	60%	0.009
Flx Metro	12.39	90%	0.012
Gillig	10.81	75%	0.007
GMC Pre-RTS	0.80	60%	0.004
GMC RTS	0.01	60%	0.001
Parts Cost Impacts			
All Buses	0.05	60%	$0.001
Flx Pre-870	3.89	60%	0.007
Flx 870	86.58	99%	0.129
Flx Metro	8.86	90%	0.009
Gillig	21.19	90%	0.045
GMC Pre-RTS	0.20	60%	0.004
GMC RTS	3.60	90%	0.010

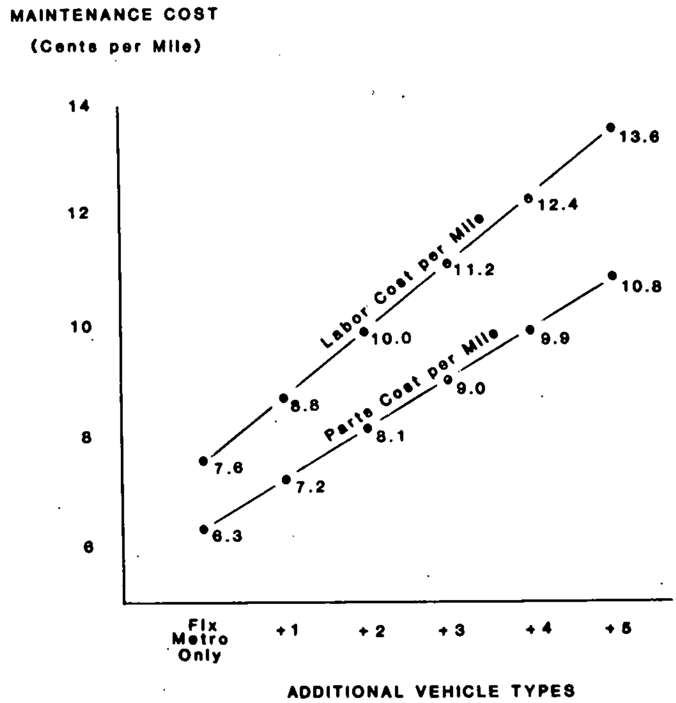

Figure 5. Parts cost analysis—maintenance cost growth related to fleet diversity for the Flx Metro.

difference in the cost per mile of the lowest to highest cost subfleet reported. The slope, confidence level, and correlation factors also vary considerably by subfleet. It is important to note that there are fewer observations in each subfleet category than in the total for all buses group, which accounts for lower statistical validity. Fewer observations also mean that a smaller range of fleet-mix experience is available (e.g., instead of having one to eight subfleets as in the total all buses analysis, some observations only have fleets with three and four distinct vehicle types to evaluate). Although the analysis spans the full breadth of options, the usable results of the analysis are generally at the higher levels (e.g., total all buses).

Engine Operating Cost Analysis

There were three basic types of bus engines operated by survey respondents—the 6V71, the 6V92, and the 8V71. Labor costs per mile, presented in Table 6, were reported as very similar among the engine types, ranging from $0.010 to $0.012 per mile, with a mean of $0.011. Parts cost per mile, as might be expected, varied to a greater degree from $0.016 to $0.029 per mile, with an average of $0.019. Total engine maintenance cost per mile was reported as $0.030.

The regression analyses (Table 7) indicate that as engine types in the fleet increase, engine maintenance costs increase. Labor costs rise about $0.002 per mile for each additional engine type added into fleet operation. There ia a 95 percent confidence level in this relationship. It is important to note that less than 3 percent of the difference in reported engine labor cost by operator is attributable to engine diversity. A different rate of change, confidence level, and correlation occurs for each individual engine type, but each has considerably fewer observations than the total for all engines.

Engine parts cost per mile also exhibits a positive slope, high confidence level, and low correlation. The cost increase of $0.005 per mile is suspect, particularly in light of the variability by engine type. The 6V71 engine shows a decrease in cost per mile as additional engine types are added into the fleet equal to the positive slope of $0.005 for all engine types. As engine maintenance costs average 15 percent of the total bus cost, minor differences in cost reporting can have a significant impact on costs.

Table 6. Average normalized engine cost per mile by engine type.

Vehicle Type	Number of Observations	Labor	Parts	Total
6V71	17	$0.012	$0.029	$0.041
6V92	47	0.010	0.016	0.026
8V71	28	0.012	0.016	0.028
All Engines	97	$0.011	$0.019	$0.030

Table 7. Mathematical relationships of the number of diverse engine types in fleet to engine cost per mile.

	R-Squared of Engine Diversity to Cost	T-Test of Engine Diversity to Cost	Slope (Cost per Mile Change per Diverse Engine Added)
Labor Cost Impacts			
All Engines	2.53	95%	$0.002
6V71	23.68	97%	0.004
6V92	5.73	95%	0.003
8V71	3.38	90%	0.001
Parts Costs Impacts			
All Engines	6.02	99%	$0.005
6V71	4.36	75%	0.005
6V92	6.19	95%	0.004
8V71	15.52	95%	0.010

Transmission Cost Analysis

As a result of detailed statistical analysis of transmission cost and configuration, transmissions were grouped into three categories: HT740, HT748 and HT750; V730 and V731; and VS and VH. Transmission configurations in each grouping closely resemble one another and have relatively consistent cost characteristics. Across all transmissions, labor costs per mile equal $0.004 and parts cost $0.009 per mile as given in Table 8. Total per mile costs range from $0.010 to $0.025, with a mean of $0.013 as reported for the purposes of this study.

The regression analysis (Table 9) reveals a flat slope, which indicates that costs do not increase as additional transmission types are operated in the fleet. There is only a 60 percent confidence level in this cost relationship, and less than 1 percent of the variability in transmission costs is explained by transmission diversity in the fleet. The slope is flat by transmission type, with even a very slight negative trend. This would imply that costs do not change with transmission diversity, or may actually decline slightly as diversity increases. All of these factors indicate that transmissions contribute little or no costs in fleet-mix issues. Overall, it should be noted that transmissions account for only 6 percent of total maintenance expenditures in the surveyed operations.

Inspection Cost Analysis

Vehicle inspection and preventive maintenance is an important and costly function at any transit operation. Inspection accounts for 28 percent of total maintenance costs at the surveyed operators, with $0.048 per mile labor costs and $0.0076 per mile in parts cost. Inspection costs per mile were very similar among the reporting operators, given the labor wage adjustment to each. This is at least partially reflective of the fact that most inspection activities are mileage driven, and that manufacturer recommendations as to the scope and frequency of inspections have a considerable influence on most operators.

Regression analysis reveals a mathematical increase of $0.001 per mile in inspection labor costs and no increase in parts cost per additional vehicle type in the fleet. Although the mathematical relationship exists, the activities and frequency of vehicle inspection do not suggest that costs logically should increase in this area as vehicle types are added to the fleet. As with the other cost elements, less than 3 percent of the variability in inspection cost is a function of fleet diversity.

Table 8. Average normalized transmission cost per mile by transmission type.

Transmission Type	Number of Observations	Labor	Parts	Total
HT740, 748, 750	12	$0.003	$0.011	$0.014
V730, V731	61	0.004	0.006	0.010
VH, VS	18	0.007	0.018	0.025
All Transmission	97	$0.004	$0.009	$0.013

Table 9. Mathematical relationships of number of diverse transmission types in fleet to cost per mile.

	R-Squared of Transmission Diversity to Cost	T-Test of Transmission Diversity to Cost	Slope (Cost per Mile per Diverse Transmission in Fleet)
Labor Cost Impacts			
All Transmission	0.24	60%	$0.000
HT740, 748, 750	15.72	90%	0.001
V730, V731	0.55	60%	0.001
VH, VS	0.04	60%	0.000
Parts Costs			
All Transmission	2.79	90%	$0.001
HT740, 748, 750	12.86	90%	0.005
V730, V731	0.32	60%	0.001
VH, VS	1.55	60%	-0.004

Vehicle Servicing and Cleaning Cost Analysis

Vehicle servicing and cleaning costs per mile average $0.00003, and include labor costs alone. No parts costs were reported in this category by any survey respondent. Based on study findings, cleaning and servicing costs comprise less than 1 percent of the total maintenance expenditure. The regression analysis demonstrated no relationship between servicing cost per mile and fleet diversity (i.e., the slope was flat at $0.000006 decrease per additional fleet operated). This relationship might be expected, given that cleaning and servicing requirements for 35-ft and 40-ft buses are quite similar and that the tasks are generally simple; therefore; additional fleet diversity should not impact task complexity. About 2 percent of the variance in servicing costs by operator is explained by fleet diversity.

Heating, Venting and Air Conditioning Cost

Heating, venting, and air conditioning costs comprise approximately 8 percent of the total maintenance cost reported by survey respondents, with labor costs of $0.009 per mile and parts costs of $0.006 per mile for a total of $0.015 per mile. Statistical analysis indicates no correlation between fleet diversity and heating, venting, and air conditioning cost, with a 99 percent confidence that no relationship exits. Assessment of survey respondent fleet and vehicle configurations confirm this mathematical finding. Results indicate that all 22 operators had a single air conditioning system in all vehicles regardless of manufacture or model. This finding confirms one report found in the literature search which stated that agencies were attempting to achieve fleet standardization through specifying particular components during bus procurements.

Brake Cost Analysis

Brakes account for about 16 percent of the total maintenance cost. The average brake cost per mile is about $0.045 and varies considerably if a brake retarder is included in the subsystem (Table 10). The regression analysis indicated no impact to cost from fleet diversity. However, it should be noted that only six of the 97 subfleets analyzed had retarders. The sample size is limited for statistical purposes.

Cooling System Cost Analysis

Cooling system costs are given in Table 11 and average $0.025 per mile. These costs comprise about 13 percent of the total vehicle maintenance cost. Cooling system diversity was examined in terms of the six vehicle-type categories, each of which indicated cost differences. The regression analysis (Table 12) indicates that cooling subsystem costs increase $0.009 per additional vehicle type added to the fleet, but the confidence and correlation levels are low and, hence, this relationship is suspect.

Table 10. Average normalized brake systems cost per mile by brake system type.

Brake Type	Number of Observations	Labor	Parts	Total
Retarder	6	$0.009	$0.011	$0.020
Non-Retarder	74	0.030	0.017	0.047
All Brake	77	$0.030	$0.017	$0.047

Table 11. Average normalized cooling system cost per mile by vehicle type.

Subfleet Type	Number of Observations	Labor	Parts	Total
Flxible (Pre-870)	7	$0.0005	$0.0018	$0.0023
Flxible 870	7	0.0094	0.0030	0.0124
Flxible Metro	14	0.0075	0.0800	0.0875
Gillig	8	0.0016	0.0021	0.0037
GMC (Pre-RTS)	13	0.0045	0.0027	0.0072
GMC RTS	28	0.0025	0.0069	0.0094
All Cooling	77	$0.0046	$0.0204	$0.0250

Air System Cost Analysis

The air system reported cost per mile averages $0.0091, comprising about 5 percent of the total vehicle maintenance costs. Table 13 presents the results of the analysis. Again, this subsystem cost was evaluated by vehicle type to discern potential fleet diversification implications. The regression analysis (Table 14) indicated a flat slope, with costs decreasing $0.001 per additional vehicle type added to the fleet. A poor confidence level and minuscule correlation (i.e., less than 1 percent of the difference in air system costs reported is attributable to differences in fleet mix). Again, the logical conclusion is that air system maintenance is not measurably impacted by differences in fleet diversity.

Table 12. Mathematical relationships of the number of diverse vehicle types in fleet to cooling system cost per mile.

	R-Squared of Vehicle Type to Cost	Slope (Cost per Mile Change per Diverse Fleet Added)
Labor Cost Impacts		
All Buses	0.57	$-0.001
Flx Pre-870	38.64	-0.002
Flx 870	12.23	-0.005
Flx Metro	17.18	-0.003
GMC Pre-RTS	26.86	0.011
GMC RTS	2.49	0.000
Parts Costs		
All Buses	4.56	$0.0090
Flx 870	0.02	0.0000
Flx Metro	23.83	0.0053
GMC Pre-RTS	6.83	0.0090
GMC RTS	0.20	0.0000

Table 14. Mathematical relationships of the number of diverse vehicle types in fleet to air system cost per mile.

	R-Squared of Vehicle Type to Cost	Slope (Cost per Mile Change per Diverse Fleet Added)
Labor Cost Impacts		
All Buses	1.54	$-0.001
Flx Pre-870	1.34	0.000
Flx Metro	0.01	-0.002
GMC Pre-RTS	0.01	0.000
GMC RTS	0.01	0.000
Parts Cost		
All Buses	0.26	$-0.001
Flx Pre-870	45.97	-0.002
Flx Metro	64.03	-0.002
GMC Pre-RTS	6.80	0.009

Table 13. Average normalized air system cost per mile by vehicle type.

Vehicle Type	Number of Observations	Labor	Parts	Total
Flxible (Pre-870)	7	$0.0073	$0.0027	$0.0100
Flxible 870	7	0.0068	0.0029	0.0097
Flxible Metro	14	0.0051	0.0016	0.0067
Gillig	8	0.0016	0.0021	0.0037
GMC (Pre-RTS)	13	0.0028	0.0051	0.0079
GMC RTS	28	0.0078	0.0032	0.0110
All Air System	77	$0.0064	$0.0027	$0.0091

Suspension and Steering System Cost Analysis

Suspension and steering subsystem maintenance costs average $0.0123 per mile for survey respondents, as shown in Table 15. They comprise about 6 percent of the total vehicle maintenance costs. Diversity was evaluated by vehicle type because different vehicles use various versions of beam or independent suspension and steering systems. The regression analysis (Table 16) indicates that, mathematically, cost per mile decreases by $0.001 per additional fleet type operated. The confidence level and correlation of cost to diversity are low. Individual vehicle types show both slightly positive and slightly negative slopes, leading to the conclusion that costs in this subsystem are not appreciably impacted by diversity.

Wheelchair Lift Cost Analysis

Wheelchair lifts account for about 4 percent of maintenance costs for those vehicles so equipped—not all fleets had wheel-

Table 15. Average normalized suspension and steering system per mile by vehicle type.

Subfleet Type	Number of Observations	Labor	Parts	Total
Flxible (Pre-870)	7	$0.0081	$0.0057	$0.0138
Flxible 870	7	0.0059	0.0039	0.0098
Flxible Metro	14	0.0063	0.0025	0.0655
Gillig	8	0.0035	0.0074	0.0109
GMC (Pre-RTS)	13	0.0035	0.0110	0.0145
GMC RTS	28	0.0087	0.0067	0.0154
All Suspension & Steering	77	$0.0072	$0.0051	$0.0123

Table 16. Mathematical relationships of the number of diverse vehicle types in fleet to suspension and steering system cost per mile.

	R-Squared of Vehicle Type to Cost	Slope (Cost per Mile Change per Diverse Fleet Added)
Labor Costs		
All Buses	0.00	$0.000
Flx Pre-870	3.10	0.001
Flx Metro	8.10	-0.002
GMC Pre-RTS	2.59	-0.003
GMC RTS	6.35	0.002
Parts Costs		
All Buses	1.64	-$0.001
Flx Pre-870	35.06	-0.003
Flx Metro	1.02	0.000
GMC Pre-RTS	3.76	0.006
GMC RTS	6.80	-0.001

Table 17. Average normalized farebox per mile cost by type.

Farebox Type	Number of Observations	Labor	Parts	Total
AMS	7	$0.00165	$0.00004	$0.00169
Cleveland	7	0.00004	NA	0.00004
GFIs/General	37	0.00025	0.0002	0.00045
Keene	6	0.00023	0.00005	0.00028
All Fare Box	62	$0.00491	$0.00014	$0.00505

Table 18. Average normalized destination sign per mile cost by type.

Destination Sign Type	Number of Observations	Labor	Parts	Total
Curtain/Scroll/Roller	22	$0.00045	$0.00027	$0.00072
Electronic	42	0.00883	0.00055	0.00938
All Destination Signs	64	$0.00090	$0.00037	$0.00127

chair lifts. Operators reported that lifts cost about $0.0116 per mile, almost evenly split between parts and labor. Wheelchair lift cost per mile was not impacted by the number of different lift types in the fleet because most fleets had only one or two lift types in operation.

Farebox Cost Analysis

Farebox maintenance requirements comprise far less than 1 percent of the total vehicle maintenance cost, with the simple mechanical fareboxes requiring almost no maintenance, to some minor level of maintenance required on electronic fareboxes. The results of the analysis of these costs are provided in Table 17. All operators responding to this survey indicated that they install and operate a single farebox type on every vehicle, regardless of vehicle make or manufacturer. The standard industry practice is to procure fareboxes for the entire fleet separately from bus procurements. The only known exceptions are the phase-in and testing periods for new equipment. Therefore, fareboxes have no fleet diversity implications.

Destination Signs Cost Analysis

Destination signs comprise less than 1 percent of maintenance costs, and were grouped into manual (curtain, scroll, and roller) and electronic categories (Table 18). Survey respondents indicated either one or two destination sign types. While reported costs are different for manual and electronic signs, neither was impacted by the presence of the other sign type in the fleet (i.e., sign diversity has no apparent cost impact).

Tire Cost Analysis

Tire cost per mile as reported by those agencies with available data is $0.035. Most operators in the survey contracted this activity out and did not provide specific cost data. Tires are highly interchangeable across many fleets and demonstrated no relationship to fleet diversity.

Ongoing Maintenance Cost Conclusions

The analysis of ongoing maintenance costs examined above clearly and repeatedly conveys several findings. First, fleet diversity has a small but measurable impact on ongoing maintenance costs. This impact is best measured on a vehicle-type basis, and does not lend itself to a vehicle subsystem by subsystem comparison. The only exception, perhaps, is engine labor costs, which measurably increase with diversity of engine types in the fleet. Individual subsystems also confirm the minor impact of diversity on costs, but are not statistically sound for forecast purposes.

Inventory of Spare Parts Impacts

Impacts on an agency's inventory of spare parts (e.g., measured by average parts inventory per vehicle) were also examined (see Figure 6). Twenty-two percent of the procurements resulted in total inventory cost increases, at an average increase of $2,124 per vehicle. It is important to note that most of the increases cited were temporary. Transit operators frequently purchase a spare parts package with new vehicles (i.e., because of capitalization opportunities, bulk purchase discounts, and new parts

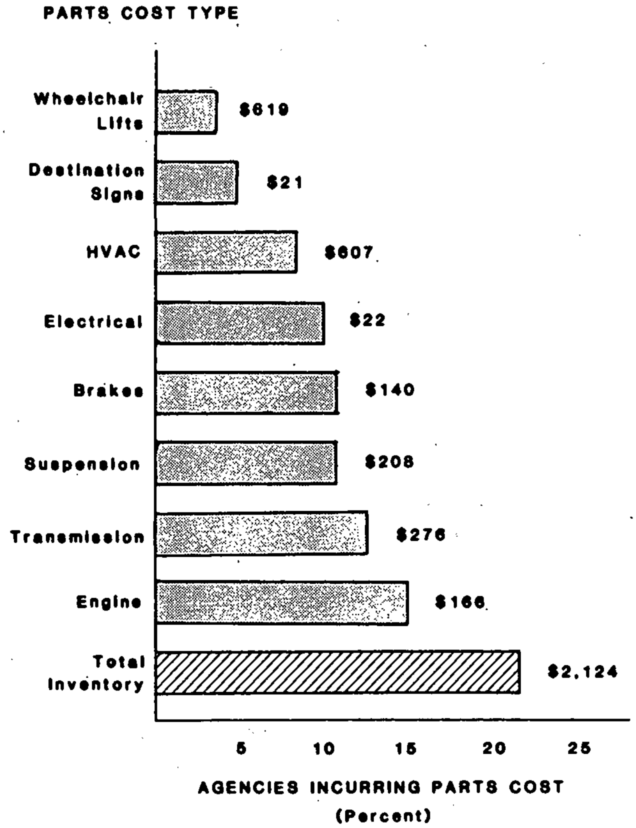

Figure 6. Percent of surveyed agencies incurring parts costs as a result of introducing new vehicle types into the existing fleet.

needed for new vehicle systems). These additional parts frequently increase inventory on-hand for several months or a year, until normal consumption reduces the inventory to its earlier levels.

Not surprisingly, engine transmission parts costs were cited as the most frequent cause of parts inventory increases. Engine parts inventory costs increased as a result of 15 percent of the procurements, at an average of $166 per engine; transmission parts costs increased in 13 percent of the procurements, at an average cost of $276 per transmission.

Although occurring less frequently, parts cost increases due to wheelchair lifts and HVAC systems were the most costly at $619 and $607 per vehicle, respectively. Parts cost increases in the area of wheelchair lifts were incurred in only 4 percent of the procurements; those due to HVAC systems, in 9 percent of the procurements.

The lowest parts cost impacts were in the areas of destination signs ($21 per vehicle in 5 percent of the procurements) and electrical systems ($22 per vehicle in 10 percent of the procurements).

Again, most transit operators in both the industry survey and the detailed cost investigation survey indicated that inventory increases generally are a temporary condition related to a fleet procurement. Although parts may be purchased with vehicles because of financial advantage or immediate need, inventory levels generally return to earlier levels within the year.

Capital Costs

As reported earlier, only a minority of bus procurements resulted in the purchase of additional capital equipment items or modifications to existing facilities. As with training, the cost of capital to a great degree depends on the distribution of the new vehicles among divisions or yards. Special tools and diagnostic equipment were the most commonly cited.

With respect to special tools, the costs ranged from just under $250 up to $60,000 per new procurement for the 24 percent of operators who reported any costs in this category. The reported average cost was $388 per bus with a standard deviation of ± $371. Agencies which distribute new buses across more than one operating division reported significantly higher costs than those which assigned new buses to a single facility.

Diagnostic equipment was most commonly purchased for trouble shooting new electronically controlled engines, new transmissions, or transmissions equipped with brake retarders. Again, the total cost incurred was strongly influenced by local policy. One agency reported that more than $100,000 was spent for new diagnostic equipment because the new subfleet was distributed to eight operating divisions. On the average, it was reported that the new equipment cost $288 per bus with a standard deviation of ± $221. Only 18 percent of the reporting agencies indicated that any cost was incurred.

Fourteen percent of the agencies reporting indicated they expended capital funds to increase parts storage space or to develop more efficient parts storage systems as a result of a new bus procurement. The average cost per bus was $711 with a standard deviation of ± $407, for those agencies incurring such an expense.

Twelve percent of the survey respondents incurred costs to modify vehicle lifts. The modification ranged from simple replacement of the lift superstructures to accommodate different axles, up to the complete replacement of vehicle lifts in order to safely raise a heavier vehicle. The cost of the new superstructure averaged $1,100 per repair bay. The cost of the replacement of an in-ground vehicle lift was as high as $43,800 per repair bay. Most agencies reported that their maintenance facilities were constructed or rehabilitated within the past 10 years. The introduction of new buses had been anticipated and the need for vehicle lifts to accommodate all buses in the marketplace was included in the construction project.

Five percent of the respondents reported the need for capital expenditures for vehicle interior cleaning equipment when a new bus type was purchased. Vehicles with pantograph (swing out) front doors require a wider extendable bellows on "buck cyclone" bus interior vacuum cleaning systems. The reported costs ranged from $125,000 to $46,000, or an average of $793 per bus for those incurring such a cost.

Only a single respondent reported capital expenses to modify existing vehicle exhaust systems and vehicle washers. The vehicle exhaust system was modified to fit both street level and vehicle top exhaust at a cost of $143 per repair bay. The reported vehicle washer was modified at a cost of $49,500 per service lane because of the introduction of a roof-mounted air-conditioning system.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

IMPACT OF FLEET DIVERSITY ON COST

As demonstrated in Chapter Two, the cost of introducing a new vehicle type into a fleet and the ongoing maintenance cost of all vehicle types is impacted by fleet diversity. The type of vehicle selected in any procurement influences the amount of training required and the maintenance cost of all vehicles, and can impact nonvehicle capital costs. The overall impact of diversity on cost observed is minor, albeit relatively consistent across the operators examined. As the number of vehicle types increases in an operating fleet, bus maintenance costs increase.

Parts inventory costs were found to increase with all procurements, but was usually a temporary occurrence and did not measurably impact costs. The cost of a higher inventory does not necessarily equate to higher parts consumption, but reflects an opportunity cost (i.e., the funds invested in parts inventory could have been put to another use). In economic terms, the cost of increased inventory would be the difference between parts price increases and inflation or interest rates, over the period of increased inventory. This research effort did not find a mathematical relationship between fleet diversity and parts inventory cost, although logically one might exist. A reason for this may be the minuscule cost related to inventory, as noted above.

At each bus procurement made (and/or vehicle retirement), transit agencies have an opportunity to reduce, maintain, or increase fleet diversity. Transit agencies participating in the research effort operated an average of four distinct vehicle types, with a range of one to eight. When replacing a bus subfleet, fleet diversity is generally impacted in one of three ways:

1. Greater standardization is achieved by retiring one subfleet, and replacing those vehicles with buses similar to those already in the fleet. In this case, a transit agency could change its fleet mix from four diverse types to three. Nonvehicle capital investments would be unlikely and initial training minimal, and ongoing maintenance costs of all vehicles are likely to decrease slightly.
2. Fleet mix is maintained by retiring one diverse fleet type and procuring another nonstandard vehicle. In this case, a transit agency would begin and end at four distinct vehicle types. Nonvehicle capital investments are possible, initial training is increased, and ongoing vehicle maintenance costs are not impacted.
3. Fleet diversity is increased by retiring only a portion of one subfleet and replacing those vehicles with a new, nonstandard vehicle. In this case, the fleet mix changes from four vehicle types to five. Nonvehicle capital costs are possible, training costs are increased, and ongoing maintenance costs increase modestly for all fleet types.

These options are somewhat simplified, but closely reflect the events reported by research participants. Vehicle deployment policies can also have a significant impact on costs related to fleet diversity. Fleet mix at specific operating divisions or yards is an important consideration, as are personnel assignments to divisions.

Where operators have multiple divisions, vehicles may be assigned to specific yards in a way to reduce the fleet mix at each operating center. This strategy requires a minimum of borrowing or trading vehicles between divisions, a practice that can improve service reliability and reduce response time and cost to some road calls. It also requires minimum operator and maintenance staff transfers among divisions, which is contrary to many labor agreements requiring semi-annual assignment picks. If these two vehicle and personnel assignment conditions can be satisfied, initial training costs for operators, service attendants, and several classes of mechanics can be reduced (e.g., inspection, running repair, general repair) by limiting training to those employees stationed at relevant yards. Training for mechanic rebuild and overhaul staff would not likely be impacted. Ongoing maintenance costs would theoretically incur a modest reduction.

Research participants did not generally meet these requirements; therefore, insufficient data were available to test vehicle deployment strategies on cost. Most operators assign new vehicles to all or most divisions (due largely to equity considerations for the passenger), trade or borrow vehicles with some regularity (helps minimize spare vehicle requirements), and/or allow semi-annual assignment shake-ups (usually a labor contract stipulation) which result in considerable shifting of personnel among divisions. While these practices do impact costs related to fleet diversity, they also satisfy other objectives and policies of transit operators.

It should further be noted that not every procurement offers the opportunity to decrease, maintain, or increase fleet mix. Vendor bids can significantly impact the range of options available to transit agencies, and the price of those bids can pressure the operator into purchasing a nonstandard vehicle.

Sage advice for all transit operators is to use vehicle procurement specifications to ensure a high degree of standardization in all procurements. This is particularly important with the engine, transmission, and other major vehicle components and subsystems. Note that vehicle standardization does not necessarily translate to a vehicle of the same make and manufacture; it is a functional and design attribute. Different manufacturers can and do produce some similar vehicles that will not appreciably impact fleet-mix costs. Use of the tools available (e.g., vehicle specification, bid package, life cycle costing) ensure that the procurement effort meets agency capital and ongoing operating requirements.

It is possible to assess vehicle standardization/diversity cost impacts during the procurement process and to use this information in evaluating low cost bids. While fleet mix costs are not likely to be particularly large, they may be useful where bid prices are in a relatively narrow range. A life cycle costing approach is suggested which considers fleet mix implications for initial and ongoing costs related to the procurement. When such a method

Table 19. Data elements required for analysis.

Data Item	Format of Value	Default Parameter Provided
1. Diverse Fleets Added (Subtracted)	Integer	No
2. New Fleet Similar to Existing	Yes/No	No
New Engine in Fleet Now	Yes/No	No
3. Total Bid Price	Dollars	No
4. Additional Cost of Capital	Dollars	Yes
5. Number of Employees to Receive Training		
• Drivers	Integer	No
• Service Attendants	Integer	No
• Mechanics		
- System Familiarization	Integer	No
- General Repair	Integer	No
- Component Rebuild	Integer	No
6. Training Hours per Employee		
• Drivers	Hours	Yes
• Service Attendants	Hours	Yes
• Mechanics		
- System Familiarization	Hours	Yes
- General Repair	Hours	es
- Component Rebuild	Hours	Yes
7. Average Wage Rate		
• Drivers	Dollars per Hour	No
• Service Attendants	Dollars per Hour	No
• Mechanics	Dollars per Hour	No
8. Average Benefit		
• Drivers	Proportion of Wages	No
• Service Attendants	Proportion of Wages	No
• Mechanics	Proportion of Wages	No
9. Systemwide Maintenance Cost per Mile	Dollars per Mile	Yes
10. Systemwide Bus Miles Driven per Year	Miles	No
11. Years to Vehicle Retirement	Years	Yes

is used, it should be described or referenced in the request for bids to ensure that vendors make their best efforts to minimize these impacts. A viable and straightforward approach to assessing the costs of standardization/diversity is presented below. Note that this methodology does not assess other cost differences of fleet bids (e.g., fuel economy, operating and maintenance cost differences of buses bid), but the methodology addresses fleet-mix issues alone.

METHODOLOGY FOR ADJUSTING BID PRICES FOR DIVERSITY

Bus procurement bid prices can be adjusted to reflect fleet-mix impacts. A form of life cycle costing is required (i.e., whole life costs or annualized equivalent costs). Whole life costs (sometimes called net present value) reflect the initial and future stream of expenses as a single value, whereas annualized equivalent costs reflect the depreciated value of initial costs over the useful life of the vehicle and the annual equivalent operating cost.

Modified whole life costs result in the easiest adjustment to bid price for fleet-mix issues. The term modified is used as the method described herein. It addresses adjusting the bid price by incremental costs attributed to vehicle standardization or diversity, rather than attempting to project lifetime costs of the new fleet. Past transit industry experience has demonstrated the difficulty of forecasting such expenses over a vehicle's useful life, and of obtaining reasonable operating cost data prior to fleet operation. This methodology overcomes this prior failure by avoiding this issue. The research effort did not investigate costs or experience related to cost differences between vehicle types and operating conditions. However, if an operator does forecast ongoing operating costs of future fleets, the incremental costs due to fleet mix are simply added onto the result. Hence, the methodology has applicability to a wide array of bid price evaluation approaches.

Data Requirements

The incremental cost analysis methodology requires information which the research team found to be generally available throughout the industry. Data availability was considered critical to the broad applicability of the methodology. Specific data requirements are given in Table 19. While specific bid and operator policy data are always preferred, default parameters calibrated from research participant experience are included for consideration. Several data items in the table warrant additional explanation:

1. *Diverse subfleets added (subtracted)* refers to the net change, if any, in the number of diverse subfleets that will be in the operators fleet if the vehicle bid is procured. It is calculated as the number of diverse fleets that will be in operation if the bid is successful less the number of fleets in operation now. In most procurements, this value will be one, zero, or minus one.

2. *Similarity of new fleet to existing* requests a yes or no response (i.e, Boolean). It is used to ascertain likely training costs.

3. *Total bid price* is the total bid value for the procurement.

4. *Additional cost of capital* refers to any additional capital outlay (i.e., capital costs not included in the bid) required to introduce the new fleet into existing operations. Such costs occur infrequently, but could be expensive. Possible capital costs to consider include tools, diagnostic equipment, lift modifications (e.g., due to weight or configuration differences), bay modifications (e.g., midshift or rear exhaust), bus washer changes (e.g., due to vehicle dimension changes like roof-mounted air conditioners), and cleaning equipment modifications (e.g., related to door configuration). Example expenses incurred by study participants are provided.

5. *Number of employees to receive training* by employee class is required to calculate training expense. Fleet deployment intentions must be considered. How many divisions will be involved and what is their staff complement by employee class?

6. *Training hours per employee* by employee class is used to project initial training cost associated with new vehicles. Every new procurement usually requires some level of training. Diverse fleets require substantially more training than do standard vehicles. Actual operator expectations for training should be used (e.g., the bid document may specify the level of training to be provided), but default parameters are provided.

7. *Average wage rates* (cost per hour) are required by employee class, again supporting estimation of initial training costs.

8. *Average fringe benefit rate* is needed as a proportion of wages by employee class.

9. *Systemwide maintenance cost per mile* is needed to calibrate the fleet diversity cost impact factor developed by this research effort into local cost terms. Note that the average wage rate reported by study participants is $11.42 for mechanics. The method uses a specific operator's cost per mile to calibrate the cost factors to that environment.

10. *Systemwide bus miles driven per year* is used to calculate ongoing cost changes due to fleet diversity. Fleet diversity impacts all bus fleet maintenance costs, not just those of the new vehicles.

11. *Years to vehicle retirement* requests the average planned useful life of the new vehicles. It is appropriate to use the UMTA funding useful life of 12 years, if so desired.

Default parameters based on the actual experience of transit agencies participating in this research effort are provided in Table 20. Again, local figures are always desirable. If local data are unavailable, consider using the default parameters developed as part of the research effort.

Table 20. Default parameters.

Data Item	Similar Vehicles	Different Vehicles
Additional Capital Costs (a)		
o Tools	$0.000	$388/bus
o Diagnostic Equipment	$0.000	$288/bus
Training Hours per Employee		
o Drivers	1.5 hours	5.5 hours
o Service Attendants	0.5 hours	2.5 hours
o Mechanics		
- System Familiarization	5.5 hours	36 hours
- General Repair	13 hours	36 hours
- Component Rebuild	15 hours	40 hours
Systemwide Maintenance Cost per Mile	$0.198	+ $0.007 for each additional diverse fleet
Years to Vehicle Retirement	12 years	12 years

Analysis of Initial Costs

Initial costs are those up-front expenditures made to effectively introduce a new vehicle subfleet into operations. These costs include the vehicle bid price, other initial capital costs required (e.g., tools and diagnostic equipment), and training costs. The formula for calculating initial costs is as follows:

$$\text{Initial cost} = [\text{Bid price} + \text{Other capital costs} + \left[\sum_{n=5}^{t} (\text{NUMEMP}_t * \text{AVETHR}_t * \text{AVEWAGE}_j * (1 + \text{BENRATE}_j)\right] \quad (4)$$

where: NUMEMP = number of employees to receive training; AVETHR = average training hours per employee; AVEWAGE = average wage per employee; BENRATE = benefits as a proportion of wages; t = type of employee training; j = employee class.

This formula assumes that the bid price includes all vehicle, spare parts and vendor training cost (e.g., instructor time, materials, travel). If additional capital costs are required to introduce the fleet bid, examine them carefully and avoid double counting (e.g., if special tools are included in the bid price, do not add them in again).

Training costs calculated in Eq. 4 are those incurred by the operator (i.e., mechanic, driver, and service attendant wages and benefits while in training). Bid documents frequently include estimated or actual training time to be provided by employee class, and should be used in the formula. In the event that these are not available, or are inconsistent with expected needs, default parameters were developed based on operator experience (shown previously in Table 20). Note that training costs vary appreciably by fleet diversity.

Analysis of Ongoing Costs

The next step is to calculate the ongoing operating and maintenance cost differences due to fleet mix. Actual operator experience indicates with high confidence that costs increase modestly with fleet diversity, and decrease mostly with fleet standardization. The formula for calculating the stream of net maintenance costs attributable to fleet diversity or standardization is as follows:

$$\text{Ongoing cost difference} = [(\text{NVT} - \text{EVT}) * (\$0.007 * (\text{MCMILE}/\$0.198)) * \text{SYSMILES} * \text{LIFE})] \quad (5)$$

where: NVT = number of vehicle types in fleet if bid successful; EVT = number of vehicle types in existing fleet; MCMILE = existing systemwide maintenance cost per mile; SYSMILES =

systemwide miles operated per year; and LIFE = expected useful life of new buses (e.g., 12 years); \$0.007 = cost escalation per diverse fleet added; and \$0.198 = cost per mile reported by study participants.

The formula estimates the future stream of ongoing maintenance cost impacts of fleet standardization and/or diversification resulting from the potential procurement. Costs are translated into a specific operator's terms. The phrase MCMILE/\$0.198 adjusts the cost escalation factor of \$0.007 to local labor and materials costing experience. If MCMILE is more than \$0.198, \$0.007 is increased proportionally. A decrease is likewise adjusted. Costs should include both labor and parts elements (the cost escalation factor for labor is \$0.006, and for parts is \$0.001). It is preferred that the operator include direct labor, benefits, and materials in the cost per mile figure, albeit the formula works with direct wages and materials alone.

If the only significant change between a fleet proposed and an existing fleet is the power train or engine, the cost escalation factor should be reduced from \$0.007 to \$0.002. Likewise, if the power train is standardized with the existing fleet but the remainder of the vehicle is different, the cost escalation factor should be changed from \$0.007 to \$0.005.

Note that the ongoing expense results exclude future inflation and do not discount for present value of future expenses today. These are assumed to be largely off-setting costs. Inflation is excluded because it is quite difficult to forecast over a 12-year period, and uncertainty regarding future costs is a major reason life cycle costing has not received broad industry support to date. This method relies on existing, known information. Because future inflation is excluded, future costs are not discounted to current day dollars, as might be done in a net present value life cycle cost approach. While inflating and then discounting a future stream of expenses is a sound academic exercise, it adds little value to this procedure and requires substantial additional effort. Tests of the methodology against actual operator experience indicates little margin of error.

Total Adjusted Bid Price

The total adjusted bid price is simply the sum of the two products calculated above:

$$\text{Adjusted bid price} = \text{Total initial cost} + \text{Ongoing cost difference} \tag{6}$$

This provides a single cost figure comprising the total cost impact of fleet diversification or standardization related to a single procurement. Although not yet tested through the UMTA procurement process, this approach appears to satisfy life cycle cost intentions and guidelines in an equitable and repeatable manner. The adjusted cost could be used to determine the low, responsive bidder. As noted previously, if it is an operator's intent to use this method in evaluating bids, it should be noted in the request for bids.

Annualized Equivalent Cost

A second method of life cycle cost analysis is annualized equivalent cost. This method spreads the initial investment cost over the useful life of the vehicle, and adds on unadjusted maintenance costs. This method should be used if the operator already employs an annualized equivalent cost methodology. Follow the steps above with two minor adjustments. The first step is to adjust the total initial cost developed above, as follows:

$$\text{Initial AEC cost} = \text{Initial cost above} * \text{Amortization factor} \tag{7}$$

The amortization factors are given in Table 21. The determining formula is provided in Eq. 8.

$$(1/(1-(1-\text{interest rate})^{-\text{years}})) \div \text{interest rate} \tag{8}$$

The ongoing maintenance cost is calculated using Eq. 7, but without multiplying the cost by the useful life of the vehicle (i.e., drop the LIFE multiple from the equation). The sum of the initial and ongoing cost represents the annualized equivalent cost adjusted for fleet diversity and standardization.

METHODOLOGY TEST RESULTS

The methodology was tested against 14 actual procurements reported by operators, of varying size, that participated in the study. Overall, the methodology was easy to apply and produced reasonably accurate results. The following specific findings should be noted:

1. The initial bid prices should be reviewed for consistency prior to applying this methodology. If a spare parts package is included in some bids but not others, this cost should be excluded from each. Also examine the training offered carefully. Most bids reviewed included specific training, but some offered additional training support on a time and materials basis. If the operator intends to use these additional services, these costs should be included in the bid price.
2. Additional capital costs should be considered carefully. Some vehicle bid offers included special tools and/or diagnostic equipment; others excluded these costs even though the operator later had to procure these items. Recall that most vehicle procurements do not incur additional capital costs, but when such costs are incurred they can be expensive.
3. Training time is often specified in the bid document, but sometimes this reflects only part of the training needed. For example, some bid documents included vendor training of bus driver trainers. Once this was complete, the transit agency's trainers trained the drivers. As noted earlier, some bid documents provided some minimal level of training and additional training support could be purchased on a time and materials basis. In both cases, comparing the bid document with past training requirements, the default factors provided in Table 7, and the range of training needs reported in Chapter Two, will help accurately estimated likely needs and costs. Note also that a deployment strategy must be assumed to determine who will likely receive training.
4. Care should be taken when determining the local systemwide cost per mile. The analyst should be fully apprised of what costs are included in the figure to ensure compatibility with other parts of the projection. Ideally, cost per mile would include mechanic and service attendant wages and benefits, and all actual materials expenditures. Some transit agencies exclude benefits, and others include fully allocated costs that include some fixed overhead. Excluding benefits will understate cost impacts, while

including fixed overhead may overstate those costs slightly. Fuel costs should be excluded.

5. In an effort to keep the methodology simple and ensure that the data are available, the model uses the current systemwide maintenance cost per mile to project future cost impacts. It does not attempt to forecast the maintenance cost per mile for the proposed future subfleet alone, assuming systemwide costs per hour as a likely base. Recall that fleet diversity impacts the cost of every fleet operated, not just the new fleet proposed. This methodology introduces some degree of error to the extent that new systemwide costs per mile vary from existing costs. In 14 tests, this methodology produced ongoing maintenance cost estimates that varied from actual reported costs by between 0.2 percent and 4.3 percent. In the latter case, the proposed fleet had a maintenance cost per mile that was 35 percent above the existing systemwide average cost per mile. As indicated, the methodology appears sound and consistent as configured.

6. Systemwide miles per year can be a difficult item to project. The test application used the last available year's mileage rather than forecast values. Again, this can introduce some error if mileage is significantly on the rise or fall. Future expectations can be added into or out of the value.

7. Frequently, transit agencies retain and use buses beyond 12 years. The test analysis used a 12-year time horizon for every fleet, which corresponds to most vehicle depreciation schedules.

As noted earlier in this section, overall, the methodology is simple, repeatable, and appears to be accurate. Prior to use in a new procurement, transit agencies can apply the method to their last procurement as a test and calibration for future use.

Table 21. Amortization factors for amortizing investment cost at 8 percent interest rate.

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

ASSESSMENT OF LIMITATIONS

The research project encompassed an extensive literature search, a broad-based industry survey, and a detailed analysis of bus fleet diversification cost impacts. The detailed analysis included 22 transit agencies and 97 subfleets. The fleet diversification and standardization cost impact methodology developed is generally applicable to any transit agency attempting to evaluate bid prices and fleet-mix implications. While the entire analysis was guided by sound research principles and the results are conservatively stated, there are some limitations inherent in the research and resulting methodology. The users of this report should be cognizant of potential limitations, as discussed below.

Constrained Sample Size

The detailed initial and ongoing costs related to fleet diversity presented in Chapter Two are based on an investigation of disaggregate 35-ft to 40-ft diesel bus costs at 22 agencies, with 97 subfleets. The training requirements analysis is based on greater participation, 66 agencies and more than 150 bus procurements. Although the participating agencies were not randomly selected, every reasonable effort was made to achieve a representative cross section of public transit agencies for vehicle procurement and maintenance analysis purposes. While this was accomplished, the sample had two absolute constraints: (1) each agency had to be able to provide the detailed initial investment and ongoing maintenance cost data required; and (2) each agency had to be willing to provide said data and work with the research team to verify and confirm the data.

Study researchers do not believe that these limitations invalidate the findings and conclusions of this analysis, but there are no data available to confirm or refute that operators without good data available have similar cost experience. This would not impact the validity of the cost impact methodology, which relies heavily on the operators' own experience in calibrating the model. Default parameters are provided for key data requirements which can be used, with prudent judgment, in lieu of local data.

Data Availability and Compatibility

Data availability was a concern, even among the survey respondents. While participating agencies provided data, this information is influenced by individual operator information systems, mechanic reporting practices, parts and materials accounting approach, and overall cost monitoring philosophy. Issues related to data availability and compatibility are discussed in the following paragraphs.

There is no industry standard for detailed maintenance information and cost reporting. Vehicle subsystems and maintenance activities may be defined differently by different operators. Significant operator and research team effort went into defining subsystem and activity components to maximize compatibility for the purposes of this study. Even so, the poor statistical correlations in subsystems other than engines and transmissions may be indicative of reporting variances. At the aggregate level, correlations and confidences were quite higher, indicating greater reliability at summary levels.

Mechanic reporting practices may vary by operator in terms of completeness of reporting and overall accuracy. If a mechanic works on more than one subsystem in general or running repair, does the mechanic report all hours to one subsystem, or divide them? Practices and the degree of oversight on individual mechanic entries vary by agency. These variances may have some impact on overall data analysis and results. In aggregate, it appears that any such deviations are offsetting.

Parts and materials cost reporting exhibits the greatest maintenance cost reporting variances in the transit industry overall. Some operators expense parts when they are received; and others, when they are installed on a vehicle. Further, some operators report parts cost on a last-in first-out (LIFO) accounting basis, resulting in a higher cost than those using a first-in first-out (FIFO) or average cost accounting basis. Finally, parts consumption is not necessarily at a constant level over a vehicle's life. Major subsystem rebuilds, increase or decrease in the inventory size, and international exchange rates can all significantly influence costs for a particular subfleet in any given year. The study team worked with operators to fairly report costs to support analysis, but the extent of variability is still a consideration in interpreting results.

Finally, most maintenance management information systems are not designed to support accounting functions, but, rather, these are designed to support maintenance management decision-making. The checks and balances, controls, and philosophy found in accounting systems is not always present in the maintenance management information system. While significant efforts were made to normalize accounting practices (e.g., wage, benefits, overhead allocation, parts expensing, and cost accumulation), these were adjustments to existing data reporting practices.

Impacts of Operating Characteristics and Policy

Operational and policy differences were not the topic of evaluation in this research effort. These factors do, however, have a significant impact on the overall cost and practices of a particular agency. This research effort has examined and noted the substantive impact of vehicle deployment and manpower assignment policies on fleet mix and cost. Operating policies and conditions likewise impact the overall magnitude of maintenance costs, and can minimize or accentuate the cost implications brought on by fleet diversity and standardization.

The degree of cost variance by subfleet (i.e., 100 percent reported by operators in this research effort) may be to a great degree influenced by differences in environment, deployment and operations, and maintenance policies and practices. This study does not suggest default values for cost by subfleet or subsystem because the factors resulting in those cost differences were not the topic of this research. Without substantive investigation of why subfleets and agencies incurred different cost experience, one cannot assume to achieve similar results.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

General

As transit systems continually seek out opportunities for cost reduction, vehicle procurement looms as a significant target for cost savings. This research effort focused on part of the issue by determining the impact of fleet diversity on transit costs. That is, the analysis assessed the degree to which transit operating and capital costs are influenced by the fact that the presence of diverse vehicle types in the same operating fleet results in higher training, parts, inventory, maintenance and capital costs. A broad-based industry survey indicated that most agencies believe that these cost categories are impacted by fleet diversity (i.e., as more diverse vehicles are added to a fleet, each vehicle type is maintained less efficiently).

This research effort concludes that transit managers and staff are right, in that operating and capital costs generally increase with increases in fleet diversification. Some transit professionals may be surprised, however, that the cost increase is relatively small. This research concludes that ongoing vehicle maintenance costs increase about 3 percent with each distinct vehicle type added to the fleet. One time cost of new vehicle training and familiarization costs generally double when a nonstandard vehicle is introduced into a fleet. Parts inventory also increases with the introduction of a nonstandard fleet, but research indicates that this is generally a temporary condition over the first year of operation. Additional capital costs are infrequently incurred when nonstandard fleets are introduced. When capital costs do occur they are usually relatively minor and relate to specialized tools and diagnostic equipment that are required.

Operating a mixed fleet, which is an industry norm in the United States, is attributed to the low bid procurement focus. Even small transit agencies report more than one vehicle type in the active fleet. The average number of different vehicle types reported by survey respondents is four, with a range from a single vehicle type to eight vehicle types. The normal and continuous exposure to mixed fleets may be a contributing factor in the relatively low impact of fleet diversity on costs. Maintaining mixed fleets over time may have helped operators and employees to address this situation effectively.

Data Availability

The data required to conduct this analysis are quite detailed, addressing labor and parts cost by subfleet and each vehicle subsystem for every operator. The ability of transit operators to provide these data reflects a marked improvement in transit maintenance management information. Most transit operators have had reasonable maintenance management information systems in place for 4 to 6 years. The systems have matured to the extent that managers can get excellent cost and activity information to help guide better decisions regarding preventive maintenance, rebuild and change-out cycles, vehicle utilization practices, bus replacement, and vehicle procurements.

Although maintenance data are much improved over prior years, most systems are designed to meet an individual transit operator's needs without the benefit of any national norms or guidelines. The resultant data are appropriate for internal use by the operator, but some problems exist in sharing information because of inconsistent definitions. The research team expended considerable effort in trying to tailor each operator's data output to a reasonably consistent set of definitions. Even so, several anomalies continue to exist. In the area of labor costs, some operators report actual wage by person, average wage for the system, wages and fringe benefits, or even allocated overhead to labor cost data. These issues are relatively easy to sort out and normalize. It was a bit more difficult to accommodate labor costs related to the bus electrical subsystem, as most operators allocated these costs to various other subsystems. The adjustment process appears to have been successful with regards to the statistical analysis which found sound confidence levels and correlations.

The parts and materials costs were much more difficult to sort out, as indicated by the lower statistical reliability than evidenced in the labor numbers overall. Each participating operator had different internal policies regarding how materials were expended in its maintenance management system. Some operators indicated that they adjusted records for returned parts (e.g., those issued to a mechanic, but not needed) on a vehicle basis, others just adjust the final expense numbers across all fleets. Transit operators indicated that they used different parts costing methods: first-in first-out (FIFO), last-in first-out (LIFO), and average cost in inventory. Some transit operators reduce subfleet parts cost by warranty recoveries for parts that failed under warranty, and others treated these dollars as revenues and did not adjust parts cost figures. Maintenance management information systems rarely support full financial accounting, and resulting dollars must be carefully reviewed as to their purpose.

Fleet Diversity Impact on Training

Vehicle procurements likely result in at least some training or familiarization costs. Staff that may receive training on the new vehicle include drivers, service attendants, and mechanics. Mechanic training falls into several categories, and not every mechanic receives all types of training. These categories include system familiarization, general repair and diagnostics, and component rebuild training. Industry experience demonstrates that training requirements vary significantly, based on the degree of vehicular similarity with existing fleets. New vehicle procurement training requirements for similar and diverse fleets include the following:

1. Driver training on similar vehicles averages 1.5 hours per driver and 5.5 hours on diverse vehicles. All drivers at the yards or divisions of new fleet deployment generally receive training.
2. Service attendant training on similar vehicles averages 30 min per attendant and 2.5 hours on diverse fleets. All attendants at the yards or divisions of new fleet deployment generally receive training.
3. System familiarity training for mechanics averages 5.5 hours for similar vehicles and 15 hours per mechanic for diverse fleets. Inspection and general repair mechanics at the divisions of new vehicle deployment generally receive training.
4. General repair training for mechanics averages 13 hours per person for similar vehicles and 36 hours for diverse vehicles. Running repair and general repair mechanics generally receive this training at the divisions of new vehicle deployment.
5. Component rebuild training averages 16 hours per mechanic for similar vehicles and 40 hours for diverse fleets. This training is usually provided to rebuild staff alone.

Overall, initial training requirements for diverse fleets average three times that associated with new vehicles similar to those already operated.

Fleet Diversity Impact on Inventory

Research indicates that an agency's inventory of spare parts (e.g., measured by average parts inventory per vehicle) may increase as a result of new vehicle procurements. Twenty-two percent of the procurements investigated in this study resulted in total inventory cost increases, at an average increase of $2,124 per vehicle. The increases noted were temporary (e.g., up to one year) as a result of spare parts packages procured with the new vehicles. An increase in inventory does not necessarily imply an increase in parts consumption. The cost is essentially the time value of the invested money, less the increase in parts value over the period of higher inventory. For all practical purposes, no real costs were incurred by operators examined in this study as a result of temporary parts inventory increases.

Fleet Diversity Impacts on Capital Costs

Only a minority of bus procurements resulted in the purchase of additional capital equipment items or modifications to existing facilities. As with training, the cost of capital to a great degree depends on the distribution of the new vehicles among divisions or yards. Special tools and diagnostic equipment were the most commonly cited additional capital expenditure incurred, with about 20 percent of the procurements resulting in some costs (e.g., reported tools cost per vehicle was $388 and diagnostic equipment cost per vehicle was $288). Far fewer operators reported additional capital expenditures to increase parts storage space (e.g., during fleet expansion), to modify bus lifts and lift superstructures, and to alter bus washers or other cleaning equipment.

Fleet Diversity Impacts on Maintenance Costs

Fleet diversity has a small but measurable impact on ongoing vehicle maintenance costs. This research indicates that labor cost per mile increases by $0.006 per additional vehicle type added to the fleet (at the normalized labor rate of $11.42), and parts cost increases by $0.001 per mile per additional vehicle type in the fleet. The cost increase impacts every vehicle in the fleet, and is not limited to the additional subfleet added from the procurement. This cost increase appears to be statistically valid with a high confidence level in the resulting cost relationship. It should be noted that fleet diversity, overall, explains less than 3 percent of the reason for different cost per mile experience of transit operators.

This impact is best measured on a vehicle-type basis, and does not lend itself to a vehicle subsystem by subsystem comparison. The only exception is, perhaps, engine labor costs, which measurably increase with diversity of engine types in the fleet (i.e., each additional engine type added to the fleet increases the engine maintenance cost per mile by $0.002 for every engine type).

SUGGESTED RESEARCH

The transit industry in recent years has been subjected to increasing pressures from a number of forces. While escalation of labor and materials costs have eased somewhat, the prospects for continued inflation and decreased external funding are real. Privatization of transit services becomes more than just a "buzz" word as the decade closes and transit managers must demonstrate that transit service is delivered in the most cost-effective manner. Maintenance cost reporting on a per mile basis is no longer acceptable and transit agencies are rapidly implementing automated cost reporting systems. However, there are no industry guidelines for compiling data, so that information exchange between transit agencies is meaningful.

In the immediate future, the transit industry is faced with introducing buses powered with alternative fuels (e.g., methanol and compressed natural gas). Prototype vehicles are currently operating at a few agencies and the number will increase significantly in the coming year. Transit professionals are predicting that these new fuels will result in major impacts on maintenance programs—far exceeding those that the industry encountered with the introduction of the advanced design buses in the late 1970's.

Maintenance Management Information System Guidelines

Common guidelines for maintenance cost reporting is needed within the transit industry. Each agency has developed its own definitions of vehicle systems and work activities over the years. While there is some common ground, there are wide differences. For example, some agencies include only minor repairs performed during scheduled preventive maintenance procedures in the inspection cost category, while others include the repair of all noted problems. The most significant variance in maintenance cost reporting found in the industry is in the manner in which parts and materials are expensed.

The objective of the suggested research effort is to prepare a glossary of terms and a definition of vehicle subsystems. In addition, methods to handle different cost elements (e.g., parts expensing, major component overhaul (expensed or capitalized)) should be defined.

Attainment of this objective can be accomplished through several means, however. The American Public Transit Association has in place a Bus Maintenance Committee which has active participation of a large number of transit maintenance managers. The tasks to meet this objective are:

1. Conduct a survey of transit agencies to obtain copies of currently used system definitions and methods for compiling different cost elements.
2. Analyze the responses to determine the most common definitions and methods.
3. Prepare preliminary guidelines for maintenance management information systems and distribute for comment.
4. Incorporate appropriate comments to ascertain guidelines that will meet the majority of user needs.
5. Publish recommended guidelines.

Bus Procurement Specifications to Reduce Costs

Transit maintenance managers reported that they have been achieving some standardization of their bus fleets through bus procurement specifications by including requirements for components similar to those in the existing fleets. Additionally, it was reported that some equipment items were specified to lower ongoing operating costs but at an increased initial capital cost. These items include transmissions with integral brake retards for increased brake lift, aluminum wheels for greater heat dissipation to increase brake and tire life, and air starters to reduce demand on batteries, resulting in less frequent battery replacements. The use of stainless steel in areas susceptible to corrosion (e.g., wheel housings) is also specified by some specification writers.

The objective of the suggested research study is to determine the long-range benefits of specifying items to reduce operating costs. Suggested tasks are:

1. Survey transit agencies to identify all items that maintenance managers believe have long-range cost savings.
2. Identify those agencies that can and are willing to provide initial capital costs.
3. Select 25 or more transit operators that can provide detailed cost data for subfleets with and without the cost saving features. Collect the detailed data and follow-up to ensure accuracy and comparability.
4. Analyze the data using commonly accepted statistical methods and assess mathematical findings for logical conclusions.
5. Develop a methodology for evaluating the trade-offs of increased initial capital costs and on-going reduced operating costs.

Bus Cost Parameters

This research effort has addressed the significance of fleet-mix implications for transit cost. Other prior research efforts have likewise addressed the impacts of specific narrow issues (e.g., vehicle age) on fleet cost. These efforts have been valuable in understanding how these subject issues impact cost. Another useful study might be one that ties together the full gamut of capital and operation issues that have major impacts on transit bus costs. This research effort concludes that less than 3 percent of the maintenance cost per mile differences reported by transit operators in this study are explained by fleet-mix issues. Cost per mile varied by more than 100 percent between operators and even between subfleets within a single operator.

What are the other independent variables influencing cost and what impact do they have for initial investments and ongoing maintenance costs? Vehicle type, specific subsystem components and configurations, climate, speed, passenger loads, accident frequencies, number of operating divisions, vehicle age, deployment practices, utilization rates, and local policies are all independent variables likely to significantly impact some aspect of transit cost.

The objective of the suggested research effort is to prepare a rigorous analysis of factors influencing bus maintenance costs, and to develop a forecast technique complete with calibration factors for analyzing operational and policy issues. Attainment of this objective can be accomplished through the conduct of several tasks, as follows.

1. Select 25 or more transit operators with appropriate detailed cost data, and which represent the range of diversity in fleets and operating characteristics found in the United States overall. Review data reporting capabilities and systems to ensure that comparable costs may be gleaned among participating operators.

2. Prepare a detailed data collection guide addressing detailed parts and labor costs by vehicle type and subsystem, operating environment and practices, maintenance policies and approach to major activities (e.g., paint and body work, inspection, running repair, distribution of mechanic responsibilities), and operating results (e.g., mileage accumulation, accident rates, passenger loads).

3. Collect detailed data from each operator and follow-up on responses to ensure accuracy, comprehension, and comparability. Review final, adjusted data with each originating operator.

4. Analyze and evaluate the data reported. Conduct mean, variance, and distribution analyses to assess the range of reported results. Perform correlation, regression, factor, and time series analyses to ascertain the causal factors driving costs and cost differences. Assess all mathematical findings for logical relationships (i.e., Are high correlation variables causal factors, or simply responding to a third independent variable?).

5. Develop a straightforward methodology for forecasting maintenance expense from variables, and for evaluating local policy options in an effort to reduce costs. The methodology should be widely applicable to the diverse range of transit operations in existence.

6. Document results and transfer research knowledge to the industry. Include several application examples for illustrative purposes. Prioritize variables impacting cost by significance and confidence in relationships.

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APPENDIX A—LITERATURE TITLES FOR FLEET STANDARDIZATION

Fleet Mix

"Bus Operators' Needs for the Nineties," Noon, A. J., Mechanical Engineering Publications Limited Box 24, Northgate Avenue Bury Street, Edmunds Suffolk 1P32 6PW England, 1985.

"The Shakeout Begins," Paul, B., Bobit Publishing Company, Metro Vol. 82 No. 7, November 1986.

Life-Cycle Costing

"Cost Effectiveness of Life-Cycle Process in Buying Transit Vehicles Questionable," General Accounting Office, 441 G Street, N.W., Washington, D.C. 20548, September 1983.

"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, RI.

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"Life-Cycle Costing for Current Rohr and AM General Buses and General Motors RTS-II Bus," Kain, H. R.; Marks, G. J.; Staszak, L. A., Advanced Management Systems, Inc., 6825 Redmond Drive, McLean, Virginia 22101; Urban Mass Transportation Administration, 400 7th Street, S.W., Washington, D.C. 20590, July 1976.

"Life-Cycle Cost Demonstration Project for Transit Coaches," Winslow, R. H.; Furniss, R.; Holcombe, G., Urban Mass Transportation Administration, Washington, D.C., June 1987.

"Life-Cycle Cost Evaluation Methods," American Public Transit Association, 1225 Connecticut Avenue, N.W., Washington, D.C. 20036, August 1982.

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"Role of Rehabilitation in Transit Fleet Replacement. Final Report," Secrist, D.; Smith, M., Pudget Sound Council of Governments, Seattle Washington; Department of Transportation, 400 7th Street, S.W., Washington, D.C. 20590, March 1983.

"The Dilemma of Life-Cycle Costing," Bobit Publishing Company, 2500 Artesia Boulevard, Redondo Beach, California 90278, Metro Vol. 79 No. 1, January 1983.

"Small Transit Vehicles How to Buy, Operate, and Maintain Them," Boghani, A. B., Palmer, D. W.; Gott, P. G.; Nayak, P. R., NCTRP, Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, D.C., 20418, January 1985.

APPENDIX B—SURVEY OF INDUSTRY EXPERIENCE IMPACTS OF STANDARDIZED VS. NONSTANDARDIZED BUS FLEETS

AGENCY: ____________________

Recent Procurements

Please list procurements of 35 and 40 foot heavy duty transit buses placed in service in the past four years.

	Manufacturer	Model	Year	Length	Quantity	Expected useful life
Procurement No. 1						
Procurement No. 2						
Procurement No. 3						
Procurement No. 4						
Procurement No. 5						

Differences from Existing Fleet

Did the new buses differ from those in the fleet at the time? Please enter the appropriate number to denote degree of difference.

1. Exactly alike existing buses
2. Minor differences
3. Significant differences
4. Completely new

	Procurement 1	2	3	4	5
Manufacturer					
Model					
Engine					
Transmission					
Electrical					
Brake					
Suspension					
Seats (e.g., cantilevered vs. pedestal)					
HVAC					
Destination Signs					
Wheel Chair lifts					

Please provide comments if there were other noteworthy differences. (e.g., air starters, retarders).

____

____

____

Have you performed a post-procurement analysis on any fleets?

Yes ☐ No ☐

Would you be willing to provide the information for use in this study?

Yes ☐ No ☐

Training Costs Associated with New Buses

Did the new buses cause the agency to spend funds to familiarize employees with the new buses? Please estimate the number of manhours per employee required for training in each of the following areas.

	Procurement 1	2	3	4	5
Operator Training/Familiarization					
Cleaner/Servicer Training					
Mechanic Training					
- System Familiarization					
- General repair/diagnostics					
- Component Rebuild Training					

Please provide any comments on other training cost impacts your agency experienced.

____

____

____

Could your agency provide actual or estimated costs or manhours in any of the above training cost categories by fleet?

Yes ☐ No ☐

Capital Costs Associated with New Buses

Did the new buses cause the expenditure of capital dollars? Please enter the appropriate number as applicable.

1 - No cost impact
2 - Minor cost impact
3 - Major cost impact

	Procurement 1	2	3	4	5
Bus Washing Equipment					
Interior Cleaning Equipment					
Vehicle lifts					
Engine exhaust systems					
Diagnostic Equipment					
Special Tools/Equipment					
Additional Parts Storage Space					
Fluid Distribution (e.g., new ATF dispenser)					

Please comment if other capital expenditures were required.

___
___
___

Could you provide actual or estimated costs in the areas of significant costs impacts?

Yes ☐ No ☐

Costs Associated with Parts Inventory

Did the agency's inventory of spare parts increase (e.g., average inventory per vehicle) due to the new buses? Please enter the appropriate number for each of the subsystems below.

1. Decrease
2. No increase
3. Minor increase
4. Significant increase

	Procurement 1	2	3	4	5
Engine					
Transmission					
Electrical					
Brakes					
Suspension					
HVAC					
Destination Signs					
Wheel Chair lifts					
Body					

Could your agency provide actual or estimated costs for any of the above?

Actual ☐
Estimated ☐
No data ☐

Could you provide the dollar value and number of line items in your inventory before and after the receipt of the new buses?

Yes ☐ No ☐

Did your agency order a spare parts package as part of the vehicle procurement?

Yes ☐ No ☐

Cost Associated with Operating and Maintaining New Buses

Has your agency noted changes in the costs associated with operating or maintaining your new buses compared with other buses in your fleet? Please enter the appropriate number.

1. Decrease
2. No increase
3. Minor increase
4. Significant increase

Procurement

	1	2	3	4	5
Fuel Consumption					
Cleaning/Servicing Time					
Preventive Maintenance Time					
Repair Time					
-Engine					
-Transmission					
-Electrical					
-Brakes					
-Cooling					
-Suspension/Air					
-HVAC					
-Destination Signs					
-Wheel Chair lifts					
Repair Parts					
-Engine					
-Transmission					
-Electrical					
-Brakes					
-Cooling					
-Suspension/Air					
-HVAC					
-Body					
-Tires					
-Destination Signs					
-Wheel Chair lifts					

Can your vehicle maintenance information system report the cost (manhours) areas above for each vehicle type in your fleet?

Yes ☐ No ☐

APPENDIX C—DATA COLLECTION GUIDE

General Instructions

This Date Collection Guide is designed to gather information on the cost of maintaining different bus types (and major components). This data from a number of transit agencies will be evaluated to determine the cost impacts of mixed bus fleets. The guide is divided into the following sections:

- Bus Fleet Profile--This information describes your current bus fleet and its overall usage. It is important that you include the model numbers for buses and components as shown in the following example:

SUBFLEET	No 1	No 2
Average Annual Mileage	35,600	38,400
Year built	84/85	87
Manufacturer	Flx	Gillig
Model	40102-6T	40TB102
No. in fleet	42	36
Engine type	6V92TA	6V92TAC
Transmission*	V731	HTB748
Retarder	N/A	Allison
A/C	ThermoKing	ThermoKing
Brake system	S-cam	S-cam
Suspension system	Solid Beam	Leyland
Farebox	GFI	GFI
Destination signs	Luminator	Luminator
Wheelchair lifts	Lift-U	N/A

Include in the Remarks section any clarification information. Please note if external retarders are installed.

- General Information--Please provide the average mechanic rate that is used in your labor charges in the subfleet/subsystem costs. This will enable us to adjust the various agencies' costs for the study.

- Subfleet Maintenance Costs--Please provide these costs for the latest twelve month period for which information is available. You may provide copies of output reports from your maintenance information system with this data. We will transfer it to our form.

It is preferred that labor costs and parts costs be reported separately, if possible.

- Subfleet Rebuild Costs--Transit agencies differ in their practices in accounting for the costs of rebuilding major components. Some capitalized such costs. Please provide your average cost for rebuilding the components/assemblies listed. Provide the average miles at rebuild for each subfleet. If you have insufficient experience with a subfleet, please provide an estimate of the anticipated mileage. Should your costs or mileage (actual or estimated) vary significantly from that reported by other agencies, we will contact you by telephone to better understand your numbers.

- Capital Associated With New Buses--In the earlier survey of industry experience with recent procurements, it was indicated that information could be provided on the one-time capital costs associated with new subfleets. Please provide your actual or estimated costs as shown.

- Parts Inventory Cost Increase--The survey indicated that the introduction of new buses resulted in minor to significant increases in the parts inventory. Estimates of these increases are requested.

SUBFLEET MAINTENANCE COSTS BY SUBSYSTEM

FOR TWELVE MONTH PERIOD ENDING: ________

LABOR DOLLARS PER YEAR

SUBFLEET	No 1	No 2	No 3	No 4	No 5	No 6	No 7
Inspections							
Body repairs							
Engine repairs							
Brake repairs							
Electrical Repairs							
Air system							
AC/heating							
Drivetrain							
Suspension/steering							
Cooling							
Farebox							
Destination signs							
Wheelchair lifts							
Tires							

PARTS DOLLARS PER YEAR

SUBFLEET	No 1	No 2	No 3	No 4	No 5	No 6	No 7
Inspections							
Body repairs							
Engine repairs							
Brake repairs							
Electrical repairs							
Air system							
AC/heating							
Drivetrain							
Suspension/steering							
Cooling							
Farebox							
Destination signs							
Wheelchair lifts							
Tires							

FUEL USEAGE

SUBFLEET	No 1	No 2	No 3	No 4	No 5	No 6	No 7
Average miles per gallon							

AGENCY: ______________________________

BUS FLEET PROFILE - ACTIVE FLEET

SUBFLEET	No 1	No 2	No 3	No 4	No 5	No 6	No 7
Average annual mileage							
Average cumulative mileage							
Year built							
Manufacturer							
Model							
No. in fleet							
Engine type							
Transmission							
Retarder							
A/C							
Brake system							
Suspension system							
Farebox							
Destination signs							
Wheelchair lifts							

Remarks ______________________________

GENERAL INFORMATION

Mechanic Labor Rate: $________ Please provide the average rate of maintenance work force that is used in determining the labor dollars in the subfleet maintenance cost.

Cleaning and Servicing Cost: $________ per year. Many agencies report these costs separately from their maintenance costs.

COST IMPACTS OF STANDARD VS. NONSTANDARD BUS FLEETS

SUBFLEET REBUILD COSTS

SUBFLEET	No 1	No 2	No 3	No 4	No 5	No 6	No 7
Power Plant Overhaul							
Average mileage at overhaul							
Average cost of overhaul							
Transmission Rebuild							
Average mileage at overhaul							
Average cost of overhaul							
Differential Rebuild							
Average mileage at rebuild							
Average cost of rebuild							
Brakes, front							
Average mileage at rebuild							
Average cost of rebuild							
Brakes, rear							
Average mileage at rebuild							
Average cost of rebuild							
Other							
Average mileage at rebuild							
Average cost of rebuild							
Other							
Average mileage at rebuild							
Average cost of rebuild							

Please provide information on your rebuilding cost experience for other components for which information is available.

Are any of these costs included in the Subfleet Maintenance Costs provided on the previous page?
Please comment ______________________________

CAPITAL COSTS

ONE TIME CAPITAL COSTS DUE TO NEW SUBFLEET

SUBFLEET	No 1	No 2	No 3	No 4	EXPLANATION
Bus Washer					
Interior Cleaning					
Vehicle Lifts					
Engine Exhaust Systems					
Diagnostic Equipment					
Special Tools					
Parts Storage Space					

If actual costs are not available, please provide your estimate and a brief explanation. (e.g. modify existing vehicle lift, engine rebuild stands)

PARTS INVENTORY COST INCREASE

SUBFLEET	No 1	No 2	No 3	No 4	EXPLANATION
Engine					
Transmission					
Electrical					
Brakes					
Suspension					
HVAC					
Destination Signs					
Wheelchair Lifts					
Total Inventory Value*					

*Please report your estimate in the increase (or decrease) in your parts inventory value as the result of new bus procurement.

Note: Earlier your agency completed a survey form which indicated that all or portions of these costs could be provided. A copy is provided for your reference. Please use the same subfleet numbers as shown in the survey.

APPENDIX D—METHODOLOGY APPLICATION

INTRODUCTION

A step by step application of the cost impact of diversification and standardization methodology developed in this report is outlined herein. The methodology is intended to provide a sound, repeatable method for adjusting bid prices to reflect the expected impact of the proposed fleet on initial and ongoing costs related to diversification or standardization. The approach requires rather minimal data input and is easy to apply. The only tools required are a calculator, pen and paper, although the method is appropriate for a computer spreadsheet application.

The methodology assesses both initial costs and ongoing diversification costs attributable to the introduction of a new bus type into the fleet. The approach focuses on whole life costs analysis, but supports an annualized equivalent cost estimate as shown. Both approaches capture both the initial on-time cost of introducing a new vehicle to the fleet, and the ongoing cost related to fleet mix. Note that the method equitably treats expansions and reductions to the number of distinct vehicle types operated in the fleet. The method is applied to both scenarios below.

TEST CASE

Anytown Transit is located in the midwestern United States and is undergoing a new bus procurement. The agency has a single division capable of handling about 300 buses. It is purchasing 57 forty foot transit buses. Only part of the subfleet is being retired.

Table D-1. Data Elements for Application.

Data Item	Bid 1	Bid 2
Diverse Fleets Added (Subtracted)	1	0
New Fleet Similar to Existing	No	Yes
• New Engine in Fleet Now	No	Yes
Total Bid Price	$9,918,000	$10,216,000
Additional Cost of Capital	$24,500	$8,400
Number of Employees to Receive Training		
• Drivers	300	300
• Service Attendants	31	31
• Mechanics	31	31
- System Familiarization	78	78
- General Repair	65	65
- Component Rebuild	18	18
Training Hours per Employee		
• Drivers	3.0 hours	2.0 hours
• Service Attendants	1.0 hours	0.5 hours
• Mechanics		
- System Familiarization	8 hours	6 hours
- General Repair	32 hours	16 hours
- Component Rebuild	64 hours	24 hours
Average Wage Rate		
• Drivers	$15.25/hour	$15.25/hour
• Service Attendants	$11.50/hour	$11.50/hour
• Mechanics	$13.90/hour	$13.90/hour
Average Benefit Rate		
• Drivers	0.250	0.250
• Service Attendants	0.220	0.220
• Mechanics	0.220	0.220
Systemwide Maintenance Cost Per Mile	$0.213/mile	$0.213/mile
Systemwide Bus Miles Driven Per Year	7,750,000 miles	7,750,000 miles
Years to Vehicle Retirement	12 years	12 years

One of the bidders is offering a bus type not included in the current fleet and another bidder is offering a similar vehicle. Expected fleet diversification impacts if this bid is successful are calculated below. Data elements needed to perform the calculations are in Table D-1.

INCREASE IN FLEET DIVERSIFICATION

One of the bids is for a new vehicle type for Anytown Transit. As diversification is expected to impact costs, the bid should be adjusted to reflect these incremental cost impacts.

Calculate Initial Costs

Initial costs are those up front expenditures made to effectively introduce a new vehicle subfleet into operations. These costs include the vehicle bid price, other initial capital costs required (e.g., tools and diagnostic equipment), and training costs. The formula for calculating initial costs is as follows:

$$\text{Initial Cost} = [\text{ Bid Price} + \text{Other Capital Costs} + \left(\sum_{n=5}^{t} (\text{NUMEMP}_t * \text{AVETHR}_t * \text{AVEWAGE}_j * (1 + \text{BENRATE}_j))\right)]$$

Where: NUMEMP = number of employees to receive training; AVETHR = average training hours per employee; AVEWAGE = average wage per employee; BENRATE = benefits as a proportion of wages; t = type of employee training; and j = employee class.

Application of this formula to the case study using the data element in Table D-1 follows:

[$9,918,000 + $24,500 + (300 * 3 * $15.25 * (1 + 0.250)) + (31 * 1 * $11.50 * (1 + 0.220)) + (78 * 8 * $13.90 * (1 + 0.220)) + (65 * 32 * $13.90 * (1 + 0.220)) + (18 * 64 * $13.90 * (1 + 0.220))] = $10,025,515 total initial costs.

Calculate Ongoing Costs

The next step is to calculate the ongoing operating and maintenance cost differences due to fleet mix. Actual operator experience indicates with high confidence that costs increase modestly with fleet diversity, and decrease slightly with fleet standardization. The formula for calculating the stream of net maintenance costs attributable to fleet diversity or standardization is as follows:

Ongoing Cost Difference = [(NVT - EVT) * ($0.007 * (MCMILE/$0.198)) * SYSMILES * LIFE)]

Where: NVT = number of vehicle types in fleet if bid successful; EVT = number of vehicle types in existing fleet; MCMILE = existing systemwide maintenance cost per mile; SYSMILES = systemwide miles operated per year; LIFE = expected useful life of new buses (e.g., 12 years); $0.007 = cost escalation per diverse fleet added; $0.198 = cost per mile reported by study participants.

Application of this formula to the case study produces:

[(5 - 4) * ($0.007 * ($0.213/$0.198) * 7,750,000 * 12)] = $700,318 additional operating costs over fleet life.

Calculate Total Adjusted Cost

The total adjusted bid price is simply the sum of the two products calculated above:

Adjusted Bid Price = Total Initial Cost + Ongoing Cost Difference

Applied to the test case, the result is:

$10,025,515 total initial cost + $700,318 additional operating costs over fleet life = $10,725,833 adjusted bid price.

This provides a single cost figure comprising the total cost impact of fleet diversification or standardization related to this single procurement. As shown herein, the adjusted cost is only 8.15 percent higher than the bid cost demonstrating that diversification has little cost impact on fleet operations. While this exercise examines an increase in diversity, note that no change in diversity and a decrease in diversity all result in changes to the bid price (e.g., other capital, training, ongoing maintenance).

Annualized Equivalent Cost Method

A second method of life cycle cost analysis is annualized equivalent cost. This method spreads the initial investment cost over the useful life of the vehicle, and adds on unadjusted maintenance costs. This method should be used if the operator already employs an annualized equivalent cost methodology. Follow the steps above with two minor adjustments. The first step is to adjust the total initial cost developed above, as follows:

Initial AEC Cost = Initial Cost Above * Amortization Factor

In the case study:

$10,025,515 * 0.1327 (from Table 3) = $1,330,386 initial AEC cost.

The ongoing maintenance cost is calculated using the second formula shown above, but without multiplying the cost by the useful life of the vehicle (i.e., drop the LIFE multiple from the equation). This yields $58,360 ongoing costs due to diversification per year. The sum of the initial and ongoing cost represents the annualized equivalent cost adjusted for fleet diversity and standardization (i.e., $1,388,746).

NO CHANGE IN FLEET MIX

A second bid is for a vehicle type very similar to another fleet operated by Anytown Transit. While additional diversification does not occur if this bid is successful, a cost adjustment must be made to allow fair comparison with the other proposal.

Calculate Initial Costs

Initial costs are calculated using the formula above and the data in Table D-1. The results are:

[$10,216,000 + $8,400 + (300 * 2 * $15.25 * (1 + 0.250)) + (31 * 0.5 * $11.50 * (1 + 0.220)) + (78 * 6 * $13.90 * (1 + 0.220)) + (65 * 16 * $13.90 * (1 + 0.220)) + (18 * 24 * $13.90 * (1 + 0.220))] = $10,268,953 total initial costs.

Calculate Ongoing Costs

The next step is to calculate the ongoing operating and maintenance cost differences due to fleet mix. Application of this formula to the second bid produces:

[(4 - 4) * ($0.007 * ($0.213/$0.198) * 7,750,000 * 12)] = $0 additional operating costs over fleet life.

Calculate Total Adjusted Cost

The total adjusted bid price is simply the sum of the two products calculated above:

$10,268,953 total initial costs + $0 additional operating costs over fleet life = $10,268,953 adjusted bid price.

Annualized Equivalent Cost Method

Using an AEC cost approach, the result is:

$10,268,953 * 0.1327 (from Table 3) = $1,362,690 initial AEC cost.

No additional ongoing maintenance costs are required, so this value is the total AEC cost for fleet two.

COMPARATIVE RESULTS

Anytown Transit has received two bus bids - one which will increase fleet diversification and one which offers continued fleet standardization. The diverse fleet bid is $298,000 less than the standard vehicle bid, a bid price difference of 2.9 percent. Adjusting each bid for diversification and standardization impacts, the cost relationship reverses - the diverse fleet is more expensive by $456,880 than the standard vehicle over the life of the buses. Examining the impacts of diversification has a significant impact on the bid award and the operator's understanding of cost impacts, as demonstrated in this case study.

Table D-2. Fleet Mix Cost Impact Worksheet

A. Calculate Initial (One-Time) Investment Cost

1. Bid Price $________
2. Other Capital Costs $________
3. Driver Training Costs
   (________ (# drivers to be trained) * $________ (driver wage rate) * (1 + ________ (driver benefit rate))) = $________
4. Servicer Training Costs
   (________ (# servicers to be trained) * $________ (servicer wage rate) * (1 + ________ (servicer benefit rate))) = $________
5. Mechanic Training Costs -- System Familiarization
   (________ (# mechanics to be trained on system familiarization) * $________ (mechanic wage rate) * (1 + ________ (mechanic benefit rate))) = $________
6. Mechanic Training Costs -- General Repair
   (________ (# mechanics to be trained on general repair) * $________ (mechanic wage rate) * (1 + ________ (mechanic benefit rate))) = $________
7. Mechanic Training Costs -- Component Rebuild
   (________ (# mechanics to be trained on component rebuild) * $________ (mechanic wage rate) * (1 + ________ (mechanic benefit rate))) = $________
8. TOTAL INITIAL COST (Sum 1 - 7) $________

Table D-2. Fleet Mix Cost Impact Worksheet (Continued)

B. Calculate On-Going Cost Difference

1. Net Change in Number of Diverse Fleet Types

____________	-	____________	=	________
number of vehicle types if bid is sucessful		number of vehicle types in existing fleet		

2. Cost per Mile Difference

   ($0.007 * (____________/ $0.198)) = $________

   existing systemwide maintenance cost per mile

3. Total Systemwide Vehicle Miles per Year ________

4. Vehicle Useful Life (e.g., 12 years) ________

5. TOTAL ON-GOING COST DIFFERENCE $________
   (1 * 2 * 3 * 4)

C. Calculated Adjusted Bid Price $________
   (A8 + B5)

D. Calculate AEC Cost

1. Initial Cost
   ($________ * ____________) = $________
   B8 Amoritization Factor

2. On-Going Cost
   (________ * ________ * ________ = $________
   B1 B2 B3

3. TOTAL AEC COST
   (Sum B1 and B2) $________

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