Impact of System and Management Factors on Bus Maintenance

JAMES F. FOERSTER, CLAIRE McKNIGHT, and MARIA KOSINSKI

ABSTRACT

Regression analysis was used to develop models of the reliability and maintenance labor statistics reported by 111 U.S. transit systems. Eight bus systems were selected for intensive analysis on the basis of deviations from the expected pattern of performance. Detailed site visits were conducted to identify local factors that were responsible for the deviations. Comparisons of the site-visit case studies identified several factors that had significant effects on performance. These included tracking and periodic evaluation of maintenance outcomes, driver involvement in prerun inspections, cooperative worker-manager relationships, and avoidance of excessively diverse fleets. A summary of productive management actions was constructed by synthesizing the approaches used at selected case study systems.

Transit maintenance has recently become a subject of considerable interest among researchers, transit managers, and government officials. Two recent TRB workshops have highlighted the importance and complexity of factors that influence maintenance performance. The first, held in 1982 (1), surveyed a number of perspectives on transit maintenance performance, including management structures and skills, use of analytical methods, personnel, recruitment, training and testing, and equipment, facility, and vehicle design. A second workshop, held in 1984 (2), focused on vehicle subsystem improvements. Each of these workshops illustrated the myriad problems encountered in maintenance and suggested a number of appropriate solutions.

The growing interest in maintenance shown by these workshops reflects an increasing concern about maintenance costs and vehicle reliability. Etschmaier (3) has previously documented the rather large amount of intersystem variation in these parameters. Further attention to maintenance has been generated by a recent General Accounting Office report (4) that highlighted apparently pervasive departures from mileage-based preventive maintenance schedules by a number of U.S. transit systems.

A review of the wide range of factors that influence maintenance performance is provided. The review is based primarily on eight case study systems that were selected from among 111 systems included in the data reported for 1981 according to the requirements of Section 15 of the Urban Mass Transportation Act of 1964 (5) on the basis of their roadcall records and labor-hour commitment to maintenance. The purpose of this paper is to illustrate differences among these systems and to identify factors that appear to differentiate between various levels of maintenance performance. The methodological approach used in this effort is that of the comparative case study. This method is particularly well suited to the subject of transit maintenance because it seeks to identify idiosyncratic sources of variation. This is consistent with the often-heard opinion that each transit system is unique, so one system cannot be compared with any other.

The remainder of this paper contains a first-level analysis of Section 15 maintenance data to illustrate how selected factors affect maintenance performance, a description of the rationale used to identify eight systems for intensive case analysis, a report of the results of these case studies, and a set of recommendations based on a synthesis of beneficial practices identified in the system studied.

METHODOLOGY

The approach taken in this research was based on the premise that a descriptive body of information on current industry practice is needed to identify practices that promote efficiency in bus maintenance. The method of comparative case study was selected for this purpose. This method involves the selection of key sites for intensive study on the basis of their departures from expected levels of performance. The unique characteristic of this method is that its focus on departures from expected performance maximizes the likelihood of identifying sources of variation that are not generally recognized in theory or conventional belief. As a result, this method is likely to generate new insights and identify approaches that have potential for improving performance if transferred to other locations.

Implementation of the case study approach involved seven steps. These were

1. Development of a set of initial research issues to be investigated in site visits,
2. Development of field-work procedures for use in the site visits,
3. Establishment of a database containing readily available information about transit maintenance,
4. Calibration of statistical models of observed maintenance performance and identification of systems that showed significant departures from expected performance,
5. Conduct of site visits to outlier agencies,
6. Documentation of site-visit findings, and
7. Cross-system analysis of similarities and differences between agencies.

The research issues identified before initiation of the field work included concerns about system management and labor, local operating environment, budget levels, and physical facilities. These issues were developed into 18 specific hypotheses about the characteristics of maintenance organizations. The details of these hypotheses and the results generated in their evaluation are given in the project report (6).

The site-visit methodology was developed around a set of 11 interview schedules that addressed the issue topics just listed. These forms contained questions and lists of information to be collected during site visits. The interview questions were purposely designed to provide overlap so that the same questions would be asked of a number of persons in different positions to permit validation of answers and analysis of conflicting opinions. Initial drafts of these questions and lists were reviewed with local transit managers and revised to incorporate suggestions about content, wording, and form. The final instrument included questions for persons at all levels of management, including the general manager, maintenance manager, purchasing director, head of operations, garage manager, mechanic, and union representative.

The information base developed for site selection was drawn from Section 15 operating reports and American Public Transit Association (APTA) fleet information listings. It included roadcalls due to mechanical failures, total labor hours for inspection and maintenance, fleet size, vehicle type, percent of vehicles with air conditioning, fleet age, average vehicle speed, peak-to-base ratio, spare ratio, and average vehicle utilization. This database was screened to eliminate systems with rail service and also to exclude systems with more than 1,000 or fewer than 45 vehicles. The decision to focus on moderate-sized systems was based on the desire to address the types of systems most commonly found throughout the United States, and the decision to delete systems with diverse service types was made to avoid problems with the allocation of joint costs.

Regression analysis was used to develop predictive models of roadcall and labor-hour utilization for the 111 systems that met the foregoing criteria. Residuals from these models were then plotted against one another to develop a display of deviations from the expected patterns of performance. Inspection of these plots identified those systems that departed significantly from expected patterns. The most obvious outliers were subject to more extensive analyses, which included reviews of fleet composition, air conditioning equipment, and consistency of Section 15 data from 1979 to 1981.

These procedures resulted in the identification of systems with the following characteristics:

- Three systems with lower-than-average roadcall rates and lower-than-expected maintenance labor requirements (fleet sizes approximately 100, 200, and 700 vehicles);
- Three systems with higher-than-expected roadcall rates and higher-than-average labor requirements (fleet sizes approximately 100, 200, and 700 vehicles); and
- Two systems with lower-than-expected roadcall rates and higher-than-expected labor input requirements (fleet sizes approximately 150 and 500 vehicles).

Each of the sites identified in this way was studied in a similar manner. This involved mailing a letter of introduction explaining the purposes of the research and requesting permission to conduct a site visit, traveling to the site to conduct personal interviews and collect necessary data forms and sample management reports, drafting a report summarizing the findings of the site visit, and reviewing the report by agency management.

Each site visit was conducted in a somewhat different format from that developed in the planning of the study because of system preferences, but all were judged to have generated a sufficient amount of information to be included in the subsequent analysis of intersystem differences. Each site visit was documented in a uniform format to provide information for use in subsequent stages of the research (7-14).

Three different approaches were used in analyzing the information gathered in the case studies. The first consisted of a close reading of each case and the development of summaries addressing each of the issue topics previously identified. These summaries were condensed into exhibits highlighting the most notable features of each system. The second analytical step was to relate each of the conditions observed in the site visit to system performance characteristics as defined by deviations from expected roadcall and labor requirements. The third step was to combine these observations into a summary of the conditions and practices that appeared to account for maintenance performance at the systems in question.

PRELIMINARY SITE SELECTION RESULTS

The regression analyses used to develop predictive models of roadcalls and labor utilization were the result of extensive analysis of the Section 15 data. The criteria used for model development included correctness and significance of coefficient signs and overall r^2 values.

The best models identified were as follows:

$$RC = -0.802 + 0.114*\log(VEH) + 8.905/SPEED \quad (1)$$

$$LH = -2.9 + 0.009*VEH + 288/SPEED + 0.8*AGE + 9.3*RC - 6.1*SPARE \quad (2)$$

where

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

These models were found to be statistically significant, but they do not account for a large percentage of the variation observed in the data. The roadcall model has an r^2 of .17, and the labor model has an r^2 of .39. Both models were significant at the 0.05 level. The individual coefficients of the variables are all significant at the 0.10 level, or better, with the exception of the AGE variable in the labor model; this variable was significant at the 0.12 level.

Speed was the most significant variable in each model. Both labor hours and roadcalls decrease as speed increases. This variable captures, to some extent, the effects of congestion levels and stop-and-go driving conditions on maintenance.

The direct relationship between fleet size and roadcalls and labor requirements may be due to the more severe operating environment found in large systems, but it is also possible that the effect identified represents diseconomies of scale; this interpretation is supported by the finding that speed and system size are not strongly correlated.

Roadcalls are directly related to labor-hour requirements, but it was not possible to produce a significant coefficient for labor in the roadcall model. This can be interpreted as an indication that labor effort, unless properly directed, may not be effective in increasing vehicle reliability. The ratio of revenue vehicles to peak vehicles was significant in the labor-hours model, indicating that higher spare ratios permit more productive use of maintenance labor. Finally, fleet age was found to be positively associated with labor requirements.

The models just presented give some indication of the effect of local factors on maintenance costs and performance, but they cannot be recommended as a way of setting standards or evaluating performance because of their low r^2 values. They should be thought of as a description of existing conditions, and their low r^2 values should be recognized as an indication of the large amount of residual variation left after standard system descriptors have been accounted for. They should not be thought of as production-possibility frontiers or minimum-cost functions.

The regression equations are nevertheless useful as a starting point for identification of systems that exceed or fall below common levels of maintenance performance. Figure 1 shows how the models were used to select case systems for intensive study. The observed labor input to the maintenance and roadcall record and the values expected on the basis of regression analyses are shown as vectors. The tails of the vectors are the values expected on the basis of the regression models, and the heads indicate observed values. The length of the vectors represents the difference between the expected and observed values. The specification of the regression models allows the interpretation of the location of the tails of the vectors as the result of service profile severity and diseconomies of scale (for roadcalls) as well as fleet age, in-service breakdowns, and spares (for labor hours). The direction in which each vector points indicates how much better (or worse) than expected each system performs. Short residual vectors indicate little variation from the expected pattern, whereas longer vectors are a sign of significant departures from expected performance. Vectors pointing upward indicate that the system has a higher-than-expected roadcall record; vectors pointing to the right indicate that the system has greater-than-expected labor requirements.

The pattern of residuals shown in Figure 1 is that of the eight systems (A-H) selected for intensive on-site analysis. The configuration of the residual vectors raises questions about why five of the systems differ along the dimension of a low ratio of roadcalls to labor versus a high ratio of roadcalls to labor and why two of the systems appear to have higher-than-expected labor requirements and lower-than-expected roadcall records.

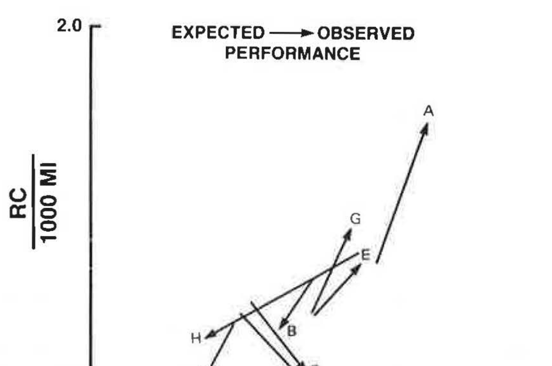

FIGURE 1 Residual variation to be explained in case analysis.

CASE COMPARISON RESULTS

Analysis of the eight case studies identified a number of practices that have a positive influence on maintenance; it also uncovered a number of problem areas. Table 1 summarizes the major factors identified in the field-work phase of the research and indexes these practices and problems to the positions of the residual vectors (A-H) in Figure 1. Footnoted items were not in place in 1981, the year the data used in these regression analyses were collected. These results are summarized in the following discussion.

Management Issues

Few of the systems visited showed any strain in the relationships between managing directors and maintenance managers. Some of the systems depended on formal, regularly scheduled meetings, and others depended on frequent informal discussions. System A reported a long history of management transitions that had interfered with communications and, in fact, had led to a serious failure of the system's inventory control system. In this system, as well as in others, steps had been taken to improve this situation. The approaches identified included formal management-by-objectives systems as well as highly interactive team-management approaches.

In every system visited it was indicated that the goals of minimizing costs and maximizing in-service reliability were endorsed. Some of the systems had written policies and rules for setting maintenance priorities, whereas others said that they relied on tradition and informal understandings. In many systems preventive maintenance (PM) schedules were the only written policy documents in existence. The existence or lack of written understandings about maintenance priorities does not have a simple relationship to system performance. Both the best and the worst systems (in terms of Figure 1) had little in the way of documentation of maintenance priorities. The important factor appears to be whether policies (written or unwritten) are known to all levels of management and whether management periodically reviews and revises these policies in response to local conditions. Systems reporting that they informally or formally review maintenance priorities on a regular basis consistently had fewer roadcalls than those systems with no tradition of self-evaluation and policy review. Those systems with the tradition of setting reasonable performance goals and tracking actual performance were generally among the better performers than systems with little maintenance accountability.

This review of preventive maintenance practices generated interesting results regarding the philosophy of preventive maintenance. Previous research (6) has indicated that there is extensive literature on mileage-based maintenance and unit exchange. Much less attention has been given to the practice of maintenance by monitoring, except for the work of Etschmaier (3), who has argued that resources can most effectively be utilized by monitoring vehicle condition instead of focusing on intensive mileage-based inspection and replacement. The field data collected did not show a strong relationship between

TABLE 1 Summary of Case Analysis

System	Positive Factors Influencing Maintenance	Problem Sources
A	New management system (MBO)[a] Performance targeting[a] Mechanic training program Testing program Refresher courses	Understaffing due to hiring freeze and loss to other firms History of transitions and reorganization No driver inspections Inventory management Adversarial labor relations Low salary levels Diverse fleet Climate and air conditioning High load factor High overtime utilization Lift orientation in garages Relationship to county
B	Stable management Good, informal management process Performance trend analysis Oil analysis[a] Dynamometer Prerun inspections Good worker input to management Mechanic training program[a] Testing for hiring and promotion Relatively uniform fleet	Lack of written procedure Older fleet Old garage and shop built for streetcars
C	Stable, experienced management Written rules and procedures Performance trend analysis Prerun and postrun inspections In-house shop capabilities Vigorous use of probationary period Uniform fleet Air conditioner retrofit program Low load factor Extensive in-house shop facilities	Climate and air conditioning
D	Weekly management staff meetings Performance trend analysis Prerun and postrun inspections Worker suggestions implemented Uniform fleet Positive management-staff relations Budget security New garage	Staff position shortages Cold weather and outdoor storage Lift capacity for RTS Transmission failures
E	Management by objective system[a] Performance trend analysis and targeting[a] High salary levels Apprenticeship program[a] Transmission ratio modifications	Poor enforcement of prerun and postrun inspections Undifferentiated bi-monthly maintenance program Old (14.5 yr avg) fleet Terrain Inadequate garage
F	Team management system Performance trend monitoring and targeting Supportive board Prerun and postrun inspections New computer record system[a] Frequent labor-management meetings Apprenticeship program[a] State-of-the-art garage[a]	Old system of eight garages (recently replaced)
G	Uniform fleet New garage (planned)[a]	No trend reporting No prerun inspections Adversarial union relationship Low wage structure Low number of mechanics and high overtime No formal testing City snow removal Inadequate inventory and garage space Budget not secure
H	Performance targeting and trend analysis Prerun inspections Frequent supervisor-mechanic meetings High wage rates Testing for hiring and promotion Apprenticeship program[a] Newer, uniform fleet Good union relations	Management style conflicts Inadequate city snow removal 100-yr-old garage Inadequate shop tools Inadequate inventory space High load factor

Note: RTS = advanced-design bus produced by General Motors Corporation.

[a]Innovations or changes occurring since 1981.

PM intervals and performance, but they graphically indicated that there is a strong correlation between the conduct of prerun and postrun inspections and performance. This finding held for each of the eight case systems. Those that conducted prerun inspections consistently had fewer roadcalls than expected, and those with no prerun checks consistently had more than expected. San Antonio, one of the case study systems, provides a good example of such procedures. Its prerun inspection requires the signature of the driver and, if a defect is reported, that of a maintenance employee. This method of involving both transportation and maintenance establishes accountability for in-service failures. It also prevents roadcalls from drivers who want a replacement vehicle just because of minor problems. (Two of the "poorer" systems visited were in the process of implementing prerun procedures.)

The preceding discussion should not be interpreted as an indication that PM inspections are unnecessary.

TABLE 2 Recruitment Practices

System	Case Study Results
A	Union claims starting salaries too low; superintendent of budget and administration claims testing too stringent; apprenticeship program successfully attracting applicants
B	Normal progression from driver to cleaner to mechanic; some problems in recuitment; apprenticeship program established
C	No problems reported; management selective in hiring (only skilled mechanics considered); many mechanics let go during probation period
D	Normal progression from driver to cleaner to mechanic, but not enough staff being recruited; new contract may change this provision
E	Maintenance manager and personnel officer believe applicants qualified; apprenticeship program being developed
F	Emphasis changed from on-the-job training of unskilled workers to apprenticeship effort drawing on local vocational education program
G	System needs mechanics with better skills in air conditioning and electrical systems
H	No problems cited in hiring qualified mechanics; apprenticeship program developed

Some of the systems had simple bimonthly inspections with no differentiation between major and minor servicing (e.g., System E), and others had elaborate three- and four-level PM programs. The differences between more elaborate programs were not evident, but simple bimonthly programs do not appear to be adequate.

Labor Issues

Several of the case study systems reported adversarial labor-management relationships, and grievance statistics showed this to be the case. However, the relationship between performance and grievance counts was not strong. What was more important as a correlate of performance is the existence and use of formal or informal channels of communication between maintenance workers and management. Productive informal meetings were cited as the norm in the low-roadcall systems, whereas those systems that had roadcall counts above expected levels emphasized only formal channels of communication and gave little indication that these channels were being used effectively.

A number of differences were found in wage rates and mechanic recruitment practices. Differences in recruitment are shown in Table 2. Systems B and D are the only ones that use a progression from driver to cleaner to mechanic, and both of these systems reported that this mechanism was not meeting their labor needs. System C is unique because it hires only skilled mechanics and is selective in retention of employees through the probationary period. The salary levels in Table 3 (15-18) show a wide range of relative and absolute variation. System C, for example, increases mechanics' wages by 44 percent as they move from entry to senior positions, whereas System G shows a 6 percent increment. Evaluation of these wage structures is difficult. Initial comparisons with regional wage levels show that wage rates are not closely tied to local conditions, and some systems are found to be paying senior mechanics much less than the wage rates in other industries. Some attrition was found in systems paying rather high wage rates because of competition from the aircraft and trucking industries for mechanics. The general relationship between performance and compensation indicates that higher mechanics' salaries are related to better performance, except in cities where there is intense competition for mechanics. This suggests a need to find ways of retaining mechanics in these more competitive labor markets.

TABLE 3 Salary Levels *(15-18)*

System	Wage ($/hr) Entry Level	Top Level (nonsupervisory)	Percent Increment
A	8.46[a]	9.75[a]	25
B	9.95[b]	12.48[a]	25
C	6.50[a]	9.40[a]	44
D	9.52[a]	11.20[a]	17
E	9.25[b]	13.00[a]	40
F	7.27[b]	9.52[a]	30
G	9.24[b]	9.88[b]	6
H	11.11[a]	12.27[a]	10

Note: Wages for maintenance workers from APTA *(15-17)*. Average wages from Bureau of Labor Statistics *(18)*.

[a]Wage rate for maintenance worker is greater than the average wage rate for production workers in manufacturing for the region.

[b]Maintenance worker's wage rate is less than the average.

Testing and training are growing concerns for many transit systems. Most have some sort of testing program for use in screening applicants, but few reported vigorous use of tests in promotion and none reported the use of periodic tests to verify abilities of current staff members. A number of different approaches to training were identified, including the establishment of formal apprenticeship programs, use of community colleges, and provision of optional refresher courses for mechanics.

Fleet Composition and Local Environmental Conditions

Vehicle age and fleet mix were obvious contributors to differences in system performance. System H had the newest and most uniform fleet in 1981; all the vehicles were from General Motors. Since then, a number of other vehicle types have been added. This has increased the complexity of the inventory significantly and created problems in procurement. Many of the parts in the inventory are double stocked under different identification codes. At other systems, fleet factors were linked to performance differences. For example, System A had the most diverse fleet in this sample, which resulted in an inventory of over 9,800 items and space and inventory control problems. On the other hand, System C, with a much more uniform fleet, had no space problems and a time-tested manual inventory control system.

Not surprisingly, all of the case study systems reported that fleet age and climate were a major influence on maintenance. Systems B and E both cited fleet age as a major cause of maintenance problems, and because their fleets were more than 12 years old, this appears reasonable. However, Systems G and F also reported age-related problems, but their fleets were 9.2 years old, which is near the mean for this sample of systems. Systems A and C reported problems with heat and humidity as did Systems D and H. Surprisingly, not all of these systems had investigated the possibility of installing air conditioner retrofits. Some of the systems appeared to have been quite aggressive in adapting their equipment to local conditions, whereas others had not. System A, for example, was experimenting with air starters, and System E had modified transmission gear ratios to increase power on hills.

Budget

Each of the eight systems studied reported line-item incremental budgeting for maintenance. Unit cost data, it was found, were either nonexistent or not complete enough for use in budgeting. The most aggressive budgeting program had been instituted in System A; this was a long-range budgeting system that would include both annual budgets and long-range capital programming for vehicle acquisition and maintenance facility planning.

Staff perceptions of their budget were not simply related to the amounts of money allocated to maintenance. Table 4 shows budget data for the eight systems. Cost per mile is strongly affected by wage rates because labor and fringe benefits make up about 60 percent of maintenance costs, and so comparisons must be made carefully. System C was notable as having the lowest cost per mile of all the systems in the sample. However, it was only the fifth lowest in terms of the percentage of the operating budget that it allocated to maintenance. This is in part because of low regional wage rates. System G has the second highest cost per mile in the sample. This is remarkable because its management cited staff reductions as a major problem. The relationship between understaffing and costs can be explained by high overtime, which was estimated to have been an average of 20 hr per week in 1981.

TABLE 4 Maintenance Budget *(5)*

System	Maintenance as Percentage of Operating Budget	Maintenance Cost per Revenue Mile (cents/mile)
A	26.2 (8)	60.6 (8)
B	18.0 (2)	40.2 (3)
C	20.0 (5)	31.6 (1)
D	21.1 (6)	32.3 (2)
E	17.7 (1)	49.0 (6)
F	18.7 (4)	44.2 (4)
G	24.1 (7)	58.8 (7)
H	18.3 (3)	45.2 (5)
Median for 111 systems	18.7	40.0

Note: Rank is given in parentheses, 1 being the lowest.

Systems A and G stand in contrast to Systems C and D because of their location on the dimension of a low ratio of roadcalls to cost versus a high ratio of roadcalls to cost in Figure 1. This contrast suggests, and the studies confirmed, that maintenance budgets per se are not the key to improving reliability; this is also evident from the regression models discussed in the previous section. The key difference between these systems appears to be management.

Maintenance Equipment and Facilities

Only a few systems reported major equipment problems. System H noted a need to replace drill presses, lathes, and chain hoists and System B had experienced problems with metric tools, but both planned to remedy these situations in the near future. A larger number of systems reported problems accommodating new vehicles because of size. These had resulted in the need to rely on blocks and portable lifts and, in some cases, to restrict purchases of new vehicles to those that could be handled with current facilities.

Old and inadequate facilities were a special problem in Systems G, H, and E. System G had only two lifts and one pit, and the space problems were so severe that scattered, on-floor storage had to be used for major components, including engines and transmissions. The garage at System H, which was over 100 years old, had layout problems that made supervision difficult and inventory access time-consuming. At System E, the garage was not extremely old, but there was not enough space to handle the current fleet and the lifts could not accommodate the system's newer, larger buses.

A number of new facilities had deficiencies in layout, including lack of space for newer vehicles and test equipment. Many of the systems reported that new garages had failed to reduce roadcall rates as had been hoped but did have a positive effect because there was less absenteeism and better worker morale.

Facility age is not always related to performance. System C showed an excellent performance record despite its 36-year-old garage, and System F reported an excellent reliability record in spite of having eight separate garages for its small (200-vehicle) fleet in 1981 when the initial data were collected. It did expect to gain labor efficiency from a recently completed garage that now houses its entire fleet. Systems D and B also turned in good performance records in spite of older (and now vacated) facilities. Systems H, E, and G, however, were clearly handicapped by their garage problems.

DISCUSSION

A number of practices that have a positive impact on maintenance were identified in this research; a number of problem sources were also documented.

The results regarding day-to-day operations and PM programs are similar to those of previous studies (19-21), which found that the major emphasis was on inspections, adjustments, lubrication, and breakdown maintenance, with less emphasis on cost analysis, use of failure data, and unit exchange planning. These results confirm those of previous studies regarding vehicle design problems, space, budget, and staff levels. They also verify that unit cost and component life statistics are generally not used in planning maintenance programs because the raw data for developing these figures are not available in many systems and, where available, are in forms that are inconvenient to use.

These findings show that prerun inspections are not always carried out by many systems. But more important, it was found that the lack of prerun inspections is highly correlated with vehicle reliability problems because these inspection procedures prevent driver use of roadcalls to obtain bus changes for minor problems and because of the importance of driver inspections in monitoring vehicle condition.

A major difference between these findings and those of earlier studies is that several of the systems in this study had established maintenance performance indicators, tracking systems, and (in some cases) performance targets. Other notable findings were the establishment of formal training programs and testing mechanisms and increased integration of maintenance into budgeting and management decision making. These findings indicate that many of the elements of a strategic planning approach to maintenance (22) are developing. The systems studied illustrate some of the critical elements of this approach to maintenance management.

The need to establish clear, quantifiable goals was indicated by the systems studied. These goals can be stated in terms of locally defined measures of reliability (roadcall definitions still vary greatly from system to system). Goals can also be stated in terms of targeted percentage reductions in roadcalls, budget requirements, and labor intensity. Both cost and reliability goals should be established because there is an implicit, undefined trade-off between reliability and cost involved in maintenance budget decisions. This trade-off should be made explicit in the development of goals and performance targets. A performance tracking and evaluation element should also be part of maintenance management. Tracking systems provide management with a tool for measuring progress toward achievement of stated goals and also motivate employees. Analysis of performance and comparison with stated goals should serve as the core of a yearly assessment of effectiveness.

A need for the development of a maintenance planning cycle was indicated by this study. The following information should be generated in this process:

1. A summary of current fleet composition, a list of expected fleet changes, and a description of anticipated impacts of these changes on staff, facility, and equipment needs;
2. A brief overview of current facilities and shop equipment, a description of deficiencies, and a list of anticipated needs resulting from fleet changes;
3. A list of currently budgeted maintenance staff positions, a review of needs for additional positions and an analysis of reasons for unfilled positions, and a description of the staffing impacts of anticipated fleet changes;
4. A summary of recruitment and training, focusing on reviews of the effectiveness of testing procedures used in hiring and promotion, the adequacy of training given to mechanics responsible for new equipment, and hiring strategies (including experience requirements, wage scales relative to other industries, and alternative training approaches);
5. A summary of the PM program used in the previous year, a list of problems encountered in compliance with this program, and a description of anticipated changes in the PM program;
6. A description of prerun inspection procedures, an assessment of driver compliance and maintenance follow-up, and a statement of changes needed to ensure compliance;
7. A summary of any problems encountered with the inventory system and an analysis of changes needed to accommodate new vehicles, special campaigns, or retrofit programs;
8. An analysis of roadcalls and missed trips to identify causes, directions of trends, and possible remedial actions, as well as an assessment of the effectiveness of strategies adopted as a result of problems encountered in previous years;
9. A comparison of budgeted and actual expenses, an analysis of the reasons for variances, an analysis of the impact of anticipated fleet changes on maintenance budgets, and a projection of next year's budget; and
10. A review of written (or unwritten) policies and procedures, a statement of proposed changes, and an evaluation of the effects of changes made over the past year.

Although this list may seem imposing, this study suggests that systems that engage in this sort of periodic review are likely to have positive performance records.

Several research and technical support needs were suggested by the site visits:

1. There was strong sentiment that a cross-listing of interchangeable parts would reduce inventory space and control problems; this list could take the form of a periodically updated paper list or a computerized cross-reference program;
2. Inventory clerks and managers cited a need for a flexible computerized inventory control system that could accommodate fleet mix changes and automatically cross-reference interchangeable parts; and
3. Technical support for computerization of management information systems was also noted; several sites reported unsuccessful attempts at computerization, and others noted that their staffs need to be educated about the capabilities of computer systems.

Fruitful areas for future research were also suggested by the site visits. The first topic, which has the highest potential immediate payoff, is prerun and postrun inspection procedures. Establishment and enforcement of these procedures were perfectly correlated with the roadcall experience of the systems studied. A study to identify potential barriers to driver involvement in inspections and develop a strategy for introducing this concept in systems that do not currently require inspections is needed.

A second area for research is maintenance inspection and maintenance policy. There were no strong indications that PM intervals were related to performance in the systems studied. It was also found that unit cost and reliability data are not often collected and that the quality of PM work is often suspect. There is therefore little basis in these systems to decide on the appropriate mix of inspections, monitoring, and unit exchange in maintenance. A careful comparison of these methods in an environment that would provide for a fair test of the costs and effectiveness of these maintenance strategies is needed. This environment should include unit-costing and failure-tracking capabilities as well as quality controls on mechanic and driver compliance with inspection and servicing schedules.

A third topic is that of manpower planning. The findings regarding training, testing, and salary levels indicate that practices in these areas are changing, but there is little consistency in the pattern observed. Because of the diversity of approaches taken to recruitment and training and the lack of evaluation mechanisms at the local level, research in this area is especially needed. A related topic is worker-manager communication. The systems studied showed a number of instances in which worker input was useful in developing and evaluating maintenance procedures and a number of rather unproductive, adversarial situations. Ways of improving communication should be identified.

A final research topic is the refinement of maintenance performance models. The regression models used in the site selection procedures had relatively low predictive ability, and these case studies identified a number of factors that should be tested in a formal modeling effort. This would include quantification of climatological variables and prerun inspection procedures, and it might also involve analysis of staffing levels and policies on utilization of old and new vehicles. A time-series analysis of the effects of PM intervals on reliability could also be conducted. These efforts would be useful for future attempts to define the range of resource requirements and performance that can be expected under changing maintenance conditions.

CONCLUSIONS

The experiences of the eight systems reviewed in this study provide ample support for the argument that every system has unique features, which makes it difficult to conduct cross-system comparisons. However, a number of practices have been identified that are typical of successful maintenance operations and that logically should contribute to positive performance gains. These practices are

1. Conduct of prerun and postrun inspections by drivers;
2. Establishment of performance targets, development of performance measures, and periodic performance trend analysis;
3. Development of written statements of (or informal consensus about) maintenance policies and procedures;
4. Coordination of vehicle procurement decisions with inventory planning and staff development activities;
5. Establishment of strategies for recruiting, testing, training, and retraining skilled staff;
6. Establishment of cooperative working relationships between workers and managers;
7. Avoidance of unmanageably diverse fleets; and
8. Periodic performance assessment and evaluation of alternative strategies for improving maintenance effectiveness.

The case studies also led to the definition of a number of research questions. These indicated the need for analysis of the role of drivers in vehicle condition monitoring, evaluation of alternative maintenance policies and PM intervals, and analysis of recruitment, training, and compensation issues.

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