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Contents

Foreword

Members of the TRB Committee on Transit Bus Maintenance have established performance measurement in maintenance as one of the priority areas for committee attention. Weaknesses related to performance measurement discussed in the papers of this Record substantiate that decision. An evaluation of some uses of data for management of transit bus maintenance based on responses to a questionnaire circulated by the American Public Transit Association (APTA) indicated that managers may not have enough established performance indicators to adequately control progress of maintenance systems toward performance objectives.

Review of the responses to the APTA questionnaire indicated biases toward only two attributes and favoring simple indicators. This result may indicate lack of balance in maintenance performance practices. Although only 2 attributes appeared to be favored from a list of 36 performance indicators cited in the original questionnaire, causes for concern are the submission by respondents of 656 other indicators and the fact that indicators developed from a similar questionnaire circulated 30 years ago do not rank in the top 10 today.

Maintenance costs for transit buses are a function, not only of management acumen, data quality, and use, but of the physical conditions under which the buses operate. One could hardly compare the cost for maintaining air conditioners in the southwest with that in the upper midwest or the cost of correcting body and undercarriage corrosion in the southwest with that for buses operating on heavily salted streets and highways in the north. However, relationships were identified between, for example, the quality of maintenance and miles per gallon in steeper environments.

Use of data banks to permit estimates of maintenance costs by element and maintenance function was suggested. Cost element contributions to total maintenance cost were identified, and graphs for estimating total maintenance cost dependent on fleet size and annual vehicle miles are presented.

Vehicle Maintenance: Cost Relationship and Estimating Methodology

JEFFREY E. PURDY AND JOHN D. WIEGMANN

An investigation into maintenance costs and programs at transit properties throughout California is summarized. The objectives of the research were to study and report on maintenance cost information, and on the need for maintenance management support. The materials presented in this paper are intended to aid maintenance managers in planning, managing, and controlling maintenance costs and effectiveness. Cost relationships are presented for the estimation of maintenance costs by element and maintenance function area. Graphs are presented for estimating total maintenance cost dependent on fleet size and annual vehicle miles. Cost element contributions to total maintenance cost are identified for repair, inspection and servicing labor, fringe benefits, and overhead; maintenance administration, material, and supply cost rates are also provided.

Providers of public transportation are being challenged by high costs, dwindling sources of support funds, and pressures to improve services. To meet these challenges, managers must balance the need to take cost reduction measures against the need to provide adequate budgets for maintaining and extending revenue equipment life.

The direct impact of inadequate maintenance on vehicle life is well documented and well known to professionals. The importance of maintenance planning and cost control is not as well documented, but is equally critical to transportation managers. In the transit industry, maintenance costs

- Can account for more than 30 percent of total costs, if fully identified;
- Have increased 33 percent faster than vehicle operations costs in recent years;
- Have increased four times faster than general/administrative costs in the same period.

The industry has responded by concentrating management resources on maintenance costs and systems.

MAINTENANCE: A CRITICAL MANAGEMENT ISSUE

Managing Maintenance as a Cost Center

Many transportation providers focus on critical maintenance issues by managing the maintenance function as a cost center. This philosophy can be (and is) applied successfully by providers over the entire spectrum of operation sizes and service offerings. Small and large properties almost invariably treat maintenance as a cost center for the following reasons:

- The magnitude of maintenance costs demands direct control and scrutiny;
- The human, material, and facility resources applied to maintenance are usually unique to this function;
- Costs can be separately collected and tracked; and
- Performance measures that reflect maintenance effectiveness and efficiency can be established.

The share of maintenance costs as part of total costs is often more than managers realize or for which they can account. Some of the maintenance resources applied to small and medium-sized transit fleets may be shared or provided by other local government organizations. Because costs picked up by other entities are not always figured into the overall maintenance costs, the real cost of maintenance is often masked. Subcontracting some functions can also mask real costs, depending on the accounting methods used.

Maintenance resources and capabilities in small organizations are as specialized and unique as in large ones. In small properties, practicality often dictates that staff and management perform more functions than just maintenance. This requirement may place a larger number of training and learning requirements on the staff, but it should not prevent allocating time and cost to the proper cost center.

Critical to establishing and effectively managing a cost center is having the capability to measure and attribute performance to the center. Vehicle and equipment maintenance lends itself well to performance indicator monitoring that enables managers to monitor performance in particular areas by evaluating specific indicators in those areas.

By breaking down areas into indicators and calculating the effects of those indicators, the manager can make reliable cost estimates and develop effective budget guidelines. This cost center strategy facilitates managing maintenance processes and functions.

Structuring Maintenance Processes and Functions

In revenue vehicle maintenance, the processes and functions that must be performed are universal. The challenges in managing these functions involve properly balancing resources among the functions and avoiding the temptation and penalties of short-range thinking. The overall relationship between effective maintenance programs and successful delivery of transportation services is clear and strong, but the long-term effects of specific maintenance management deficiencies are not always obvious or immediate.

Booz-Allen & Hamilton Inc., Transportation Consulting Division, 400 Market Street, Philadelphia, Pa. 19106.

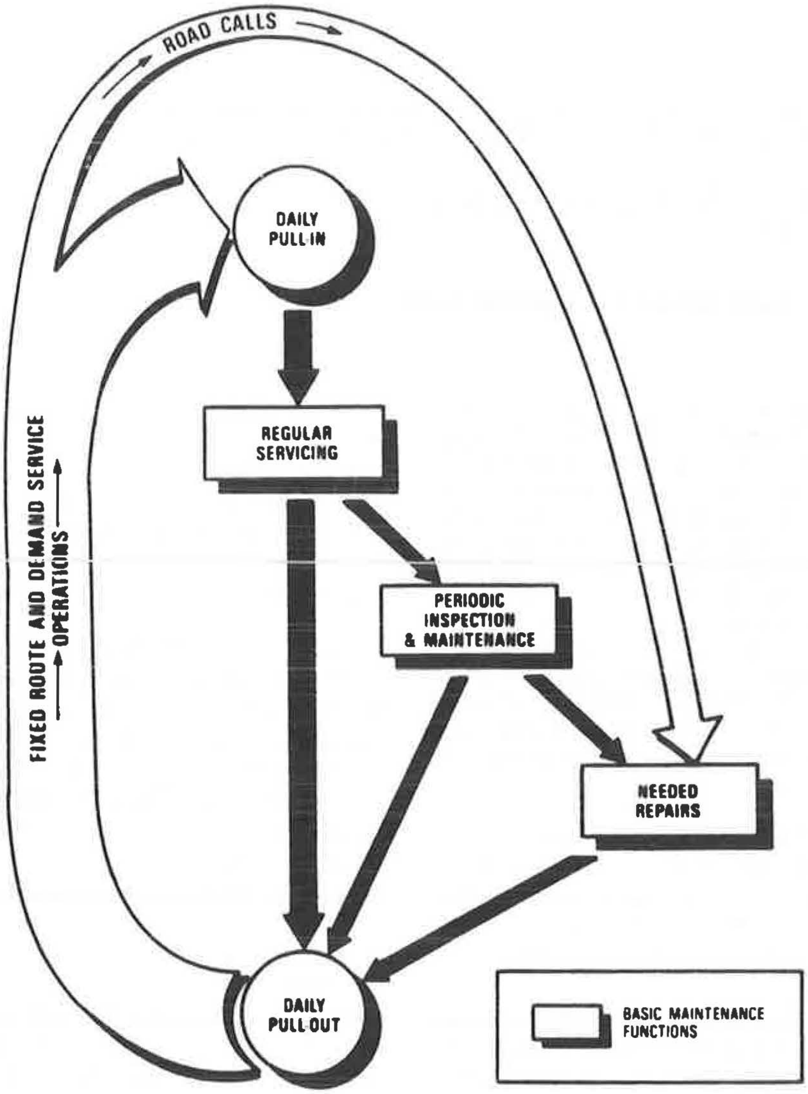


FIGURE 1 Relationship of basic maintenance functions.

Figure 1 shows the relationship of the three basic maintenance functions to overall transportation operations. Servicing, inspection and maintenance (I/M), and repair are functions that are indispensable to operations on a daily or periodic basis. How frequently repairs are needed is related largely to the effectiveness of the servicing and I/M programs. Failure to apply appropriate resources to any of the three basic functions has certain and predictable negative impacts on transportation services, or requires continuous, large investments in new equipment. For properties large or small,

- Too little service capacity limits daily vehicle availabilities—an immediate effect;
- Neglecting periodic I/M cuts vehicle life and availability and increases road calls—deferring but increasing expenditures; and
- Poor-quality or slow repair work increases road calls and can steadily reduce availability, slowing transit services.

Problems with vehicle life and availability rates directly translate into the need to expend scarce capital to replace or increase the size of the transit fleet. Road calls are, of course, a major transportation service quality issue.

Revenue for vehicle maintenance is either a cornerstone or a bottleneck. When managed well, it is important but is not noticed. Problems with maintenance are highly visible and have a deep impact on the transportation provider. Properly allocating resources to the basic maintenance functions is a matter of defining clearly the overall requirements and balancing the resources well. Put another way, there is little benefit to be derived from too much capability in any one functional area, but shortfalls can be punishing and can drive up costs.

Typical flow of work and of information in transit maintenance is shown in Figure 2. In this simplified diagram, the basic functional areas are shown as rectangles with flows of equipment, materials, and information indicated by appropriate arrows. Key, minute-to-minute decision points and management actions are shown as circles. In some way, all these actions and functions occur in even the smallest transit organizations. The features that tend to vary with the scope of transit operations are

- The degree to which responsibilities for more than one function are consolidated in individual managers; and
- The extent to which some or all of the functions are

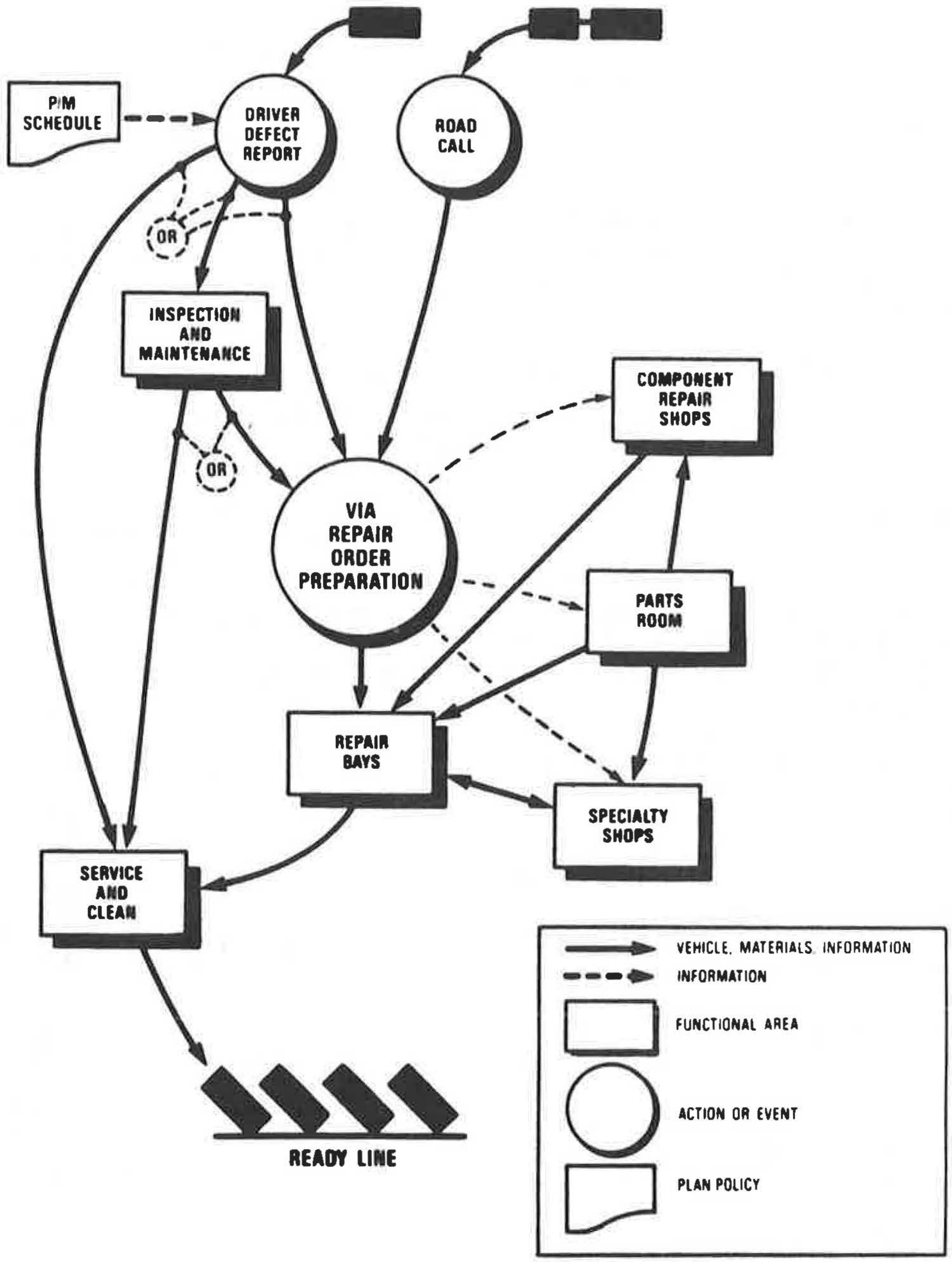


FIGURE 2 Typical work flow for maintenance functions.

contracted or performed outside the direct supervision of the transit provider.

As buses pull in after completing operations, one of three directions can be taken in the work flow, as follows:

- If a driver reports a defect needing immediate repair, the vehicle queues for repair by the preparation of a repair order;
- If the preventive maintenance plan or policy calls for I/M at the time, the vehicles is routed to the I/M function queue; and
- If neither of the preceding conditions holds, the vehicle is routed through the service-and-clean function.

Driver's defect reports, I/M, and road calls can all result in identification of a needed repair. In this case, a repair order is the key authorization and control document. Preparation of the repair order authorizes activity and provides planning information in the repair bays, the parts supply function, and the component and specialty shops (body and paint, upholstery, etc.), if necessary.

The repair order, driver's defect reports, preventive maintenance schedule, I/M reports, and road call reports form the basis of most production control and performance measurement systems in transit. Most other information on parts inventory, vehicle histories, fleet condition, and trends are keyed or reconciled to these reports.

The typical work flow is presented as a guide and reminder to transit managers that each of the basic functions and processes shown should be evaluated, allocated proper resources, and monitored, whether or not these functions have separate organizational entities.

RESEARCH APPROACH

The purposes of the research effort presented in this paper were to assess the maintenance information problem, to provide materials, and to aid transit maintenance managers. Its objectives were to

- Study and report on maintenance cost information collected and monitored by transit operators in California;
- Inform managers of and sensitize them to the significance of maintenance costs; and
- Develop rules of thumb that managers can utilize in developing and structuring an effective maintenance program.

The study was conducted in two phases during the fall of 1985 and early 1986.

STUDY PERFORMANCE

Phase 1 of the study included several activities focused on obtaining the participation of California transit organizations that provide motor buses and demand responsive transit. At the onset of the study, 501 organizations were canvassed for basic budget data and fleet composition. From the returned questionnaires, 68 transit properties were selected for comprehensive cost element and maintenance function expense identification based on availability of cost data and minimal use of maintenance contract service.

A further screening conducted through a telephone interview produced 28 transit properties for participation in the final onsite data collection effort. The purpose of the final effort was to develop cost element and maintenance function expense distributions and patterns. Data from some transit properties were not included in the distributions due to the following factors: inadequate cost accounting, unavailability of staff to assist project team members, and difficulties in meeting project schedule requirements.

Products of the Phase 1 effort were focused on quantifying cost element relationships and functional area cost distributions. The products included

- Total cost distribution by fleet size into operating budgets, maintenance budgets, and general administration budgets;
- Maintenance cost distribution by fleet size into cost elements that included direct labor, fringe benefits, overhead, maintenance administration, and material and supply expense; and
- Maintenance cost distribution by fleet size into function areas that included servicing, I/M, running repair, corrective maintenance, wheelchair system repair, and road call expense.

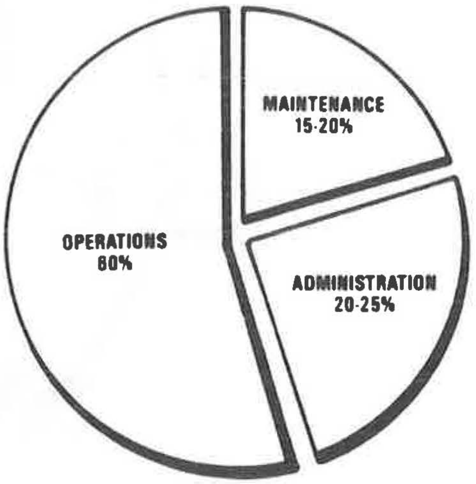
Phase 2 of the study synthesized maintenance cost and program guidelines to assist managers in program development. Maintenance cost guidelines were developed following basic transit cost allocation techniques and cost building methodologies based on cost elements. The cost allocation and estimating methodologies were calibrated for use by California properties based on cost trends and patterns identified in Phase 1. Maintenance planning and management guidelines were developed to focus and aid managers in establishing and evaluating the programs. The materials, though intended for use in California, are easily used by transit managers anywhere in the country, because cost relationships and proportional distributions are identified.

MAINTENANCE SHARE OF TOTAL OPERATING EXPENSE

Maintenance costs are well worth careful attention in budgeting transportation services. In fleets of fewer than 25 vehicles, maintenance costs are almost always in the hundreds of thousands of dollars; in larger fleets, costs are usually in the millions of dollars. Maintenance also makes up a large slice of total costs and is a good target for cost improvement efforts. The general distribution of costs found among transit providers in California is shown in Figure 3 for two broad categories. In both cases, the operating budgets (including drivers dispatchers, running costs, etc.) fall in a narrow band at about 60 percent. The remaining budgets are divided between

- Costs clearly identified by the organizations as maintenance—service, I/M, and repair; and

UNDER 100 VEHICLES



100 VEHICLES OR MORE

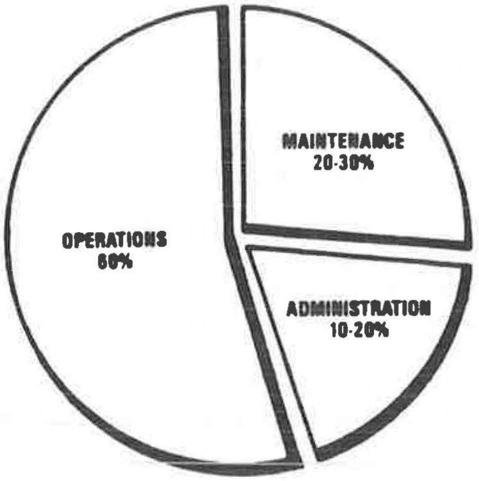


FIGURE 3 Typical budget distributions.

- Costs for administrative functions including general management, legal, marketing, and planning.

For properties operating fewer than 100 vehicles, costs accounted for (and specifically identified) as maintenance costs typically amounted to between 15 and 20 percent. The remaining nonoperations costs are identified as administrative and as other. For properties with 100 or more vehicles, operating costs average about 60 percent of the total, but a large proportion of budget (20 to 30 percent) can be specifically attributed to maintenance. Many factors dramatically influence maintenance costs; those factors must be considered on a case-by-case basis as specific transit properties are addressed.

The tendency for larger organizations to identify a larger portion of costs as maintenance may well be due to the scale and specialization of activities.

- Larger organizations are more likely to assign and fully dedicate management personnel to purely maintenance functions.
- Costs of all kinds tend to be accounted for in greater detail and specificity in larger organizations, permitting clearer definition by function.
- Systematic preventive maintenance programs are more common and elaborate in the larger properties because the fleets are too large for a diagnostic response approach in which knowing when maintenance is needed is based on observation and judgment.
- Information systems, work order control, and other monitoring and records needs tend to increase with scale of operations.

Notwithstanding the variation in budget proportions that can be expected over a spectrum of transit system sizes, the most powerful factors that influence costs are as follows (in order of impact):

- Total operating miles per year,
- Number of units operated, and
- Prevailing wage and cost structure in a locality.

As will be shown in the next section, these factors (in the order shown) far outweigh other maintenance planning considerations. Any one of the factors can, by itself, change the order of magnitude of a maintenance budget estimate if all other factors remain constant.

DEVELOPING BUDGET COST ESTIMATES: BASIC ASSUMPTIONS

Estimation of a total maintenance budget and costs depends on a host of variables that are fleet and property specific. Managers should examine the assumptions and generalizations underlying the development of the guidelines in order to interpret and apply the guidelines in specific operating and maintenance environments. When significant discrepancies occur between the actual costs and those identified by the guidelines, the cause of the discrepancy should be investigated. The investigation should explore the assumptions underlying the guidelines and examine areas where productivity and efficiencies can be achieved.

In this section the factors and trends are discussed and specific assumptions for developing the material for estimating total maintenance cost are presented.

In general, cost rates (e.g., cost per vehicle) are expected to increase as fleet size becomes larger. As fleet size increases, transit properties tend to use standard (40-ft) transit buses for the bulk of their fleet, whereas small properties use a mix of small (30-ft) buses, modified vans, and other specialty vehicles to provide transportation service. Larger vehicles typically have greater maintenance requirements due to their heavier weight and the manner in which they are deployed.

Geographic location also influences cost rates in California because the major urban centers (e.g., San Diego, San Francisco, and Los Angeles) have some of the highest cost-of-living rates in the country. Larger properties in California tend to be located in regions with higher cost-of-living rates (i.e., for salaries, wages, and rents), causing fringe benefit and overhead expenses to escalate as competition for skilled labor is encountered and adequately sized facility sites compete with other potential land use.

For the same reason, salaries and wage rates increase as the property's size increases. However, numerous small transit properties are also located in areas with high cost (in wage rates) relative to small properties operating in more rural environments. For these reasons, typical wage rates for various property sizes and locations were developed for estimating total maintenance costs. Typical wage rates such as the following were used to determine direct labor costs.

	Typical Wage Rates ($/hr)			
	Mechanics		*Servicers*	
Property Size (no. of vehicles)	*Low*	*High*	*Low*	*High*
1–9	9.00	12.00	5.50	8.50
10–24	7.00	12.00	5.50	8.00
25–99	11.00	13.00	7.50	8.50
100+	11.30	15.80	8.50	12.50

Small transit properties, with 1 to 9 vehicles, tend to have higher wage rates than properties with 10 to 25 vehicles. Small transit properties operating in low-cost rural areas and in small-employment markets often must offer higher wages for skilled diesel mechanics because these regions tend not to need skilled diesel mechanics beyond the transit property itself. In high-cost areas, small operations must compete with several organizations such as other transit properties and alternative businesses to attract relatively unskilled bus servicers and washers. The competition tends to increase wages most significantly for this category.

In the following table, representative fringe benefit and overhead factors are presented as percentages of direct labor expense.

	Fleet Size (no. of vehicles)			
Cost Element	*1–9*	*10–24*	*25–99*	*100+*
Fringe benefit factor	0.30	0.30	0.30	0.45
Overhead factor	0.15	0.15	0.15	0.20
Maintenance administration ($/veh)	2,000	5,000	5,000	5,000

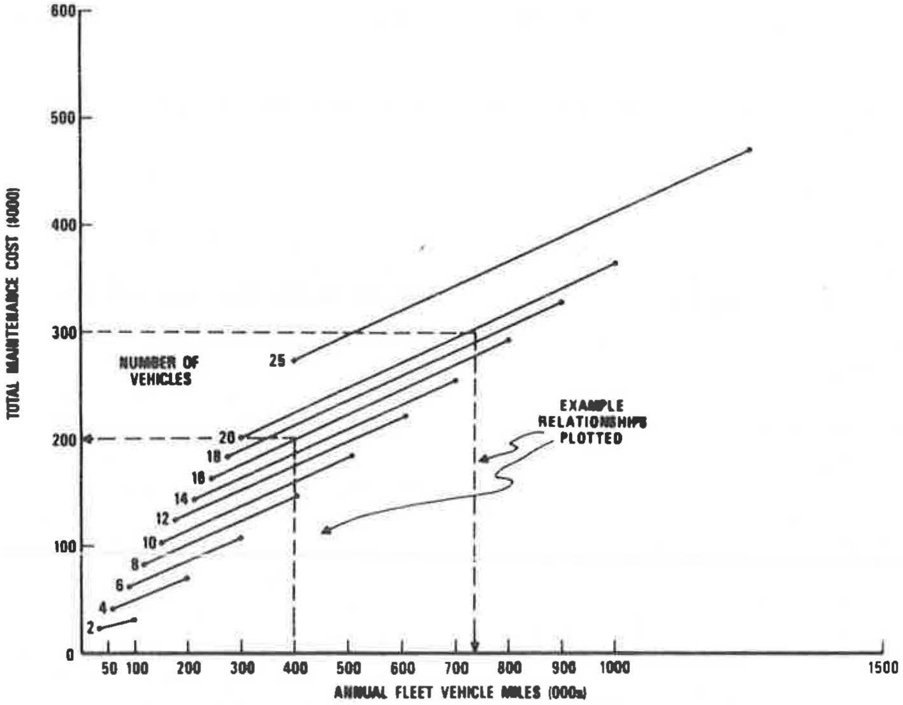


FIGURE 4 Total maintenance costs for fleets of 1 to 25 vehicles in high-cost area.

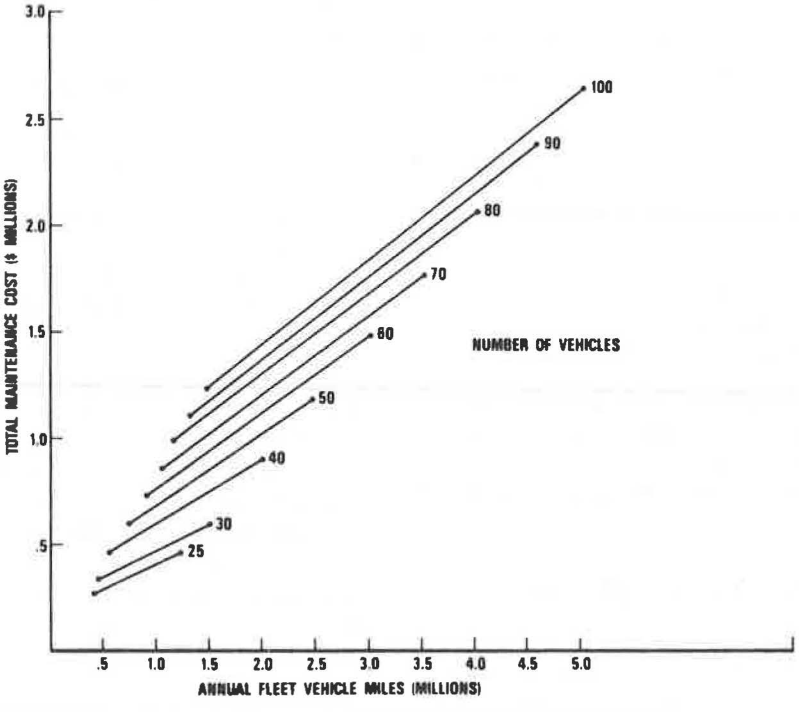


FIGURE 5 Total maintenance costs for fleets of 25 to 100 vehicles in high-cost area.

The table also presents estimates of approximate maintenance and administrative costs per vehicle. Generally, the cost factors provided in the exhibit are shown to escalate as fleet sizes increase. The forces behind the escalation include geographic location and fleet characteristic differences between small and large properties.

TOTAL MAINTENANCE COST ESTIMATE

Total maintenance cost curves were developed as a function of the annual fleet vehicle miles and total fleet size. Traditional transit cost allocation models typically use these two variables as well as vehicle operating hours. However, vehicle operating

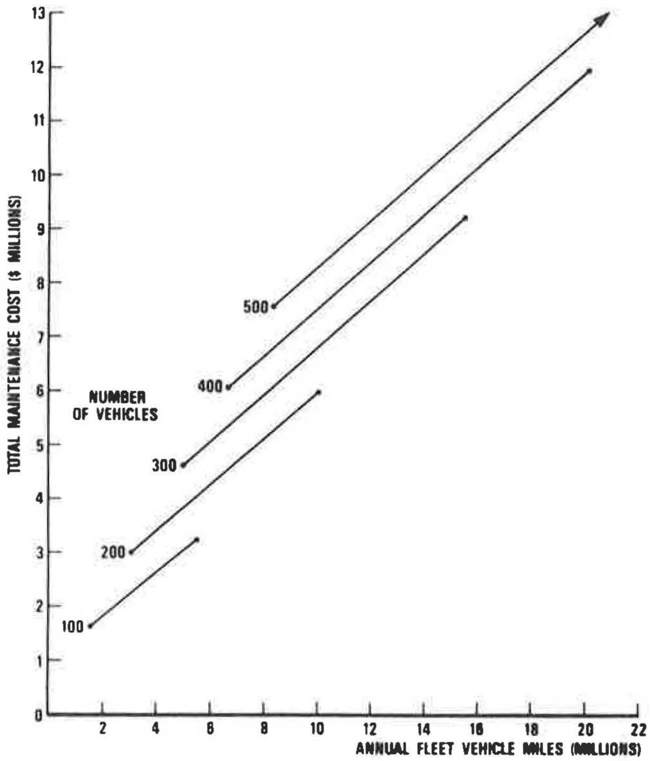


FIGURE 6 Total maintenance costs for fleets of 100 or more vehicles in high-cost area.

hours are primarily the driving factors behind operating costs, whereas vehicle miles and fleet size are primarily drivers of maintenance cost and fixed costs (e.g., general and administrative costs).

Total maintenance cost curves in Figures 4–6 reflect estimation of costs based on an assumed typical high-wage cost area.

The exhibits correspond to fleet size groupings of 1 to 25 vehicles, 25 to 100 vehicles, and 100 or more vehicles. Cost curves for low-wage cost areas are provided in Figures 7–9 for the same fleet size groupings. The cost of fuel is not included in total maintenance cost for any set of curves.

On these charts as fleet size becomes larger, the annual fleet mileage appears more important in determining maintenance cost. That is, the range of total maintenance cost for a given fleet size becomes larger as annual fleet mileage increases. This trend is explained by a tendency toward increased vehicle utilization rates; therefore, maintenance requirements increase as more inspections are performed, and components reach maximum service lives more quickly.

For small fleets (1 to 25 vehicles), the number of vehicles tends to be the predominant factor in determining maintenance cost. For these fleets, the maintenance labor requirements are generated primarily by fueling and other routine service activities that are controlled by the number of vehicles used in a day.

Managers of transit properties approaching a fleet size of 100 vehicles should use the charts with caution because there are some discontinuities at the 100-vehicle fleet size. For fleets of about 100 vehicles that operate in a major urbanized area, managers should use the charts for 100 or more vehicles. These charts reflect higher cost-of-living rates and other economic factors associated with the major urbanized regions of California.

Examples of the use of these charts can be shown in Figure 4.

1. A motor bus operator with a fleet of 16 buses operating about 400,000 veh-mi/year in a high-cost area checks for an appropriate budget order of magnitude. The operator locates 400,000 mi on the lower axis of Figure 9 and plots vertically to

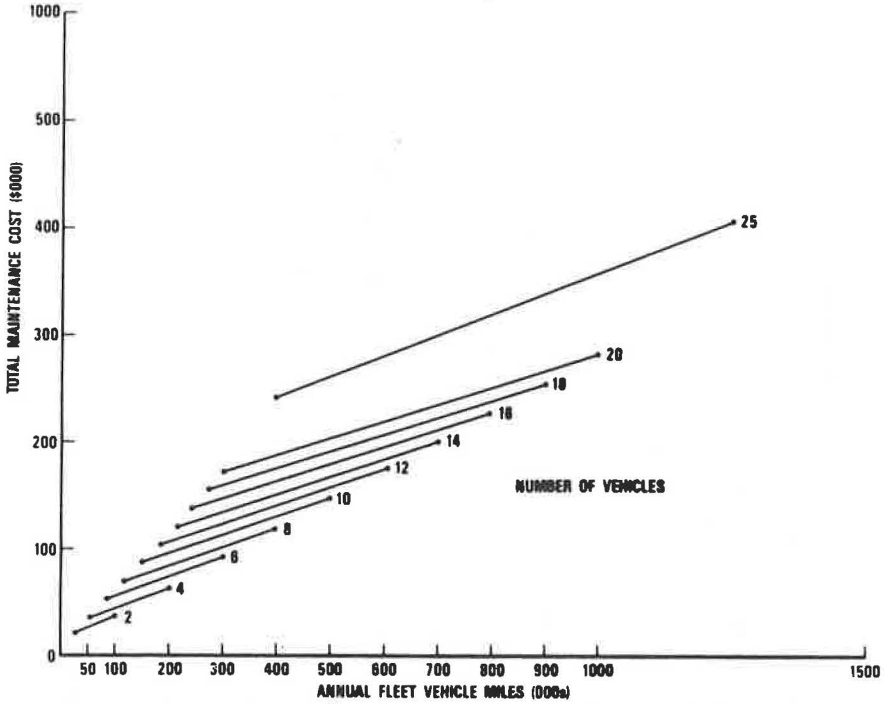


FIGURE 7 Total maintenance costs for fleets of 1 to 25 vehicles in low-cost area.

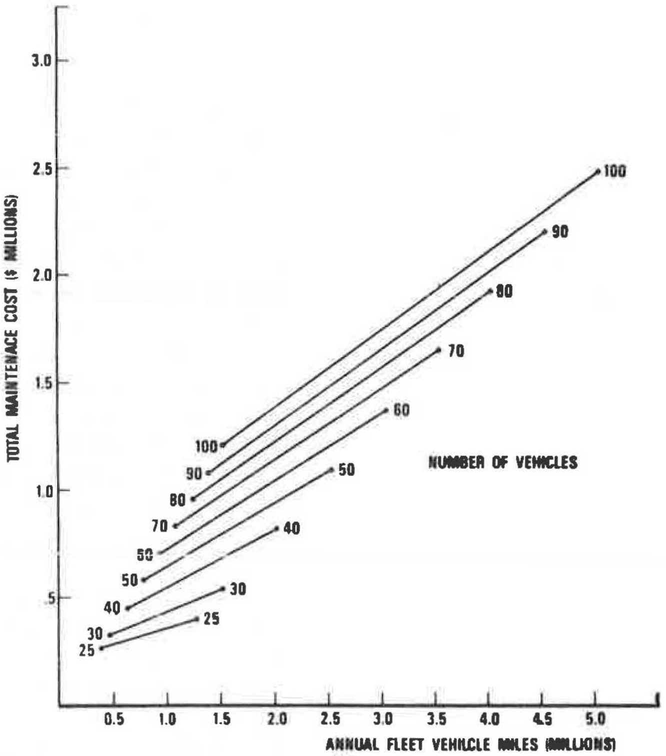


FIGURE 8 Total maintenance costs for fleets of 25 to 100 vehicles in low-cost area.

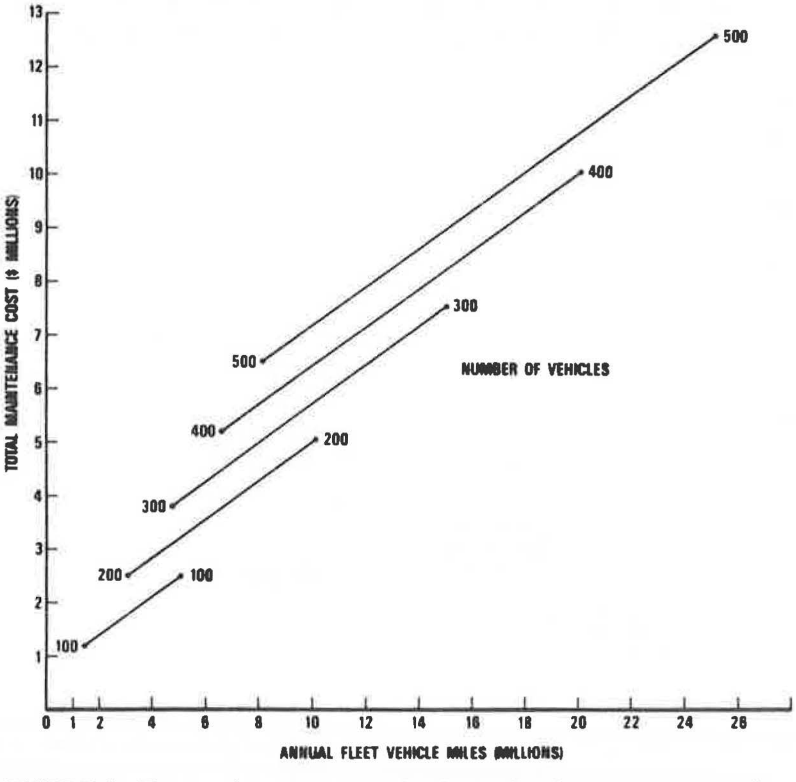


FIGURE 9 Total maintenance costs for fleets of 100 or more vehicles in low-cost area.

a point on the 18-vehicle line. The overall $200,000 cost estimate is read on the left axis level with the point plotted.

2. An operator of 20 buses in a high-cost area with an annual maintenance cost of $300,000 wants to compare his program with typical expectations. The operator locates $300,000 on the left axis and plots horizontally to the 20-bus fleet line. The operator reads about 725,000 veh-mi/year on the lower axis directly below the point. If the operator is operating significantly less total mileage, yet sustaining $300,000 in maintenance costs annually, he should examine his program to find the reason for the departure, highlighting either a problem or a logical explanation of the difference.

BUDGETING THE COST ELEMENTS

The development of maintenance budget estimates relies on the identification and allocation of expenses to five basic cost elements as shown in Figure 10. Each cost element can be further segmented to provide increasing levels of detail. However, for general budget guideline purposes, it is appropriate to segment the direct labor cost element into three basic functional areas, and to divide material and supply costs into consumable and nonconsumable categories. As the exhibit shows, some organizations may further disaggregate repair labor into four additional categories—running repair, corrective maintenance, wheelchair equipment repair, and road calls. However, even in larger organizations, the necessary distinctions are too fine or data quality is too low to correctly allocate and monitor to this level. In fact, a good example of this problem is in wheelchair equipment repair; many organizations report wheelchair-related road calls are so frequent that most repair of this equipment is performed in connection with the road calls.

Total Direct Labor Proportion of Maintenance Cost

Estimates of the percentage of direct labor to maintenance costs are provided in Figures 11–13. Again, the charts correspond to fleet sizes of 1 to 25 vehicles, 25 to 100 vehicles, and 100 vehicles or more. The charts show that direct labor costs tend to be more volatile for small transit properties as the number of vehicle-miles increases than they are for large transit properties. As fleet size increases, direct labor costs represent a smaller percentage of total cost and the percentage range decreases, reflecting less sensitivity to incremental maintenance needs.

Direct Labor Budget by Functional Area

Managers are advised to budget direct labor costs by functional area to account for differential wage rates and staff specialization. Disaggregation between repair activities and I/M activities should be made because mechanics performing preventive maintenance activities are typically paid less than mechanics responsible for component overhauls and rebuilds. Servicing labor cost should also be separated because personnel responsible for fueling, washing, and cleaning vehicles are typically the lowest paid of the maintenance labor force.

Figures 14–16 show charts for estimating the direct labor percentage of total maintenance costs for repair activities according to different fleet size groups. Figures 17–19 show charts for estimating inspection labor costs.

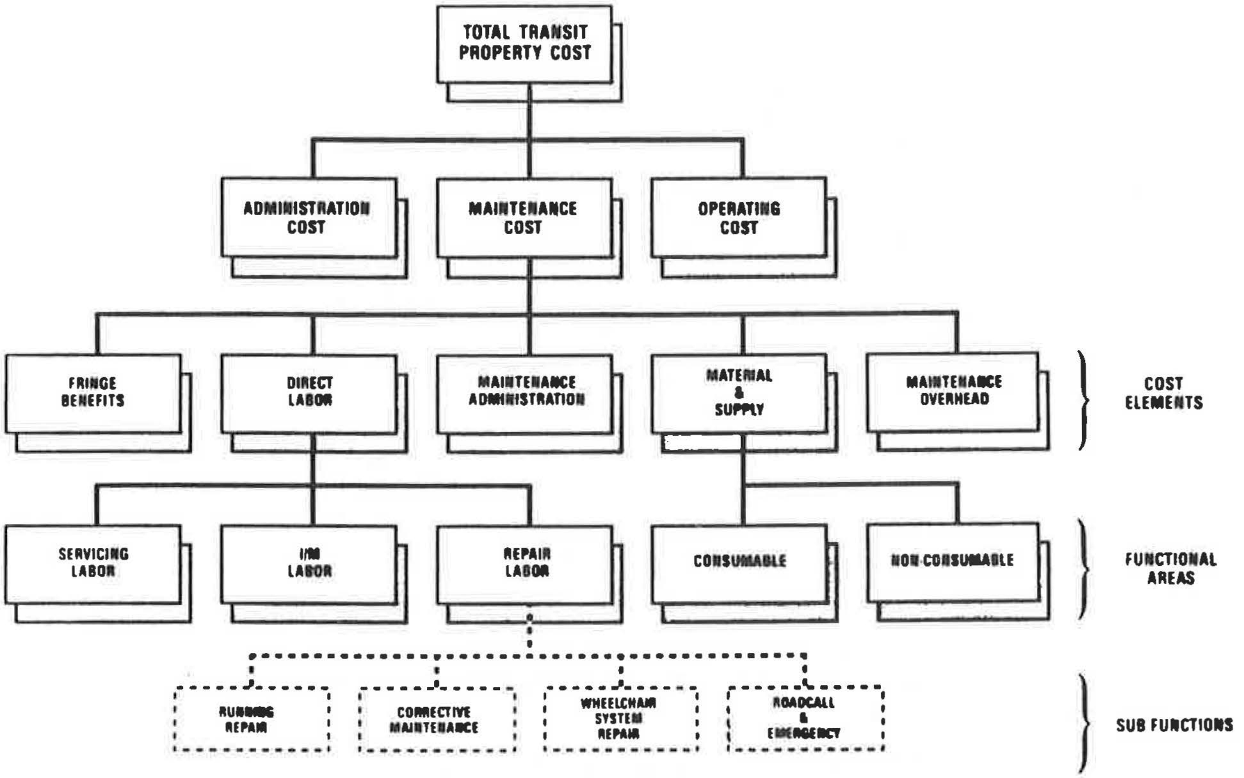


FIGURE 10 Maintenance cost disaggregation.

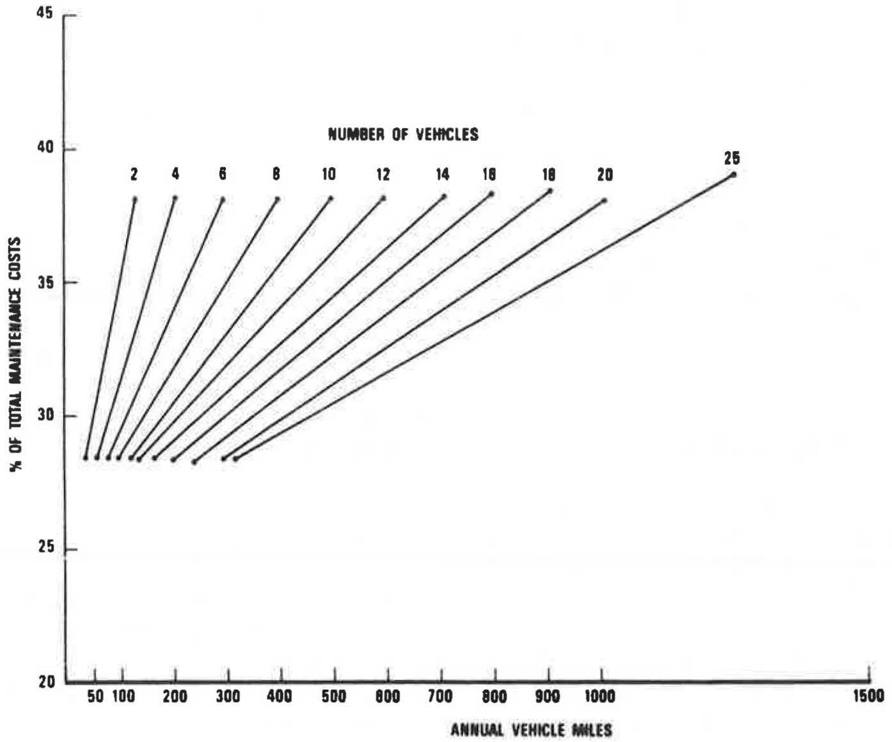


FIGURE 11 Total direct labor cost percentage of total maintenance costs for fleets of 1 to 25 vehicles.

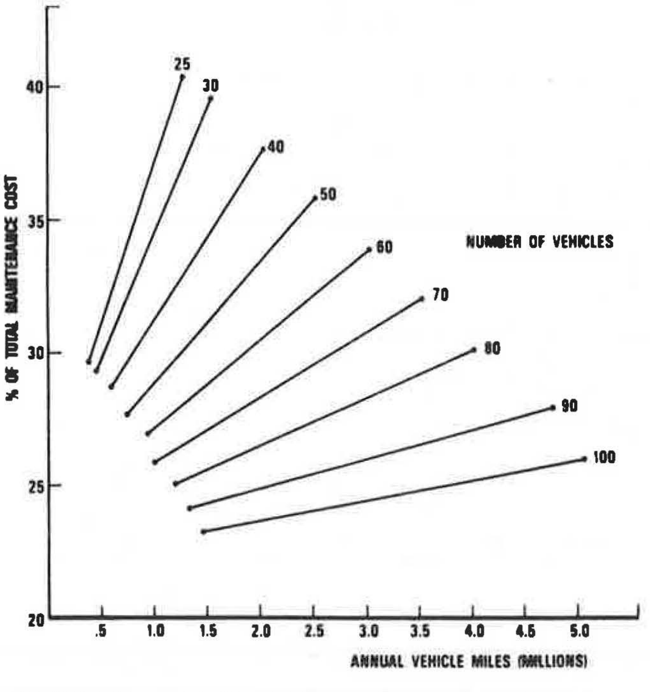


FIGURE 12 Total direct labor cost percentage of total maintenance costs for fleets of 25 to 100 vehicles.

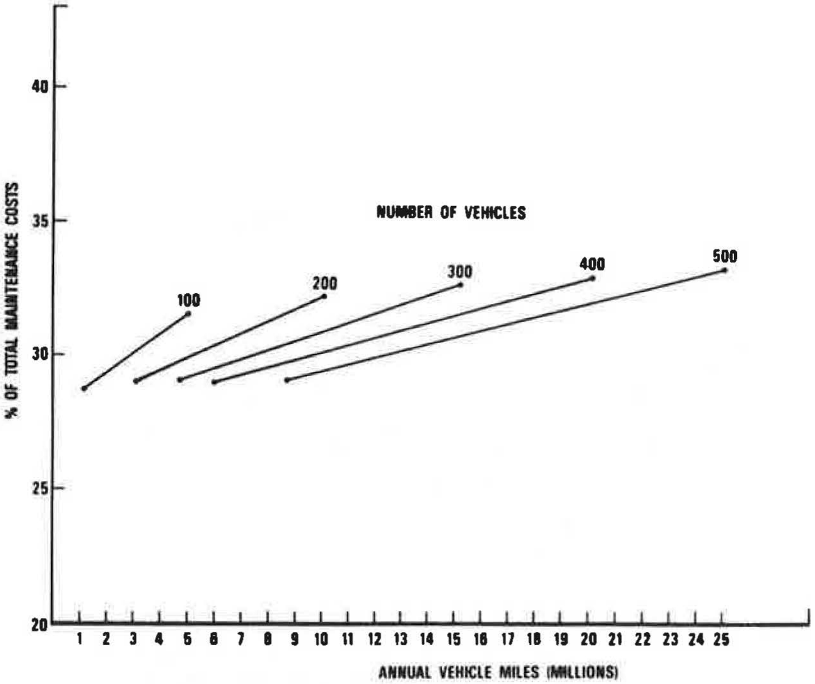


FIGURE 13 Total direct labor cost percentage of total maintenance costs for fleets of 100 or more vehicles.

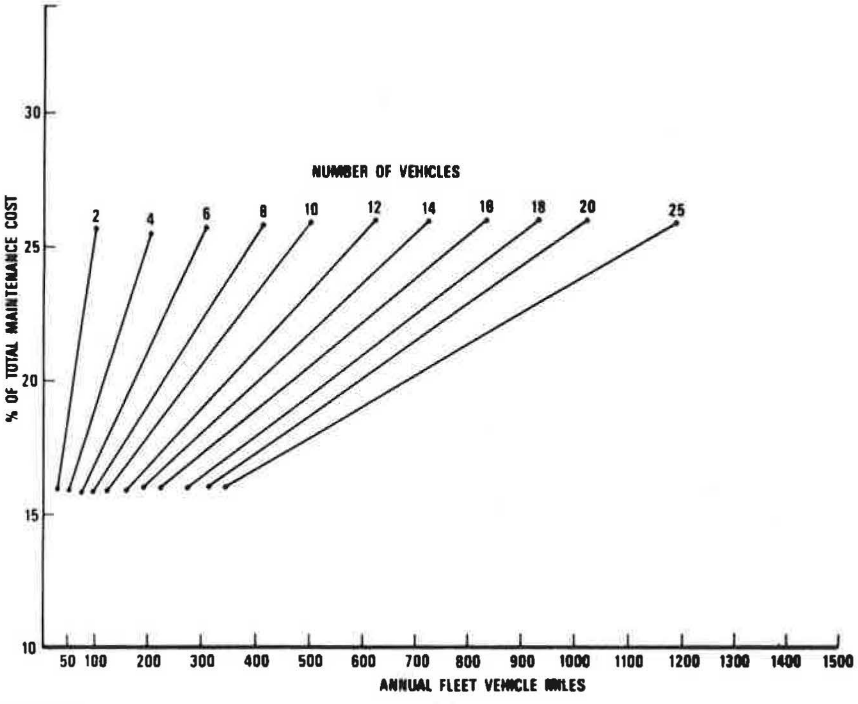


FIGURE 14 Repair direct labor cost percentage of total maintenance costs for fleets of 1 to 25 vehicles.

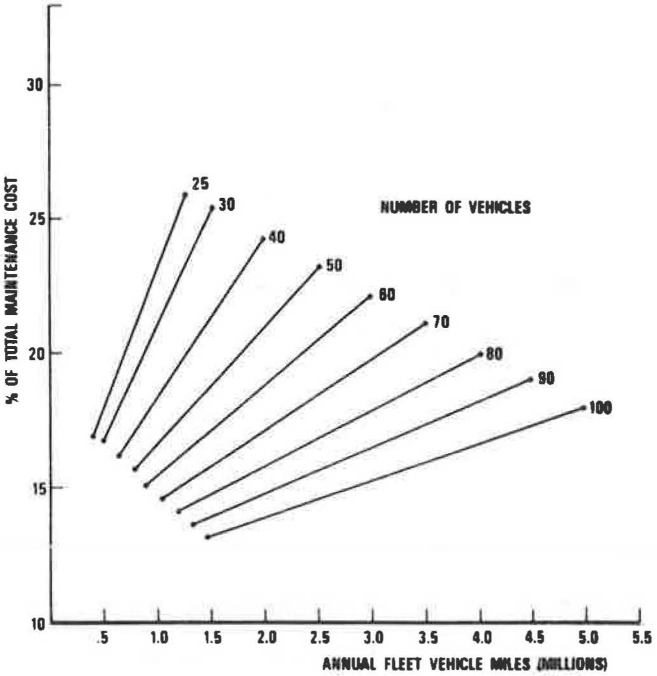


FIGURE 15 Repair direct labor cost percentage of total maintenance costs for fleets of total maintenance costs for fleets of 25 to 100 vehicles.

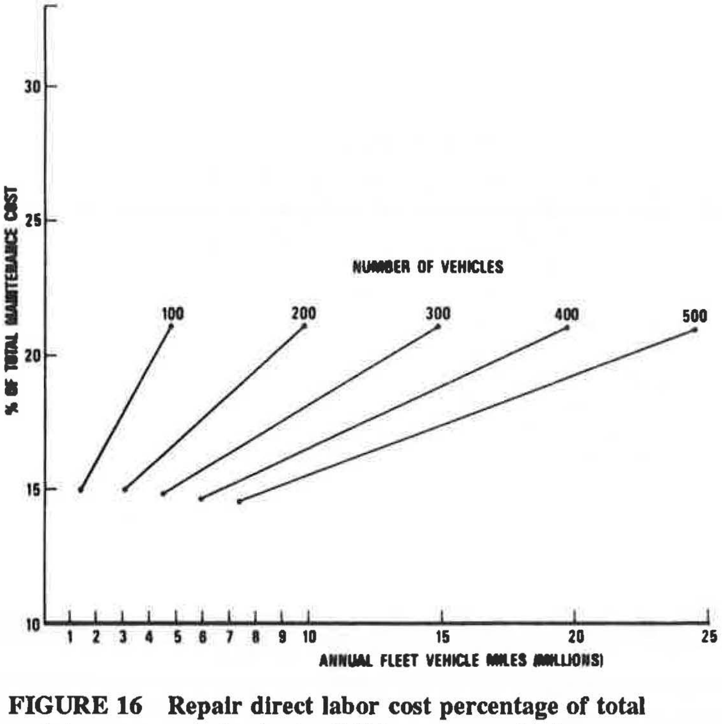


FIGURE 16 Repair direct labor cost percentage of total maintenance costs for fleets of 100 or more vehicles.

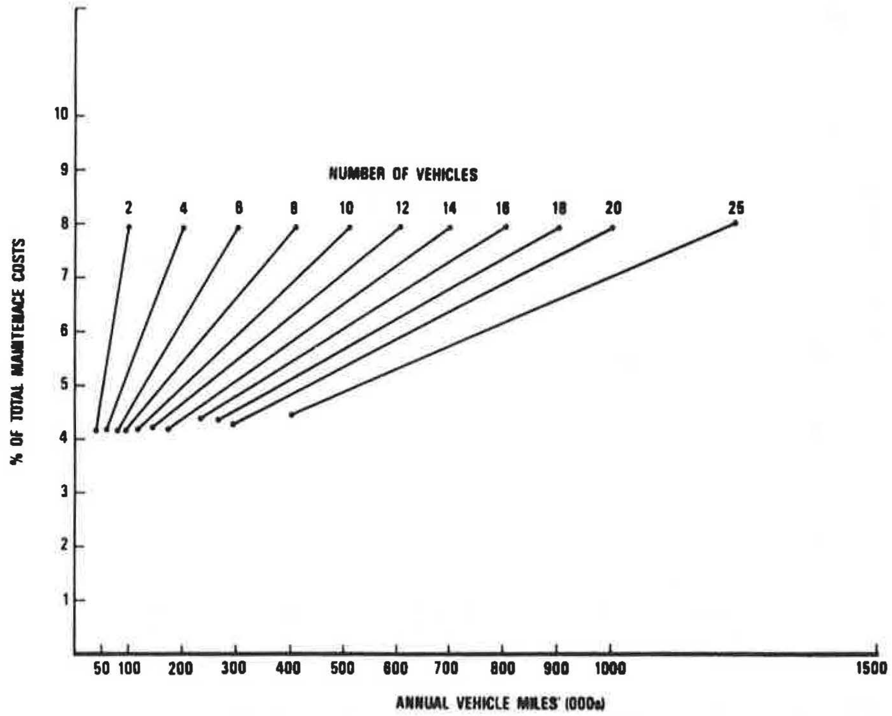


FIGURE 17 Inspection direct labor cost percentage of total maintenance costs for fleets of 1 to 25 vehicles.

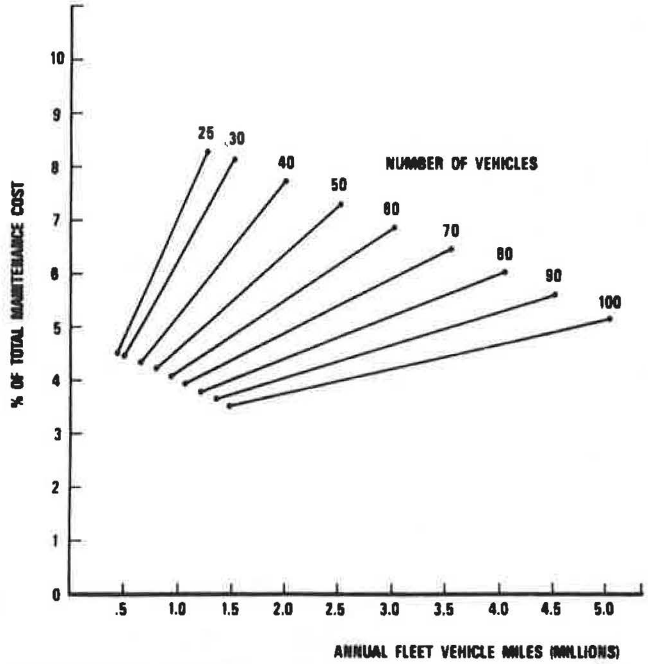


FIGURE 18 Inspection direct labor cost percentage of total maintenance costs for fleets of 25 to 100 vehicles.

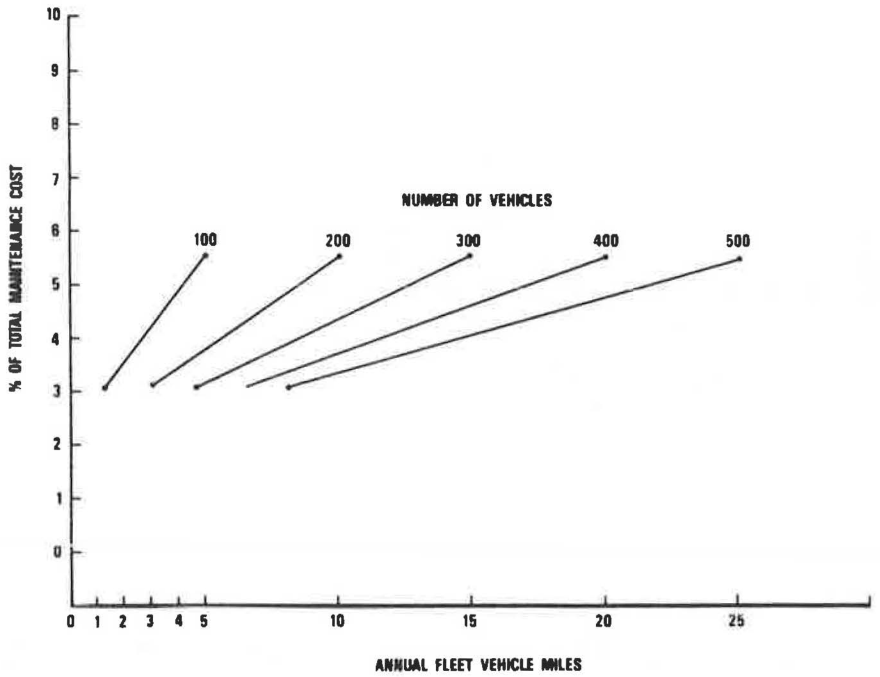


FIGURE 19 Inspection direct labor cost percentage of total maintenance costs for fleets of 100 or more vehicles.

Finally, Figures 20–22 show charts for estimating servicing labor costs as a percentage of total maintenance costs by fleet size group.

Some general trends and principles can be observed in the charts. Servicing labor cost is driven more strongly by the number of vehicles than by the number of vehicle-miles, explaining the decreasing contribution of service labor to total direct labor cost. As more vehicles are put into service, more labor is needed for servicing when vehicle mileage remains constant. This trend shows that the incremental time necessary

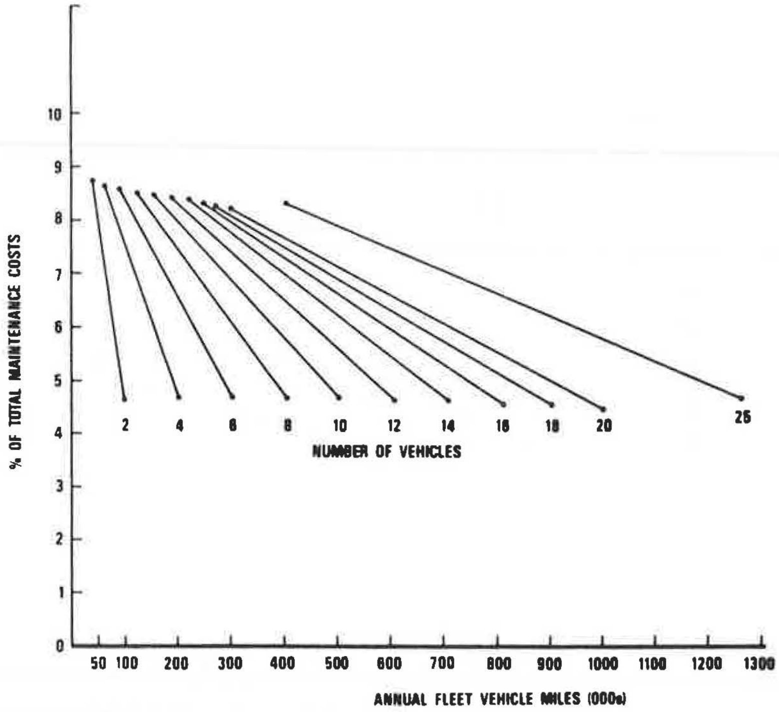


FIGURE 20 Servicing direct labor cost percentage of total maintenance costs for fleets of 1 to 25 vehicles.

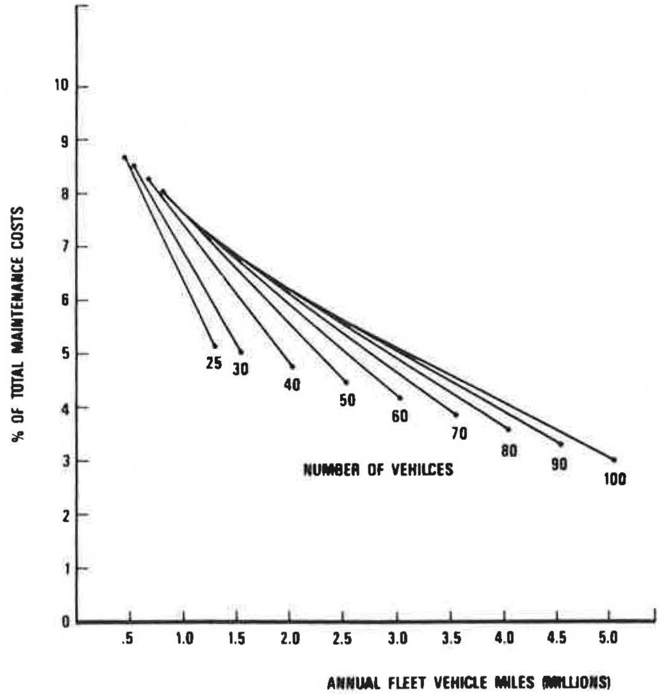


FIGURE 21 **Servicing direct labor cost percentage of total maintenance costs for fleets of 25 to 100 vehicles.**

to service buses with high daily mileage versus buses with low daily mileage is considerably less than the time required to retrieve buses from service queues, fuel and service the buses, and park the buses on the ready line. Inspection and repair labor follows an opposite trend. As vehicle mileage rises, direct labor for these functional areas increases, contributing to the decreasing percentage of service labor for total costs.

Fringe Benefit Expense

Fringe benefit expenses, as a percentage of direct labor, generally increase with property size starting from a typical low of approximately 13 percent of total direct labor cost for properties with fleet size of under 10 vehicles to a high of approximately 59 percent of direct labor cost for fleets of 100 vehicles

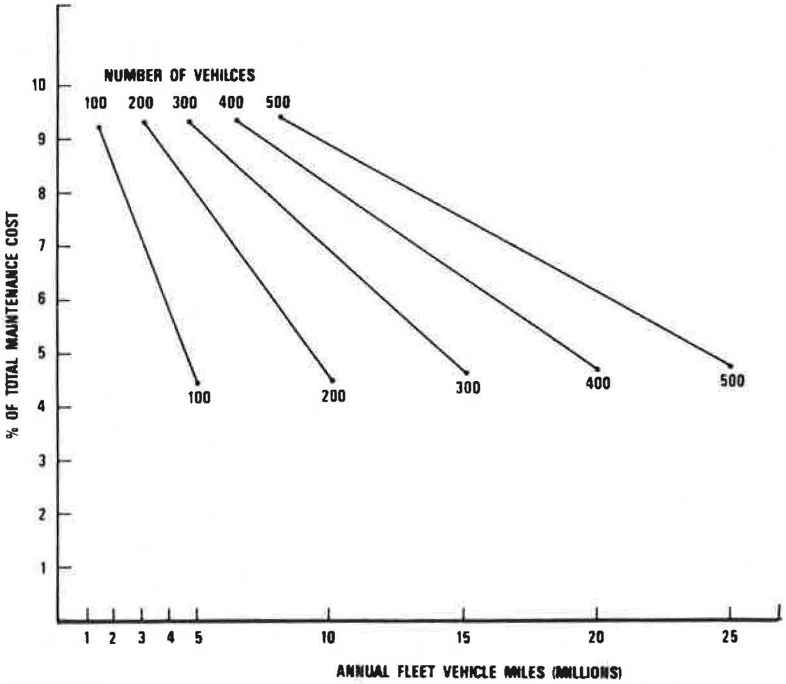


FIGURE 22 **Servicing direct labor cost percentage of total maintenance costs for fleets of 100 or more vehicles.**

or more. Study findings by fleet size and high- versus low-cost areas in California are shown in the following table. Obviously, the fringe benefit expense for an individual property is highly variable and subject to many local considerations.

	Expense (% of labor) by Fleet Size			
Level	*1–9*	*10–24*	*25–99*	*100+*
Low	0.13	0.34	0.26	0.45
Average	0.25	0.37	0.34	0.52
High	0.38	0.40	0.43	0.59

The trend of increasing fringe benefit expenses with increasing fleet size probably reflects increased competition for skilled personnel in competitive employment market areas. As a mechanic's skill level increases, compensation (including fringe benefits) must be competitive with other organizations requiring skilled diesel mechanics. Competitors for skilled mechanics include municipal organizations, trucking companies, construction companies, and some energy-related companies that rely on diesel equipment to operate pumps and remote power-generating facilities.

Maintenance Overhead Expense

Overhead expense incurred as a function of maintenance activities is frequently not allocated to the maintenance department. However, to reflect true costs, managers should include overhead expense.

Overhead is conventionally allocated as a percentage of total direct labor. Overhead varies significantly among properties of similar size. Overhead factors as a percentage of direct labor for California properties appear to increase as fleets become larger, as shown in the following table.

	Expense (% of labor) by Fleet Size			
Level	*1–9*	*10–24*	*25–99*	*100+*
Low	0.14	—	0.06	0.13
Average	0.39	0.17	0.14	0.22
High	0.64	—	0.22	0.31

More important, the research indicated that overhead expense data were typically not available or not allocated to transit maintenance activities. Maintenance facilities were frequently owned by municipalities and serviced both the transit fleet and other municipal vehicles. This shared-facility use made overhead expense identification difficult at even the best-managed small transit authorities.

The apparent higher overhead factor for large properties of 100 or more vehicles can be attributed to several factors. Facilities for these operations typically are dedicated to transit. Furthermore, larger properties carry specialized equipment and facilities, which translates into higher overhead expense.

Maintenance Administration Expense

Maintenance administration activities performed at a transit property are difficult to allocate to specific functional areas because an administrator's time is spent on a variety of activities spanning several functional areas. Maintenance personnel accounted for in this expense category usually include the maintenance director, manager, engineer, superintendents, supervisors, nonworking foreman, secretaries, clerks, and other staff who do not directly maintain the fleet.

Maintenance administration expense is particularly difficult to identify at small properties where one person may perform the duties of director of operations, director of maintenance, and director of personnel. In larger organizations, particular administrative personnel are more often dedicated to supporting and managing the maintenance functions. Not only does property size influence administrative costs, but the maintenance philosophy also influences administrative costs. Transit properties sometimes experience increased administrative expense and reduced direct labor expense by relying on contract maintenance service.

Maintenance administration and support expense found for California operators is shown in the following table. The data indicate that a significant difference occurs between fleets of less than 10 buses and fleets with more than 10 buses.

	Expense ($/veh) by Fleet Size			
Level	*1–9*	*10–24*	*25–99*	*100+*
Low	600	1,600	2,300	900
Average	1,900	5,100	5,100	5,100
High	6,100	6,600	7,800	7,800

The relatively constant average administrative expense per vehicle reflects the increased productivity and utilization of maintenance administrative staff as fleet size exceeds 10 buses. Intuitively, maintenance administration expenses should decrease on a per-vehicle basis as fleet size increases. However, each vehicle generates a constant flow of maintenance-related information regardless of service levels and fleet deployment. Even though more streamlined systems are often used, additional administrative activities tend to be needed as the overall operation becomes more complex. The two trends appear to be offsetting.

Material-and-Supply Expense

Material-and-supply expense can be allocated to two categories, consumable and nonconsumable expense. Consumable expense includes fuel cost, oil cost, and the cost of other liquids used to maintain and operate vehicles. Frequently, fuel costs are not assigned to the maintenance department because the fuel costs are driven primarily by service levels (i.e., the number of vehicle-miles). Maintenance managers should be aware of fuel costs and general trends in fuel costs because overall vehicle condition, frequency of tune-ups, and other factors can increase fuel mileage.

Nonconsumable expense is associated with the cost of parts, components, and other items used primarily in repair activities, although some nonconsumable expense is attributed to I/M activities (e.g., belts and hoses). Nonconsumable expense is driven by the amount of repair activity. Repair activity is primarily influenced by the number of vehicle-miles, type of vehicle, age of vehicle, and the operating environment (e.g., the terrain, passenger levels, and temperature).

In California the following consumable (including fuel) and nonconsumable cost rates were found:

- For fleet size between 1 and 25 vehicles, a typical consumable cost was $0.20/veh-mi; nonconsumable cost was $0.065/veh-mi.
- For fleet size of 25 vehicles or more, consumable cost was typically $0.27/veh-mi; nonconsumable cost was $0.180/veh-mi.

These cost rates will fluctuate from property to property. Therefore, managers should strive to develop their own consumable and nonconsumable cost rates. The cost rates are significantly influenced by the type of vehicles operated, vehicle age, terrain, and other factors.

IMPLICATIONS FOR MAINTENANCE MANAGERS

To plan and control maintenance costs, managers must know what cost components can be influenced, and they must use appropriate tools, approaches, and strategies. The cost relationships discussed in this paper provide managers a starting point for the assessment of their maintenance cost structure.

Maintenance costs are influenced by factors internal and external to a maintenance manager's span of control and often outside the overall transit organization.

Economic conditions such as employment levels and inflation rate are examples of external factors that affect the amount of servicing and cleaning vehicles require as well as the amount of repair activity needed to replace worn seats, and so forth. Inflation rates influence wage rates and the cost of materials and supplies.

There are several factors within a manager's span of control that influence maintenance costs, especially in relation to operating costs and overall administrative costs.

The cost relationships presented in this paper are applicable to transit operations located across the country. Though total maintenance costs in other areas may differ from those found in California, their contributions to total operating expense are not expected to vary significantly. Likewise, because no deviation between low- and high-cost areas in California was identified, the contributions of repair, inspection, and servicing labor to total maintenance costs are not anticipated to vary significantly.

ACKNOWLEDGMENTS

The research report in this paper was conducted under a study cosponsored by the Division of Mass Transportation, California Department of Transportation (Caltrans), and UMTA. The original research effort produced three reports available through Caltrans. The success of the research effort can be attributed to the eager participation of the California transit operators in providing the cost and management information necessary to conduct the analyses.

Theory and Practice of Transit Bus Maintenance Performance Measurement

THOMAS H. MAZE AND ALLEN R. COOK*

In this paper the role of performance measurement in a comprehensive system of maintenance management functions is summarized. It is pointed out that performance measurement is only valuable to the individual bus transit maintenance manager when performance measures seek to control the progress of the maintenance system toward performance objectives. Performance measurement should be a reflection of performance objectives. The paper also contains the results of a questionnaire administered to 92 maintenance managers of U.S. transit systems. The maintenance managers were asked to rank 36 candidate performance indicators. The resulting aggregate ranking showed a bias favoring simple indicators consisting of simple ratios or indexes and favoring indicators of two performance attributes, vehicle reliability and vehicle maintainability (essentially the cost and effort involved in maintaining vehicles). The bias towards only these two attributes may define a lack of balance in maintenance performance measurement practice.

The purpose of this paper is to examine performance measurement of transit bus maintenance. The approach departs from the common avenues taken by performance measurement investigations. The literature examines performance measures by determining what is used in practice *(1)*, or seeks to determine which indicators tend to do a good job of measuring various attributes of performance. [Common performance attributes include effectiveness, efficiency, and reliability *(2, 3)*.]

Maintenance performance measurement is only a valuable exercise when the results of the measurement are incorporated into management decision making. Performance measures should be used by management to determine if maintenance operations are achieving their objectives, and if not, management should take steps to correct the system's deviation from performance objectives. Further, to derive the most value from performance measures, they should be formally incorporated into decision making through a management plan.

In this paper, fundamental relationships between planned management decision making and performance measurement activities are discussed in a bus transit maintenance context. The paper concludes by suggesting performance indicators that may be used to control specific attributes of the progress of a transit bus maintenance department toward management objectives. The results of a performance measurement questionnaire are highlighted in the discussion of performance indicators. The questionnaire asked 92 maintenance managers of U.S. transit systems the value of candidate performance indicators. The candidate performance indicators were then ranked according to the questionnaire's results.

MANAGEMENT BY OBJECTIVES

Performance measuring implies the existence of management objectives. For example, a maintenance manager may periodically review the cost performance of the maintenance system with the objective of controlling cost. Maintenance cost control may be a formally developed and documented objective or an implicit objective; but the periodic review of cost performance clearly indicates the existence of a cost control objective. However, whether a management objective is formal or informal, it must precede performance measurement and the role of the performance measure is to ensure management that its objective is being achieved.

Koontz and O'Donnell *(4)* define management as the "design or creation and maintenance of an internal environment in an enterprise where individuals, working together in groups, can perform efficiently and effectively towards the attainment of a group goal." Therefore, it is the maintenance manager's responsibility to select the series of actions that the transit agency should take to achieve a set of maintenance objectives determined in advance. This is called management by objectives (MBO).

An MBO program starts with the development of a comprehensive set of objectives that define what is expected or desired from the maintenance department. The objectives should be expressed in quantitative terms so that their fulfillment is easy to measure. Specific deadlines for the achievement or status review of objectives should be established by management and then sufficient authority to perform the tasks needed should be delegated. Objectives, then, are the heart of the MBO program.

However, management is an inexact science and management actions do not always achieve the objectives desired. Therefore, because the effects of actions are not totally certain, known relationships between actions and results are not facts, but principles. Principles are relationships that managers use to determine the procedures that are likely to achieve the desired result. For example, it is a commonly accepted principle that in-service breakdowns are less likely to occur when mechanics carefully inspect vehicles during periodic preventive maintenance and perform all needed and anticipated corrective maintenance. However, the development of management principles requires a structured system to measure the positive impacts of

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the application of procedures. Without performance measures as a yardstick for the effectiveness of management principles, the manager has only intuition to judge the benefits of future application of the same procedure.

Management principles provide the conscientious manager with guidelines to be used to solve problems without engaging in time-consuming research or risky trial-and-error tests. Therefore, management principles can be used to improve the efficiency of a manager by providing a procedure that will, in all likelihood, move the organization towards its objective.

Determining objectives, policies, principles, and procedures for achieving objectives is called planning. Just as a ship's navigator must plan a route for the vessel before embarking on a journey, a fleet manager must have a plan to guide the maintenance operation.

Once a management plan has been developed, controls (performance measurement) must be established to guide the implementation of the plan. Controlling is the function that measures the agency's progress toward its planned objectives. Although planning precedes controlling, planning is ineffective if there are no controls in place because plans are not self-achieving. The progress of the transit agency is guided by its controls as it attempts to reach its objectives.

Therefore, to be effective, planning and controlling must be inseparable. Because management planning is a necessary precursor to controlling, the fundamental theory of developing a management plan is briefly discussed first, followed by a similar discussion of the fundamentals of controlling.

FUNDAMENTALS OF PLANNING

The most basic function of management is planning. Planning involves the making of decisions to determine the future course of the transit agency. All other management functions are carried out to pursue the planned course for the agency. In other words, all other management functions are subordinate to planning.

Planning requires that choices be made between possible alternatives, and this necessitates decision making. Planning covers making of agency objectives, setting of policies and rules, and developing programs. Budgeting and staffing implications of these steps must also be considered when developing a management plan.

The first step of planning is to develop objectives. All of the other aspects mentioned are designed to achieve the established objectives. These planning elements are discussed in the following paragraphs and shown in Figure 1.

Objectives

Objectives or goals are the driving elements of a plan. Objectives are statements of what is expected by transit management, usually within a specific period of time. Because objectives are a basic element of any plan, they must be carefully designed. Well-designed objectives have the following attributes:

Quantification

Objectives should be clearly defined and, if possible, quantified. Examples of well-defined objectives would be keeping average maintenance costs to $0.50/veh-mi or maintaining an average of 7,000 revenue miles between road calls for mechanical and electrical problems.

Time Limits

Objectives should include a time period or limit. For example, the objectives cited may pertain to the next budget year, or the next fiscal quarter. Without time references, the motivation to accomplish the objectives may diminish, and progress towards these objectives may be retarded even more in the long run.

Appropriateness

Objectives must be scaled to meet the targeted level in the

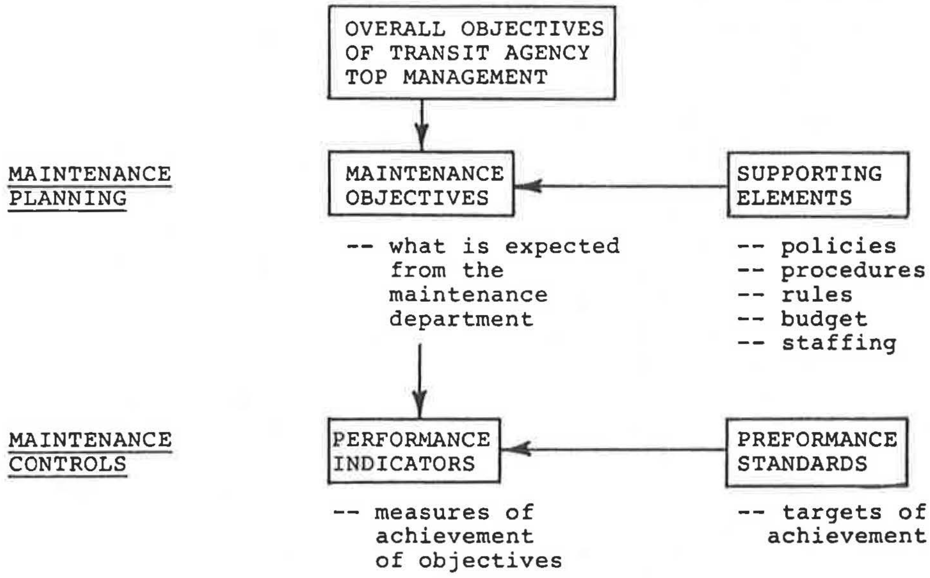

FIGURE 1 Management by objectives.

management hierarchy. For example, a meaningful objective for top management may be to cut the deficit per mile by 10 percent in the next budget year while keeping fares constant. Management may conclude that this objective can be achieved in part by increasing overall maintenance productivity. When the maintenance manager delegates the responsibility of meeting this objective to the front-line equipment managers, for example, the shop foreman and the inventory manager, it is not sufficient to just tell them to increase their productivity. Instead, more detailed objectives must be developed that specifically target each individual's role in the management chain. For example, the inventory manager's contribution to the agency-wide objective may be to reduce the dollar value of the parts inventory by 10 percent, thus reducing the inventory overhead costs.

Trade-Offs Between Objectives

Some objectives may conflict with others. Clear levels of preference between competing objectives should be articulated. For example, any productivity objective must have a corresponding quality objective so that productivity gains are not made at the sacrifice of maintenance quality and hence level of service. An objective to provide a check-and-balance for the parts inventory manager may be to make sure that parts stock-outs do not increase while inventory value decreases. The larger the parts inventory, the less likely that the inventory will run out of a specific part. Thus, the inventory manager, when pursuing these conflicting objectives, must clearly understand the trade-offs between them.

Policies

A policy is an element of the plan because it provides guidance to future actions. Policies direct decision making toward the achievement of maintenance objectives. One example of a policy would be to do preventive maintenance on buses, and do it within 500 mi of the scheduled mileage. This policy assumes that doing preventive maintenance will reduce the frequency of road calls and reduce maintenance costs in the long run. If these are objectives of the maintenance department, then the policy dictates some of the steps to be taken routinely to meet the objectives. This policy also provides some flexibility for the foremen in scheduling work while specifying that the job must be done within a certain mileage interval.

Koontz and O'Donnell *(4)* state: "Objectives are end points of planning, while policies channel decisions along the way to these ends." Consider a policy to promote employees from within whenever it is reasonable to do so. Thus, senior mechanics would be the first candidates considered for an open foreman position. The overall objective is increased productivity, and this policy is promulgated in the expectation that it will foster employee morale and ensure that experienced workers will occupy senior positions, both of which should increase productivity.

Finally, this employment policy is a guide to decision making for the maintenance manager, one that is understood by all employees, when job vacancies do occur. Policies are not intended to make specific choices for a maintenance manager. Rather, policies limit choices and they tend to maintain consistency in choices from one decision to the next.

Procedures

Procedures are the elements of the plan that identify the actions to be taken whenever a specific policy is implemented. For example, it may be the policy of the transit agency to conduct a preventive inspection of each bus every 3,000 mi. The set of actions to be taken during this inspection is a procedure. Procedures are a mandatory set of ordered steps.

Foerster et al. *(5)* noted the policy of the San Antonio VIA transit system to require drivers to do a prerun inspection of their buses. The prerun inspection form requires the signature of the driver and, if a defect is reported, the signature of a maintenance employee. They comment: "This method of involving both transportation and maintenance establishes accountability for in-service failures. It also prevents road calls from drivers who want a replacement vehicle just because of minor problems." Thus, a procedure is established for conducting a prerun inspection with an appropriate check-list form. This procedure is the means for accomplishing a policy of requiring prerun inspections that should move the transit agency toward its objectives of reducing road calls and minimizing maintenance expenditures.

Rules

Rules are simple, required planned actions that permit no alternatives. No smoking by mechanics except in the mechanic locker room is an example of a rule. The management of Madison Metro in Wisconsin became so frustrated over passenger complaints when the air conditioning malfunctioned in advanced-design buses in the early 1980s that they established a rule that stated that advanced-design buses with air conditioning problems were not to be put in service *(7)*. As long as spare buses were available, no exceptions were permitted.

Programs

Programs are coordinated sets of policies, procedures, and rules that fulfill an objective. For example, a maintenance manager may develop a program to increase productivity of mechanics. The program may include mechanic training, an incentive system, and the establishment of task time standards. This program involves a complex of associated policies, procedures, and rules to achieve its objective.

Budgets

Typically, a program that requires a high level of effort needs a budget and staff plan associated with it. The budget is that element of a plan where all actions are quantified in terms of work force allocation or money. Making a budget is clearly a planning function. It requires that the manager define future flows of resources (labor, parts, and money) and the timing of those flows. Because a budget allocates resources, it provides a primary controlling measure for the achievement of other planned actions. Thus the priorities expressed through the budget must clearly reflect the priorities expressed in the planning objectives.

Summary

Planning reduces the uncertainty involved in the decision making process and provides for consistency in choices. Planning helps to focus the attention of management on achieving the transit agency's objectives. Most importantly, planning establishes the objectives of the agency and delineates the steps to be taken to achieve these objectives. By understanding the desired course of the agency, management can create a control structure to determine whether or not the agency is on its desired course. The more clearly and comprehensively a plan identifies the course towards the agency's objectives, the more certain management is of the actions to take to achieve them.

FUNDAMENTALS OF CONTROLLING

Controls are intended to measure the agency's progress towards its objectives, as indicated in Figure 1. Therefore, the measurement of performance through controls implies that there exist objectives and a management plan. Naturally, the more concise and comprehensive the plan is and the longer the time period of the plan, the more complete can controlling be.

The Control Process

Managerial controlling involves three steps.

Establishing Performance Indicators

Establishing a set of indicators that measure system performance is by far the most difficult step in controlling. Once a performance indicator system is established, the other steps merely follow through with the required actions to maintain the plan objectives. Thus the other two steps are subordinate.

Establishing Performance Standards

The standards used to measure performance are reference points or targets for control. For example, mechanic task time standards are intended to represent the time required for a qualified mechanic to complete a specific task. Thus, a time standard provides a reasonable reference point for measuring the relative productivity of a mechanic or the joint productivity of all mechanics. Determining the standard involves the collection of performance data.

Correcting Deviations from the Standard

If control measures indicate that the performance is deviating from the standard, then management should determine the cause and take corrective actions. For minor deviations, management may take planned or ad hoc corrective steps. However, if the deviations are a result of the original plan being unworkable or because the standards are too high or low, then the plan or the control must be redesigned.

A flow diagram of the control process is shown in Figure 2. The process begins with planning and the determination of objectives. Next, based on these objectives, the controls (performance indicators) are designed. Finally, the plan and controls are applied to fleet operations through management direction. If the fleet operations performance indicators are satisfactory, the process flow takes the path indicated in Figure 2 by the far right-hand loop. If the performance indicators do not meet the standards, then the maintenance manager must decide whether the deviation from the standard can be corrected or if the plan or controls are unworkable. If the deviations from the standards are correctable, a correction strategy is developed and implemented through management direction. If the plan or controls are unworkable, then they must be reevaluated and the flow goes back to the start.

Performance Indicator Development

Developing meaningful performance indicators is a difficult task. In the next section of this paper, typical transit industry fleet performance indicators are provided and evaluated. However, each transit system has its own distinctive operating conditions and objectives, which necessitates the creation of locally defined sets of controls. The following paragraphs list attributes of good performance indicators that can be used for guidance when selecting controls.

Applicability

Controls should be designed to meet the needs of the level of management using them. For example, top management may find it useful to judge the overall performance of the maintenance department with one indicator, maintenance cost per vehicle-mile. However, maintenance costs may include the costs of fueling, cleaning and washing, and body maintenance, in addition to mechanical system maintenance. Further, the total maintenance cost per mile will be averaged across all the models of buses in the fleet. Such an aggregate control would not provide the detail necessary for the fleet manager to adequately monitor the performance of the maintenance operation. At the fleet manager level more detailed performance indicators are required.

Promptness

Controls should indicate deviations from the planned objectives in a timely manner. Furthermore, the degree of timeliness depends on the nature of each performance indicator. For example, fleet managers commonly monitor individual bus fuel and oil consumption and flag consumption rates that vary from normal levels. Deviations from the norm may indicate a mechanical problem and should trigger an inspection of the bus. To provide timely notice of mechanical difficulties through consumption rate tracking, the performance indicator (in quarts or gallons per mile) should be monitored frequently, preferably

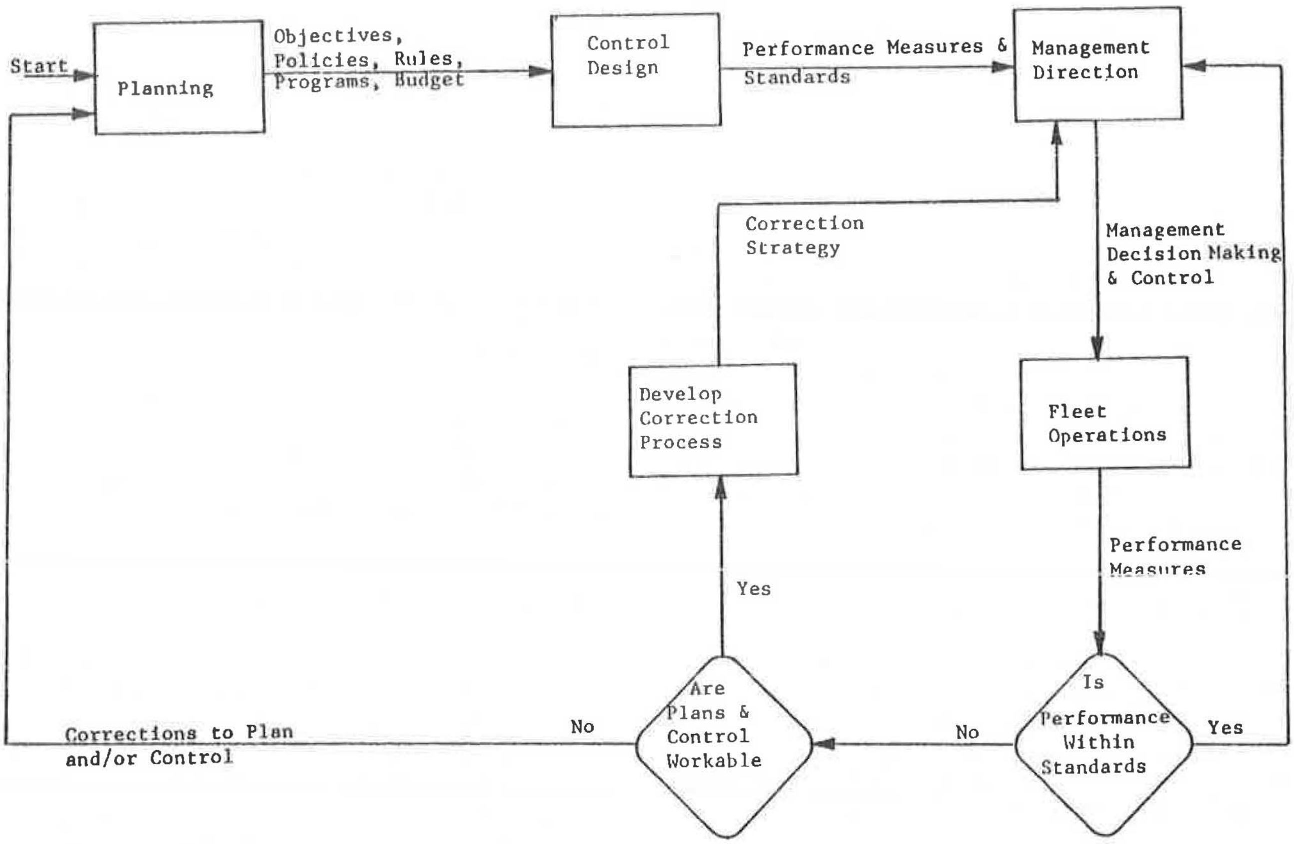

FIGURE 2 Flowchart of the controlling process.

every day, and reported the next day. Other performance indicators, for example, distance in miles between road calls, are timely even if they are collected less frequently (i.e., weekly or monthly). Whatever the time period, for the performance indicator to be useful in management decision making, it should be a management policy to require that the measure be reported promptly after the end of the collection period.

Critical Exceptions

Deviations from standards for some performance indicators may have a great deal of significance, while in other cases a deviation may not be important. For example, suppose that the average duration of open maintenance work orders is used as a measure of work flow and backlogged jobs. An increase in the number of open work orders may bear little significance to the performance of the maintenance department. An increase may be triggered by extremely cold weather or other conditions that management can do little about. However, an increase in the number of work orders that are repeats of previously completed work orders (repeat repairs or misdiagnosed repairs) may be highly significant and indicates that the maintenance system is wasting materials and labor, and tieing up buses for maintenance longer than necessary. Controls that measure critical exceptions aid management in directly detecting critical problems. Thus, whenever possible, controls should point out critical deviations from standards.

Objectivity

Often, there are cases in which a performance indicator requires the use of subjective judgment. For example, suppose that the fleet manager wishes to measure repeat repairs and misdiagnosed repairs. To calculate the number of repeat and misdiagnosed repairs, the manager must review a chronological listing of repairs made to each vehicle and decide which repairs were repeated or misdiagnosed. Subjective and judgmental indicators can be inaccurate and influenced by personality. Objective measures are more accurate and consistent, and, therefore, are preferable.

Clear Definitions

Performance indicators and procedures for control must have clear and accurate definitions. This is particularly true if indicators are applied at more than one location within an agency or if comparisons of the performance indicators are made between two agencies. Unless performance indicators are clearly defined and applied using exactly the same procedures, comparisons are inappropriate.

Economy

Controls must be worth the cost of their collection. Elaborate control systems may be economical for large organizations with a complex managerial system, but for medium and small transit systems in which fleet managers can personally track a broader span of management functions, elaborate systems may be uneconomical. For each individual case, the selection of controls should be judged in light of the value of the control versus the corresponding cost of the control. Clearly, the benefit of each performance indicator should exceed the cost of the indicator's collection.

Understandability

Performance indicators should be easily understood and the attribute that an indicator measures should be easily identified. Performance indicators that are based on complex formulas, advanced mathematics, or sophisticated theories may fail to communicate their meaning to front-line management. Direct indicators and simple ratios are the most readily understood.

Applications of Performance Indicators

Now that the role of performance measurement in maintenance management has been examined, the application of performance indicators in practice will be discussed in the next section. The discussion of performance indicators covers two areas of application to fleet management control: (a) vehicle mechanical and cost performance indicators (e.g., vehicle reliability, maintainability, and availability), and (b) performance indicators for the maintenance system (e.g., work quality, worker productivity, and maintenance management control). Vehicle performance and maintenance system performance are interdependent. For example, the introduction of buses that are easier to maintain should cause the maintenance system to appear more productive. Similarly, positive vehicle performance impacts should result from improvements to the maintenance system.

Controls or performance indicators may be further divided by their scope. There are two types of controls, direct and indirect. Direct performance indicators provide knowledge of the maintenance system performance by themselves. For example, distance in miles between road calls is a direct control. As the number of miles between road calls increases or decreases, it directly indicates a change in the mechanical reliability of the buses. Direct controls often are simple ratios or indexes; they are easy for management to interpret and therefore are quite powerful tools for measuring performance. Direct controls are most useful in making day-to-day or week-to-week corrections to the maintenance system. Therefore, their value is increased when they are reported promptly.

Indirect controls are data indicators that are collected, analyzed, and only used in decision making analysis. The results of the analysis can be used as performance indicators, but not without some interpretation. For example, a maintenance manager should collect the failure mileage for each major bus component that fails, for example, air compressors. Because failures are random events, the fact that one failure occurs at a specific mileage determines only that it is possible to fail at that mileage. It is not a useful performance indicator by itself. However, once several units of the same component have failed and the mean mileage between failures is calculated, the manager can use the mean mileage between failures in management decision making. For example, if the mean mileage between failures of air compressors is unusually small, the maintenance manager should investigate whether it arises from poor-quality replacements, improper preventive maintenance, or other cause. Indirect controls tend to have their greatest application in the long term, and they generally represent the culmination of a long-term data collection effort.

BUS MAINTENANCE PERFORMANCE MEASUREMENT PRACTICE

Performance indicators are reflections of the transit agency objectives. Management objectives for a bus maintenance department should be a function of top management and maintenance management philosophies, the physical characteristics of the fleet, the service duty cycle, the maintenance facilities, and other characteristics. Because these characteristics are unique at each system, each system's specific management objectives should be unique. For example, suppose a maintenance manager is having a problem with mechanic productivity and the manager attempts to achieve greater productivity by the combination of a training program and a pay incentive program. To determine if these programs are effective in achieving their objective, specific indicators are created to reflect the performance of the programs. For example, one unique indicator may be the amount of incentive pay given to maintenance workers. Because of the uniqueness of management objectives, the combination of performance indicators that are most meaningful varies from system to system. On the other hand, there are certain fundamental objectives that are common to all transit agencies such as cost control, and therefore there should be a degree of commonality in performance indicators.

The purpose of this section is to present a series of bus maintenance performance indicators. The value of each of these performance indicators is assessed through the results of a questionnaire administered to 92 maintenance managers. Although each transit system should have its own unique objectives, because there should be some commonality between systems, the performance indicators presented should provide systems designing or reviewing their performance indicators with new candidate measures and an indication of the indicator's utility at other systems. Further, the performance indicators are categorized by the attribute they measure. The categorization of indicators permits the manager who is designing a performance measurement system to select a group of indicators that comprehensively covers each attribute of maintenance performance.

Maintenance Manager Perspectives

The transit maintenance manager has two primary concerns in developing performance indicators. The first is that indicators are needed that top management can use to evaluate the overall performance of the maintenance department. The second concern of the manager, however, is for indicators that can be used to monitor the internal performance of the maintenance department. They should help the manager in evaluating internal productivity and assist the manager in the development of management principles.

It is one thing to monitor vehicle-miles per road call, but quite another to understand and monitor the many factors that contribute to road call performance. For top management, it is an easy indicator to understand and useful because it assesses maintenance performance directly in a manner that also reflects on the public image of the transit system and its level of service. For the maintenance manager, it provides the same assessment but does not express what needs to be done to change its value. The development of such internal indicators is the subject of the remainder of the paper.

Candidate Performance Indicator Questionnaire Survey

Transit maintenance managers throughout the United States were asked to evaluate the utility of 36 candidate performance indicators for themselves and for top management. The questionnaire was distributed and analyzed as part of a project for the Urban Mass Transportation Administration *(7)*. The candidate indicators were selected in part from a prequestionnaire sent in February 1985 to eight knowledgeable maintenance managers who were responsible for fleets of 50 to 3,000 buses. The prequestionnaire included candidate indicators derived from interviews with transit maintenance managers and from the literature. Some of the candidate indicators that remained in the questionnaire were considered by the authors to be beyond the current state of the art of performance measurement practice and suggestive of future practice that has worked successfully in the measurement of maintenance performance in other industries. For example, some of the indicators required availability of labor time standards and currently few transit agencies are known to have available time standards that may be applied on an activity-by-activity basis *(8)*.

Based on prequestionnaire results, the final questionnaire was developed and mailed in April 1985. The questionnaire asked maintenance managers to score a series of candidate performance indicators on a scale from worthless to vital. Further, the maintenance managers were asked to scale the indicator's value both to themselves and to top management. Out of about 120 sent out, 92 completed questionnaires were received. The response rate was high considering that no follow-up contacts were made to those who did not return the questionnaire.

Categories of Performance Indicators

The 36 performance indicators were grouped into six categories.

Fleet Reliability Indicators

Reliability is the likelihood that the bus and its components will operate properly at any given time. Common indicators of reliability include the average distance in miles between road calls and the average age of major components.

Fleet Maintainability Indicators

Maintainability is a measure of the labor and material costs needed to operate the buses, fix failures, and perform preventive maintenance. For example, maintenance costs per vehicle-mile, fuel and oil costs, and the number of work orders per bus model are indicators of maintainability.

Fleet Availability Indicators

Availability is the likelihood that a given number of buses will be operational at any point in time. Common indicators of availability include the average duration of open work orders and the number of open work orders.

Work Quality Indicators

Work quality is a measurement of the quality of the maintenance work performed. High-quality corrective maintenance should completely restore a failed, worn-out, or malfunctioning component or part to its proper operating condition. High-quality preventive maintenance should diagnose impending problems and correct them. Measures of work quality include repeat road calls, repeat repairs, and the percentage of corrective work diagnosed during inspections. For example, if the number of repeat failures for the same reason is relatively high, then the maintenance system is not performing high-quality work.

Work Productivity Indicators

Work productivity measures the amount of work accomplished during a specific period in comparison to a fixed work time standard. A common way to measure productivity is to set a time standard for various activities and measure how well the maintenance system performs with respect to the standards. Other less complicated measures of productivity would include the average number of work orders processed per day and the average length of time taken to conduct common tasks like inspections.

Maintenance Management Control Indicators

Maintenance management control indicators measure how well management is able to fulfill the objectives of the agency. For example, many transit agencies place a great deal of importance on performing preventive maintenance on time and therefore a measurement of management control might be the average lateness of periodic inspections. The ability to execute a regimented schedule or periodic schedule indicates maintenance management's ability to fulfill its objective of performing inspections on time. On the other hand, the frequency with which preventive inspections lead to the preventive corrections of mechanical problems, as opposed to later maintenance of failure, is related to quality of work conducted (Category 4).

Value of Candidate Indicators to Maintenance Managers

Individual responses to each question were assigned the following numerical scores in order to numerically rank the candidate performance indicators:

5 = Vital
4 = Very useful
3 = Useful
2 = Limited value
1 = Worthless
0 = No answer

The responses were then tabulated and each performance indicator was ranked according to its average numerical score. For example, suppose that half the respondents thought that a performance indicator was very useful (a score of 4) and the other half thought that it was of limited value (a score of 2). Then the average numerical score would be 3.0. The average scores of the candidate performance indicators are presented in Table 1 for their values to maintenance managers. Also presented in Table 1 are the most frequent response (the mode) and the median response. Missing responses were infrequent; they were treated as missing data and not included in the results presented in Table 1.

The candidate performance indicators, grouped by the six categories, are presented in Table 1. Within each category, the candidate indicators are ordered with respect to average score. The indicator that received the highest average score is listed first. The rankings extend from 1 to 36 regardless of the category.

Although no maintenance manager marked everything as being vital, all candidate performance indicators were considered vital by at least a few managers. For example, average daily number of maintenance jobs in the backlog (a fleet availability indicator) was ranked 26th out of 36 indicators, but it was considered a vital indicator by 16 managers. Also, there were few indicators that were not considered worthless by one

TABLE 1 VALUES TO MAINTENANCE MANAGERS OF CANDIDATE PERFORMANCE INDICATORS

Rank	Performance Indicator	Most Frequent Answer	Median Answer	Average Score
Fleet Reliability Indicators:				
1	Miles per Road Call	Vital	Vital	4.33
7	Road Calls per Bus per Month	Very Useful	Very Useful	4.03
13	Average Age of Major Components on Each Bus Model	Very Useful	Very Useful	3.95
Fleet Maintainability Indicators:				
5	Maintenance Cost per Vehicle Mile	Vital	Very Useful	4.15
6	Maintenance Cost per Vehicle	Vital	Very Useful	4.08
10	Maintenance Labor Cost per Vehicle Mile	Vital	Very Useful	4.01
11	Average Fuel and Oil Cost per Bus Model Versus the Total Fleet	Very Useful	Very Useful	3.97
12	Maintenance Material Cost Per Vehicle Mile	Very Useful	Very Useful	3.95
19	Maintenance Labor Cost per Bus Model Versus the Total Fleet	Very Useful	Very Useful	3.66
22	Maintenance Cost per Bus Mile per Bus Model Versus the Total Fleet	Very Useful	Very Useful	3.55
25	Average Value of Parts Used by Each Model of Bus in the Fleet	Very Useful	Very Useful	3.38
27	Maintenance Work Orders Per Bus Model Versus the Total Fleet	Very Useful	Very Useful	3.38
31	Total Value of Parts Used per Month Versus the Total Value of the Part Inventory	Useful	Useful	3.14
32	Maintenance Labor Cost Versus Material Cost	Useful	Useful	3.18

TABLE 1 *continued*

Rank	Performance Indicator	Most Frequent Answer	Median Answer	Average Score
35	Dollar Value of Parts in Inventory for Each Bus Subsystem	Useful	Useful	2.94
Fleet Availability Indicators:				
14	Current Number of Open Maintenance Work Orders	Vital	Very Useful	3.88
26	Average Daily Number of Maintenance Jobs in the Backlog	Very Useful	Very Useful	3.36
28	Average Miles Traveled Per Bus Model Versus the Total Fleet	Very Useful	Useful	3.33
30	Average Duration of Open Work Orders	Very Useful	Useful	3.20
Work Quality Indicators:				
3	Number of Repeat Repairs per Month	Very Useful	Very Useful	4.25
4	Number of Repeat Breakdowns in the Same Month	Very Useful	Very Useful	4.25
17	Corrective Maintenance Diagnosed During P.M. Inspections Versus Total Corrective Maintenance	Very Useful	Very Useful	3.70
21	Total Labor Hours Spent on P.M. Versus Total Labor Hours	Useful	Very Useful	3.61
Work Productivity Indicators:				
2	Total Regular and Overtime Maintenance Labor Hours per Month	Vital	Vital	4.25
15	Average Labor Time Taken to Perform Each Type of P.M. Inspection	Very Useful	Very Useful	3.80
16	Average Labor Time Taken to Make Corrective Repairs	Very Useful	Very Useful	3.79
23	Estimated Maintenance Labor Hours Required to Complete Maintenance Backlog	Very Useful	Very Useful	3.47

TABLE 1 *continued*

Rank	Performance Indicator	Most Frequent Answer	Median Answer	Average Score
33	Average Daily Estimate of Maintenance Labor Hours Backlogged	Very Useful	Useful	3.08
34	Estimated Labor Hours to Complete Closed Work Orders (Based on Time Standards) Versus Actual Hours	Very Useful	Useful	3.07
Maintenance Management Control Indicators:				
8	Total Number of P.M. Inspections Scheduled Per Week Versus Inspections Actually Performed	Very Useful	Very Useful	4.03
9	Percent of P.M. Inspections Performed Within the Prescribed Interval	Very Useful	Very Useful	4.03
18	Of the P.M. Inspections Performed Past the Inspection Interval, the Average Miles Past the Interval	Very Useful	Very Useful	3.68
20	Number of Stock Outs During the Month	Very Useful	Very Useful	3.61
24	Parts Inventory Value Over Time	Useful	Useful	3.45
29	Actual Labor Hours to Complete Closed Work Orders Versus Total Labor Hours (productive hours vs productive plus unproductive)	Very Useful	Useful	3.30
36	Parts Room Overhead Cost Versus Value of Inventory	Useful	Useful	2.68

or more managers. In general, maintenance managers appeared to prefer direct controls over indirect controls.

Performance indicators in all six categories were considered of value by the maintenance managers. Fleet reliability and fleet maintainability indicators appeared to be valued the most, whereas fleet availability indicators appeared to be of least interest. Maintenance Management Control Indicators also seemed of lesser interest to the managers.

The lack of balance between performance categories is likely to be a result of the emphasis, or lack of emphasis, placed by top management on certain maintenance attributes. For example, vehicle reliability clearly has the most direct and immediate connection between maintenance and overall transit service performance and service integrity. Buses that break down delay schedules and disgruntle passengers. Clearly, vehicle reliability has direct impacts on the entire transit service, and hence the visibility of vehicle reliability performance. On the other hand, the relationship between overall service performance and maintenance management control is not as direct and not as obvious. Therefore, it can be assumed that, in general, top management is less likely to be aware of maintenance management control performance and less likely to pressure the maintenance department to improve management control over maintenance performance. Unfortunately, regardless of the visibility of a performance attribute, the performance indicators should all be held in roughly equal importance in a comprehensive performance measurement system.

The eight indicators that no maintenance manager considered worthless were

1. Miles per road call (fleet reliability indicator), ranked no. 1;
2. Total regular and overtime maintenance labor hours per month (work productivity indicator), ranked no. 2;
3. Number of repeat repairs in the same month (work quality indicator), ranked no. 3;
4. Maintenance cost per vehicle mile (fleet maintainability indicator), ranked no. 5;
5. Maintenance cost per vehicle (fleet maintainability indicator), ranked no. 6;
6. Road calls per vehicle per month (fleet reliability indicator), ranked no. 7;
7. Maintenance labor cost per vehicle mile (fleet maintainability indicator), ranked no. 10; and
8. Average fuel and oil cost per bus model versus the total fleet (fleet maintainability indicator), ranked no. 11.

Of these eight performance indicators, only two cannot be calculated through performance reporting data required by the U.S. government of all transit systems receiving federal operating assistance (Section 15 data). Of those two (number of repeat repairs in the same month, and average fuel and oil cost per bus model versus the total fleet), fuel and oil cost is almost uniformly kept by all transit systems and only the repeat repairs indicator is unusual.

In summary, the results appear to indicate that the most accepted indicators are those that are already commonly collected. Further, the most highly ranked candidate indicators are generally those that are most visible and are most directly related to overall service performance. Unfortunately, this points to a lack of balance in importance placed on maintenance performance attributes. However, because there appears to be a broad variance in the responses (most indicators were considered worthless by some and vital by others), there appears to be little consensus among maintenance managers on what information is important, and the results of questionnaire rankings only indicate general trends.

Value of Candidate Indicators to Top Management

On the average, maintenance managers felt that all of the performance measures were of more value to themselves than to top management. Complete results of the value to top management question are given by Maze *(7)*. The maintenance managers considered miles per road call the most valuable indicator for their own use, but it was second to maintenance cost per vehicle mile in value to top management. The rankings of few indicators differed substantially between their value to maintenance managers (themselves), and their value to top management. One notable exception was parts inventory value over time (a maintenance management control indicator), which was considered by maintenance managers as ranked only 24th in value to themselves, but 7th in value to top management (and the top maintenance control indicator).

There also was broad variance in the scores given to the value of indicators to top management. All candidate indicators were scored vital by at least a few respondents and all candidate indicators were considered worthless by at least a few respondents. This indicates high variance in what the respondents think is important. Most of the highly ranked indicators were those that are commonly kept by transit systems (e.g., miles per road call, maintenance cost per mile, and maintenance cost per vehicle).

Top Management's Understanding of Maintenance

When asked, "How well do you believe the top management of your transit system understands maintenance?" maintenance managers gave the following answers:

Answer	*Number*	*Percent*
Not at all	1	1.24
Somewhat	14	17.28
Moderately well	24	29.63
Very well	38	46.91
Perfectly	4	4.94
Total	81	100.00

About half of the maintenance managers believed that top management understood maintenance very well or perfectly and only about 20 percent believed that top management understood maintenance somewhat or not at all. Therefore, the majority of the maintenance managers appeared to believe that their top management understands maintenance relatively well. However, 11 of the respondents did not answer this question, slightly biasing the results.

Other Performance Indicators Suggested by Maintenance Managers

The following list contains additional performance indicators that were suggested by the transit maintenance managers, grouped by the six categories. Additional fleet reliability and maintainability indicators included those that provided more detail on road calls, the reliability of such components as wheel-chair lifts and air conditioners, and more cost indicators. Under maintenance control, some managers included indicators that detailed labor utilization and labor management.

Fleet Reliability Indicators

Road calls by system failed
Road calls by type by fleet model
Mechanical versus nonmechanical breakdowns
Percentage of wheelchair lifts operable
Mean miles between engine and transmission failures
Percentage of air conditioning systems operable

Fleet Maintainability Indicators

Miles per quantity of fluids other than fuel
Maintenance labor hours per 1,000 bus miles
Number of brake relines performed per month as a percentage of the fleet
Parts inventory per bus
High-cost items (e.g., tires and fluids other than fuel) per type of bus versus the fleet
Material cost per 1,000 mi
Tire cost per 1,000 mi

Fleet Availability Indicators

Percent of active fleet waiting for repairs—deadlines
Actual spare ratio versus scheduled spare ratio

Work Quality Indicators

Maintenance required within 15 days of preventive inspection
Repeat repairs diagnosed and solved through preventive maintenance inspections
Breakdowns versus number of days past preventive inspection
Number of defects reported by operators
Number of defects found and corrected during preventive inspections
Percent preventive versus corrective maintenance

Work Productivity Indicators

Percent of total fleet cleaned daily
Ratio of mechanics to buses
Average number of parts people per 50 buses
Average number of mechanics per work shift

Maintenance Management Control Indicators

Personnel status—available hours versus assigned hours
Parts on back order and how long
Maintenance labor hours lost due to employee absence per month versus estimated workload hours per month
Total labor hours spent on indirect labor activities versus total labor hours
Percentage of fleet without visible interior or exterior disorders (e.g., torn seats, leaks, and body damage)
Percentage of absentee labor
Percentage of labor hours that are overtime
Percentage of overtime paid due to absences as compared to total overtime
Percentage of overtime paid to complete backlogged work orders as compared to total overtime

CONCLUSIONS

In this paper the fundamental role of performance measurement in maintenance management is described. Performance measurement is used to ensure that maintenance objectives are being achieved; therefore, performance indicators should reflect management objectives. The development of objectives is the most important function of management planning. Because performance measurement reflects management objectives, the development of a management plan (including objectives) should be conducted first followed by the development of a complementary performance measurement system. Further, performance measurement is most valuable when the measurements are incorporated into decision making through planned policies, procedures, rules, and programs.

A series of candidate performance indicators are also presented, and the value of each is shown in practice from a questionnaire administered to maintenance managers. The variability found in the importance of each maintenance performance indicator probably reflects the natural variability in management objectives from one transit system to the next. However, the list does provide some general guidance to the relative utility of indicators in practice. This guidance may be used in the design of performance measurement systems.

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Bus Maintenance Performance Indicators: Historical Development and Current Practice

GEORGE LIST AND MARK LOWEN

Choosing the right performance indicators to control the quality of vehicle maintenance has been and continues to be a problem of concern to the transit industry. Transit operators today see increasing pressure to obtain greater use from their existing equipment, a goal that can only be achieved by closer attention to the maintenance function. The purpose of this paper is to report the results of a recent survey sponsored by American Public Transit Association (APTA) regarding bus maintenance performance indicators and to compare those results with other surveys and related projects that have been conducted in the past. Generally, the survey shows clear points of agreement among the maintenance managers. Roadcalls are the predominant initial point of focus, followed by a search for cause (e.g., drivetrain performance) and a monitoring of costs, labor, and vehicle condition (i.e., inspections). Individual indicators ranking high on the list include miles per gallon, miles per quart of oil, miles per roadcall, periodic roadcalls, maintenance cost per mile and repeat work. There are differences of opinion, however, as shown by the list of 656 free form indicators submitted and ranked by the respondents. Compared to other lists of indicators, the survey shows close similarities with those developed recently, and marked differences with those developed some 30 years ago by the APTA [then known as the American Transit Association (ATA)]. Among the recent surveys, all show roadcalls to be of primary importance along with costs, labor productivity, and quality control (through inspection programs). Compared to the indicators developed by the ATA, there is still a clear overlap, but the indicators deemed important then do not rank in the top 10 today.

The transit industry has been working earnestly in recent years to improve the quality of its bus maintenance. Among all the issues being addressed, the monitoring problem has been of particular concern. It is especially important now because of cutbacks in federal support for the acquisition of new buses and belt tightening by state and local governments. Transit operators see increasing pressure to obtain greater use from their existing equipment—a goal that can only be achieved by closer attention to the maintenance function.

In this paper, the results of a recent survey [sponsored by the American Public Transit Association (APTA)] designed to identify the bus maintenance performance indicators in current use are presented, and these results are compared with other surveys and related projects that have been conducted in the past.

TRANSIT PARS

The search for bus maintenance performance indicators stretches back at least 35 years to 1951, when at the annual meeting of the American Transit Association (now the APTA), a panel of association operating company executives presented a proposal to establish a set of transit pars, measures of industry performance intended to help management test the adequacy of revenues and the efficiency of their enterprises (*1*).

Based on meetings, correspondence, and special conferences, the committee's 1952 report identified two types of measures; the first type was revenue based, such as the percentage of operating revenues devoted to maintenance, repair, and servicing; the second type was to be supporting yardsticks, ratios of one operating statistic to another, intended to guide managers in pinpointing the reason for good or bad par performance. As the 1952 report indicated:

> [The supporting yardsticks] are special types of ratios based, in almost every case, on statistics other than revenue. In the opinion of the Committee, the principal purpose of such supplementary ratios [is] to provide management and department heads with additional criteria: For judging the efficiency of operation; to assist in pinpointing sources of trouble in phases of the overall operation which may need special attention; provide an answer to the basic question of whether revenue is too low or expenses too high; and possibly for other specific purposes that may develop in the use of pars (*1*, p. 6).

Although the committee could see that the spectrum of possible yardsticks was virtually unbounded, it restricted itself to measures that would be helpful in a limited number of situations, such as testing the efficiency of the organization responsible for maintaining the vehicles (*1*, p. 7).

SUPPORTING YARDSTICKS

Development of a mature set of supporting yardsticks for maintenance as well as purchases and stores spanned 6 years from 1951 to 1957. The 1952 report of the Transit Pars Committee mentioned five yardsticks pertaining to maintenance (*1*, p. 6):

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- Number of thousands of seat-miles operated per vehicle failure;
- Number of seat-miles operated per maintenance personnel work-hour;
- Number of maintenance workers per maintenance executive, administrative, and supervisory personnel;
- Number of maintenance workers per purchases and stores personnel; and
- Number of all transportation maintenance workers to general office workers.

> But when the subject of transit pars and supporting yardsticks was advanced to the regional session of the Mechanical Division in Washington, D.C. in May of 1953, considerable resistance was encountered among the superintendents of equipment there present. There was an apparent reluctance to enter into this activity, which some members present considered a tool of management with which to harass the mechanical departments; a dubious one not based upon fair measures of mechanical department activities and processes (2, Appendix A, p. 1).

A few of the people present felt cooperation was better than resistance, and because of this a Committee on Supporting Yardsticks within the Mechanical Division was appointed for 1953–1954. The 1953 Report of the Committee on Transit Pars indicated the following (*3*, p. 4):

> The Committee does not consider it advisable at this time to submit any. . . .ratio. . . .as [a] recommended. . . 'yardstick' or to develop a critical value for such [a] 'yardstick'. Certain of the ratios discussed, as for example investment-to-revenue and maintenance man-hours per 1,000 vehicle miles, are regarded as useful criteria by many members of the Committee; but there were too many unresolved questions concerning both the definition of terms and what the critical value of each ratio should be to permit unified Committee action on any of the yardsticks considered.

However, during the years 1954 to 1957 a consensus emerged. The 1954 report (*4*, p. 14) cites three important measures: maintenance wages per pay-hour, maintenance pay-hours per 1,000 veh-mi, and maintenance pay-hours per scheduled vehicle. A fourth, pay-hours of maintenance personnel to vehicle-hours, is listed as being discontinued because it lacked significance in comparison to maintenance pay-hours per 1,000 veh-mi. Additionally, eight other indicators were cited as being potentially useful: the proper amount of normal inventory and the use of materials in maintenance (for purchases and stores); hours of direct labor per vehicle-mile, a servicing efficiency measure, time standards, expected component lifetimes, a reasonable bad-order ratio for mechanical division purposes, and separate indicators for nonvehicular maintenance activities (e.g., buildings, track, and catenary). In 1955, the pars report listed the first approved yardsticks.

Yardsticks for maintenance (*2*, Appendix A, p. 3) were as follows:

- 1.0 man-hr per bus-day for servicing labor; and
- 18.0 equivalent man-hr per 1,000 veh-mi for maintenance, repair, and overhaul (MR&O), including repairs to damaged vehicles. (Contract work was converted to man-hours using 1 man-hr for every $5.00 of contract work.)

Yardsticks for stores (*2*, p. 6) were as follows:

- 60 man-hr per bus-year for administrative personnel; and
- $425 of inventory per bus.

By 1956 *(5)*, the figure of 1.0 man-hr per bus-day was adjusted downward to 0.90 and the figure of 18.0 equivalent man-hours per 1,000 veh-mi for MR&O was adjusted upward to 18.5. Further, two new tentative maintenance yardsticks were established:

- 2.8 maintenance department supervisory and clerical man-hours per 1,000 bus-mi; and
- 30.0 total supervisory, clerical, servicing, and equivalent MR&O man-hours per 1,000 bus-mi.

Also, yardsticks for purchases and stores were as follows:

- 50 man-hr per bus-year for purchases and stores administrative labor (instead of 60);
- $325 in inventory per bus owned; and
- An annual inventory turnover ratio of 2.0.

As given in the following list, the 1957 report *(6)* summarized the performance indicators from the transit pars and presented further adjustments to the yardstick values.

- Motor bus maintenance

  0.90 man-hr per bus-day for servicing;
  18.5 equivalent MR&O man-hr ($5.00/hr for contract work) per 1,000 veh-mi;
  2.65 man-hr of supervisory and clerical labor per 1,000 veh-mi;
  30.0 equivalent man-hr, overall, per 1,000 veh-mi; and
  A spares ratio of 6 percent.

- Purchasing and stores

  50.0 purchasing and stores administrative man-hours per bus;
  $325 inventory per bus;
  2.50 annual turnover rate (tentative); and
  $19.50 of materials disbursed per 1,000 veh-mi (tentative).

MORE RECENT LISTS

More recently, other lists have been developed. Section 15 is one example *(7, 8)*; the recent survey by Maze *(9)* is another; and the APTA-based survey presented here is a third. Lists have also been developed by various analysts such as Hauser *(10)*, Fowler *(11)*, and Foerster et al. *(12–15)*.

To review briefly, the present Section 15 database *(7)* includes three maintenance-related indicators: vehicle-miles per maintenance dollar, vehicle-miles per roadcall, and revenue vehicles per maintenance employee. Although the statistics themselves have been criticized as unreliable *(16)*, so far no one has decided that they should be eliminated. Recently, these indicators have been under careful review, and a new group of indicators presented in the following list has been proposed for the Section 15 database *(8)*. They include measures of mechanic labor hours and maintenance performance in addition to an improved set of roadcall measures.

- Roadcalls (may be broken down based on effect: service disruption versus no service disruption)

  Maintenance-related,
  Other mechanical, and
  Nonmechanical.

- Mechanics' labor-hours worked in inspection, maintenance, and repair

  Hours devoted to revenue vehicle inspection and maintenance, and
  Hours devoted to accident or vandalism repairs to vehicles.

- Maintenance performance

  Average weekday vehicles available for peak service
  Average weekday spare vehicles available for peak service
  Average weekday vehicles out of service for maintenance
  Quarts of oil added between normal oil changes
  Average engine life to first overhaul
  PM inspections performed on schedule (±1,000 mi)
  PM inspections more than 1,000 mi late

- Externalities affecting maintenance

  Vehicle-miles on city streets;
  Vehicle-miles on highway and freeways;
  Existence of facilities for heavy repairs (yes/no);
  Existence of facilities for major component rebuilds (yes/no);
  Peak vehicles equipped with lifts;
  Peak vehicles with air conditioning;
  Local terrain (flat, hilly, mixture); and
  Local climate (hot, cold, severe weather).

Maze *(9)* distributed questionnaires containing the following list of performance indicators to 120 transit properties:

Maze (9)

Miles per roadcall
Regular and overtime labor-hours per month
Repeat repairs per month
Repeat breakdowns per month
Cost per vehicle-mile
Cost per vehicle
Roadcalls per vehicle per month
PM inspections scheduled versus performed (per week)
Percent of PM inspections performed within a prescribed interval
Labor cost per vehicle-mile
Fuel and oil cost per bus (by bus model)
Material cost per vehicle-mile
Average age of the major components in each bus
Number of open maintenance work work orders
Labor hours per PM inspection (by type of inspection)
Labor-hours per repair
Percent of maintenance work identified during inspections
Average mileage overage for overdue inspections
Labor cost per bus (by bus model)
Stockouts per month
PM labor-hours as a percent of total labor-hours
Cost per bus-mile (by bus model)
Labor-hours required to complete the maintenance backlog
Value of the parts inventory
Parts cost per bus (by bus model)
Maintenance jobs in the backlog
Work orders per bus (by bus model)
Miles per bus (by bus model)
Actual labor hours to complete closed work orders versus total labor-hours
Average time per open work order
Parts cost per month versus the value of the parts inventory
Labor cost versus material cost
Labor hours backlogged
Actual versus standard hours for work performed
Value of the parts inventory (by bus subsystem)
Parts room overhead cost versus value of inventory

Hauser (10)

Cost per mile
Percent runs missed
Miles between roadcalls
Breakdown of maintenance staff by category (percentages and ratios)
Coaches per mechanic
Coaches per fueler, cleaner, hosteler, utilityman, and tireman
Coaches per garage
Hoists and pits per 100 coaches
Square feet of garage per coach
Distribution of garage workspace
Service stalls per 100 coaches
Square feet per work stall
Hoists and pits per 100 coaches
Dollars of inventory per coach in the active fleet
Spares ratio
Miles per bus
Average age of the fleet

Fowler (11)

Total mechanical roadcalls
Miles between roadcalls
Roadcalls broken down by category
Number of nontraceable problems
Labor cost per mile
Parts cost per mile
Total cost per mile without fuel or lubricants
Total cost per mile with fuel and lubricants
Costs (labor, parts, total, per mile) by component
Buses being repaired (by garage)
Buses awaiting repair (by garage)
Buses awaiting parts (by garage)
Assigned labor hours
Straight versus overtime labor hours
Labor hours worked (from repair orders)
Labor hours assigned per 1,000 bus-mi
Labor hours paid per 1,000 bus-mi

Labor-hours worked per 1,000 bus-mi
Buses out of service due to maintenance (by cause)
Catch-up maintenance man-hours
Inspections due (by category)
Inspections accomplished (by category)
Inspections overdue
Lapse time and labor-hours per inspection (by category)
Materials/parts cost per inspection (by category)
Inspection labor cost (by category)
Cost of the preventive maintenance program
Tire mileage (new, used, by size)
Damaged tires

The managers were asked to score the indicators on a scale from worthless to vital. Also, they were asked to score each indicator's value to top management as opposed to the maintenance manager. Ninety-two of the questionnaires were returned. Miles per roadcall scored as the most valuable performance indicator; total regular and overtime maintenance labor-hours per month ranked second; the number of repeat repairs in the same month ranked third; and the number of repeat breakdowns in the same month ranked fourth. However, the rankings of these indicators were 4.33, 4.25, 4.25, and 4.25 out of 5 respectively, so it is difficult to say how meaningful the rankings were. As Maze *(9)* indicates:

> Our findings on desirability of various performance indicators are very mixed. It seems those most favored are those most commonly kept (e.g., miles per road call, maintenance cost per mile, etc.). Other indicators which are considered vital by some maintenance managers are considered worthless by others (*9*, cover letter).

In addition, Maze reports that only 8 of the 36 indicators were considered worthwhile by everyone. The eight were miles per roadcall, regular and overtime maintenance labor-hours per month, number of repeat repairs in the same month, maintenance cost per vehicle-mile, maintenance cost per vehicle, roadcalls per vehicle per month, maintenance labor cost per vehicle-mile, and average fuel and oil cost per bus model versus the total fleet. All 8 ranked in the top 11 indicators. The respondents also suggested some 35 other performance indicators, suggesting that perhaps some useful measures had been omitted.

There have been further lists developed by analysts for the purpose of conducting various investigations. Hauser's *(10)* list was based on the supporting yardsticks discussed previously to describe what a successful maintenance operation should be. His list reflects a heavy emphasis on work quality, costs, physical resource capacity utilization, and labor utilization and distribution.

Fowler *(11)* believed his list of data items should be included in a maintenance management information system. Although this is not a list of indicators per se, it does give a clear picture of what a maintenance manager needs to know in order to manage effectively. The list includes measures of overall bus performance, labor utilization, deferred maintenance, costs, roadcalls, preventive maintenance, and tire performance. For example, the roadcall indicators include total mechanical roadcalls per unit time, miles between mechanical roadcalls, a breakdown of roadcalls by cause, and the number of nontraceable problems.

Foerster et al. *(12–15)* developed a list of performance indicators based on a series of bus maintenance management case studies. In one of the case studies *(13)*, the general superintendent of maintenance and the special projects administrator said (*13*, p. 14):

> The maintenance division uses the following performance indicators:
>
> Roadcalls per week,
> Average miles per roadcall,
> Missed runs per week,
> Number of late outs,
> Number of buses out of service, and
> Spare ratio.
>
> In addition, maintenance cost per mile is used during the budget process, although it is not one of the indicators used on a regular basis. They look for trends in the indicators; for some they have limits they try to adhere to. According to the general superintendent, the most important indicators are those concerned with roadcalls, particularly average miles per roadcall.

Between this and two other case studies *(14, 15)* presented in Table 1, 15 performance indicators were cited. They included roadcalls (per week, per month, and per mile), cost measures (per mile, per hour, and budget adherence), vehicle component performance (especially, fuel and oil consumption), overall bus performance (out-of-service buses, spares ratio, missed runs, late outs, availability, general bus appearance), and labor (in this case, buses per maintenance employee).

THE 1985 APTA SURVEY

In July 1985, the American Public Transit Association's (APTA's) Bus Maintenance Management Subcommittee elected to conduct its own survey of maintenance managers to determine what indicators they used to monitor maintenance performance and what skills they considered most important for first-line maintenance managers *(17)*. Each respondent was asked to answer four questions using the form shown in Figure 1: (a) list the 10 most important performance indicators you use to monitor maintenance performance; (b) describe the characteristics of your transit system in terms of average road speed, frequency of stops, ambient temperature, and five other criteria; (c) list the five most important skills your first-line supervisors need to do their job effectively; and (d) provide a breakdown of your fleet based on size (the percentage of buses under 35 ft long, 35 to 40 ft long, and articulated).

Responses

One hundred two properties submitted responses, of which 100 are included in this analysis. These represent a diversity of system types ranging from those where all buses are under 35 ft long to others where over 25 percent of the fleet is articulated. They encompass approximately 32,000 buses or 50 percent of all North American transit buses, with fleets ranging from small (under 50) to large (over 4,000). They are located primarily in the United States with a few from Canada and one from Guam.

TABLE 1 PERFORMANCE INDICATORS FROM THREE CASE STUDIES *(13–15)*

	CENTRO Syracuse, NY			Gary Public Trans. Corp		Spokane Trans. Auth.		
Indicator	G-M	AGM	M-M	G-S	H-M	DTO	S-M	LDM
Roadcalls per week or month	x	1	1	1	1	x	1	2
Cost per mile	x	2	3		3	1	3	x
Fuel and oil consumption						3		1
Appearance of the bus	1							
Out-of-service buses (% of fleet)	x		x			x	2	x
Spares (% of fleet)		3	x		2			x
Cost per hour						2		
Oil consumption				2				
Availability of buses	2							
Budget Adherence	3		x					
Fuel consumption				3				
Missed runs per week or month	x					x	x	
Late outs	x	x	x					
Buses per maintenance employee				x	x			x
Roadcalls per mile			x				x	

Key

G-M: General Manager
AGM: Assistant General Manager
M-M: Maintenance Manager

1: most important
2: second most important
3: third most important

Standardized Indicators

Rather than asking the respondents to rank a number of possible indicators, the committee believed it would be better to let the respondents create their own entries, hoping to eliminate any biases that might be generated by including some indicators and potentially omitting others. The committee recognized that this meant the responses would all be in free format, making it difficult to mechanize the summary process without some form of interpretation and categorization. But the benefits of having direct input were felt to outweigh the costs of interpreting the responses.

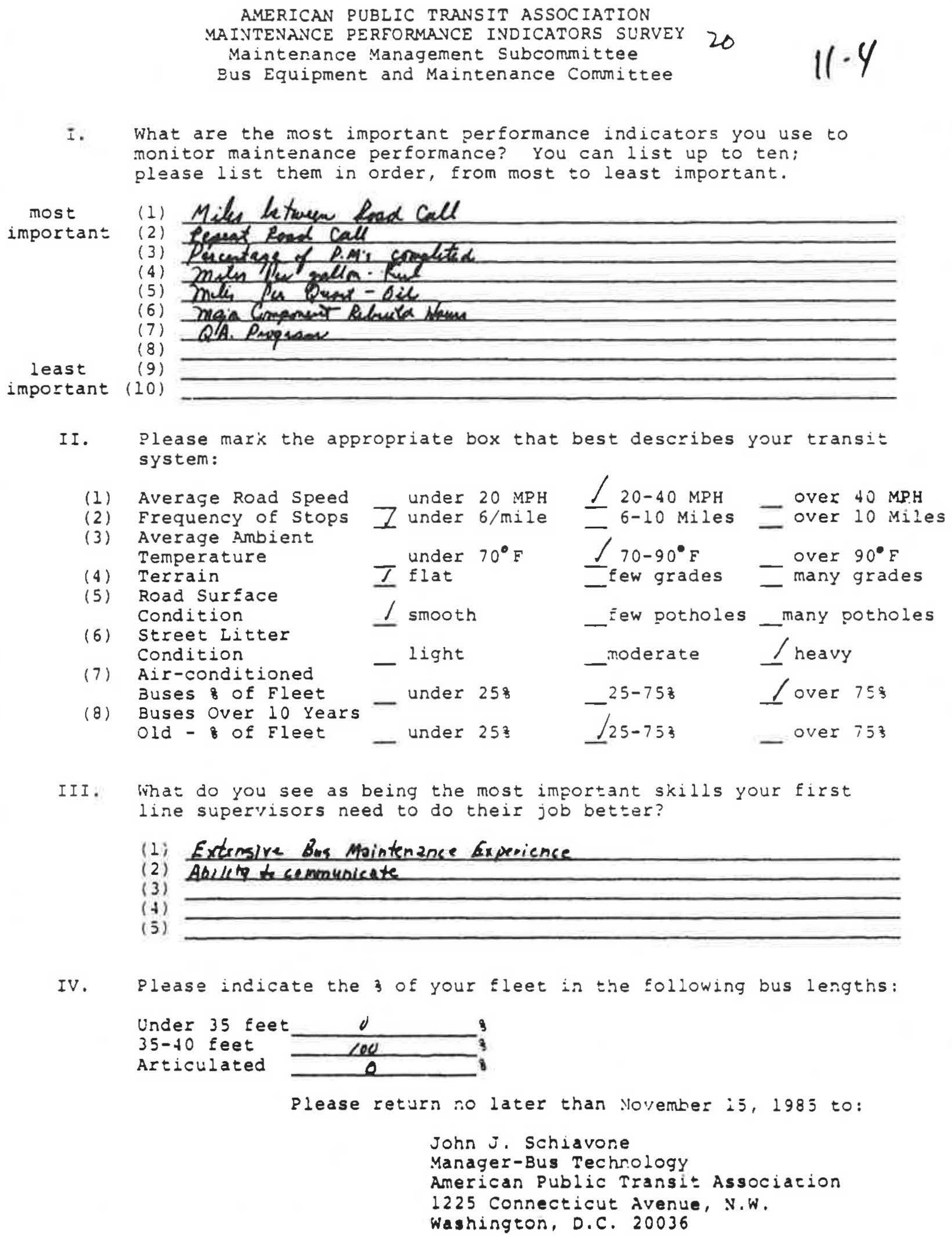
Once the responses were received, it was evident that the categorization process would be quite straightforward. Only the 126 indicators presented in the following list were required to capture all of the entries cited in the survey responses. They fall naturally into several groups: cost, factors of production (as related to the maintenance function), maintenance activities, interface with operations, and miscellaneous. For the first three, subcategories help to add additional clarity (i.e., for types of costs, factors of production, and types of maintenance activities, respectively).

COSTS

Operating
  Overall

Budget performance	BDG PERF
Maintenance cost per bus	M $/B
Maintenance cost per mile	M $/MI
Management cost per mile	MGMT $/MI
Mechanical operating costs per mile	MC OP $/MI
Periodic costs (unspecified)	PER $
Periodic costs for corrective maint.	PER $ CORR

Periodic costs for prevent. maint.	PER $ PM
Repair costs	REP $
Labor Costs	
Actual time versus pay time	ACT T/PD T
Direct vs. indirect vs. paid time	DIR/IND/PD
Pay time versus reported time	PD T/RP T
Periodic labor costs	PER L $
Workmens compensation claims filed	WKMN COMP
Parts Cost	
Parts cost per mile	PRT $/MI
Periodic material costs	PER MT $
Periodic value of inventory	PER $ IV
Tire cost per mile	TIRE $/MI
Value of inventory per active fleet	$ IV/B
Warranty Billing	WARR BILL
Capital Investments	
Average age of fleet	FL AGE
Number of bays per fleet size	# BY/FL
Size of spare fleet to total fleet	S FL/TO FL
FACTORS OF PRODUCTION	
Labor	
Absenteeism	ABSENT



AMERICAN PUBLIC TRANSIT ASSOCIATION
MAINTENANCE PERFORMANCE INDICATORS SURVEY 20
Maintenance Management Subcommittee
Bus Equipment and Maintenance Committee

11-4

I. What are the most important performance indicators you use to monitor maintenance performance? You can list up to ten; please list them in order, from most to least important.

most important (1) Miles between Road Call
(2) Repeat Road Call
(3) Percentage of P.M's completed
(4) Miles Per gallon - Fuel
(5) Miles Per Quart - Oil
(6) Major Component Rebuild Hours
(7) Q.A. Program
(8) ________
least (9) ________
important (10) ________

II. Please mark the appropriate box that best describes your transit system:

(1)	Average Road Speed	☐ under 20 MPH	☑ 20-40 MPH	☐ over 40 MPH
(2)	Frequency of Stops	☑ under 6/mile	☐ 6-10 Miles	☐ over 10 Miles
(3)	Average Ambient Temperature	☐ under 70°F	☑ 70-90°F	☐ over 90°F
(4)	Terrain	☑ flat	☐ few grades	☐ many grades
(5)	Road Surface Condition	☑ smooth	☐ few potholes	☐ many potholes
(6)	Street Litter Condition	☐ light	☐ moderate	☑ heavy
(7)	Air-conditioned Buses % of Fleet	☐ under 25%	☐ 25-75%	☑ over 75%
(8)	Buses Over 10 Years Old - % of Fleet	☐ under 25%	☑ 25-75%	☐ over 75%

III. What do you see as being the most important skills your first line supervisors need to do their job better?

(1) Extensive Bus Maintenance Experience
(2) Ability to communicate
(3) ________
(4) ________
(5) ________

IV. Please indicate the % of your fleet in the following bus lengths:

Under 35 feet 0 %
35-40 feet 100 %
Articulated 0 %

Please return no later than November 15, 1985 to:

John J. Schiavone
Manager-Bus Technology
American Public Transit Association
1225 Connecticut Avenue, N.W.
Washington, D.C. 20036

FIGURE 1 Survey form.

Adequate supervision	OK SUP
Labor accountability	L ACCOUNT
Maintenance labor time per mile	M L T/MI
Morale of mechanics	MCH MORALE
Number of buses per maint. worker	# B/M W
Number of buses per maint. sup. pers.	# B/SP P
Number of buses per maint. svc. pers.	# B/SV P
Number of buses per mechanic	# B/MCH
Number of maint. workers per mile	# M W/MI
Ratio of overtime to total time	OT T/TO T
Time allocation	T ALLOCAT
Time guide	T GUIDE
Total labor time	TO L T
Total overtime required	OV
Training of shop personnel	TRG SHP P
Training of supervisory personnel	TRG SUP P
Work force alignment	WF ALIGN
Vehicle Fleet	
Average availability	AVG AV
Average avail. as percent of demand	AVG AV/DEM
Historical data by bus or bus type	HIS DATA/B
Number of days down per bus	# DY DN/B
Number of down buses	# DN B
Number of repeat fail. by bus type	# RPT/TYPE
Total down time	TO DN T
Spare Parts	
Inventory turnover rate	IV TURN
Number of stockouts	STOCK
Parts availability	PRT AV
Scrap bin	SCRAP BIN
Vehicle Components	
Drive Train	
Engine life	ENG LF
Fluid consumption (unspecified)	FLU CNS
Fuel consumption	MPG
Oil analysis	OIL ANAL
Oil consumption	MPQ OIL
Transmission fluid consumption	MPQ TRAN
Transmission life	TRAN LF
Other Components	
Air conditioner availability	A-C AV
Brake life	BR LF
Lift failure	LIFT FAIL
Miles per brake reline	MI/BR REP
Tire life	TIRE LF
Wheelchair reliability	WLCHR REL
General	
Component life (unspecified)	PRT LF
Failure trends	FAIL TREND
Miles on changed-out components	MI C-O PRT
Miles on rebuilt components	MI REB PRT
Part reliability	PRT RELIAB
Periodic defects reported	PER DEF RP
Shop Facilities	
Cleanliness of shop	SHP CLN
Lift availability	LIFT AV

MAINTENANCE ACTIVITIES

General	
Adequate safety programs	OK SAFE
Comp. with other transit agencies	AGENCY COM
Gen. qual. of maint. work	GEN QUAL W
Production	PROD
Repeat work	RPT W
Scheduled/unscheduled work	SCH/USCH W
Shop retention time	SHP RET T
Work done on time	W DONE O/T
Work order comparison	W ORD COM
Work volume through shop	W THRU SHP
Roadcalls	
Miles per failure	MI/FAIL
Miles per mechanical roadcall	MI/RC MC
Miles per nonmechanical roadcall	MI/RC NMC
Miles per repeat roadcall	RPT RC
Miles per roadcall (unspecified)	MI/RC TL
Miles per tow-in	MI/TOW IN
Miles per service interruption	MI SV INT
Mechanical/nonmechanical roadcalls	MC/NMC RC
Number of accidents	ACCID
Number of roadcalls per PM interval	RC/PM
Periodic repeat roadcalls	PER RPT RC
Periodic roadcalls	PER RC
Periodic service interruptions	PER SV INT
Roadcalls with mechanic on street	RC W/MCH
Inspections	
Adequate PM program	OK PM
Correct diagnosis/troubleshooting	OK DIAGNOS
Defects uncovered during PM	DEF PM
Miles per PM inspection	MI/PM
Overdue PM inspections	LA PM
Performance after inspections	PERF>INSP
Periodic A/C inspections	PER A-C
Periodic bus inspections	PER B INSP
Results of (State) safety inspect.	SAVE INSP
Supervisory spot-checks	SUP INSP
Light Repairs	
Appropriate replacement of part	OK PRT REP
Overdue brake adjustments	LA BR ADJ
Percent of fleet cleaned on schedule	% SCH CLN
Periodic brake adjustments	PER BR ADJ
Periodic bus cleanings	PER CLN
Proper servicing of fleet	OK SV
Heavy Repairs	
Backshop backlog	SHP BACKLG
Miles/major overhaul	MI/MAJ OV
Miles/major repair	MI/MAJ REP
Time to rebuild a component	T/REB PRT
Unit repair production	REP PROD

INTERFACE WITH OPERATIONS

Cleanliness complaints	CLN CMP
Complaints about maintenance work	CMP M W
Operator reported defects	OP DEF
General appearance	GEN APP
Meeting goals	O-T PERF
Number of late starts	LA STARTS
Number of no-go's	# NOGO
Number of replace. buses dispatched	# REP B DES
Passenger complaints	PAX CMP
Percent (or number) of trips missed	% MISS TRP

TABLE 2 DIFFERENCES BETWEEN PRIORITY RANKING AND OVERALL POPULARITY RANKING

INDICATOR	PRIORITY LEVEL ON THE SURVEY FORM FIRST	 SECOND	 THIRD	TOTAL
		Entries by Priority Level		
INDICATOR A	70	10	5	85
INDICATOR B	10	35	60	105
INDICATOR C	20	50	25	95
None	0	5	10	15
TOTAL	100	100	100	300
		Cumulative Entries by Priority Level		
INDICATOR A	70	80	85	85
INDICATOR B	10	45	105	105
INDICATOR C	20	70	95	95
None	0	5	15	15
TOTAL	100	200	300	300

MISCELLANEOUS

Maintenance time per mile on sup. veh.	T/SP V MI
Meeting goals (unspecified)	GOAL
Miles per bus	MI/B
Missed injection (?)	MISS INJE
MPG for support veh. per service mile	SP MPG/MI
Periodic mileage	PER MI
Periodic transfers	PER TRANSF

Ranking Methodology

Usually, the process of ranking is simple and straightforward, particularly if the items to be ranked are given a single-dimensional score by the respondents. But here, the process is not quite as simple because the respondents have created their own indicators, listing only as many as they felt were important, and listing them in rank order. Hence, a difference can exist between the relative importance of an indicator and the number of times it is listed. Consider the hypothetical situation presented in Table 2, where a group of 100 respondents has listed three indicators in varying orders (i.e., priority rankings) such that one indicator (A) is dominant in the top-priority slot, but fails to be significant thereafter. A second indicator (B) is not mentioned often at either the first- or the second-priority slots, but represents almost all of the entries at the third-priority slot, and a third (C) is mentioned most often in the second-priority slot. Although an aggregate Indicator B is listed most often (i.e., has the most entries), Indicator A ranks first because it dominates the other two at the top-priority level. Moreover, Indicator C falls ahead of Indicator B because it accumulates high-level entries faster than Indicator B. However, it is clear that Indicator B is widely accepted, appearing more times on the various lists than any other. Indicator C is next most popular, followed by Indicator A. Hence, an understanding of each indicator's importance requires two dimensions: the first considering the rates at which the indicators accumulate entries across the priority levels and the second considering the breakdown of total entries. Each is important.

Analysis of the Results

Of the 1,000 entries that were possible (100 respondents times 10 entries each), 656 were provided, an average of about 6 per respondent. Twenty-six respondents listed 10 and seven more respondents provided at least 8. (This in itself is an important finding because it shows that managers typically use only a limited number of indicators to monitor performance.)

The respondents clearly give roadcall indicators top priority. Half of them list a roadcall indicator first (Table 3); 18 list one second and 12 list one third (Table 4). Overall, 99 of the entries (15 percent) involve a roadcall indicator.

After roadcalls, drivetrain indicators accumulate entries faster than any other group (Table 5), ranking them second. In

TABLE 3 BREAKDOWN OF 98 TOP-PRIORITY INDICATOR CANDIDATES

Indicator	Main Category	Sub-Category	Number of Occurances
Maintenance dollars per bus mile	COST	Overall	7
Maint. cost op. dollars per bus mile	COST	Overall	1
Periodic labor cost	COST	Labor cost	1
Number of buses per maintenance worker	FACTORS	Labor factor	1
Maintenance labor hours per bus mile	FACTORS	Labor factor	1
Average availability	FACTORS	Vehicle overall	4
Total down time	FACTORS	Vehicle overall	1
Fluid consumption	FACTORS	Component (DTRAIN)	1
Miles per gallon	FACTORS	Component (")	5
Miles per quart of oil	FACTORS	Component (")	3
Oil analysis	FACTORS	Component (")	1
Failure trends	FACTORS	Component (general)	1
Repeat work	MAINT ACT	Overall	4
Work orders completed	MAINT ACT	Overall	2
Adequate safety programs	MAINT ACT	Overall	1
Miles per roadcall (unspecified)	MAINT ACT	Roadcalls	25
Periodic roadcalls (e.g. per month)	MAINT ACT	Roadcalls	15
Miles per failure	MAINT ACT	Roadcalls	6
Miles per roadcall, mechanical cause	MAINT ACT	Roadcalls	4
Defects found during inspection	MAINT ACT	Inspections	2
Deferred preventive maintenance	MAINT ACT	Inspections	2
Miles between inspections	MAINT ACT	Inspections	2
Periodic brake inspections	MAINT ACT	Inspections	1
Miles between major overhauls	MAINT ACT	Major repairs	1
Part availability	MAINT ACT	Inventory manag.	1
Percent missed trips	INTERF OP	-	2
General appearance	INTERF OP	-	1
On-time performance	INTERF OP	-	1
Operator defects	INTERF OP	-	1

Note: DTRN = drivetrain

TABLE 4 COUNTS OF CANDIDATES BY INDICATOR CATEGORY AND PRIORITY LEVEL

	PRIORITY LEVEL ON THE SURVEY FORM										
CATEGORY	FIRST	SECOND	THIRD	FOURTH	FIFTH	SIXTH	SEVENTH	EIGHTH	NINETH	TENTH	TOTAL
COSTS											
Overall costs	8	10	10	11	2	3	3	2	3	2	54
Labor costs	1			2	2	4	2	1			12
Parts costs		3	2	3	1	1	3	1		1	15
Capital invest				1	1			1	2	1	6
Warranty billings								1			1
SUBTOTAL	9	13	12	17	6	8	8	6	5	4	88
FACTORS OF PRODUCTION (FOR MAINTENANCE)											
Labor	2	11	8	10	7	7	5	3	10	5	68
Comp.(drivetrain)	10	18	22	17	18	10	11	9	4		119
Comp.(other)		2		1	2	8	1	2	1	4	21
Comp.(general)	1	1	3	4	4	1		1		1	16
Vehicles	5	6	6	10	3	3	2	4			39
Facilities				1		1		1		1	4
SUBTOTAL	18	38	39	43	34	30	19	20	15	11	267
MAINTENANCE ACTIVITIES											
Overall	7	11	6	6	6	5	6	3	1	3	54
Light repairs			2	1	2	2		2			9
Roadcalls	50	18	12	5	7	3	1	2	1		99
Inspections	7	7	11	8	4	2	4			2	45
Heavy repairs	1	1	2	1	2	2	1	1			11
Inventory manag.	1		2		2	4	2	1	1		13
SUBTOTAL	66	37	35	21	23	18	14	9	3	5	231
INTERFACE W/OPER	5	8	8	8	10	4	7	2	5	4	61
MISCELLANEOUS		2	2	1	1	1	1		1		9
BLANK	2	2	4	10	26	39	51	63	71	76	344
GRAND TOTAL	100	100	100	100	100	100	100	100	100	100	1000

TABLE 5 CUMULATIVE COUNTS OF CANDIDATES BY INDICATOR CATEGORY AND PRIORITY LEVEL

	PRIORITY LEVEL ON THE SURVEY FORM									
CATEGORY	FIRST	SECOND	THIRD	FOURTH	FIFTH	SIXTH	SEVENTH	EIGHTH	NINETH	TENTH
COSTS										
Overall costs	8	18	28	39	41	44	47	49	52	54
Labor costs	1	1	1	3	5	9	11	12	12	12
Parts costs		3	5	8	9	10	13	14	14	15
Capital invest				1	2	2	2	3	5	6
Warranty billings								1	1	1
SUBTOTAL	9	22	34	51	57	65	73	79	84	88
FACTORS OF PRODUCTION (FOR MAINTENANCE)										
Labor	2	13	21	31	38	45	50	53	63	68
Comp.(drivetrain)	10	28	50	67	85	95	106	115	119	119
Comp.(other)	0	2	2	3	5	13	14	16	17	21
Comp.(general)	1	2	5	9	13	14	14	15	15	16
Vehicles	5	11	17	27	30	33	35	39	39	39
Facilities				1	1	2	2	3	3	4
SUBTOTAL	18	56	95	138	172	202	221	241	256	267
MAINTENANCE ACTIVITIES										
Overall	7	18	24	30	36	41	47	50	51	54
Light repairs			2	3	5	7	7	9	9	9
Roadcalls	50	68	80	85	92	95	96	98	99	99
Inspections	7	14	25	33	37	39	43	43	43	45
Heavy repairs	1	2	4	5	7	9	10	11	11	11
Inventory manag.	1	1	3	3	5	9	11	12	13	13
SUBTOTAL	66	103	138	159	182	200	214	223	226	231
INTERFACE W/OPER	5	13	21	29	39	43	50	52	57	61
MISCELLANEOUS		2	4	5	6	7	8	8	9	9
BLANK	2	4	8	18.	44	83	134	197	268	344
GRAND TOTAL	100	200	300	400	500	600	700	800	900	1000

Table 4, 10 respondents list a drivetrain indicator first, 18 list one second, 22 list one third, and 17 list one fourth. This means that drivetrain indicators accumulate entries faster than any other category except roadcalls (Table 5). Overall, 119 entries (18 percent) fall into this category. The main specific indicators are miles per gallon (51 entries) and miles per quart of oil (38 entries).

After drivetrain performance, cost indicators gain entries the fastest. Eight respondents list an overall cost indicator first, 10 list one second, and 10 list one third. Overall, 54 of the 656 entries (8 percent) relate to overall cost. The most common indicator is maintenance cost per mile with 27 entries.

Beyond these three, the category that gains the most top-level entries is inspection program performance, followed by interface with operations; labor performance; overall maintenance performance; vehicle (i.e., indicators of overall vehicle quality); performance of specific components other than the drivetrain (brakes, tires, air conditioning, and wheelchair lifts); and general indicators of vehicle component performance.

The breakdown of total entries shows that the ranking based on popularity is slightly different. As Figure 2 shows, drivetrain performance measures have the most overall entries, followed by roadcalls and labor performance. Despite these differences, however, the 10 top categories are the same in either case, as shown in Table 6. The two indicator categories with the greatest difference in the rankings are overall costs (3 versus 5) and labor performance (6 versus 3).

Other perspectives provide additional insights. When the top 25 individual indicators are ranked according to total entries, miles per gallon ranks first followed by miles per quart of oil and miles per roadcall (Table 7). In Table 8, which lists the three top indicators for each priority level, roadcalls are dominant at first, but cause-related measures then increase in importance, especially miles per gallon and miles per quart of oil. At lower levels, transmission life, absenteeism, and general bus appearance receive top attention. Separately, there are numerous ties for third place, showing a wide diversity of opinion.

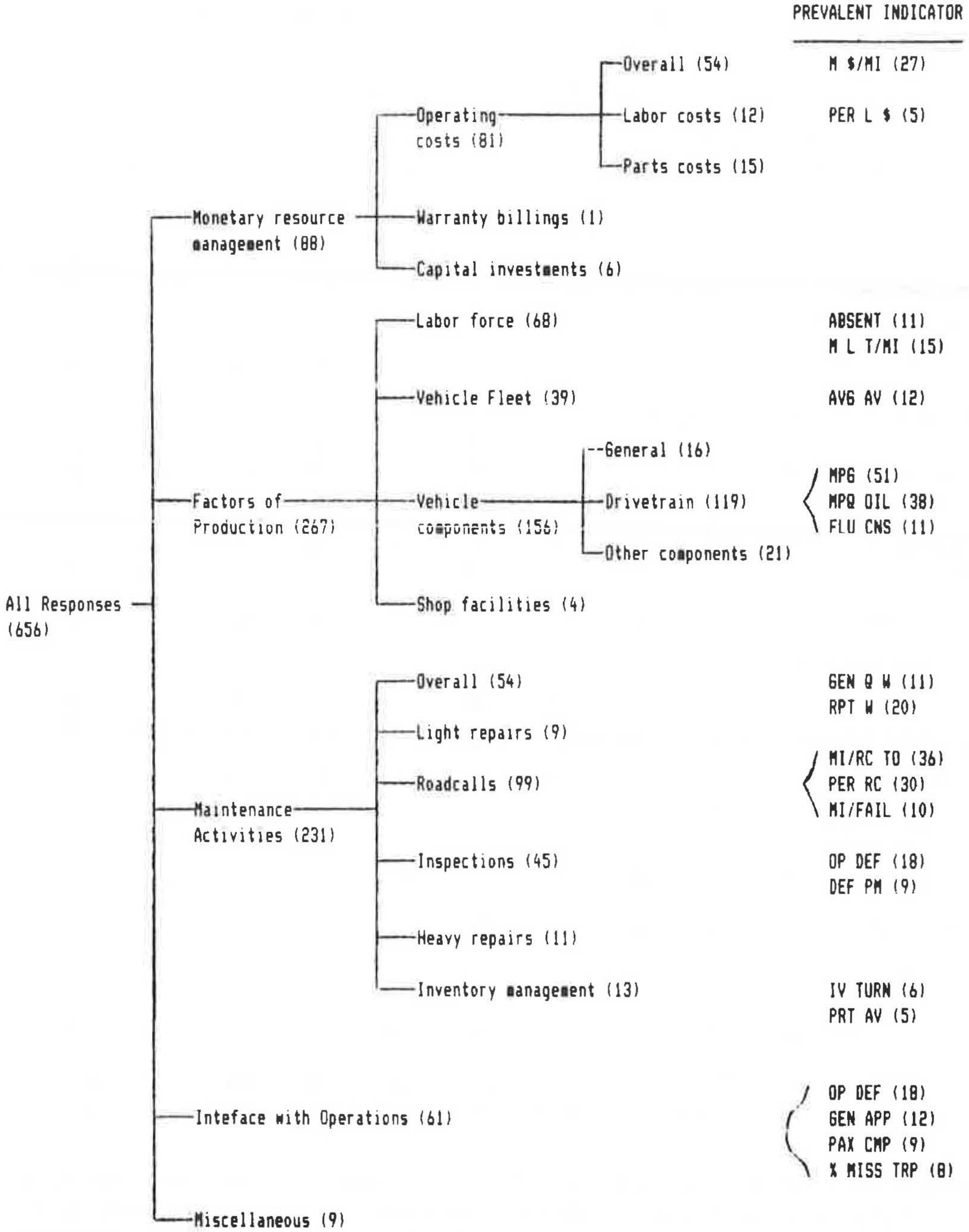


FIGURE 2 Breakdown of 656 indicator candidates.

Other observations (Tables 2–8) are as follows:

- Although labor is not a Priority Level 1 concern, it does have deep-rooted importance. At Priority Level 9, where only 29 entries are given, 10 of them relate to labor indicators. Manpower ratios were discussed intensively at the Bus Maintenance Workshop held in Houston, Texas, March 5–7, 1985 (*18*, pp. 4–5).
- The separate costs of labor and parts are not major indicators, even though total cost receives significant attention.
- Inspection-related indicators are listed frequently only at Priority Levels 3 and 4.
- The adequacy of investment in shop capacity is not given much attention despite Hauser's (*10*) intense focus on this area.
- Heavy repairs and inventory management never receive major attention.

Consistency Across Environments

One can theorize that the value of certain performance indicators should be sensitive to the system's operating environment. With this in mind, the survey included two questions that were used to test this idea. Question 2 (Figure 1) asked the respondent to describe his environment in terms of average road speed, stopping frequency, average ambient temperature, grades, potholes, street litter, percent of buses air conditioned, and percent of buses over 10 years old. Question 4 asked the

TABLE 6 RANKING OF INDICATOR CATEGORIES

Category	Ranking based on Accumulated Entries	Ranking based on Overall Entries
Roadcalls	1	2
Drivetrain performance	2	1
Overall costs	3	5
Inspection program perf.	4	7
Interface with operations	5	4
Labor performance	6	3
Overall maint. performance	7	6
Vehicles (quality)	8	8
Comp. (specific, but not drivetrn)	9	9
Comp. (generalizations)	10	10

TABLE 7 TOP 25 FUNDAMENTAL INDICATORS

Abbreviation	Meaning	Number of Entries
MPG	Miles per gallon	51
MPQ OIL	Miles per quart of oil	38
MI/RC TO	Miles per roadcall (unspecified)	36
PER RC	Periodic roadcalls (e.g. per month)	30
M $/MI	Maintenance cost per mile	27
RPT W	Repeat work	20
OP DEF	Operator reported defects	18
LA PM	Inspection (PM) backlog	15
M L T/MI	Total labor man-hours per bus mile	15
AVG AV	Average bus availability	12
GEN APP	General bus appearance	12
FLU CNS	Fluid consumption	11
ABSENT	Absenteeism	11
GEN QUAL W	General quality of maintenance work	11
MI/FAIL	Miles between failures	10
PAX CMP	Passenger complaints	9
DEF PM	Defects discovered during inspections	9
# DN B	Number of inoperative buses	8
OV	Overtime	8
MI/RC MC	Miles per roadcall - mechanical cause	8
% MISS TRP	Percentage of trips missed	8
M $/B	Maintenance cost per bus	7
PRT $/MI	Parts cost per mile	7
BR LF	Brake life	7
OIL ANAL	Oil analysis	7

Note: These top 25 account for 395 of the 656 entries (60%)

TABLE 8 THREE TOP FUNDAMENTAL INDICATORS FOR EACH RANK ORDER POSITION

Rank and Indicator	Entries	Rank and Indicator	Entries
FIRST		SECOND	
Miles per roadcall	25	Miles per gallon	11
Periodic roadcalls	15	Miles per qt of oil	7
Maint. cost per mile	7	Maint. man-hrs per mi	6
THIRD		FOURTH	
Miles per gallon	11	Miles per gallon	7
Periodic roadcalls	8	Op ident. defects	6
Miles per qt of oil	7	Maint cost per mile	6
FIFTH		SIXTH	
Miles per qt of oil	10	Miles per gallon	5
Miles per gallon	6	Inventory turnover	3
Three-way tie	3	Nine-way tie	2
SEVENTH		EIGHTH	
Fluid consumption	9	Transmission life	3
Complaints about work	4	Miles per gallon	2
Seven-way tie	2	No. of disabled buses	2
NINTH		TENTH	
Absenteeism	5	General appearance	3
Maint cost per mile	3	Brake life	2
All the rest	1	Overtime	2

TABLE 9 PERCENTAGE USE OF ROADCALLS AS THE TOP-PRIORITY PERFORMANCE MEASURE BASED ON SYSTEM FLEET CHARACTERISTICS

Fleet Characteristic	Number of systems	Systems using Roadcalls	Percent
All buses 35-feet long or shorter	7	4	57%
51-99% of the fleet 35-foot or shorter	11	7	64%
11-50% of the fleet 35-foot or shorter	17	6	35%
1-10% of the fleet 35-foot or shorter	14	7	50%
100% of the fleet between 35 and 40 feet	27	11	41%
1-10% of the fleet is articulated buses	16	9	56%
over 10% of the fleet is articulated	8	6	75%
Total responses	100	50	50%

respondent to break down the bus fleet in terms of small (under 35 ft long), full-sized (35 to 40 ft long), and articulated buses.

Although intuitive correlations between these characteristics appear to hold true, there is little evidence that they affect the choice of maintenance indicators. For example, the breakdown of Priority Level 1 indicators appears to be the same regardless of operating environment. Roadcalls account for about 50 percent of the Priority Level 1 indicators regardless of the fleet composition (Table 9). Other breakdowns by fleet size and environmental characteristics fail to show any obvious trends, with the conclusion that environmental factors do not play a major role in determining what indicators are important.

DISCUSSION

Comparing the present results with the studies discussed earlier, one is struck by both similarities and differences. The phrase that appears to apply most clearly is "The more things change, the more they stay the same." For example, although 35 years have passed since the supporting yardsticks were developed, they are still in use today albeit to a lesser degree. Also as was true 35 years ago, although some indicators seem to rank higher than others, diversity of opinion is still the norm.

While all nine of the pars indicators can be found in the lists submitted by the survey respondents, comparison with the 10 top-ranked individual indicators presented in Table 7 shows that the supporting yardsticks match only those ranked 9th and 10th, none higher. Miles per gallon is missed as well as miles per quart of oil, miles per roadcall, periodic roadcalls, maintenance cost per miles, repeat work, operator defects, and overdue preventive maintenance. Moreover, the yardsticks lack representation from 5 of the 10 top categories (Table 6). There are no supporting yardsticks for roadcalls, drivetrain performance, overall costs, inspection program performance, interface with operations, or the other two-component (specific and general) performance-related categories. Several explanations are possible. This lack may be an indication of change—that maintenance managers have more reason to focus on roadcalls today than they did in the past. Alternatively, they may be more service-oriented; the buses may be less reliable; or the buses may be more reliable, with the result that preventive maintenance intervals are longer and failures are more difficult to catch before they occur. Another possibility is that 35 years ago maintenance managers knew what factors to watch in order to keep others under control. Also, the committee members may have gotten trapped by trying to specify target values for all yardsticks and found it impossible to identify universally applicable values for indicators such as roadcalls per vehicle-mile; hence, such indicators were dropped from the list. In any event, the old yardsticks do not reflect the indicators in use today.

The newly proposed Section 15 indicators fare considerably better. Equivalents for all nine can be found in Table 2; and collectively, treating them as a supplement to other indicators already available in the Section 15 data, there are matches for the first-, second-, third-, and fourth-ranked indicators presented in Table 7. Moreover, vis-à-vis the top indicator categories presented in Table 6, the Section 15 list includes one or more indicators for each of the four top categories: (a) roadcalls, both total and mechanical; (b) miles per gallon and miles per quart of oil; (c) overall maintenance cost per mile; and (d) percent of preventive maintenance performed on schedule. The categories lacking indicators are interface with operations, labor performance, overall maintenance performance, and either the component-specific or unspecific performance categories. Thus, while the Section 15 list could be expanded further to capture indicators of lower importance, the proposed list is quite good.

Maze's *(9)* indicators also do well. Of the 36 proposed, equivalents for 30 are presented in Table 2. Moreover, there are matches for the 3rd-, 4th-, 5th-, 6th-, 8th-, and 10th-ranked indicators (Table 7), the missing ones being miles per gallon, miles per quart of oil, operator-identified defects and total maintenance labor man-hours per mile. Separately, vis-à-vis the 10 top categories listed in Table 6, the ones lacking representation are drivetrain performance, interface with operations, and specific component performance other than drivetrain (e.g., brakes and air conditioner).

Comparison with Maze's *(9)* survey also highlights two important points. First, by having the respondents score a list of preselected indicators, the survey showed whether the indicators were useful but not whether they would be or were being used. Second, the survey missed indicators that the respondents thought were important. This lack limits the utility of the results.

Hauser's *(10)* list fares the poorest, with matches in Table 6 for only the third-, fourth-, and fifth-ranked indicators. This result may not be because the list was wrong, but rather because the maintenance managers are being too shortsighted about identifying the real source of their performance problems. Hauser believes that too little facility capacity can lead to overtaxation of existing resources, backlogs, and poor-quality work.

Fowler's *(11)* list does better than Hauser's *(10)*. Although it does not have many exact matches in Table 2, ratios based on the list have matches for all but four. Clearly, Fowler's list reflects the industry's current thinking.

Finally, all the indicators identified by Foerster et al. *(12–15)* have matches in Table 1. However, this result is not surprising because the properties that were studied were also surveyed in the work presented here. However, Foerster's short list of 15 indicators captures the ones ranked 2nd, 3rd, 4th, 5th, and 10th (Table 7). Also, as was the case in this survey, roadcalls were found to be the leading indicator used to monitor performance.

IMPLICATIONS FOR RESEARCH AND PRACTICE

The scope of this paper has been limited to the measures that are in prevalent use today. This process may only determine what measures are easiest to obtain and interpret at the maintenance management level, not necessarily those that are the most useful. Better measures may be needed, but the data to support them may presently be too diffcult to obtain, store, and analyze. Roadcall measures are easy to use because the events are well-defined and always recorded. They are also most visible to the public and therefore sensitive from a system's public-image perspective. Labor time standard performance, on the other hand, is far more difficult to capture without some of the more sophisticated maintenance management information systems now becoming available. Yet, labor time is likely to be an effective means for measuring performance.

A number of questions need to be addressed as extensions to the work presented here.

- How effective are the present indicators?
- How well are they being used?
- Are the indicators fool-proof, or is following some of them (e.g., cost per vehicle-mile) at the expense of others misleading?
- Do they measure what is believed that they measure?
- What other indicators are needed?
- Where can new ideas for indicators be found (e.g., from aircraft maintenance)?
- If target values for the indicators (e.g., yardsticks) are developed, are they transferable between systems or between divisions within the same system?
- Can these 126 indicators be reduced to a small set of comprehensive measures that provide a succinct view of the maintenance performance of a given transit property?
- Can a set of vital indicators be identified that should be monitored all the time, deferring use of the others to times when problems occur?
- How is such a hierarchical structure for the indicators to be developed?

SUMMARY AND CONCLUSIONS

The survey appears to have succeeded in (a) determining what indicators are being used by maintenance managers today, and (b) providing an indication of their relative ranking. The respondents show clear points of agreement, such as the initial focus on roadcalls, followed by a turn inward to search for cause (e.g., drivetrain performance) and to monitor labor and monetary productivity. But the industry is far from consensus, and perhaps that is to be expected. Differences in managerial philosophies appear to stand in the way of an agreement on a single list of indicators and their ranking. In fact, this diversity may be a sign of health, not weakness, in that it shows individual opinion and experimentation are constantly being used to test the validity of old measures and to determine the value of new ones.

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Terrain Effects on Bus Maintenance Performance

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In this paper, a methodology to classify terrain is presented. The taxonomy is devised using a terrain template based on evidence from topographic maps, and the resulting classes are characterized as steep, intermediate, and flat terrain peer groups of transit authorities. A set of 181 transit authorities was classified according to terrain type; in borderline cases, graphic displays were used to supplement the tabular display format of the classification. The terrain template was derived from applying allometric growth and census data to topographic evidence. Sets of Section 15 bus maintenance performance indicators were examined within terrain peer groups as an example of the potential for the application of these procedures. When the indicators miles per gallon, employees per vehicle-mile, and cost per vehicle-mile were displayed by terrain peer groups, relationships were found between quality of maintenance and miles per gallon in steeper environments.

Steep grades in bus routes create strain on the motor and power train of a bus, and frequent alternation between uphill and downhill operations on the bus creates further stress on its internal systems. Terrain peer groups for buses, formed from a set of transit authorities participating in the Section 15 reporting system, assist in understanding the impact terrain might have on bus maintenance performance. The application of a simple terrain template permits either transit managers or UMTA to place an arbitrary transit authority into a flat, intermediate, or steep terrain peer group. A set of 181 transit authorities was classified according to terrain type, and graphic displays were used to supplement the tabular display format of the classification.

To illustrate one way to employ the taxonomy, Section 15 indicators were used to consider the effect terrain might have on bus maintenance performance. Miles-per-gallon indicators were stratified into subclasses according to terrain and maintenance quality type. When independent variables other than terrain such as climate or congestion were introduced into the analysis, a comprehensive view of bus maintenance performance as a function of environmental, as well as of routing and economic, considerations followed.

More specifically, when the methodology was applied, it suggested numerical maintenance subclasses within terrain peer groups, with which transit authorities might compare their miles-per-gallon figures. Because the application of method was to maintenance data, this study meshed with the authors' previous methodological study *Climatic Effects on Bus Durability (1)*, suggesting the potential for cross-class empirical comparisons of cross-sectional performance data.

The primary contribution of this research is to introduce methodology to classify sets of transit authorities according to terrain type. As the scale of an arbitrary research study ranges from local to global, modifications suited to scale demands might be superimposed on this basic methodology to reflect the needs of the project at hand. The goal is to present ideas in their broadest form to suggest the range of uses for these procedures to a variety of researchers.

TERRAIN PEER GROUPS

The mechanics of developing terrain peer groups involves constructing a template to be used to standardize differences in elevation on U.S. Geological Survey topographic maps as applied, in this case, to the map series of scale 1:250,000. The construction consists of two parts: first, the approximation of the boundary of each transit authority, and second, the determination within this boundary of the terrain as predominantly steep, intermediate, or flat.

To achieve the former goal, allometry with standard techniques *(2, 3)* was used to represent the city as a circle centered in most cases on city hall, with radius proportional to total population. Because each city was then represented with a circular boundary, visual comparisons of topographic evidence within the set of cities under study were facilitated. To create these circular cities, census data pertaining to the city itself, rather than to a larger metropolitan region or urbanized area, were used because bus routes run predominantly across terrain interior to the city. Total population figures rather than population density data were used because density figures, which do reflect directly the likely extent of wear and tear on buses, do not reflect variation at the city scale in terrain. As a pure terrain measure is sought, allometry appears well suited to the task; there is no additional input from phenomena unrelated to terrain such as density to confound the terrain data.

To determine terrain type within the circular boundaries, sets of evenly spaced lines were used to sample the unevenly spaced contour lines within the allometric circle and to classify the underlying terrain as steep, intermediate, or flat. The details of these procedures are described next.

To construct a set of circles representing cities of various sizes, the law of allometric growth was used to determine circle radius corresponding to city population as given in the 1980 census. Biologists use allometry to predict the size of an entire individual within a given species from the size of one of its parts; pediatricians apply this idea to predict adult heights of

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children *(2)*. Nordbeck and Tobler *(3)* used allometry to represent city size as a circle proportional to the size of the built-up area and to population inhabiting the built-up area. It was found from empirical studies that the area of a U.S. city can be estimated by $A = 0.00151\ P^{0.8757}$, where A is area in square miles and P is total city population *(2, 3)*. Using $A = \pi R^2$ with R the radius of a circle of area A associates a radius R with each city given its population as $R = 0.0219237\ P^{0.43785}$ *(3)*. Calculations were then made to determine population sizes that corresponded to radii of 0.5, 1.0, 1.5, 2.0, 2.5, . . . , 23.0 mi. Population intervals were centered on integral mile values for radii R, and these radii were converted to the scale of a 1:250,000 map. Table 1 presents these values of radii, which include all cities in the study. A set of circles of radii 0.25, 0.51, 0.76, 1.01, . . . , 5.58 in. were drawn on transparent plastic; when superimposed on a topographic map of scale 1:250,000 and centered on a central point distinguished on the map, the circumference served as the city boundary.

In Table 1, transit authorities were rank-ordered from the 1980 census within terrain classes by total city population *(5, 6)*. The numbers used to partition each terrain class represented the size of the radius of the associated allometric circle in inches at a scale of 1:250,000. Within an allometric subclass, cities were ordered from large to small. No cities fell into the population intervals represented by the allometric radii 5.32, 5.07, 4.82, 4.56, 4.31, 4.06, and 3.55. Consequently, these values were not included in this table.

To analyze the terrain within a circle required sampling the spacing between the line pattern of contour lines. Hammond *(4)* commented that terrain steeper than about an 8 percent grade causes problems for virtually any sort of vehicle, while Ullman (unpublished data) noted that most railroad tracks run across terrain of less than 1.5 percent grade. Thus, a city with a significant percentage of 8 percent grade was characterized as steep, one with terrain of grade largely less than 2 percent as flat, and all others as intermediate, but using other percentages would not alter the general procedure.

Generally, contour lines are wiggly; locally, however, all are topologically equivalent to short straight-line segments. Thus, a sequence of parallel short straight-line segments was spaced to

TABLE 1 TERRAIN TYPE AND ALLOMETRIC RADII OF 181 TRANSIT AUTHORITIES

STEEP TERRAIN: 20 Transit Authorities[a]

5.58—No entries
3.80—Los Angeles, Calif.
3.30—No entries
3.04—No entries
2.79—No entries
2.53—No entries
2.28—San Diego, Calif.
2.03—San Francisco, Calif.; Washington, D.C.
1.77—Boston, Mass.; Seattle, Wash.; Kansas City, Mo.
1.52—Pittsburgh, Pa.; Cincinnati, Ohio/Newport, Ky.; Oakland, Calif.; Omaha, Neb.
1.27—Yonkers, N.Y.
1.01—Worcester, Mass.
0.76—Duluth, Minn.; San Mateo, Calif.; Ventura, Calif.; Charleston, W.Va.; Dubuque, Iowa
0.51—Johnstown, Pa.
0.25—No entries

INTERMEDIATE TERRAIN: 80 Transit Authorities[a]

5.58—No entries
3.80—No entries
3.30—No entries
3.04—Philadelphia, Pa.
2.79—No entries
2.53—No entries
2.28—Dallas, Tex.
2.03—Baltimore, Md.; San Antonio, Tex.; Memphis, Tenn.; Minneapolis/St. Paul, Minn.; Milwaukee, Wis.; San Jose, Calif.
1.77—Cleveland, Ohio; Denver, Colo.; Nashville, Tenn.; St. Louis, Mo.
1.52—El Paso, Tex.; Atlanta, Ga.; Fort Worth, Tex.; Portland, Oreg.; Austin, Tex.; Charlotte, N.C.
1.27—Birmingham, Ala.; Akron, Ohio; Colorado Springs, Colo.; Jackson, Miss.; Mobile, Ala.; Dayton, Ohio
1.01—Des Moines, Iowa; Montgomery, Ala.; Knoxville, Tenn.; Lincoln, Neb.; Madison, Wis.; Riverside, Calif.; Syracuse, N.Y.; Chattanooga, Tenn.; Columbus, Ga.; Salt Lake City, Utah; Flint, Mich.; Little Rock, Ark.; Springfield, Mass.; Raleigh, N.C.; Rockford, Ill.; Hartford, Conn.; Winston-Salem, N.C.; New Haven, Conn.; Peoria, Ill.; Erie, Pa.; Topeka, Kans.; Youngstown, Ohio; Cedar Rapids, Iowa; Ann Arbor, Mich.
0.76—Eugene, Oreg.; Davenport, Iowa; Stamford, Conn.; Boise, Idaho; Albany, N.Y.; Roanoke, Va.; Brockton, Mass.; Canton, Ohio; Lowell, Mass.; Laredo, Tex.; Manchester, N.H.; Salem, Mass.; Scranton, Pa.; Sioux City, Iowa; Tallahassee, Fla.; Kalamazoo, Mich.; Oceanside, Calif.; Waterloo, Iowa; Utica, N.Y.; Wilmington, Del.; Huntington, W.Va.; Appleton, Wis.; Lynchburg, Va.; Fayetteville, N.C.; Altoona, Pa.; Binghamton, N.Y.; Asheville, N.C.; Harrisburg, Pa.
0.51—Augusta, Ga.; Haverhill, Mass.; Jackson, Mich.; Kent, Ohio
0.25—No entries

FLAT TERRAIN: 81 Transit Authorities[a]

5.58—New York City, N.Y.
3.80—Chicago, Ill.
3.30—Brooklyn, N.Y.
3.04—No entries
2.79—Houston, Tex.
2.53—Detroit, Mich.
2.28—No entries
2.03—Phoenix, Ariz.; Indianapolis, Ind.
1.77—New Orleans, La.; Columbus, Ohio; Jacksonville, Fla.
1.52—Long Beach, Calif.; Buffalo, N.Y.; Toledo, Ohio; Miami, Fla.; Oklahoma City, Okla.; Tulsa, Okla.; Albuquerque, N. Mex.; Tucson, Ariz.
1.27—Louisville, Ky.; Wichita, Kans.; Sacramento, Calif.; Tampa, Fla.; Norfolk, Va.; Rochester, N.Y.; Corpus Christi, Tex.; St. Petersburg, Fla.; Baton Rouge, La.; Richmond, Va.; Fresno, Calif.; Shreveport, La.; Lexington, Ky.
1.01—Lubbock, Tex.; Fort Wayne, Ind.; Spokane, Wash.; Tacoma, Wash.; Providence, R.I.; Fort Lauderdale, Fla.; Gary, Ind.; Stockton, Calif.; Amarillo, Tex.; Bridgeport, Conn.; Savannah, Ga.; Torrance, Calif.; Orlando, Fla.; Garden Grove, Calif.; Hampton, Va.; San Bernardino, Calif.; South Bend, Ind.
0.76—Bakersfield, Calif.; Allentown, Pa.; Springfield, Ill.; New Bedford, Mass.; Urbana-Champaign, Ill.; Decatur, Ill.; Clearwater, Fla.; Norwalk, Calif.; Gainesville, Fla.; Kenosha, Wis.; Saginaw, Mich.; Waukegan, Ill.; West Palm Beach, Fla.; Portland, Maine; Pensacola, Fla.; Lancaster, Pa.; Daytona, Fla.; Des Plaines, Ill.; Montebello, Calif.
0.51—Oshkosh, Wis.; La Crosse, Wis.; Rock Island, Ill.; Gardena, Calif.; St. Cloud, Minn.; Bay City, Mich.; Santa Cruz, Calif.; Bradenton, Fla.; Gretna, La.; Kingston, Pa.
0.25—Harahan, La.

[a] Numbers are rank-ordered by allometric radius and are proportional to city size.

represent 2 and 8 percent grades on a 1:250,000 topographic map with a 50-ft contour interval to evaluate spacing between contours *(4)*. Adjustments may be made easily for 100- and 200-ft contour intervals. A 2 percent slope at a scale of 1:250,000 would be represented by a set of short, vertical parallel line segments spaced 0.12 in. apart; an 8 percent slope at 1:250,000 would be represented by a set of short vertical parallel line segments spaced 0.03 in. apart. When a horizontal line is drawn perpendicular to each set of vertical parallel line segments through the set of vertical parallel lines, a comb-like configuration appears, corresponding to each spacing pattern. Each contour comb is then transferred to a transparency. When either transparency is superimposed on both the allometric circle and the topographic map so that the horizontal line (comb handle) passes through the center of the circle, the horizontal line samples contour line spacing. Rotating this line about the center produces a scan of the city using the contour comb. Use of the allometric circle and the contour comb as a template of transparencies applied to USGS maps permitted rapid (under 1 min each) determination of the general terrain of most cities as steep, intermediate, or flat. Table 1 presents the results of applying the template to a set of 181 transit authorities; in Table 1 this set of transit authorities is partitioned into steep, intermediate, and flat terrain classes.

Of course, some cities did not fall clearly into one terrain type or another. These were included in the steeper of the two categories if more than just a single hill or ridge or small group of them was of the steeper type; they were included in the flatter of the two categories if the relatively steep parts appeared from the road pattern or from shading on the map not to lie in regions likely to be served by buses. To make these decisions, it was useful to make supplementary maps by tracing both the drainage pattern and rail pattern onto the allometric circle. Figure 1 includes maps of this sort for selected transit authorities that did not fall clearly into a particular terrain type. Figure 1 also includes maps of terrain in transit authorities typical of each terrain type. The river and rail networks partitioned these circles into a number of regions, within each of which it was determined using the contour combs whether they were flat, intermediate, or steep, and they were shaded accordingly. The content of Figure 1 is organized, generally, according to increasing steepness of terrain; in flat cities it appeared that rails were often straight and that no topographic advantage was gained by running rails in river valleys. Thus, rail lines in flat cities as well as those in substantially flat coastal areas of nonflat cities (e.g., Oakland) were omitted in Figure 1. In nonflat cities, both river and rail patterns were shown; in fact, curviness in railnet generally suggested nonflat cities.

Within the flat group of cities shown in Figure 1, Detroit, Indianapolis, Sacramento, and Stockton are all clearly flat; however, the drainage pattern in Indianapolis suggests a more undulating surface, and a corresponding increase in expected wear on bus brakes and power train, than does that of Detroit. Sacramento and Stockton both appear to have surfaces that show more topographic variation (resulting from the need to cross the river) than does Detroit, but less than does Indianapolis. River width also helps to determine the extent of undulation; narrow streams may be bridged at grade level whereas wider streams, not easily bridged in that fashion, force change in elevation. Judging from local Ann Arbor field evidence, streams that appear on maps at a scale of 1:250,000 are wide enough to be of the latter sort.

Louisville and San Jose are both predominantly flat. An eastern section of Louisville near a stream feeding into the Ohio River is somewhat hilly; the general pattern of contour lines suggests a clearly flat region elsewhere. On the other hand, San Jose might have been classed as intermediate, or even as steep, if the road pattern suggested that people lived in the hills to the northeast of the center. No evidence suggests this distribution and thus San Jose is classed as flat because it appears that most bus routes cross flat terrain.

In the intermediate class, the flattest city is Jackson, Michigan, and the steepest is Baltimore. Jackson and Brockton are the least steep; however, both maps display curvy railnets, at least one line in each of which runs along the river next to terrain classed as intermediate, suggesting topographic advantage from such placement. Dayton, Minneapolis-Saint Paul, and Kalamazoo show a mixture of flat and intermediate regions but appear on the whole to be predominantly intermediate. Ann Arbor, Lowell, and Haverhill are all intermediate as determined both from contour combs and from the shape of rail lines. Baltimore has a few steep areas; as these occur mainly in parklands, the city is placed in the intermediate class.

In the steep class, Boston and Washington contained a fairly even mixture of flat, intermediate, and steep regions. In both cases, a substantial amount of the steep terrain appeared to be in residential areas, requiring buses to shift through the entire spectrum of terrain types; thus, these were classified as steep. The remaining four cities (Worcester, San Francisco, Oakland, and Cincinnati) appeared clearly steep, although each in a different way.

NATIONWIDE TERRAIN PEER GROUPS

In Table 1, all transit authorities that are steep are grouped in one terrain class or peer group, all transit authorities that are intermediate are grouped in another terrain peer group, and all transit authorities that are flat are grouped in a third terrain peer group. The point of the procedure developed in the previous sections was to come to such a classification of transit authorities by terrain type; the terrain snapshots graphically supplement the numerical classification.

As with any taxonomy, the underlying decisions on which it is formed involve a certain degree of arbitrariness. In this case, a finer partition of terrain type into more than three classes would permit finer distinctions among transit authorities. Although this notion has some merit, there may be considerable sacrifice in grasping the broad terrain picture when partitioning is extended. Further, it appears undesirable to claim that some number of categories is best; any reasonable number will have advantages and drawbacks. It is for this reason that the supplementary evidence shown in the terrain snapshots is useful. These snapshots show the whole picture at a single glance in a way that refinement in data partitioning cannot.

An additional advantage to choosing three as the number of classes in this taxonomy is the retaining of classificatory structure that parallels the form underlying the research in *Climatic Effects on Bus Durability*, thereby facilitating cross-class comparisons between corresponding climate and terrain peer

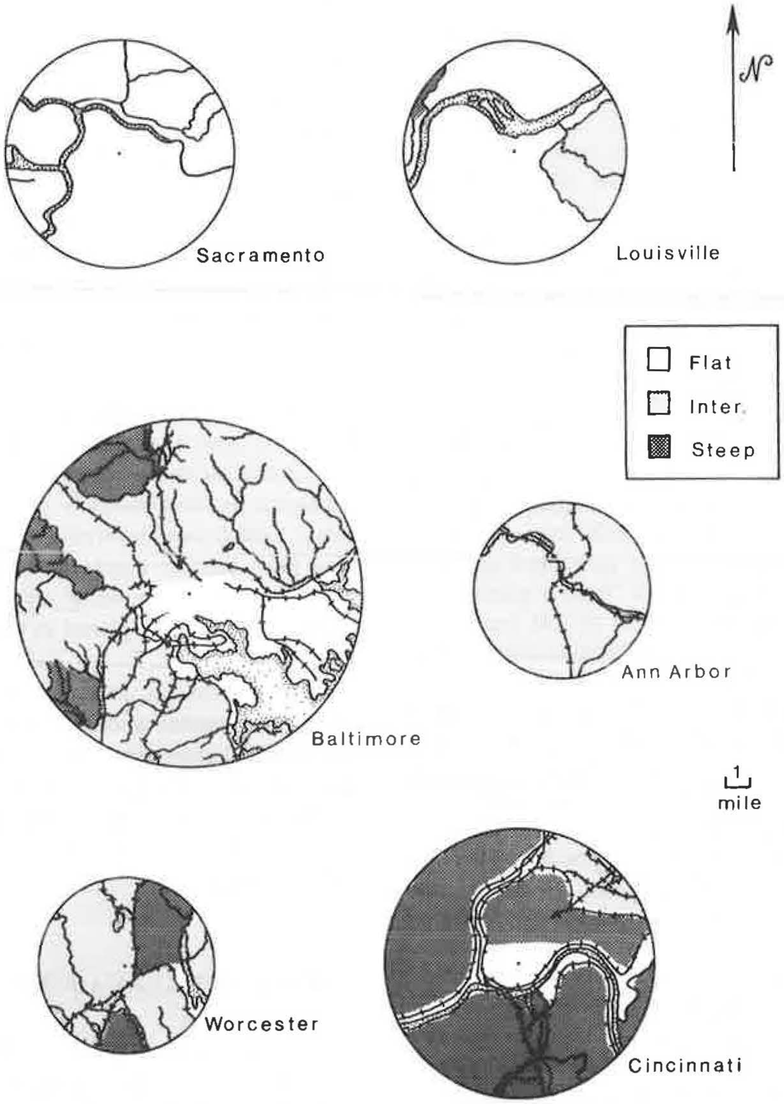

FIGURE 1 Terrain snapshots.

groups. Further, this research is an effort involving the development of methodology, as was the climate research. Therefore, it appears appropriate to keep underlying assumptions as uncluttered as possible to permit the widespread dissemination and use of these ideas by researchers from a variety of backgrounds.

The material that follows, which shows one application of this classification, is presented to illustrate possible uses for this sort of methodology. In it, maintenance data expressed in terms of dependent variables selected for illustrative purposes were extracted from Section 15 data and were examined within each of these nationwide terrain peer groups.

MAINTENANCE DATA IN TERRAIN PEER GROUPS

In this application, maintenance performance is measured with two indicators: maintenance value and maintenance efficiency, where maintenance value equals total vehicle-miles per dollar of maintenance expenses, and maintenance efficiency equals total vehicle-miles per maintenance employee. Data for the first indicator appear directly in the *National Urban Mass Transportation Statistics (7)*; data for the second indicator were calculated as total vehicle-miles divided by the number of maintenance employees per vehicle in maximum scheduled service where such an employee is assumed to work 2,000 hr/year. For both indicators, higher values reflect higher quality in maintenance. When both maintenance value and efficiency indicators are calculated for each of the 181 transit authorities, and these data are partitioned by quartiles, 16 mutually exclusive subclasses based on maintenance quality appear in the data.

When the set of transit authorities is also partitioned by quartiles according to the miles-per-gallon indicator, bars placed in each maintenance subclass of Figure 2 showed (a) by their length, the percentage of the set of 181 transit authorities within each; (b) by their internal partitioning, the percentage of entries ranked by the miles-per-gallon indicator within that subclass coming from the top, second, third, and bottom quarters of the set. The result is that Figure 2 compresses four dimensions of data (maintenance value, maintenance efficiency, percentage per quarter of the miles-per-gallon indicator, and percentage of transit authorities per maintenance subclass) into two geometric dimensions. For example, the bar in the

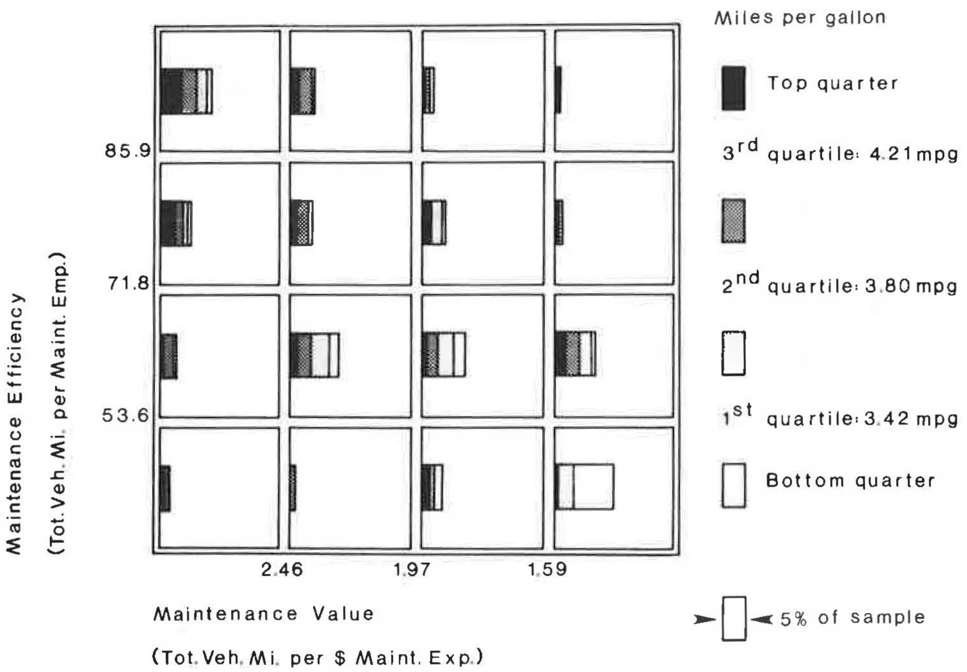

FIGURE 2 Miles-per-gallon indicator within maintenance subclasses (sample size: 181 transit authorities).

upper-left-hand corner of Figure 2 is between two and three times as long as the 5 percent box in the legend. This length demonstrates, graphically, that about 12 percent of the 181 transit authorities fall into this best subclass. The partitioning internal to this bar shows by shading that, of the transit authorities in this subclass, about 46 percent fall into the top quarter of the miles-per-gallon indicator, about 32 percent fall into the second quarter of the miles-per-gallon indicator, about 18 percent fall into the third quarter of the miles-per-gallon indicator, and 4 percent lie in the bottom quarter of that indicator. Good maintenance efficiency and maintenance value and good fuel economy graphically correspond across the entire sample in Figure 2. The subclass in the lower-right-hand corner has the poorest value and efficiency. The shading internal to the bar shows that almost all transit authorities achieve mileage worse than the median and that a substantial majority score in the bottom quarter, indicating that bad mileage corresponds to bad maintenance as well. Because Figure 2 provides graphic support for the natural notion that transit authorities achieving the highest maintenance value and efficiency achieve higher miles-per-gallon figures than do those reporting poor maintenance, it serves as a graphic standard against which to test the

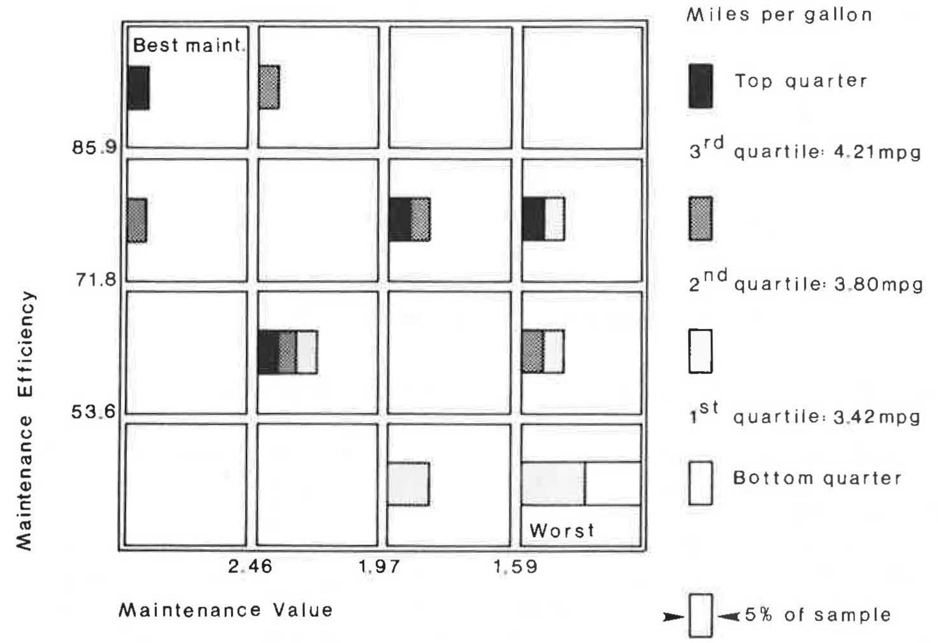

FIGURE 3 Miles-per-gallon indicator within maintenance subclasses measured across the steep-terrain peer group (sample size: 20 transit authorities).

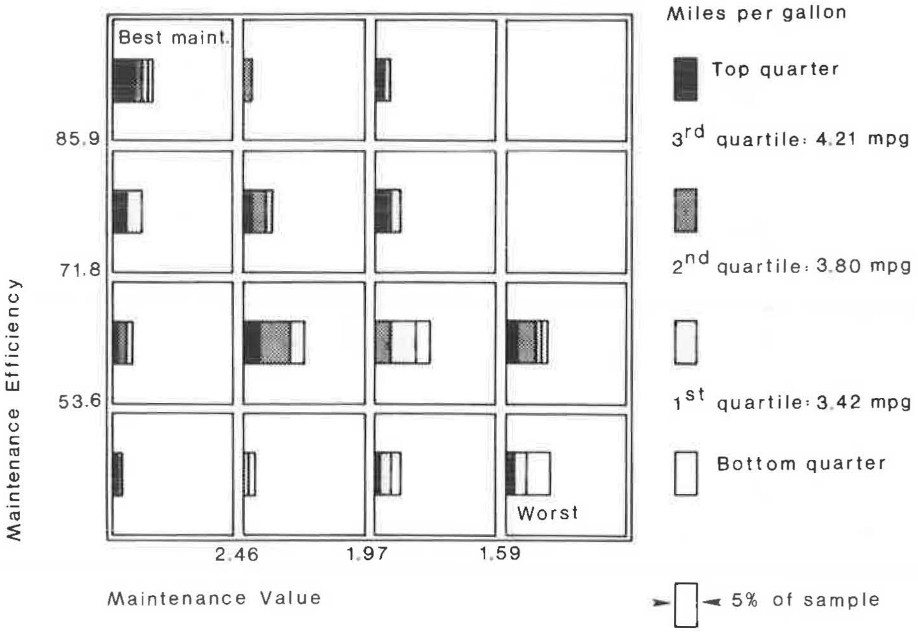

FIGURE 4 Miles-per-gallon indicator within maintenance subclasses measured across the intermediate-terrain peer group (sample size: 80 transit authorities).

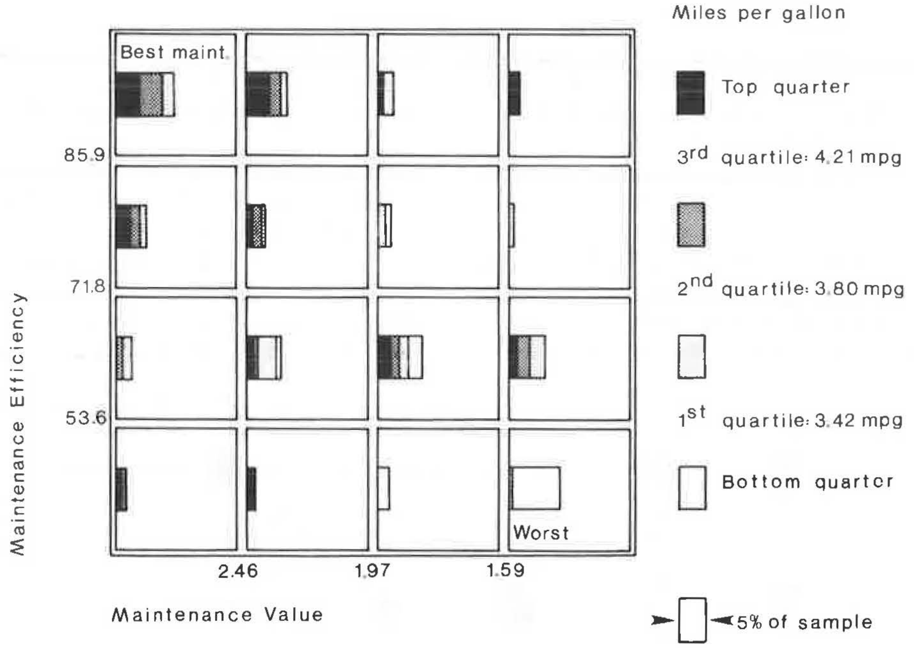

FIGURE 5 Miles-per-gallon indicator within maintenance subclasses measured across the flat-terrain peer group (sample size: 81 transit authorities).

same sort of chart when these data are also stratified according to terrain class.

When the data from Figure 2 were sorted using a fifth data dimension according to terrain peer group, Figures 3–5 emerged. Abstractly these figures represent two-dimensional portraits of miles-per-gallon data within maintenance subclasses for the steep, intermediate, and flat terrain peer groups, respectively. Figure 3 graphically suggests that the ties between maintenance value and efficiency and miles per gallon are stronger in steeper environments than they are in the whole sample in Figure 2; in flatter surroundings other factors apparently overshadow the effects of terrain on the miles-per-gallon indicator (Figures 4 and 5).

The distinctions among maintenance subclasses within a figure fade increasingly from steep terrain (Figure 3) to flat terrain (Figure 5). This result suggests that, in the steep-terrain peer group, transit authorities with low miles per gallon are more likely to have lower maintenance and efficiency values than are corresponding properties in the intermediate-terrain peer group; and, that those in the intermediate-terrain peer group with low miles per gallon are more likely to fall into lower maintenance and efficiency value subclasses than are corresponding properties in the flat-terrain peer group. In addition, there is a greater proportion of transit authorities in the upper-left-hand square subset or the four small boxes of Figure 5 than there is in the corresponding position in Figure 4, suggesting better performance in flat terrain.

One implication of this sort of approach is that any transit authority might classify itself according to terrain type and then use charts such as these as constructive guidelines to focus the direction of its maintenance effort. On the other hand, UMTA might use them to evaluate the quality of the maintenance effort of a particular transit authority as compared to its peers in conjunction with other factors mentioned previously. In either application, (a) the guidelines suggested by these charts are general, and (b) the numerical figures associated with these graphical displays are based on data that very from year to year.

At a deeper level, when the effect of terrain on fuel consumption is viewed as but one element derived from cross-sectional performance data, to measure some component of maintenance performance and bus durability, opportunities to use this methodology for classifying terrain in conjunction with other types of data emerge. Such a merger of methodologies permits a more comprehensive evaluation of the effects of this and other independent variables such as climate and congestion on bus maintenance and equipment life *(1)*.

CONCLUSION

The major contribution of this report is to classify transit authorities according to terrain type into steep, intermediate, or flat peer groups. The typology is formed on the basis of empirical topographic evidence accumulated at the 1:250,000 scale using a terrain template. Nationwide terrain peer groups established using this terrain template are displayed in Table 1.

When the variables miles per gallon, maintenance efficiency, and maintenance value, quantified by Section 15 indicators, are introduced into these terrain peer groups, connections are found between maintenance value and efficiency and miles per gallon in steeper environments. As this is a first effort in analyzing the relation between maintenance and terrain, a significant function of these data is to suggest a framework in which to test other transit concepts.

These broad terrain categories might be used in a regression analysis context involving several factors in addition to terrain, related to vehicle performance (e.g., frequency between stops and passenger load). Or, they might be used to restructure this classification, using different percentage slopes to correspond to steep or intermediate terrain. However, an arbitrary attempt to even out the numerical size of terrain peer groups would result in misclassification because there are fewer steep cities. At an integrative empirical level, this taxonomy might be used in conjunction with climate peer groups and congestion peer groups formed on the basis of route curviness, stop spacing, and population density to serve as one arm of a more comprehensive empirical study of *Environmental Effects on Bus Durability* (*1*; *8*; Arlinghaus and Nystuen, unpublished data). Another avenue for further research is suggested by the observation that this method of classifying terrain appears to lend itself to automated analysis using computer techniques. At the theoretical level, fractal geometry, which has been used to simulate terrain, might be used to identify self-similar terrain characteristics that prevail independently of the partition chosen for terrain classes *(9–13)*. At the pragmatic level, the usefulness of the peer groups produced using this methodology likely rests on their capability to augment the explanatory power of other indicators to improve our understanding of system level performance statistics.

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