Systems Approach to Transit Bus Maintenance

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ABSTRACT

A review of transit bus maintenance shows that, as widely suspected, there are serious problems. Solutions to parts of the problem have not succeeded in improving the overall situation. Instead, a total system approach is advocated. Elements of such an approach are outlined.

A number of recent studies have pointed out that significant problems exist in maintenance of transit buses. Figure 1, reproduced from Malec (1), shows that between 1973 and 1982 maintenance costs for buses in transit service increased fivefold, from around $0.20 per mile to close to $1.00, an average annual rate of increase of 20 percent. At the same time, the miles that a bus operated between road calls decreased from more than 5,000 to a mere 2,000. Although the decrease in miles between road calls may have leveled off recently, indications are that the cost increase continues.

The Committee on Public Works and Transportation of the U.S. House of Representatives, as quoted in a report by the General Accounting Office (2), finds a tendency among transit companies to defer maintenance work in order to defer cost. Because the consequences of deferred or not-performed maintenance often are not evident until much later, the report states that "the chickens usually come home to roost at some later date, when a new cast of characters may be in place."

The report by the General Accounting Office cites numerous specific incidents of transit companies not following their own maintenance programs, performing inspections called for in these programs either late or not at all. In contrast with this situation is a public sentiment of increasing impatience with inefficiency or ineffectiveness of any form of public service. The public refuses to go along with ever-increasing fares and demands a reduction in the subsidy payments for transit. Transit companies thus find themselves in a squeeze: continuously increasing cost versus resources that are steady at best and declining in some instances. Clearly some change is necessary.

The General Accounting Office report recommends a federal policy for transit bus maintenance. They recognize that there are significant differences among transit companies throughout the country. The policy they call for, therefore, is to be flexible and to leave room for the individuality of each transit company. This conclusion points in the same direction as the work that has been going on for more than 2 years under the sponsorship of the Planning and Methods Division of UMTA at the Transportation Systems Center.

The work at the Transportation Systems Center has led to the formulation of a dynamic approach to management of maintenance (3). The central idea of this

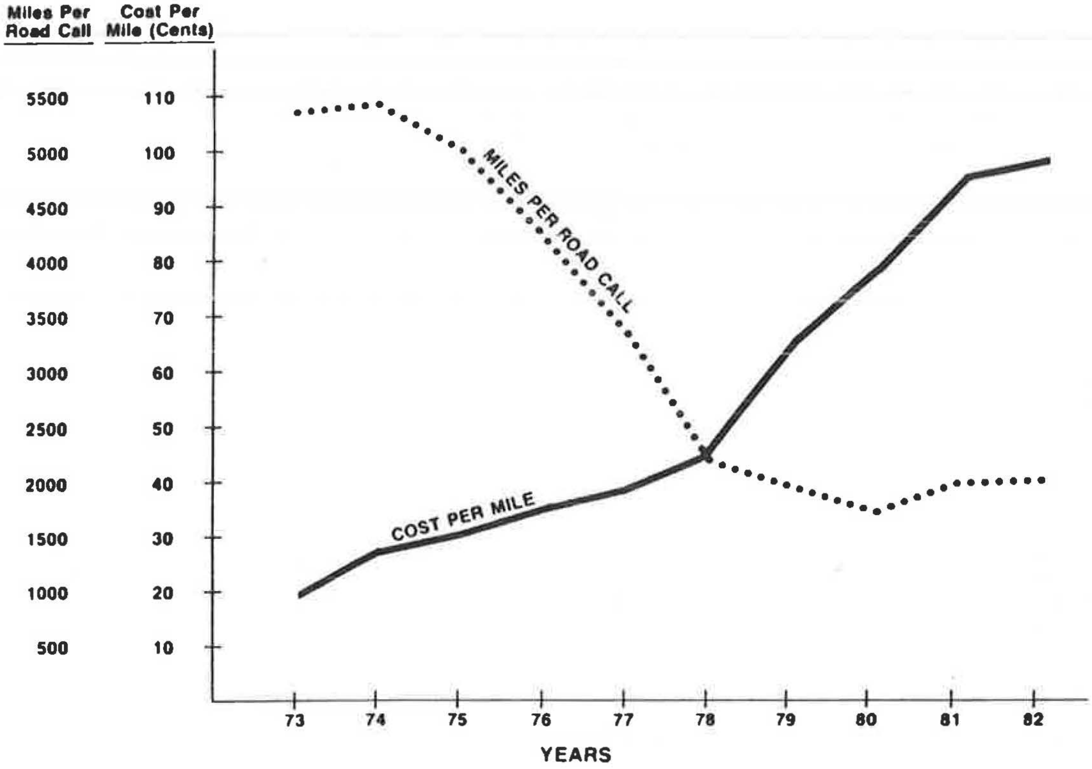


FIGURE 1 Cost and performance of transit bus maintenance, taken from Malec (1).

approach is that the deterioration of operating equipment is by its very nature random. Maintenance, if it is to be efficient, therefore has to be structured in a flexible manner so that it can respond to any randomly arising need for work. The best design of a maintenance system is based on an intimate understanding of the design and operating environment of the equipment. Also, it takes into account the resources available and applies these resources to most effectively meet the maintenance needs. The best understanding of resources and equipment resides within each transit company itself. A dynamic maintenance system will therefore have to evolve from within each transit company. The methodology formulated at the Transportation Systems Center is intended to support this evolution.

Efforts at improving the situation in transit maintenance have been under way for a long time. Much good work has been done, but most of it has been focused on isolated parts of the entire problem. To the extent that a systems concept behind these efforts can be identified, that concept appears to be improvement of the hardware design of a bus and its components, or automation of maintenance to reduce the reliance on humans in the performance of maintenance.

The purpose of improving the hardware is to reduce the frequency of failures and the amount of maintenance work required. The introduction of air starters and the tests of alternate brake linings are examples of these efforts. At the bus level, the introduction of life-cycle costing is motivated by the desire to force consideration of maintenance expenses into the procurement process.

Automating maintenance is an attempt to get around the sometimes difficult labor situation. Some transit companies appear to be limited in the qualification standards they can demand of mechanics, others have to deal with highly restrictive work rules. The Automatic Bus Diagnostic System tested in New York City (4) is an example of such an effort.

Both types of efforts may have led to improvements in the areas they were directed at. However, implementation of solutions often proved expensive. Above all, as the figures quoted previously show, no significant improvement either in cost or in performance has materialized. The conclusion of the work at the Transportation Systems Center is that significant improvements in overall performance can be expected only if these efforts are part of an overall systems approach.

The dynamic approach to maintenance is the result of efforts to provide a guide for the use of the systems approach in transit bus maintenance. In the following sections a brief overview of the most important features of this approach will be given, and some of the potential for improvement of the situation that might be expected to result from its implementation in transit bus maintenance will be pointed out.

A SYSTEM VIEW OF MAINTENANCE

The role of maintenance in a transit company is to provide the vehicles required for the performance of the planned operations at the time when these vehicles are needed and to assure that the vehicles are, and will continue to be throughout the duration of their assigned mission, in safe operating condition. Maintenance, thus, has no purpose in itself; it exists only as a support function. However, the service that a transit system can offer is determined by the characteristics and capabilities of maintenance, as it is by the characteristics and capabilities of other parts of the system. A view of a typical transit system is shown in Figure 2. The three major functional elements, marketing, operations, and maintenance, are all interdependent and share coequally in the responsibility for the support of the entire system.

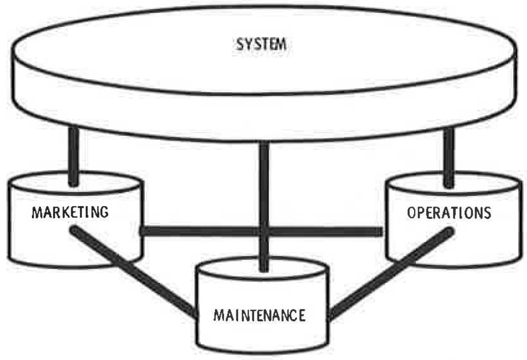


FIGURE 2 Typical transit system.

One review of transit maintenance (5) shows that, contrary to this view, maintenance is frequently isolated from the rest of the company. Top management often does not understand maintenance and "too often . . . [maintenance] is viewed as an operating function which mysteriously works by itself" (6). Although there are increasing numbers of attempts to hold maintenance accountable and to measure its performance through management information systems, there is little evidence of attempts to understand the role and special needs of maintenance. Maintenance personnel typically are not listened to but talked down to. Their jobs are considered dead ends on a career path and few of them ever make it into top management ranks. If they do, it is often by moving to another career path. The situation of maintenance in transit is by no means unique. It appears that, with the exception of some industries with very high technology and with obvious safety implications of bad maintenance, a lack of understanding of maintenance is commonplace. Characteristically, the word maintenance is frequently used as a euphemism for janitorial service.

A systems analysis of maintenance has to be preceded by an analysis of the entire transit system and the definition of a consistent set of objectives. This will lead to a definition of objectives, role, and mission of maintenance within the total system. Critical in this definition is the identification of interests that overlap those of other functional areas.

Examples of interests that overlap those of the operations function include the following areas:

- Assembly of bus runs. Maintenance is interested in the starting and finishing times of each run, as well as the slack times within runs. Run starting and finishing times determine the work-load profile for maintenance. Duration and geographic location, relative to maintenance facilities, of slack times determine whether or not problems encountered during the day can be corrected without disruption of service.
- The total number of buses in service during the course of the day and the number and positioning of standby buses and drivers within the system.
- Definition of response strategies to in-service difficulties.
- Design of communications and other interfaces

between bus operators, dispatchers, and maintenance. Examples of this are debriefing of drivers, bus starting and servicing, and assignment of individual buses to runs.

Examples of overlapping concern with marketing are the appearance of the buses as well as the design, selection, and mode of operation of systems for passenger convenience and comfort such as seats and air conditioning.

After all areas of overlapping concern with all parts of the property have been delineated and responsibilities for them resolved, it is possible to arrive at an overall statement of responsibilities for the maintenance function. (It should be understood that the process described here in a linear fashion in reality is an interactive one, requiring many iterations before all conflicts are resolved.) A definition of responsibilities for the maintenance function includes the following areas:

- Evaluation and participation in selection of new equipment (buses, bus configurations, tools and support equipment, and so forth).
- Selection, training, and promotion of personnel.
- Maintenance of an inventory of spare parts.
- Definition of components and subsystems that are to be treated as repairables. For each of these components, determination of optimal float levels and control of the cycle (i.e., assurance of an adequate level of components in serviceable condition).
- Evaluation of proposed future bus operations schedules.

DETERMINISTIC VERSUS DYNAMIC APPROACHES TO MAINTENANCE

A review of maintenance practices in transit companies shows a strong tendency to make maintenance predictable, deterministic. If a manager of maintenance could plan work a long time into the future, there would be no surprises and no crises. The task of maintenance management would become much easier and much of the well-developed methodology of production management could readily be applied.

Unfortunately, maintenance is by its very nature random and any effort to make it deterministic is bound to be expensive. The alternative to the deterministic approach is a maintenance system that is capable of dynamically responding to ever-changing situations. In this section these two approaches will be contrasted.

As far as component repair, replacement, and reconditioning are concerned, the deterministic approach strives to have all work performed at predetermined times. Components are thus removed on the basis of time or accumulated operating time or mileage. The amount of work to be done on a component after removal is fixed and known in advance. A constant shop load is achieved by controlling the input into the shop. Initially, this may require removing some components earlier than necessary. But when a uniform distribution of the age of active components has once been established, a smooth shop load is assured without further planning or corrective measures. The process may be viewed as an open-loop control system.

In contrast, the dynamic approach whenever possible only calls for work to be done in response to actual needs (i.e., when the condition of the equipment requires it). Instead of completely reconditioning a component after each removal, only the work that is necessary is performed. The resulting random work load is controlled by assuring a mix of work loads with various degrees of urgency in each shop. A properly sized and managed float of spare components will accomplish this. Also, for the most expensive and significant components the occurrence of a removal may be forecast in the short run. This is the case when the condition of the component indicates that it will soon deteriorate to a state in which the occurrence of an undesirable situation (such as an expensive failure) will be likely. Depending on the availability of serviceable spares for that component, it might be removed soon after the condition is recognized, or the removal might be delayed for some time. In terms of control theory, the control of the shop work load may be viewed as a closed-loop control system with feedback and feed forward.

Part of the deterministic approach is the idea that over the life of a component an optimal point can be determined at which the component should be removed for reconditioning or discard. This point is determined by balancing the cost of an expected in-service failure against the cost of a preventive replacement. The analysis required is part of the standard repertoire of classical reliability theory. Implicit in this approach is the acceptance of in-service failures as a fact of life, and the assumption that it is permissible to determine the "best" rate of such failures on the basis of economic considerations. To reduce the rate of in-service failures the replacement age may be reduced or the reliability of the component (i.e., decrease the failure rate during the early part of the life) may be increased. Both alternatives may be costly; the second one is frequently referred to as gold-plating.

Underlying the approach that replaces a component on the basis of age are two important assumptions that often go unnoticed:

- The lives of components at failure are assumed to be identically distributed, independent random variables and
- The age of the component is the only information available to warn about increasing likelihood of a failure.

Neither of these conditions is true in most practical situations. Over the life cycle of a system the age at failure of components may undergo significant changes as the design evolves and maintenance practices and operating conditions are modified. Also, for most components, much better indicators of increasing wear than the age of the component are available. Many of these involve nothing more than observing the performance of the component during operations. Others may involve simple measurements or possible nondestructive testing methods. Thus the life of an individual component is differentiated from the universe of lives of like components. Although a probability density function of the life of the component at failure cannot be provided, the point at which the probability of a failure starts to increase can be identified. Thus any individual component may be replaced when its individual probability of failure dictates replacement. The results, clearly, are an increase in the average age at removal for all components and a decrease, or possible elimination, of the probability of an in-service failure. Provided that identifying the point of increasing probability of a failure is not too expensive, this approach clearly dominates the policy of replacement on the basis of age.

An additional difficulty associated with the deterministic approach is that it is based on statistics of past behavior of a component. By the time sufficient statistical information becomes available, a component may be well into the middle of its life cycle. Thus, unless prohibitively expensive testing precedes the introduction of a system to service, the deterministic approach may not be practical at all in real transit systems.

The point of departure for the dynamic approach is considerably different from that of the deterministic approach. Instead of searching for an optimal point in a parameter space, given a fixed policy (i.e., replacement on the basis of age), it concentrates the search in the policy space. The subsequent optimization of parameters for a selected policy usually turns out to be rather simple and is often dictated by circumstances. In many cases, economic results as well as other performance measures are little changed as long as the parameters are selected within reason.

Maintenance programs in the dynamic approach are developed through logical analysis, following the branches of a precisely defined decision tree. The first part of the decision tree is devoted to analyzing the consequences of a failure and to determining whether the occurrence of the failure can be detected by the operator. After that, possible maintenance tasks are explored, starting with condition monitoring, and age replacement is considered only as a method of last resort.

The decision tree approach was first developed by airlines (7) where it is known by the acronym MSG. The armed services have also widely embraced this approach. It is known there as reliability centered maintenance (RCM).

Although the basic structure of the decision tree is always the same, the details of it have to be carefully adjusted to the type of system under review. Figure 3 shows an adaptation for an analysis of transit buses.

One of the objectives of the dynamic approach is to eliminate life threatening failures altogether, at least as far as that is possible by the design of

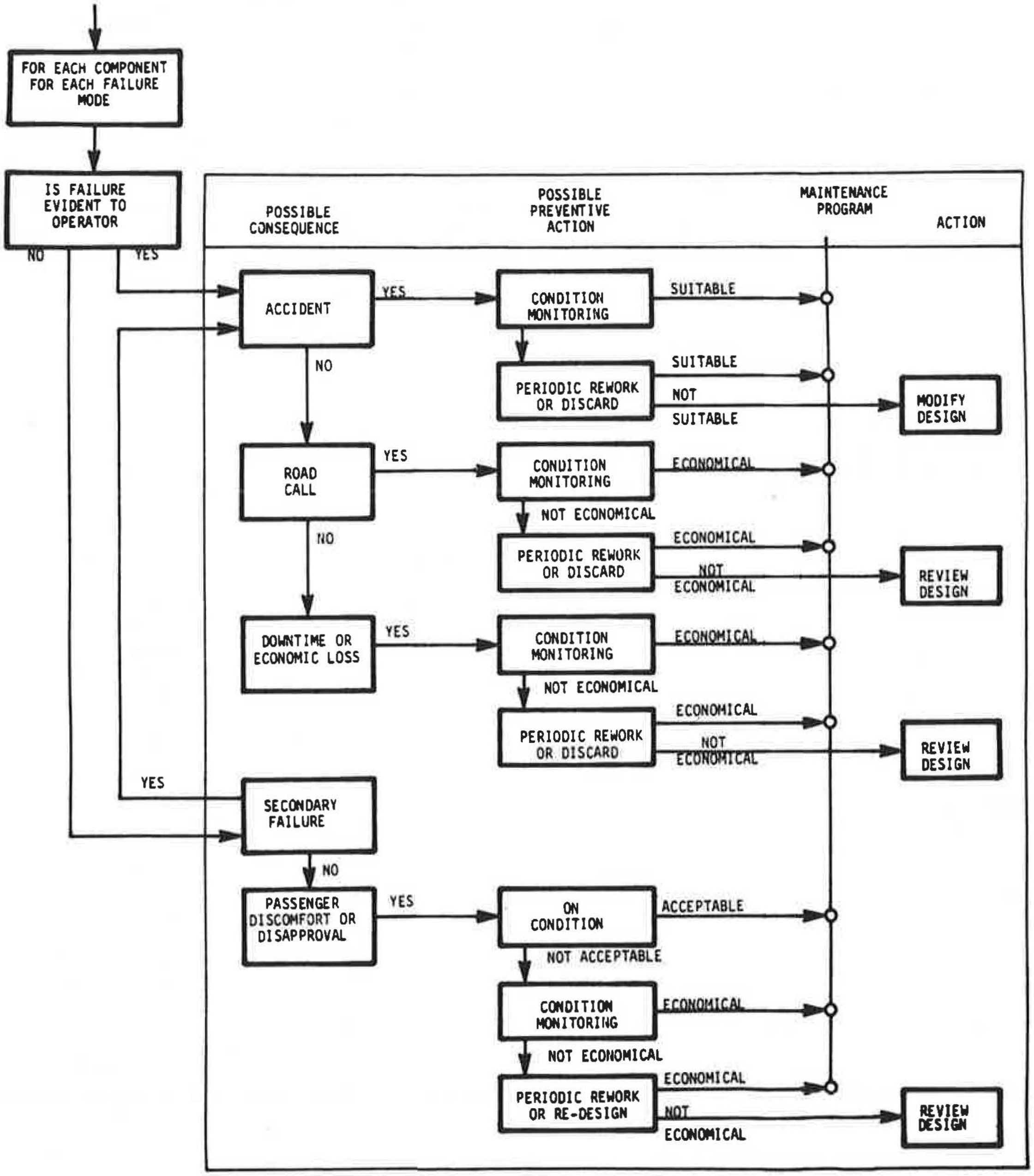


FIGURE 3 Decision tree for analyzing transit bus components.

the system. When it is not possible to achieve a satisfactory level of safety through maintenance measures, the analysis points out that a modification of the system is required to meet the objective. This analysis, together with the type of information that becomes available through an organized condition monitoring process, provides momentum for ongoing product improvement.

It is often assumed that condition monitoring requires complicated and expensive instrumentation either in the shop or on board the vehicle. However, much condition monitoring can be done by the operator or by servicing personnel during their normal contact with the vehicle. As an example, in airlines almost 50 percent of all corrective maintenance work is triggered by crew reports. The need for the other 50 percent is identified by mechanics during scheduled inspections (8). Experience with extensive onboard instrumentation has generally been disappointing. Apart from the fact that it often generates more information than can be processed effectively, the instrumentation and associated wiring may require expensive maintenance. Failures of them may lead to unreliable signals that may cause unnecessary maintenance to be performed. For examples of on-board instrumentation see Birkler and Nelson (9) who deal with turbine engines for military aircraft, and Casey (4) who describes an experiment for transit buses. In general, the most successful on-board diagnostic systems use signals that are already available for purposes of control. In transit buses, the electronic control units for engines and transmissions appear to have a strong potential for such use.

DESIGN OF A DYNAMIC MAINTENANCE SYSTEM

Many of the elements of the dynamic approach to maintenance can be implemented strictly within the boundaries of current maintenance organizations. However, these elements implemented in isolation would most likely produce only minor improvements in the performance of maintenance, at least compared with what would be made possible by a full implementation of the dynamic approach. The reason is that many of the problems of maintenance today stem from badly defined interfaces with other functional areas of the company and from the fact that the responsibility for some areas that constitute an integral part of the maintenance function is located outside the maintenance department.

A proper implementation of the dynamic approach to maintenance thus requires the attention of the entire company and the active support of top management. In most transit companies introduction of the dynamic approach will mean a modification in the corporate culture. This will not be easy and can only be done in an evolutionary process from within each company. Change agents brought in from the outside can be expected only to guide this process. In the following discussion, the key steps in the development of a dynamic maintenance system will be treated briefly. Excluded from the discussion is the development of a maintenance program, which was discussed in the third section.

Overall Optimization of the Maintenance System

The mission of a transit company requires that a predetermined number of buses (the "active fleet") be in good condition and running without en route breakdowns during the time the schedule calls for. Any bus that is not in the active fleet at least part of the day is an extra expense to the system. Some of these buses may need to have maintenance work performed on them. The rest may be justified as standbys for charter or other purposes. The investment cost for the reserve buses needed for maintenance constitutes an integral part of the maintenance expenses in the same way spare repairable components do. Holding maintenance accountable for these costs and for the cost of en route breakdowns will give maintenance personnel an incentive to define their work in such a way that it is optimal from the point of view of the entire transit system.

Overall optimization requires that all resources of the company be used for the purpose of effective maintenance. For example, although the bus operator is part of a different department, he has to be made an integral part of the condition-monitoring system.

Planning and Control Methods

Management of maintenance has to be structured so that maximum flexibility (i.e., response capability to unforeseeable work loads) is attained. Because the human ability to recognize patterns, relationships, and unique conditions is far superior to that of a computer, at least for a long time to come the human will be a central element in maintenance.

The development of planning and control methods, especially computerized ones, has to be sensitive to the special circumstances of a maintenance environment. It also has to recognize the needs of humans for satisfying work. Radically new concepts may have to be embraced. An adaptation of systems and methods developed for production systems, for example, will not suffice.

Materials Management

The overriding concern in materials management is the relatively small size of the problem, which does not justify big expenditures but which also permits people to have a good grasp of the overall situation. The most promising approach appears to be bringing experts together for decision making. This can be expected to lead to considerable side benefits in the form of comparisons of work procedures among mechanics, which will lead to improvements in overall procedures.

There are two categories of bus components, the repairable components, which, when they require work, are exchanged against like components and worked on independently of the bus, and the expendable components, which are only removed from the bus when they are to be discarded. For each component a determination has to be made of whether it should be treated as a repairable or as an expendable component. Treating it as a repairable component may lead to substantial savings in bus downtime. On the other hand, the cost of setting up and managing the float has to be considered. Also, removal of the component and replacement with a serviceable one may require considerable time and thus be expensive. These expenses have to be traded off for each part against the benefits of reduced bus downtime.

For each repairable component the optimal float level has to be determined. The float has to assure that, in spite of the randomness of the removal process and the repair process, the frequency with which the need for a serviceable component cannot be satisfied is below some small level. However, because repairs can be accelerated and, to some extent, removals delayed when the level of serviceable parts is low, this is by no means an easy problem to solve. Because, in reality, many kinds of parts and in some cases buses also compete for the same shop capacity, this problem becomes quite complex. Considerable work on this subject has already been done in aviation. For an overview of this work, see Etschmaier (10). This work will have to be adapted to the special situation in transit maintenance, especially to the small scale of the problem.

Methods also have to be developed for scheduling component repairs through the shops. This issue ties materials management directly to the planning and control methods discussed previously.

For all components and parts, future usage has to be predicted for the short as well as the long range. The number of parts required for maintenance of transit buses is small enough that automatic forecasts are not necessary. Instead, it is possible to review past usage patterns for each part and to determine how these patterns are tied to different kinds of maintenance activities. Given a forecast of future maintenance activities, this information can immediately be turned into forecasts of parts usage. The forecasts are best developed in conference by teams familiar with the details of design and maintenance procedures, probably lead mechanics, foremen, and parts men. They should be assisted by formalized procedures in the form of worksheets, either on paper or computerized. Computerization could relieve them of some of the number-crunching activity that is unavoidable in this process.

Access to spare parts for mechanics has to be made as immediate as possible, without creating chaos. In a small shop the effort devoted to parts control can easily become excessive. Reorder procedures for expendable components and parts have to be developed.

Mobilization of Personnel Resources

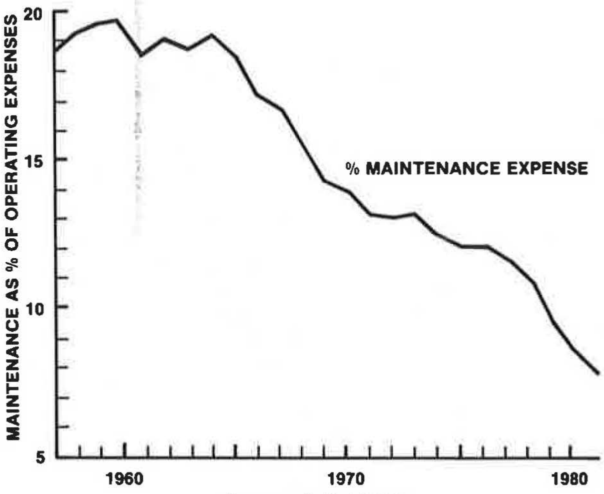
The most significant factors that currently inhibit the effectiveness of maintenance labor and in some properties lead to worker apathy and resignation are adversity in the labor-management relationship, restrictive work rules, inconsistencies in mechanics' training, and the absence of a clear definition of purpose visible to the workers.

The problems are extremely complex and there are no easy or fast answers. Certainly there are no answers that can be imposed on a transit system from the outside. Instead, solutions have to be found for one system at a time by immersion in the situation and the special problems faced by the system. What is needed is skill and leadership, vision and sensitivity, and above all a fundamental sense of fairness. Solutions have to be found by working with workers and their unions and listening to them as fully emancipated partners in this process. The approach taken has to be based on solid realism, but also on a firm belief in, and respect for, the quality of workers as well as sensitivity to their needs and feelings. There is little room for the application of fads or isms, nor should this be a playground for ivory tower research. Mobilizing the personnel resource of a property almost certainly requires the temporary infusion of a change agent from the outside, but whoever he may be, he must have a full grasp of all aspects of maintenance and be willing to "get his hands dirty." He must, of course, also have the full support and understanding of all levels of management. The line between success and failure in such an undertaking is narrow, but the potential for improvement and the sense of reward for all involved can be tremendous.

CONCLUSIONS

The systems approach provides an opportunity to reexamine the performance of maintenance in a transit system and to redefine the relationship between maintenance and the rest of the company. Clearly, it is not something that can be imposed on a company from the outside. Instead, it requires a long process of evolution from within that has the full support and understanding of all levels of management. If this process is to succeed much hard work and dedication by many people within a company are required. This work appears fully justified because it can be expected to produce significant improvement in the performance of maintenance and to halt the escalation of cost of the maintenance department as currently defined. Significant reductions of the cost of the overall maintenance function as defined in this paper will occur with certainty.

To provide an indication of just how significant the savings through the application of the systems approach may be, Figure 4 is a graph [reproduced from Ralf (11)] showing maintenance cost as a percentage of total operating cost in airlines between 1957 and 1981. The systems approach was introduced gradually beginning in the early 1960s and was fully implemented around 1970. During this period maintenance expenses decreased from around 19 percent to 12 percent of total operating expenses. They have continued to decrease since then; however, some of the decrease has to be attributed to the increase in fuel prices. Although the authors are not suggesting that the success of airlines maintenance can be duplicated in transit, they expect the results to be convincing.



Soruce: Ralf (1982)

FIGURE 4 Experience of U.S. airlines (*11*).

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REFERENCES

1. R. Malec. Bus Maintenance: Keeping the Lid on. Presented at APTA Annual Meeting, Oct. 1983.

2. DOT Needs Better Assurance that Transit Buses are Maintained. Report GAO/RCED-83-67. General Accounting Office, 1983.
3. M.M. Etschmaier and G. Anagnostopoulos. Dynamic Maintenance for Rail Transit. Staff Study, SS-66-U. 3-05. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1983.
4. R.F. Casey. The Automated Bus Diagnostic System Demonstration in New York City. Staff Study SS-64-U. 3-1. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1983.
5. M.M. Etschmaier. Review of Transit Bus Maintenance in the United States. To appear in Transportation Research, 1984.
6. P.J. Ringo. Transit Operations--The Manager's Perspective. In G.E. Gray and L.A. Hoel, eds., Public Transportation: Planning, Operations, and Management, Prentice Hall, Englewood Cliffs, N.J., 1979.
7. F.S. Nowlan and H.F. Heap. Reliability-Centered Maintenance. Dolby Access Press, n.p., 1978.
8. F.S. Nowlan and H.F. Heap. Reliability-Centered Maintenance. Proc., 1978 Annual Reliability and Maintainability Symposiums, 1978.
9. J.L. Birkler and J.R. Nelson. Aircraft Turbine Engine Monitoring Experience: An Overview and Lessons Learned from Selected Case Studies. Report R2440-AF. Rand Corporation, Santa Monica, Calif., 1980.
10. M.M. Etschmaier. Contributions of Operations Research in the Area of Maintenance and Inventory Control of an Airline. Technical Report No. 12. Department of Industrial Engineering, University of Pittsburgh, Pa., 1973.
11. J.E. Ralf. Reducing Maintenance Cost--Reliability, Innovation, and Regulatory Relief. Presented at Engineering and Maintenance Forum of the Air Transport Association of America, Minneapolis, Minn., 1982.

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Management Information Systems for Small, Fixed-Route, Fixed-Schedule Operators

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ABSTRACT

Guidance is provided for managers of small, fixed-route, fixed-schedule services who are considering the purchase of a microcomputer and the necessary software for management information purposes. The major management-related functions of such services, which require the tabulation and analysis of data, are reviewed in detail and categorized into six groups: (a) administrative, (b) planning, monitoring, and evaluation, (c) operations management, (d) materials and equipment ordering and inventory, (e) maintenance, and (f) financial management. Following this review, source forms for the actual collection of the data are proposed and management reports for each function are suggested. Reference is also made to a set of criteria and standards to assist managers in the selection of the type of microcomputer and the required peripherals and software. To illustrate the use of these criteria and standards, three alternative hardware and software systems are formulated. Each system is intended to aid in all information management functions, to accommodate the processing of the data that have been entered from the source forms, and to generate the necessary reports. Each system consists of "off-the-shelf" software (including a data-base manager and some application programs and report generation capabilities). The hardware includes the most popular and widely used mircrocomputers and printers. Each system can be purchased for a total cost of approximately $10,000 to $12,000.

The use of microcomputers is becoming prevalent in many areas of transportation (1). The first phase of the research consisted of a broad-based and detailed review of a representative group of existing, automated, management information system (MIS) applications, the development of an evaluation framework, and the use of this framework to identify deficiencies among the existing MISs (2). MISs were studied at nine different transit sites in several different areas of the country. Sites were selected to represent widely varying fleet sizes, service area characteristics, and modes of service. In addition, a number of non-site-specific software and hardware packages were reviewed, including several within the public domain that were developed with