Bus Maintenance Performance: Findings and Direction for Research

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Some performance indicators may be used to identify transit systems with superior bus maintenance performance. A literature review was conducted to identify factors often reported as affecting maintenance performance. A data base was created using all of the reported factors available in the 1984 UMTA Section 15 information. Analyses using the data base were conducted to design performance indicators and peer groups of transit systems. Within each of the peer groups, transit systems with superior bus maintenance performance were identified. The methodological procedures used for this paper were modeled on the approach used by Fielding in work for UMTA to develop indicators and peer groups for overall transit performance analysis. This work (like Fielding's) was limited by the lack of a comprehensive data base from which to extract significant information relevant to the research. For example, the absence of climatic and topographic data may make the natural groupings of peer transit systems suspect to maintenance experts. Additionally, much information on the effectiveness performance or quality of maintenance work was also absent. Such limitations may have a direct bearing on the validity and industry acceptance of the results, so the following actions are recommended: (a) adopt the methodological procedures of this paper and extend the data base to include the data not found in UMTA Section 15 that are believed to be important to bus maintenance performance and (b) on the basis of the results of an evaluation using the revised data base, select several systems with high performance and several systems with low performance and conduct field audits to identify the causes of their performance differences. Using the results of the field audits, prepare guidelines that document the procedures and practices of superior bus maintenance programs. If the resources of transit systems are to be protected and preserved, it is important to implement the recommendations. The results will assist transit systems to identify deficiencies within their own program and to achieve superior maintenance performance.

As public transportation funding becomes scarcer, many transit managers and funding institutions are asking how to preserve and increase the productive life of their fleets. The answer is maintenance: on this answer have followed systematic efforts to determine the efficiency and effectiveness of transit systems' maintenance performance and to identify successful maintenance programs. UMTA sponsored a study (*1*) that addressed these issues. The study was intended to

- Determine which maintenance performance indicators best identify transit systems with superior motor bus maintenance performance, and
- Identify peer groups for transit systems to analyze maintenance performance.

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RELEVANT ISSUES

Maintenance performance is critically important to all transit systems. The goal of transit vehicle maintenance is to efficiently provide clean, comfortable, safe, and reliable vehicles in accordance with the service demands of the transit system (essentially the demands of the transportation function for scheduled and unscheduled service).

Despite the importance of maintenance performance, the literature review (Appendix A) revealed that relatively little research has been conducted to identify superior maintenance performance or to group transit systems on the basis of the success of their maintenance programs. Given the state of work in the field, this study was unusually ambitious and confronted several difficulties. There is no consensus on how to quantify superior maintenance performance; the data required are extensive and in many cases not available in secondary sources. Research assumptions in the field are vague and sometimes contradictory in two principal areas: "What is superior maintenance performance?" and "What factors affect maintenance performance?"

What is Superior Maintenance Performance?

Transit maintenance performance can be evaluated according to at least two criteria:

- Effectiveness, an ability to deliver or provide quality services to meet public transportation needs and attract riders, and
- Efficiency, the amount of service produced for the resources (labor, materials, supplies) expended.

Although most maintenance managers and analysts agree on these two criteria, there is little agreement on specific aspects of maintenance performance. The following areas of performance must be considered:

- Safety,
- Reliability,
- Comfort,
- Cleanliness,
- Appearance, and
- Economy.

Transit systems generally have different standards for each of these areas of performance and often use different definitions. How clean is clean? How reliable (or safe) is very reliable (or safe): when is a transit vehicle unreliable, unsafe, or uncomfortable? Each of these questions addresses the quality of transit maintenance and may be considered in evaluating the effectiveness of a vehicle maintenance program.

Economy, the last area of performance listed, may include the total expenses of vehicle maintenance, maintenance labor expense, the number of maintenance employees (or mechanics), the number of hours expended by maintenance employees, and the expense of maintenance materials, services, and supplies. Economy is considered in evaluating maintenance efficiency (use of resources), which, although somewhat easier than evaluating maintenance effectiveness (i.e., quality issues), is still complex. The evaluator must consider the possibility that less preventive maintenance or fewer vehicle overhauls impact service quality and ultimately shorten the useful life of the fleet, thus requiring greater capital investments.

Although maintenance managers are responsible for and concerned about the performance of vehicle maintenance, various consumer groups ultimately judge the efficiency and effectiveness of a maintenance department's efforts. These groups include transit system executives and managers, bus operators, and the riding public. Each of these groups may have different standards for the areas of performance listed above. In short, there is little agreement on the characteristics of superior maintenance performance, for effectiveness or efficiency.

What Factors Affect Maintenance Performance?

At least seven categories of factors affect maintenance performance, influencing the type, frequency, and cost of vehicle maintenance requirements. These categories are included in the following list. Many other items in these categories may affect maintenance performance or allow for peer groupings of systems—the following items are illustrative only.

- *Fleet characteristics.* The type and number of active, spare, and inactive vehicles; fleet age; fleet size and weight; mix of vehicle manufacturers; fuel grade and type; and vehicle amenities (i.e., air conditioning and wheelchair lifts).
- *Vehicle operating environment.* Weather, topography, traffic congestion, ridership levels, roadway conditions, and other service area characteristics.
- *Vehicle maintenance work force characteristics.* Size, seniority, skill or competence level, work hours (straight and overtime), nonwork hours (benefit and absence), available training programs, and turnover.
- *Employee work conditions.* Work area (heating, ventilation, lighting, size, configuration, crowding, and age); maintenance supervision (level, skill, and competence); and availability of parts, inventory, equipment, and tools.
- *Maintenance management.* Policies and practices pertaining to performance, preventive maintenance, pre- and post-run inspections, cleanliness and safety inspections, work shifts, management information system (data adequacy and accessibility), training, and union-management relations.
- *Labor agreement.* Provisions and work rules resulting from collective bargaining that may affect the efficiency and productivity of maintenance operations.
- *Other.* Adequacy or abundance of funding from federal, state, and local sources.

In many cases, these factors are local, dependent on a particular environment or reflecting decisions made by transit management or boards that cannot be changed immediately. For this paper, only nonlocal factors that cut across all systems were used to distinguish maintenance performance.

MAINTENANCE DATA AND INDICATORS

Important first steps in the study were to identify the data needed to measure maintenance performance and to define meaningful peer groups for performance comparison. This effort required the collection of certain information about transit systems and their operating environments. First, the data ideally needed to evaluate maintenance performance were identified; next, the general availability of these data was researched. Availability and cost to obtain data determined which items were included in the data base.

Statistics To Analyze Maintenance Performance

Data in the following categories can be used to describe and measure maintenance performance:

- *Resource inputs.* The resources expended to perform vehicle maintenance include labor, capital, material, services, and other measurable items and may be classified as financial or nonfinancial.
- *Service outputs.* These nonfinancial operating results of resource expenditures may be numerical measures, such as miles or hours of services, or quality statistics, such as number of accidents, roadcalls, delays, or measured cleanliness.
- *Customer results.* The actual results of service outputs may be expressed in consumption or customer impact terms. For example, this measure may include the number of passenger or operator complaints, injuries or fatalities due to mechanical failures, or passenger-trips or passenger-miles.

Data elements for these categories initially considered were the following.

Resource Inputs

- Vehicle maintenance expense,
- Vehicle maintenance labor expense,
- Vehicle mechanic labor expense,
- Vehicle maintenance employee work-hours,
- Vehicle mechanic work-hours,
- Vehicle maintenance employees,
- Vehicle mechanics,
- Inspection and maintenance hours,
- Vehicle maintenance material expense,
- Fuel consumed, and
- Active vehicles.

Service Outputs

- Vehicle revenue-miles,
- Vehicle revenue-hours,

- Vehicle-miles,
- Vehicle-hours,
- Peak vehicles or vehicles operated in maximum service,
- Base vehicles,
- Mechanical roadcalls,
- Other mechanical failures,
- Revenue-hours lost to mechanical failures,
- Missed pullouts because of mechanical failures,
- Late pullouts because of mechanical failures, and
- Number of collision accidents.

Customer Results

- Passenger complaints because of mechanical failures,
- Passenger fatalities and injuries because of mechanical failures,
- Driver complaints or comments,
- Passenger-trips, and
- Passenger-miles.

Data Availability

Data useful in evaluating transit maintenance performance can be found in primary and secondary transit industry and nontransit industry sources.

- *Primary transit industry data.* Data are available directly from all transit systems, in records, reports, and interviews. These primary sources produce the most detailed, up-to-date, and complete information.
- *Secondary transit industry data.* Transit system data are also available through the UMTA Section 15 data base, a secondary source published annually and recorded on tapes. The U.S. Department of Transportation maintains a more extensive Section 15 data base.
- *Primary and secondary nontransit industry data.* Data that may be used to evaluate transit maintenance performance are also available from sources other than transit systems. These primary and secondary sources may require surveying local communities to determine distinguishing characteristics of the transit operating environment or researching documents that report on topography, weather, or roadway conditions. These data could be best used to identify peer groupings for transit systems.

Data Base Development

Clearly, the most detailed source of data on transit performance is individual transit systems. Collecting these data from transit systems would have produced a rich data base, but the expense was prohibitive under the terms of this study. The Section 15 data base of the U.S. Department of Transportation included statistics pertaining to a number of factors in transit maintenance performance. Although it did not contain all the information desired for this study, this data base is a recognized source of uniform transit data; it was used because time and the funds for this study did not permit the use of either primary transit industry data or nontransit industry data.

The Section 15 data base included selected data for 1984 on fleet characteristics, vehicle operating environment, resource inputs, and service outputs. The data base included data in all categories but was not exhaustive in any category. This data base has a uniform structure and format, which permit the merging of different data elements to create data bases for particular purposes. The following UMTA Section 15 data elements were included in the bus maintenance data base for this study:

- Transit system identification number;
- Year being examined;
- Urbanized area number;
- Vehicles operated in maximum service;
- Number of roadcalls, mechanical failure;
- Number of roadcalls, other reasons;
- Total roadcalls;
- Labor-hours for inspection and maintenance;
- Total number of light maintenance facilities;
- Maintenance employees, executive/professional/supervisory;
- Maintenance employees, support;
- Maintenance employees, review vehicle maintenance mechanics;
- Maintenance employees, other maintenance mechanics;
- Maintenance employees, vehicle service persons;
- Number of accidents, collision;
- Number of accidents, noncollision;
- Number of accidents, station;
- Annual vehicle-miles (thousands);
- Annual vehicle-hours (thousands);
- Annual unlinked passenger trips (thousands);
- Annual passenger miles (thousands);
- Maximum number of vehicles operated in average base period;
- Total operating expenses ($ thousands);
- Vehicle maintenance expense;
- Materials and supplies: fuel and lubrication;
- Materials and supplies: tires and others;
- Total active fleet;
- Average age of fleet (years);
- Gallons of diesel fuel (thousands);
- Gallons of gasoline (thousands);
- Gallons of LPG/LNG (thousands);
- Gallons of bunker fuel (thousands);
- Kilowatt-hours of power (thousands);
- Name of the transit system;
- City location of transit system;
- State location of transit system; and
- Mode of operation.

Data Validation

Analyzing public transportation performance using Section 15 data requires that the data be reviewed and checked, since data validity is especially important. Although uniform definitions for each Section 15 data item exist, data validation procedures were found to be necessary. Transit systems nationally continue to experience reporting errors that reflect misinterpretations of data definitions, new staff's lack of familiarity with the reporting requirements, and continuations of past reporting practices. These errors needed to be identified and resolved as much as possible to meaningfully evaluate transit performance. Often, reporting errors are not identified until an analysis is complete and inaccurate conclusions have been drawn.

Section 15 transit system financial and operating data were reviewed in a number of different ways. Individual statistics were examined, as were performance indicators. Although validation procedures cannot ensure that all data are accurate, they can screen the data and identify questionable items. The data validation procedures used in this project included statistical tests and screening tests.

Statistical tests were performed to identify outlying data that did not fit generally within the standard normal curve. The statistical tests included calculating the standard deviation, means, minimum, maximum, skewness, and kurtosis of the data. In those instances in which the data were out of the specified ranges, the suspect data (not the entire system) were removed from the data base. Previous experience with transit data has demonstrated that it generally fits within a normal distribution.

Screening tests were performed using a battery of 25 validation tests. The screens included acceptable ranges in which the data should fall to be included in the data base. Again, if data fell out of these ranges, the suspect data were removed, not the entire system.

STRUCTURING PERFORMANCE INDICATORS

Vehicle maintenance is important to public transportation service. The vehicle maintenance function affects not only the overall efficiency of transit operations, but the quality and effectiveness of a system's service. As performance evaluation procedures have evolved in the public transportation industry, three general measures have proven useful to public officials, system managers, and researchers. These measures were identified by Fielding (*2*) as

- Cost-effectiveness,
- Service effectiveness, and
- Resource efficiency.

Performance Indicator Definitions

Fielding (*2*) defined the performance measure of cost-effectiveness as the consumption of public transportation services in relation to the resources expended. An evaluation of these measures attempts to answer the question, "How much public transportation service is used or passenger revenue is received per dollar or resource expended?" Consumption is measured by passenger trips or revenue received, and costs are measured in terms of resources expended to produce the public transportation service. The more passengers carried or revenues received in relation to resources expended, the more cost-effective the service.

Service effectiveness is defined as the consumption of public transportation service in relation to the amount of service available. An analysis of these measures attempts to answer the question, "How much public transportation service is consumed (or revenue received), at an established fare, in relation to the amount of service available?" The more service consumption (or passenger revenue) in relation to service output or availability, the higher the level of service effectiveness. Factors reflecting service quality and influencing the use of and perceptions about public transportation services by the public are important elements of service effectiveness. An analysis of service quality indicators may show how available, reliable, attractive, safe, and comfortable the public transportation services are. In many respects, these issues are less easily quantified and measured than other performance areas.

Resource efficiency is the amount of public transportation service produced for the community in relation to the resources expended. An analysis of these measures attempts to answer the question, "How much public transportation service is produced per dollar of resource expended?" Amounts of service produced are measured in terms of service outputs, such as vehicle hours or vehicle miles. Resources expended include labor, capital, materials, and services. The more service produced per resource expended, the greater the resource efficiency of the public transportation service.

Fielding's (*2*) performance concept was used to structure indicators to evaluate vehicle maintenance performance for this paper. This evaluation focused on key vehicle maintenance performance indicators, which measure resource efficiency and service effectiveness. While cost-effectiveness indicators may be more important to an overall performance evaluation than either resource efficiency or service effectiveness indicators, cost-effectiveness indicators were not developed to analyze vehicle maintenance performance, because the maintenance function only partially contributes, albeit importantly, to the overall performance of public transportation service.

The list of indicators that were considered to measure the vehicle maintenance performance of U.S. bus transit systems follows.

Resource Efficiency

- Total vehicle-miles per dollar of vehicle maintenance expense,
- Total vehicle-hours per dollar of vehicle maintenance expense,
- Vehicles operated in maximum service per dollar of vehicle maintenance expense,
- Total vehicle-miles per inspection and maintenance labor hours,
- Total vehicle-hours per inspection and maintenance labor hours,
- Vehicles operated in maximum service per inspection and maintenance labor hours, and
- Total vehicle-miles per gallon of fuel.

Service Effectiveness

- Total passenger trips per mechanical roadcall,
- Total passenger-miles per mechanical roadcall, and
- Total vehicle-miles per mechanical roadcall.

The list was limited by the availability of data in the 1984 UMTA Section 15 annual report. Data limitations handicapped the study, especially in evaluating the quality and effectiveness of vehicle maintenance performance. In addition, roadcall incident data in the Section 15 report have historically been considered suspect because of definitional problems.

Vehicle-miles per mechanical roadcall is a service effectiveness indicator. This indicator is, in fact, a performance descriptor, because it measures neither the efficiency nor the effectiveness of vehicle maintenance performance. However, because there is a lack of maintenance quality statistics in the UMTA Section 15 report and because the descriptor has long been used by the transit industry as a measure of maintenance proficiency, it was included. Had other data on the quality or effectiveness of vehicle maintenance performance been available, they might have been used in lieu of the performance measure vehicle-miles per mechanical roadcall.

Identifying Key Indicators

Fielding (*1*) identified several candidate vehicle maintenance performance indicators. Making his decision on the basis of 1980 UMTA Section 15 data, Fielding omitted all indicators that included roadcalls, passenger miles, and fuel data because of perceived reliability and definitional problems. On the basis of a principal components analysis, Fielding concluded that total vehicle-miles per maintenance employee and peak vehicles per maintenance employee were the best available indicators to measure vehicle maintenance efficiency. He reported no vehicle maintenance service effectiveness indicators.

This study applied 1984 UMTA Section 15 data, which is considered more reliable than the 1980 data used by Fielding (*1*), although roadcalls and employee count data are still considered to be inconsistent by many researchers. Because the focus of the study was vehicle maintenance and not total system performance, resource efficiency and service effectiveness indicators were included after an independent validation of the data was conducted to remove as many suspect values from the data base as possible.

A type of multivariate or factor analysis called principal components analysis (PCA) was conducted to reduce many measures and ratios to those few that statistically explain high percentages of performance variance (*1*). There are two main types of factor analysis: PCA and inferential or classical factor analysis. PCA assumes that the entire population of cases—not a sample—is analyzed. Analytical solutions describe the data at hand and the relationships among the variables as represented in the input data. Inferential factor analysis adjusts analytical solutions to make predictions about a larger, ideal population. Because the entire population of motor bus systems was represented in the data base, and because one objective of this study was to identify relevent groupings of systems, the use of PCA was considered appropriate (*1*).

The PCA of both resource efficiency and service effectiveness indicators identified those indicators whose variability best reflected the vehicle maintenance performance of bus transit systems. Resource efficiency performance was best described in the following key indicators:

- Vehicle-miles per dollar of vehicle maintenance expense (40.5 percent) and
- Vehicle-miles per inspection and maintenance labor hour (38.3 percent).

Service effectiveness performance was best described by the following indicators:

- Passenger-miles per mechanical roadcall (36.6 percent) and
- Vehicle-miles per mechanical roadcall (35.5 percent).

The values contained in the parentheses after each performance indicator represent the percent of total variability explained by the indicator in the final principal components analysis.

Comparison of performance among transit systems over time is best accomplished by a comparison of similar transit systems. Analysts and policy makers can be misled by comparing the performances of transit systems that are essentially unlike. Comparisons can be more meaningful when peer groups of transit systems are identified. In addition, the relationship of operating characteristics and performance can be examined by focusing on differences in performance across peer groups with different operating characteristics. Finally, transit industry changes over time can be evaluated in relation to operating characteristics of the transit systems (*1*).

An important objective was to identify factors or variables on which to base a stratification of transit systems into vehicle maintenance peer groups. Again, PCA was used to identify those factors that statistically explained high percentages of variance among the transit systems. Such factors may include transit system characteristics and factors external to transit systems, such as weather and topography.

Selecting Topology Variables

Topology variables are factors that may be used to separate transit systems into groups to conduct analyses such as maintenance performance analysis. Topology variables may also be used to periodically classify or reclassify transit systems. Such variables, previously described, include fleet characteristics, vehicle operating environments, maintenance work force characteristics, employee work place conditions, maintenance management policies and procedures, and labor agreement provisions and work rules. The data available for analysis and the selection of topology variables were limited to the information available from Tables 2 and 3 of the *1984 UMTA Section 15 Annual Report*. This data limitation is important, because it ultimately affected the validity of results produced from this study.

The following list of variables or factors was initially considered to develop the vehicle maintenance topology:

- Total vehicle-miles per vehicle-hour,
- Vehicles operated in maximum service per vehicle operated in base service,
- Total vehicle-hours per vehicle operated in maximum service,
- Total vehicle-miles per vehicle operated in maximum service,
- Total passenger-miles per vehicle-miles,

- Average fleet age,
- Total vehicle-miles per collision accident,
- Total vehicle-miles,
- Total vehicle-hours,
- Total vehicles operated in maximum service,
- Total active fleet, and
- Total active fleet per vehicle operated in maximum service.

A principal components analysis revealed that several of these variables were highly correlated (e.g., vehicle-miles and vehicle-hours). Although the analysis identified patterns of variable equality, the final set of variables was selected on the basis of the perceived quality and availability of bus maintenance statistics. The variables selected for use were

- Total annual vehicle-miles (16.8 percent),
- Average active fleet years of age (16.6 percent),
- Total annual vehicle-miles per vehicle operated in maximum service (16.8 percent), and
- Total annual vehicle-miles per collision accident (16.7 percent).

The values contained in the parentheses after each factor represent the percent of total variability explained by the variable in the final PCA. The low percentages found here indicate that no factors were overwhelmingly significant in explaining the underlying topological structure.

The final set of topology variables did not include many external factors that may affect vehicle maintenance performance. For example, weather, climate, and topography were not included because the data were not readily available. The following variables were selected:

- *Total annual vehicle-miles.* This variable captures the magnitude of the transit system's overall operation and, therefore, its maintenance needs. It tends to distinguish between larger and smaller systems, where collective bargaining provisions and work rules may affect performance.
- *Average active fleet years of age.* This variable distinguishes between transit systems with older equipment, which may cause problems because of fatigue, and systems with newer but perhaps more complex equipment.
- *Total annual vehicle-miles per vehicle operated in maximum service.* This variable distinguishes system fleets that are heavily used from those that are less used. Vehicles may be heavily used because of relatively high operating speeds, low peak-to-base service ratios, or longer periods of daily service operation. Lower average vehicle use may result from relatively high peak-to-base service ratios, lower operating speeds, or shorter periods of daily service operation.
- *Total annual vehicle-miles per collision accident.* This variable identifies transit systems that are experiencing accident rates causing vehicle maintenance expenditures that are higher or lower than average, which affects resource efficiency performance.

Developing Maintenance Peer Groups

One of the final objectives was to identify groups of transit systems that operate in similar vehicle maintenance performance environments. Using the best stratifiers, a cluster analysis was conducted. This analysis used complete or average linkage algorithms to develop dendograms, which in turn were used to develop appropriate peer groups.

Cluster analysis is a general term referring to a large number of procedures that have in common the goal of constructing groups of items (either data items or variables) on the basis of their similarity across a profile of observations. The result of a cluster analysis is the formation of a number of groups of items and the assignment of each item to one of these groups.

Cluster analysis and similar data grouping techniques differ from methods such as discriminant analysis, which attempts to classify objects into known groups. Such analyses require that the groups be known in advance, whereas cluster analysis constructs the groups.

Dendograms were used to develop peer groupings of transit systems on the basis of the variables or stratifiers that best explained vehicle maintenance performance variability.

The centroid method of cluster analysis was employed to identify bus maintenance peer groups. The four selected topology variables of each transit system were standardized to Z-scores, and the closeness of transit systems was measured using the Euclidian distance between their locations. After several trials, 21 clusters were identified, with the largest cluster containing 84 transit systems and the smallest cluster containing just 2 systems.

An analysis of variance (ANOVA) test was used to determine whether each of the 21 identified transit clusters was significantly different from all others or was part of a larger combination of clusters. The ANOVA test was conducted using the four previously identified maintenance performance measures of resource efficiency and service effectiveness.

If there was no significant statistical difference ($p \geq 0.10$) in any of the four performance indicators between each cluster pair, then the pair would be combined into a single peer group. This procedure was continued until all clusters were statistically different. The number of clusters was reduced from 21 to 8. The final bus maintenance topology tree is shown in Figure 1.

Table 1 presents statistical information about the performance values for each of the eight peer groups. Each 1984 peer group is briefly described in the following paragraphs.

Group A contains 52 bus systems, each operating fewer than 1.1 million veh-mi annually with a fleet whose average age is less than 12 years. Group A bus fleets have relatively low use and below-average safety records. Both vehicle maintenance resource efficiency and service effectiveness performance are above average.

Group B contains 110 bus systems, each operating fewer than 12 million veh-mi annually with a fleet whose average age is generally less than 12 years. Group B bus fleets have relatively high use and good safety records. Their resource efficiency performance is above average. Although the average rate of roadcalls is low, passenger miles are also low, making their service effectiveness performance average.

Group C contains 27 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average age of the fleets is less than 7 years, and they have below-average use. The Group C vehicle maintenance performance is considered average.

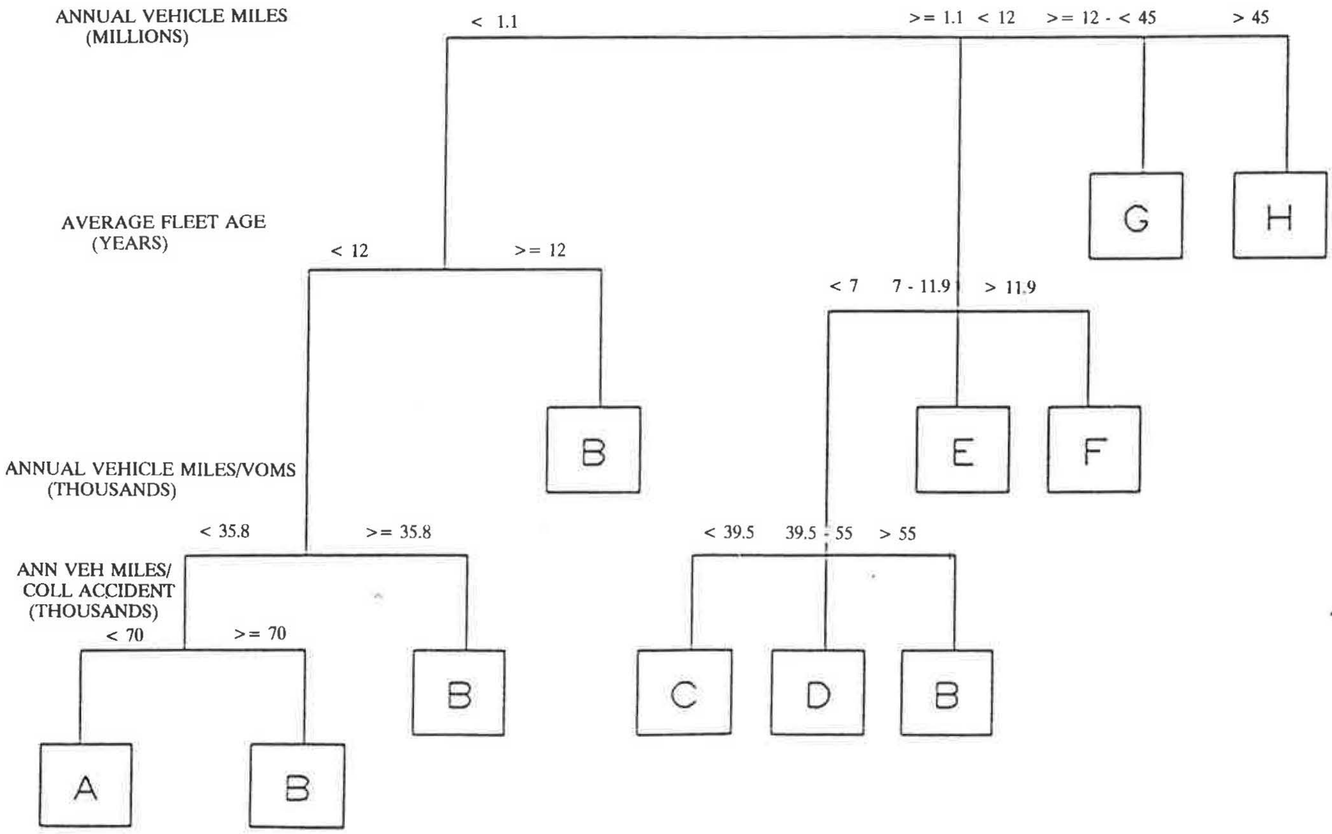

FIGURE 1 Bus maintenance topology tree.

Group D contains 24 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average fleet age is less than 7 years, and vehicle use is average. Their resource efficiency performance is above average, while their service effectiveness performance is average.

Group E contains 79 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average fleet age is between 7 and 11.9 years. Both resource efficiency and service effectiveness performance are average to below average.

Group F contains 14 bus systems, each operating between 1.1 and 12 million veh-mi annually. This group is distinguished by its average fleet age, which is equal to or greater than 11.9 years of age. Their resource efficiency performance is below average, and their service effectiveness is average to below average.

Group G contains 23 bus systems, each operating between 12 and 45 million veh-mi annually. These are bus systems operating in the larger urbanized areas of the United States. Their performance is characterized by both low resource efficiency and low service effectiveness.

Group H contains 5 bus systems operating in the larger to largest urbanized areas of the United States. Their resource efficiency performance is the lowest of any peer group, but their service effectiveness performance is above average, because their high passenger-miles overcome a lower-than-average rate of roadcalls per mile.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective was to identify performance indicators that may be used to identify transit systems with superior bus maintenance performance. A literature review was conducted to identify factors often reported as affecting maintenance performance. A data base was created using all of the reported factors available in the 1984 UMTA Section 15 information. Analyses using the data base were conducted to design performance indicators and peer groups of transit systems. Within each peer group, transit systems with superior bus maintenance performance were identified. The remainder of this section contains the conclusions and recommendations resulting from these analyses.

The methodological procedures used here were based on the approach used by Fielding (*2*) in his work for UMTA to develop indicators and peer groups for overall transit performance analysis. Several approaches are possible and were considered to achieve the study's objectives; the procedures used are considered sound and appropriate given the resources available. The report to UMTA (*1*) identified the names of the transit systems that were most resource efficient and service effective by peer group, but it would be premature to present these systems here. This study's work (as was Fielding's) was limited by the lack of a comprehensive data base from which to extract significant information relevant to the

TABLE 1 STATISTICAL CHARACTERISTICS OF PERFORMANCE INDICATORS FOR BUS MAINTENANCE PEER GROUPS

PEER GROUP	STATISTICAL CHARACTERISTIC	VEH MILES / VEH MAINT $	VEH MILES / INSPEC & LABOR HOUR	PASS MILES / MECH RDCL	VEH MILES / MECH RDCL
A	Count	52	50	48	52
	Min	0.97	13.1	1921	1310
	Max	4.53	185.0	645600	128533
	Mean	2.43	66.1	112104	20242
	SD	0.92	33.9	148932	25492
B	Count	109	104	103	110
	Min	0.90	23.9	2173	833
	Max	6.38	526.7	297000	92140
	Mean	2.83	54.9	44712	12079
	SD	1.14	68.9	52488	17066
C	Count	27	25	22	24
	Min	1.07	28.3	9468	1210
	Max	3.37	89.7	285388	33240
	Mean	1.94	54.9	62882	7077
	SD	0.60	16.3	77606	7664
D	Count	23	23	19	24
	Min	1.15	48.8	9897	1293
	Max	3.90	292.3	173662	17633
	Mean	2.44	99.7	49494	5331
	SD	0.64	48.8	44338	3991
E	Count	79	71	70	79
	Min	0.55	19.8	663	246
	Max	5.02	266.5	383493	25706
	Mean	2.06	68.5	45149	5049
	SD	0.72	39.0	52301	4325
F	Count	14	12	13	14
	Min	0.86	19.4	9617	630
	Max	2.34	95.4	155153	44721
	Mean	1.57	45.8	40162	7467
	SD	0.46	21.2	36930	11436
G	Count	23	22	20	22
	Min	0.83	22.8	11817	991
	Max	2.29	81.7	92702	6015
	Mean	1.35	49.3	32162	2973
	SD	0.38	15.1	19736	1465
H	Count	5	5	5	5
	Min	0.55	13.5	27622	1108
	Max	1.37	49.7	128825	7115
	Mean	0.98	33.6	61903	3612
	SD	0.26	12.3	37458	2177

research. Such limitations may have a direct bearing on the validity and industry acceptance of the results.

On the basis of these conclusions, the following recommendations are made:

- Use the methodological procedures of this study and extend the data base to include data believed to be important to bus maintenance performance but not found in UMTA Section 15. This extension of the data base may result in different maintenance performance indicators, topology variables, and peer group structure.
- Identify bus transit systems, by peer group, whose maintenance performance is characterized by the recommended methodology to be superior (i.e., resource efficient and service effective). In addition, identify bus transit systems, by peer group, whose maintenance performance is characterized by the recommended methodology to be inferior.
- Conduct onsite maintenance performance audits. These field audits must be comprehensive enough to include all of the factors that affect maintenance performance (as previously described) and must be focused on identifying the principal underlying causes of superior or inferior performance.
- Prepare guidelines that document the procedures and practices of superior bus maintenance programs.

Finally, if the resources of bus transit systems are to be protected and preserved, it is important to implement the study recommendations. The results will assist transit systems to identify deficiencies within their own program and to achieve superior maintenance performance.

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APPENDIX A

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