Analysis of Bus Transit's Maintenance Efficiency Using Section 15 Data

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ABSTRACT

Vehicle maintenance expenses contribute approximately 21 percent to the total operating expenses and are the second highest expense category after vehicle operations. In addition, the cost efficiency of vehicle maintenance is declining. If maintenance becomes more cost efficient, overall cost reductions and service quality improvements are possible. Direct comparisons among systems are not generally useful, because cost variations are largely a function of factors that are determined by system operating characteristics and the environment in which the system operates, and are mostly outside the system operator's control. In this paper, the relationship and effect of these factors on vehicle maintenance efficiency and productivity components are explored. A cross-sectional analysis is performed through a set of regression equations that may be used by transit managers as a tool to identify and diagnose the sources of their inefficiencies, and assist them in the development or modification of their maintenance policies.

Rapidly increasing costs and declining productivity made the majority of the nation's transit systems increasingly more dependent on public subsidies over the last 2 decades (1). Furthermore, transit has been given the assignment to accomplish an array of social objectives, ranging from energy conservation to providing mobility for the poor and the handicapped. All this has led to an increased interest in the performance evaluation of the nation's transit systems.

There is no general agreement on how to define and measure the performance of a transit system, because the goals to be accomplished are often vague and conflicting. However, most researchers agree that transit performance is a multidimensional concept consisting of some or all of the following elements (2-4):

- Efficiency,
- Effectiveness,
- Quality of service, and
- Societal impacts.

In this paper, not all of these elements of performance are dealt with; rather, the focus is on only the cost-efficiency concept as it relates to the vehicle-maintenance function.

Vehicle maintenance expenses contribute approximately 21 percent to total operating expenses and are the second highest expense category after vehicle operations (5). Transit managers and policy makers have not given the maintenance function the interest and attention that its importance warrants. This was mainly the result of the "80-20" federal share for capital assistance, which allows transit properties to buy new vehicles at a cost to them of only 20 cents on the dollar, and often much less, because local and state governments provide additional capital funds. Thus, most systems find it more cost-effective to defer maintenance and replace vehicles prematurely. However, as federal sources of funds become less certain, increased attention has been paid not only to the costs associated with maintenance, but also to the quality and effectiveness of the maintenance practices, as road calls and missed runs contribute heavily to the quality of service offered and consequently affect the number of passengers attracted and, therefore, the fare revenues collected by the system.

Vehicle maintenance cost efficiency as measured by vehicle-miles per dollar spent is declining whether expenses are measured in actual or constant dollars (5). If maintenance becomes more cost efficient, overall cost reductions and, more important, service quality improvements are possible. Direct comparisons among systems are not generally useful (because cost variations are largely a function of factors that are determined by system operating characteristics and the environment in which the system operates and are mostly outside the system operator's control). In this paper, the relationship and effect of these factors on vehicle maintenance efficiency and productivity components are explored.

PREVIOUS STUDIES ON VEHICLE MAINTENANCE

A number of studies have dealt with vehicle maintenance and have identified the following major critical issues:

- Transit systems do not have adequate preventive maintenance programs and, in many systems, the established preventive maintenance schedule is not adhered to (6,7).
- Although vehicles have become highly complex technologically, there is little progress in vehicle mechanic training, promotion, and recruitment practices (6,8).
- Most systems do not have proper inventory control methods for spare parts and supplies, which

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results in overstocking or maintenance work being held up while waiting for delivery of replacement units (6,8).

- Bus maintenance facility needs have not been properly addressed. Most garage, storage, and main maintenance facilities have become antiquated and are not geared to efficiently servicing the needs of the bus fleets (8).
- Vehicle history and status information recording methods are mostly inadequate for diagnostic purposes, often resulting in incomplete repairs (8,9).
- Quality assurance (QA) methods are not being extensively used in evaluating the degree to which established standards of performance are being attained (10).
- Most systems do not have an adequate maintenance information system (MIS), which is a prerequisite for the proper scheduling of maintenance activities, and which enables the correct usage of labor and material resources (9-11).

It is obvious from the studies just outlined that a wide range of problems exists in all areas of the vehicle maintenance function. Improvements in facilities, equipment, personnel, and procedures can make the delivery of the maintenance function more effective and efficient and reduce costs, as well as improve fleet reliability and quality of service. Realizing all this, Pake et al. (12) developed a generalized, descriptive managerial framework for bus maintenance. They defined the maintenance function as a set of eight component activities (work assignment, maintenance scheduling, work force development, labor allocation, inventory management, equipment management, information systems, and monitoring and evaluation) and classified transit systems according to the degree of sophistication with which they perform each activity. They also concluded that activity sophistication should be a function of the environment in which a system operates. Unfortunately, there are few studies that deal quantitatively with the effects of environmental factors.

Meyer et al. (13), in their analysis of mass transportation productivity, used a sample of 42 bus systems for 1970 to develop a formula that explains the variance in the maintenance costs as follows:

$$\text{mc} = 0.331 - 0.017\ \text{mph} + 0.00003\ \text{size} - 0.00021\ \text{age} + 0.00008\ \text{temp} \qquad \text{adj.}R^2 = 0.42$$

where

mc = maintenance costs (\$/bus-mile),
mph = average speed,
size = number of vehicles owned,
age = percent of buses over 10 years old, and
temp = the average number of days temperatures fell below zero per year.

The only variables found significant in the preceding regression equation were speed and fleet size, although the addition of the operator wage rate as an independent variable acting as an index for the maintenance wage rates only slightly increased the explanatory power of the equation (adj.R^2 = 0.50). This led the authors to conclude that most of the unexplained variation is attributable to differences in the skill of the maintenance personnel.

In two similar studies, Foerster et al. (7,14) survey the factors that influence transit bus maintenance costs and labor requirements. Employing multiple regression analysis and using Section 15 data from 107 transit systems, they produce the following model:

$$\text{LH} = -2.9 + 0.0009\ \text{VEH} + 0.88/\text{SPEED} + 0.80\ \text{AGE} + 9.3\ \text{RC} - 6.1\ \text{SPARE} \qquad R^2 = 0.37$$

where

LH = hours of maintenance labor per 1,000 revenue miles,
VEH = revenue vehicles,
SPEED = average speed,
AGE = mean age of fleet,
RC = roadcalls due to mechanical failure per 1,000 revenue miles, and
SPARE = revenue vehicles per peak vehicle.

The regression equation is able to explain only a small percentage of the variation, and the coefficient of the age variable is insignificant. The effect of fleet size and speed variables is in agreement with Meyer's earlier findings.

Wilson (15), in his examination of operating cost categories, developed a model for forecasting repair man-hours per thousand bus-miles. His findings show that the value of this resource consumption index is negatively influenced by the system's output as measured by the square root of bus-miles. This leads the author to conclude that there are economies of scale in this component and that positive impacts are found by the variables representing private ownership and annual snowfall, which are attributed to the poor financial state of private systems and to the increased care required for transit systems operating in colder climates. Wilson's model achieves a high coefficient of determination (0.861) when the regression is run on weighted data, but it explains only 50 percent of the variation when it is fitted to the raw data. Its major weakness, however, is that it is based on a small data base (only 20 transit properties).

STUDY APPROACH AND DATA SOURCES

Most of the data used in the analyses were obtained from the fourth year of statistics reported under Section 15 of the Urban Mass Transportation Act of 1964 as amended, which established a Uniform System of Accounts and Records and Reporting System, which required transit systems that receive federal operating assistance to annually submit financial and operating information.

The vehicle maintenance function costs are, according to Section 15, about 21 percent of the total operating costs as given in Table 1. In examining the cost efficiency of maintenance, regression equations can be developed that have as their dependent variable the ratio of a maintenance function input over a system output unit. Input units can be either employees or dollars. Vehicle-miles or platform (vehicle operating) hours can represent system outputs. Cost efficiency ratios can also be derived for the entire function, an individual object class, or a combination of object classes.

By combining inputs, outputs, and object classes, 12 vehicle maintenance efficiency elements were developed. They are given in Table 2 with all independent variables and are shown in Figure 1. The first six measures describe the efficiency of the most important object class--the salaries of maintenance employees, which accounts for about one-half of the maintenance function expenses. The first two elements use salaries in the numerator and the next four use actual employee hours as an input and can

TABLE 1 Vehicle Maintenance Expenses by Object Class

Object Class	Operating Costs (% of total)	VM Function (% within)
Salaries of maintenance employees	10.11	48.0
Fringe benefits	4.19	19.9
Services	0.72	3.4
Materials and supplies	5.79	27.5
Other (utilities, taxes, casualty and liability, expense transfers)	0.25	1.2
Total	21.06	100.0

TABLE 2 Dependent and Independent Variables

Variable	Description
Dependent	
SALPH	Salaries, vehicles, and maintenance/platform hour
SALVM	Salaries, vehicles, and maintenance/vehicle mile
EMPPH	Vehicle maintenance employees/platform hour
EMPVM	Vehicle maintenance employees/vehicle mile
MECPH	Vehicle mechanics/platform hour
MECVM	Vehicle mechanics/vehicle mile
SAFPH	Salaries + fringes in VM/platform hour
SAFVM	Salaries + fringes in VM/vehicle mile
SFSPH	Salaries + fringes + services in VM/platform hour
SFSVM	Salaries + fringes + services in VM/vehicle mile
TOTPH	Total vehicle maintenance/platform hour
TOTVM	Total vehicle maintenance/vehicle mile
Independent	
X1	Average monthly earnings of city employees
X2	Percentage of work trips made utilizing public transportation
X3	Mean January temperature (°F)
X4	Average seating capacity
X5	Ln (revenue vehicles)
X6	Total vehicle capacity—mileage weighted
X7	Platform hours/vehicle mile
X8	Vehicle mile/platform hour
X9	(Active vehicles*annual hours of operation)/platform hour
X10	Active vehicles/platform hour
X11	Active vehicles/vehicle mile
X12	Mean July temperature (°F)
X13	Fleet age—mileage weighted
X14	Active vehicle/vehicle in maximum service period
X15	Median county family income (1980)
X16	Ln (operating employees total)
X17	Platform hours/active vehicle
X18	Average capacity—vehicle weighted
X19	Active vehicles/vehicle midday
X20	Ln (total fleet capacity)
X21	Passenger miles/passenger

be considered as measures of employee productivity. The last six elements gradually add all other object classes to the salaries, starting with fringes. Services are added again to investigate possible tradeoffs between salaries and maintenance contracting. Finally, all expenses are included in the last two elements. Half of the elements use platform hours as a unit of output, and the other half are expressed per vehicle mile. They are distinguished by having a "PH" or "VM" as the last characters in their abbreviated description.

In addition to Section 15, which provided data for all dependent and most of the independent variables, the 1983 edition of the County and City Data Book (16) was used to extract information on the

- Percent of persons using public transportation for the work trip for both the county and city area,
- Percent of the unemployed civilian labor force in the county and city,
- Percent of area (county) that is urbanized,
- Mean temperature (in degrees Farenheit) in January and July, and
- Heating and cooling degree-days in a year.

(Note that items 1 and 3 are from the 1980 census and item 2 is a Bureau of Labor Statistics figure for 1982.)

Data on average monthly earnings of city employees were derived from government statistics reports on city employment (17). These reports provide data for the month of October of each year. Reports for 1980, 1981, and 1982 were used to extrapolate data and make them coincidental with the sixth month of each system's fiscal year.

ANALYSIS OF VEHICLE MAINTENANCE COST ELEMENTS

Basic Salary and Productivity Ratios

Salaries per platform hour (SALPH) and vehicle mile (SALVM) that represent the overall cost efficiency of the first and major vehicle maintenance object class should be influenced by the average basic maintenance wage rate and the productivity of the

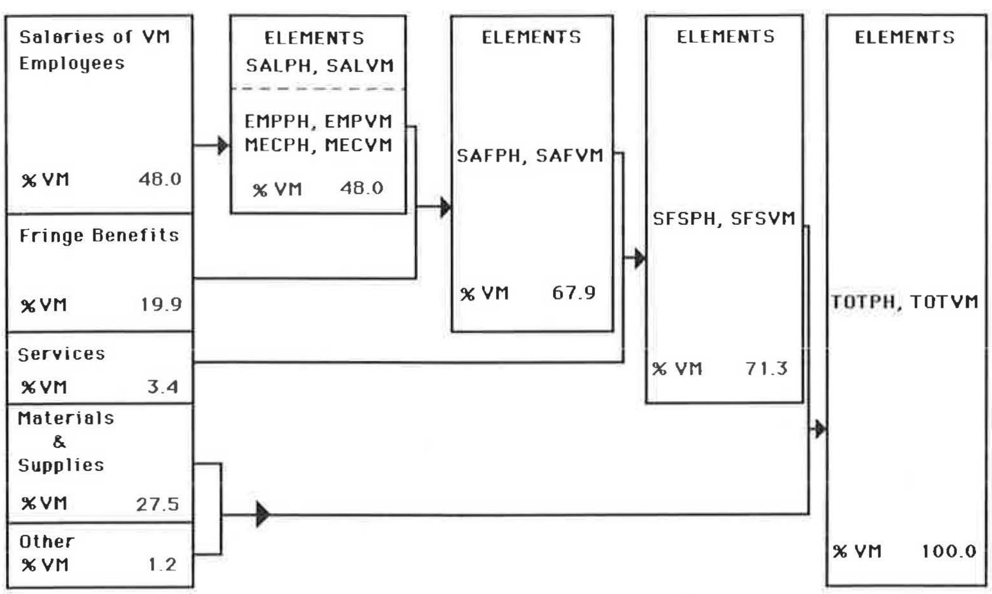

FIGURE 1 Derivation of analyzed elements in the VM function.

maintenance personnel. The basic wage rate can be computed from Section 15 information and expressed as salaries for maintenance employees/employee hours of vehicle maintenance personnel. Maintenance personnel productivity was defined for the purpose of this paper as employees per platform hour (EMPPH) and vehicle mile (EMPVM), and mechanics per platform hour (MECPH) and vehicle mile (MECVM).

The variables that are hypothesized to influence the productivity ratios are

1. Vehicle capacity--This variable should affect employee productivity ratios because systems with higher capacity vehicles will require more maintenance employees to perform the necessary maintenance tasks. The per-vehicle-mile and per-platform-hour productivity ratios hide the capacity factor because vehicles produce the same vehicle miles and platform hours regardless of their capacity.

2. Speed (miles/hour) and Slowness (hours/mile)--The assumption regarding these variables is that in the mileage equations, lower speeds will result in more maintenance employees per mile although in the hourly equations, higher speeds could result in more employees per hour. The reasoning behind these assumptions is that in the mileage equations, systems with lower speeds have their vehicles operating for a greater period of time for the same mileage, thus creating the need for more maintenance and, consequently, employees. By applying the same logic in the hourly equations, systems with higher speeds produced more vehicle miles for the same hours of operation, thus requiring more employees. It is much more likely, however, that the speed variable will be predominant in the mileage equations because maintenance employees (supervisory and support staff as well as mechanics) are hired more on the basis of annual hours of operation and number of vehicles in service than on the mileage vehicles accumulated. This creates an inherent distortion because systems with lower speeds would seem more unproductive in the mileage equations.

3. Degree of fleet and vehicle underutilization as measured by (a) (active vehicles x annual hours of operation) per platform hour, (b) active vehicles per vehicle mile, and (c) active vehicles per platform hour--It is assumed that low utilization factors would result in more maintenance employees per vehicle mile and platform hour. Certain maintenance functions are dependent on the number of vehicles, as all vehicles must be inspected, cleaned, repaired, painted, and so forth. Thus, the higher the values of the preceding variables, the higher the need for maintenance employees.

4. Climatic conditions--Systems operating in warmer areas are more likely to experience air-conditioning problems and systems in the colder regions will be affected by cold starts, heating system breakdowns, and corrosion caused by the melting snow and ice dripping from the undercarriage. Thus, the overall effect of the climatic factors is uncertain.

5. Vehicle age--The effect of this variable is also uncertain. Maintenance needs increase for older vehicles because of their time and mileage wear, and the sophistication and complexity of newer vehicles may also cause an increase in the amount of time required for their maintenance.

6. Spare ratio (measured by active vehicles/vehicles in maximum scheduled service period)--The impact of the spare ratio on the productivity factors could also be adverse. On one hand, large spare ratios allow for a greater time span for the maintenance of vehicles and a less intensive use of vehicle mechanics. On the other hand, the spare ratio, being closely related to the degree of the fleet's utilization, could increase the need for maintenance employees as more vehicles have to be maintained at any time. The effect of a similar variable, active vehicles per vehicles midday, which incorporates the degree of "peakness" in service was examined as well as active vehicles per vehicles midday = (active vehicles/vehicles in maximum service) x (vehicles in maximum service/vehicles midday).

7. System size--The main purpose for the inclusion of this variable was to detect possible economies or diseconomies of scale.

The wage rate of the vehicle maintenance employees was assumed to be influenced by the same factors that affect the operators' wage rate (4). They are as follows:

- City employee wages in the system's area of operation.
- Income per capita in the county of operation.
- Transit system size (i.e., fleet size, number of employees, annual hours of operation).
- Public transportation's degree of utilization in the city of operation.
- Geographical region of system's operation.
- Vehicle capacity (seating, total).

Various linear and nonlinear functional forms for all independent variables were tested. Variables were checked for multicollinearity problems and were included in the equations only if they entered at a 0.05 level of significance or better. The number of cases (N) is indicated for all regressions, and includes the maximum number of bus-only systems that had clean data. The standardized regression coefficient, along with the F-value of each independent variable, are presented in brackets and parentheses, respectively.

RESULTS

The analysis of the productivity ratios (EMPPH, EMPVM, MECPH, and MECVM) and the wage rate was impeded by the questionable values of the Section 15 data on employee equivalents, which were involved in the calculation of the wage and all productivity ratios.

The variables hypothesized to influence the wage rate of the maintenance employees were indeed correlated with the dependent variable. The strongest relationships exhibited by variables were average monthly earning of city employees (X1, $r = 0.555$), the percentage of people using public transportation for the work trip (X2, $r = 0.577$), and the average vehicle-seating capacity (X4, $r = 0.461$). However, none of the regression equations was able to explain more than about one-half of the variation in the wage rate. A reason for this may be that maintenance employee wages are, to a large degree, related to operating personnel wages or system-wide contracts. The following two equations were the best predictors of the maintenance personnel wage rate:

$$\text{Wage Rate} = 0.644 + \underset{\substack{\{0.29\} \\ (9.0)}}{0.192*10^{-2}*X1} + \underset{\substack{\{0.44\} \\ (29.3)}}{0.682*10^{-1}*X2} + \underset{\substack{\{0.25\} \\ (7.1)}}{0.168*10^{-3}*X15} \quad (1)$$

$R^2 = 0.520$ (adjusted = 0.502) N=84

$$\text{Wage Rate} = -2.057 + \underset{\substack{\{0.42\}\\(22.1)}}{0.282*10^{-2}*X1} + \underset{\substack{\{0.21\}\\(5.0)}}{0.911*10^{-1}*X4} + \underset{\substack{\{0.23\}\\(6.2)}}{0.583*X9} \quad (2)$$

$$R^2 = 0.434 \text{ (adjusted} = 0.412\text{) } N=84$$

The correlation matrix of the productivity ratios (EMPPH, EMPVM, MECPH, and MECVM) and the independent variables in Table 3 show that the slowness variable (X7) exhibited the strongest positive relationship in the mileage-related ratios (EMPVM and MECVM), confirming the assumption made. Speed (X8) showed a conflicting but nonsignificant relationship with the hourly productivity ratios (EMPPH and MECPH). Fleet age (X13) produced a weak negative relation and positive influence was found to be exerted by the vehicle capacity (X6) and fleet underutilization factors (X9, X10, X11). In addition, some positive influence is denoted by the coefficient of the spare ratio variable (X14), and the sign of the temperature variable (X12) suggests the usage of more maintenance employees for systems operating in warmer areas.

TABLE 3 Correlation Matrix of Elements EMPPH, EMPV, MECPH, and MECVM with Independent Variables

	Simple r			
Variable	EMPPH	EMPVM	MECPH	MECVM
X6	0.220	0.399	0.286	0.435
X7	–	0.644	–	0.586
X8	0.021	–	-0.128	–
X9	0.369	0.288	0.302	0.254
X10	0.219	–	0.165	–
X11	–	0.533	–	0.480
X12	0.237	0.138	0.12	0.044
X13	-0.167	-0.041	-0.101	-0.005
X14	0.248	0.271	0.061	0.098

The regression equations did not have satisfactory coefficients of determination. Nothing satisfactory could be obtained for MECPH, and the best equations for the other three productivity ratios are as follows:

$$\text{EMPVM} = -0.278*10^{-1} + \underset{\substack{\{0.28\}\\(10.6)}}{0.265*10^{-3}*X6} + \underset{\substack{\{0.51\}\\(36.7)}}{0.293*X7} + \underset{\substack{\{0.27\}\\(10.9)}}{0.118*10^{-1}*X14} \quad (3)$$

$$R^2 = 0.516 \text{ (adjusted} = 0.498\text{) } N=84$$

$$\text{EMPPH} = -0.153 + \underset{\substack{\{0.20\}\\(4.3)}}{0.172*10^{-2}*X6} + \underset{\substack{\{0.30\}\\(9.6)}}{0.563*10^{-2}*X12} + \underset{\substack{\{0.32\}\\(10.4)}}{0.302*10^{-1}*X16} - \underset{\substack{\{-0.37\}\\(13.9)}}{0.755*10^{-4}*X17} \quad (4)$$

$$R^2 = 0.287 \text{ (adjusted} = 0.251\text{) } N=84$$

$$\text{MECVM} = -0.148*10^{-1} + \underset{\substack{\{0.43\}\\(23.1)}}{0.179*X7} + \underset{\substack{\{0.25\}\\(8.1)}}{0.170*10^{-3}*X18} + \underset{\substack{\{0.24\}\\(7.9)}}{0.244*10^{-2}*X19} \quad (5)$$

$$R^2 = 0.460 \text{ (adjusted} = 0.440\text{) } N=84$$

The regression equations explaining maintenance salaries per platform hour (SALPH) and vehicle mile (SALVM) have much higher coefficients of determination than those just shown for the wage rate and the productivity elements because the values of these elements are not influenced by the questionable entries in the employee equivalent data. The best regressions are

$$\text{SALPH} = -3.49 + \underset{\substack{\{0.55\}\\(48.4)}}{0.49*10^{-1}*X2} + \underset{\substack{\{0.23\}\\(10.3)}}{2464.44*X10} + \underset{\substack{\{0.15\}\\(4.1)}}{0.77*10^{-1}*X8} + \underset{\substack{\{0.37\}\\(23.6)}}{0.42*X20} \quad (6)$$

$$R^2 = 0.603 \text{ (adjusted} = 0.583\text{) } N=85$$

$$\text{SALVM} = -0.28 + \underset{\substack{\{0.54\}\\(74.7)}}{0.49*10^{-2}*X2} + \underset{\substack{\{0.19\}\\(7.8)}}{1.22*X7} + \underset{\substack{\{0.28\}\\(11.8)}}{2357.72*X11} + \underset{\substack{\{0.27\}\\(21.2)}}{0.31*10^{-1}*X20} \quad (7)$$

$$R^2 = 0.766 \text{ (adjusted} = 0.755\text{) } N=85$$

As expected, the independent variables represent factors that were found to be related to the components (i.e., wage rate and productivity) of the preceding elements such as X2 (the degree of usage of public transportation in the area), X20 (a system size variable), X10 and X11 (the underutilization factors), and X8 and X7 (the speed and slowness variables) in the mileage and hourly equations, respectively. All have positive coefficients indicating that labor maintenance costs should be increasing as they do.

Composite Elements and Total Costs

Total vehicle maintenance costs can be obtained if fringes, services, and other miscellaneous expenses are added to the basic wages. Because these additional elements are relatively small in proportion to the maintenance salaries, the structure of the regression equations should not be altered substantially, and all earlier hypotheses should still be valid.

RESULTS

The results obtained from the analysis of the composite and total maintenance function elements are presented below:

$$\text{SAFPH} = -4.39 + \underset{\substack{\{0.47\}\\(38.9)}}{0.59*10^{-1}*X2} + \underset{\substack{\{0.24\}\\(11.2)}}{3614.82*X10} + \underset{\substack{\{0.42\}\\(32.1)}}{0.69*X20} \quad (8)$$

$$R^2 = 0.599 \text{ (adjusted} = 0.584\text{) } N=85$$

$$\text{SAFVM} = -0.48 + \underset{\substack{\{0.50\}\\(65.0)}}{0.66*10^{-2}*X2} + \underset{\substack{\{0.20\}\\(8.4)}}{1.84*X7} + \underset{\substack{\{0.24\}\\(12.3)}}{3553.00*X11} + \underset{\substack{\{0.30\}\\(26.5)}}{0.51*10^{-1}*X20} \quad (9)$$

$$R^2 = 0.764 \text{ (adjusted} = 0.753\text{) } N=85$$

$$\begin{aligned} SFSPH = &-4.49 + 0.17*10^{-2}*X1 + 0.55*10^{-1}*X2 \\ &\qquad\quad \{0.33\} \qquad\qquad \{0.42\} \\ &\qquad\quad (16.9) \qquad\qquad (29.0) \\ &+ 3617.18*X10 + 0.43*X20 \qquad (10) \\ &\quad \{0.23\} \qquad\quad \{0.25\} \\ &\quad (10.2) \qquad\quad (\ 9.7) \end{aligned}$$

$$R^2 = 0.592 \text{ (adjusted = 0.572) } N=86$$

$$\begin{aligned} SFSVM = &-0.47 + 0.11*10^{-3}*X1 + 0.64*10^{-2}*X2 + 1.84*X7 \\ &\qquad\quad \{0.20\} \qquad\qquad \{0.49\} \qquad\quad \{0.25\} \\ &\qquad\quad (\ 9.1) \qquad\qquad (51.4) \qquad\quad (0.67) \\ &+ 3612.12*X11 + 0.34*10^{-1}*X20 \qquad (11) \\ &\quad \{0.25\} \qquad\quad \{0.20\} \\ &\quad (12.0) \qquad\quad (\ 9.8) \end{aligned}$$

$$R^2 = 0.746 \text{ (adjusted = 0.731) } N=86$$

$$\begin{aligned} TOTPH = &-7.58 + 0.29*10^{-2}*X1 + 0.64*10^{-1}*X2 \\ &\qquad\quad \{0.37\} \qquad\qquad \{0.34\} \\ &\qquad\quad (25.2) \qquad\qquad (13.5) \\ &+ 6511.82*X10 + 0.13*X4 \qquad (12) \\ &\quad \{0.29\} \qquad\quad \{0.26\} \\ &\quad (16.1) \qquad\quad (\ 7.7) \end{aligned}$$

$$R^2 = 0.609 \text{ (adjusted = 0.590) } N=86$$

$$\begin{aligned} TOTVM = &-0.74 + 0.19*10^{-3}*X1 + 0.77*10^{-2}*X2 \\ &\qquad\quad \{0.24\} \qquad\qquad \{0.41\} \\ &\qquad\quad (15.0) \qquad\qquad (23.0) \\ &+ 2.37*X7 + 0.95*10^{-2}*X4 + 6960.71*X11 \qquad (13) \\ &\ \{0.18\} \qquad \{0.19\} \qquad\qquad \{0.32\} \\ &\ (\ 6.0) \qquad (\ 6.2) \qquad\qquad (19.7) \end{aligned}$$

$$R^2 = 0.745 \text{ (adjusted = 0.729) } N=86$$

The findings are supportive of the earlier hypotheses, as they demonstrate that vehicle maintenance costs are associated with the

- Degree of public transportation utilization (X2),
- Transit system size (X20),
- Wages of city employees (X1),
- Number of vehicles utilized in the provision of services (X10, X11),
- Slowness factor (inverse of speed) in the mileage equations (X7), and
- Average seating capacity of the vehicles in the fleet (X4).

MAINTENANCE EFFECTIVENESS

Although the analysis of the vehicle maintenance costs provided some insights on the influence of the environmental variables on these functional elements, it should be noted that the overall success or effectiveness of vehicle maintenance is measured by the ability to keep the fleet running at all times without missing trips, avoiding mechanical breakdowns, and, at the same time, minimizing the associated costs.

Although it is not in the scope of this paper to examine the effectiveness of vehicle maintenance actions, an effort was undertaken nevertheless to link the effectiveness measure of vehicle miles or platform hours per road call (mechanical failure) to a number of system characteristics and environmental variables. However, the Section 15 data on road calls caused by mechanical failure proved to be unreliable and produced regressions with low coefficients of determination, the best of which follows.

Road calls/vehicle mile =

$$\begin{aligned} &0.442*10^{-3} + 0.162*10^{-4}*X2 - 0.598*10^{-4}*X21 \qquad (14) \\ &\qquad\qquad\quad \{0.62\} \qquad\qquad \{-0.40\} \\ &\qquad\qquad\quad (47.4) \qquad\qquad (\ 19.5) \end{aligned}$$

$$R^2 = 0.400 \text{ (adjusted = 0.385) } N=84$$

Others were equally unsuccessful in producing reasonable regression fits. For example, Foerster (7,14) produced the following two models that explained less than 20 percent of the variation in road calls per revenue and vehicle mile, respectively. In Model I

$$RC = -0.802 + 0.114 \text{ Ln(VEH)} + 8.905/\text{SPEED}$$

$$R^2 = 0.175 \quad F = 11.48$$

where

RC = road calls due to mechanical failure per 1,000 revenue miles,
VEH = revenue vehicles, and
SPEED = average speed (mph).

In Model II the dependent variable is mechanical failures per vehicle mile

R^2 = .19
F (4,57) = 3.42
P .01

The independent variables are as follows:

Independent Variables	Coefficient	Significance Level
Constant	.00012	
Labor hours per vehicle mile	+.0046	.21
Annual per peak mileage per vehicle	$+.922*10^{-10}$	.009
Annual total system mileage per vehicle	$-.666*10^{-10}$	.07
Section 5 (dollars per bus mile)	$-.038*10^{2}$	.06

Road calls appear to be unpredictable because of their inconsistent definition among systems that chose not to follow the Section 15 standard, as well as reporting inaccuracies. For 86 fourth-year Section 15 systems, the variable vehicle miles per road call had a mean of 6,839, a standard deviation of 10,565 and ranged from 459 to 60,047. Similarly, the variable platform hours per road call had a mean of 525, a standard deviation of 803, and ranged from 58 to 4,942. Obviously, it is impossible to predict variables that are distributed so widely. Vehicles miles per road call are computed and given in Table 4 for all bus systems and each of the five Section 15 annual reports currently available. During the first 4 years, vehicle miles per road call kept declining and, in the fifth year, they increased sud-

TABLE 4 Trend in Vehicle Miles per Road Call

Year	Vehicle Miles	Road Calls (number of mechanical failures)	Vehicle Miles per Road Call
1	1,328.9	504,519	2,634
2	1,461.1	766,636	1,906
3	1,541.1	825,412	1,867
4	1,523.6	980,091	1,554
5	1,554.4	612,920	2,520

denly to reach practically the first-year level. This sudden increase could be partially attributed to overestimates of vehicle miles because this variable is used to allocate a portion of federal subsidies. Vehicle miles did increase in the fifth year, but the sharp decline in road calls was responsible for the jump in vehicle miles per road call. Whether this is an aberration or a new trend will be determined as more Section 15 data become available in the future.

CASE STUDY AND SUGGESTIONS FOR FURTHER RESEARCH

It was shown that system characteristics and environmental conditions influence, to a large extent, the amount of maintenance resources consumed by a transit system. Given the environment in which they have to provide service, transit managers can use the regression models of this paper to evaluate their relative position among their peers. The results of an application case study are given in Table 5. A system was picked at random, and the values of the environmental variables pertaining to it were substituted in Equations 6 through 13 to obtain the predicted column. The values of the observed column were derived from the system's Section 15 report. The absolute and percent differences between the observed and predicted values are presented in the last two columns, with positive values indicating that the predicted values are exceeded and, therefore, that the system underperforms.

TABLE 5 Case Study Results

Element	Equation Number	Predicted	Observed	Difference	Difference (%)
SALPH	6	2.63	2.83	0.2002	7.611
SALVM	7	0.17	0.19	0.0247	14.908
SAFPH	8	3.54	3.61	0.0716	2.023
SAFVM	9	0.23	0.24	0.0127	5.576
SFSPH	10	3.95	3.70	-0.2547	-6.439
SFSVM	11	0.27	0.25	-0.0208	-7.688
TOTPII	12	5.88	6.25	0.3678	6.252
TOTVM	13	0.37	0.42	0.0458N	12.234

The results of Table 5 indicate that the system is spending more than was anticipated on the basis of its environmental setting for the salaries and fringe benefit components (SALPH, SAFPH, SALVM, SAFPM). However, this course is reversed and cost savings are realized when the service component is added (SFSPH, SFSVM). This seems to indicate that the system achieved an overall reduction in costs by conducting a large portion of the maintenance work in-house as opposed to contracting it out. But these cost savings are short-lived, as the addition of the other maintenance component costs (mainly materials and supplies) produces total vehicle maintenance unit costs (TOTPH, TOTVM) that are higher than expected, resulting in an overall inefficiency in the vehicle maintenance function.

The model's usefulness and ability to pinpoint inefficiencies in the maintenance function ends at the object class level. In addition, no corrective action can be immediately devised by just inspecting the results. The case study system, for example, underperforms when materials and supplies and other expenses are added. This could be the result of a chaotic inventory control system, unusually high utility bills and liability premiums, or wasteful employees. The exact cause(s) can be identified only by the system's management that has an intimate knowledge of its operating and procedural details.

Combining the models' results with the degree of sophistication to which each of the eight previously mentioned component activities of maintenance are performed will probably be the best direction that future research efforts could take. Successful results in that area will not only refine the models presented here, but, in addition, a quantification of the descriptive framework of Pake et al. (12) will become possible. Another research area could be the establishment of a relationship between environmental factors and maintenance effectiveness either by using future years of cleaner Section 15 data or through an independent data collection effort. Finally, if the models are to be refined, in order to be able to determine the effects of environmental factors at a level more detailed than the object class, Section 15 information will be insufficient. For that purpose, additional and extensive data collection efforts will have to be undertaken, although the desirability of such an effort may be doubtful because wages will totally overshadow any minor expense category.

Recognizing the importance of the maintenance function, ways must be found to improve all of its aspects. Opportunities must be identified, trends should be examined, and policies formulated that will lead to the more efficient and effective use of resources, so that the transit industry can provide dependable and reliable service to the public, while simultaneously achieving operating expense reductions.

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Climatic Effects on Bus Durability

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ABSTRACT

The purpose of this paper is to provide climate peer groups that may be used in combination with any set of Section 15 indicators as a guide to understanding the impact of climate on participating transit authorities. The method of deriving these climate peer groups involves applying three climatic indicators to partition 203 transit authorities into "harsh," "intermediate," and "benign" climate peer groups. The results are mapped and are displayed in tabular form. The simple numerical procedure is checked using elementary linear algebra, and the resulting climate peer groups are again mapped and displayed in tabular form. The hypothesis that bus durability is adversely affected in harsh climates is then tested, using data from Section 15 indicators, to illustrate the method of employing these climate peer groups. Section 15 indicators on "age distribution," "distance between road calls," and "vehicle miles per maintenance dollar," partitioned by climate class, provide support for this hypothesis. Implications resulting from the testing of this hypothesis suggest which climate peer groups might benefit from additional evaluation of their maintenance strategy and which climate peer groups might serve as maintenance models for others.

Cars and buses heavily scarred from rusty sores are a familiar sight to residents of the Great Lakes Basin as well as to those in other regions that experience heavy concentrations of snow and road salt, or heat and airborne salt, near urban surface routes. Other environmental stresses that contribute to the aging of a bus fleet might involve the steepness of the underlying terrain and the density of traffic congestion. Steep grades produce extra strain on the motor and power-train, and frequent stopping and starting wear the brakes, the engine, and the drive train. However, major "surgery" often fixes component breakdowns, via brake transplant or electrical bypass, resulting from the various strains on the visceral bus system. Distintegration of the bus skin, however, is irreparable and often forces vehicle replacement; one response to this problem is to build rust-proof buses of stainless steel that resist corrosion from road and airborne salt. This change in material could extend bus life, thereby presenting transit authorities, in adversely affected climatic regions, with an opportunity to build healthier, more efficient bus fleets.

The major contribution of this work is to derive measures of climatic conditions that can be used in the analysis of several factors related to vehicle performance. This exploits the "Potential Data Applications" suggested in the Fourth Annual Section 15 Report of National Urban Mass Transportation Sta-

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