Theory and Practice of Transit Bus Maintenance Performance Measurement

THOMAS H. MAZE AND ALLEN R. COOK*

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

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

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

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

*Deceased.
T. H. Maze, Department of Civil and Construction Engineering, Iowa State University, Ames, Iowa 50011.

MANAGEMENT BY OBJECTIVES

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

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

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

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

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

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

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

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

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

FUNDAMENTALS OF PLANNING

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

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

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

Objectives

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

Quantification

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

Time Limits

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

Appropriateness

Objectives must be scaled to meet the targeted level in the

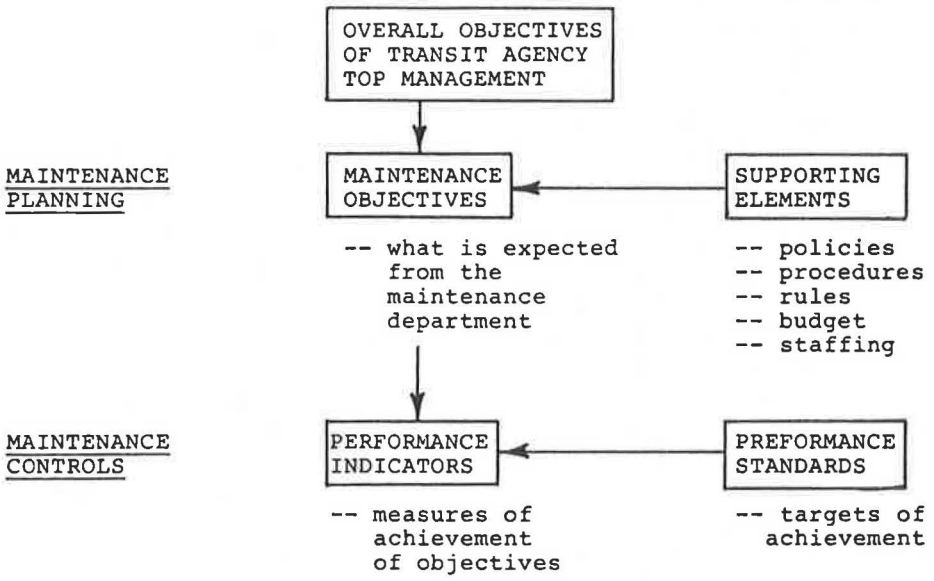

FIGURE 1 Management by objectives.

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

Trade-Offs Between Objectives

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

Policies

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

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

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

Procedures

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

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

Rules

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

Programs

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

Budgets

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

planned actions. Thus the priorities expressed through the budget must clearly reflect the priorities expressed in the planning objectives.

Summary

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

FUNDAMENTALS OF CONTROLLING

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

The Control Process

Managerial controlling involves three steps.

Establishing Performance Indicators

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

Establishing Performance Standards

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

Correcting Deviations from the Standard

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

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

Performance Indicator Development

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

Applicability

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

Promptness

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

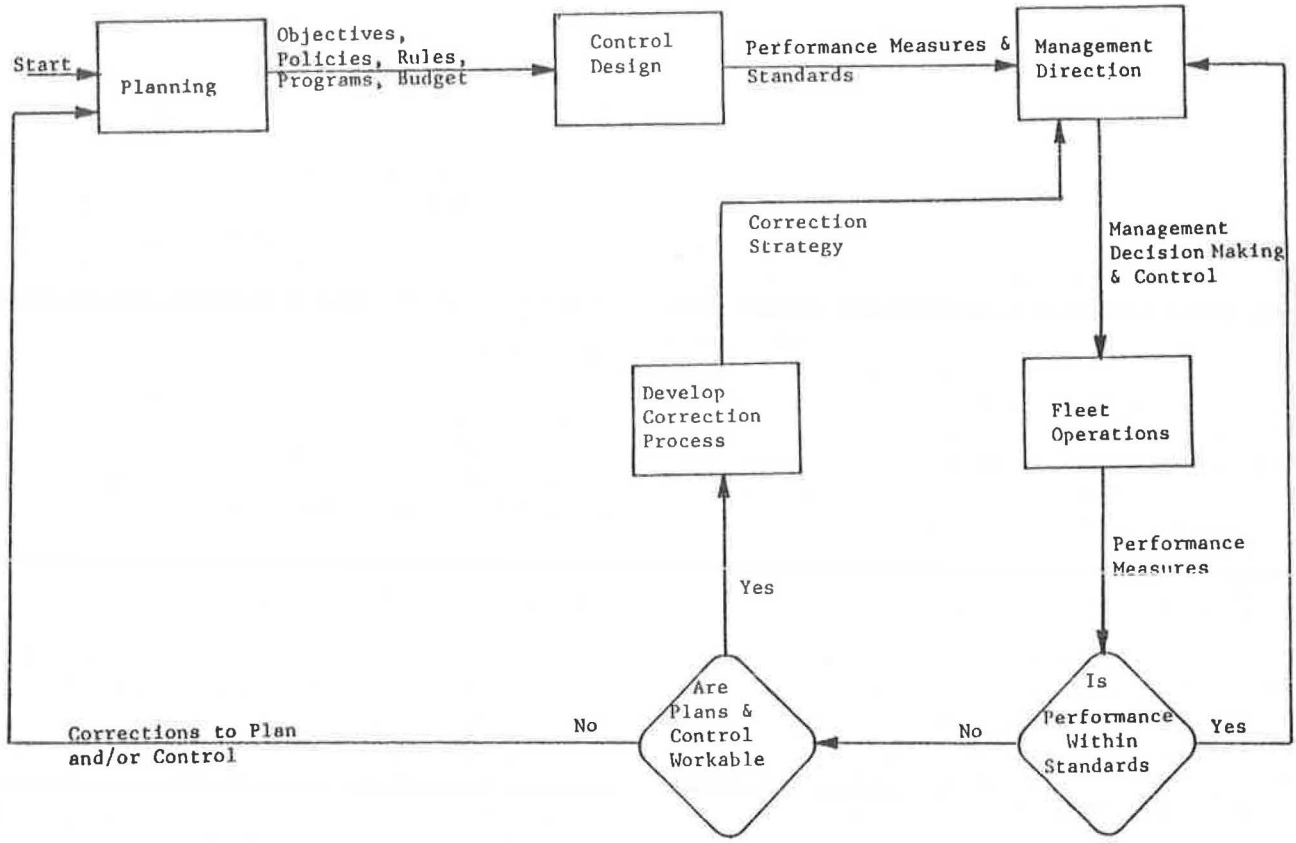

FIGURE 2 Flowchart of the controlling process.

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

Critical Exceptions

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

Objectivity

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

Clear Definitions

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

Economy

Controls must be worth the cost of their collection. Elaborate control systems may be economical for large organizations with a complex managerial system, but for medium and small

transit systems in which fleet managers can personally track a broader span of management functions, elaborate systems may be uneconomical. For each individual case, the selection of controls should be judged in light of the value of the control versus the corresponding cost of the control. Clearly, the benefit of each performance indicator should exceed the cost of the indicator's collection.

Understandability

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

Applications of Performance Indicators

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

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

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

BUS MAINTENANCE PERFORMANCE MEASUREMENT PRACTICE

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

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

Maintenance Manager Perspectives

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

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

Candidate Performance Indicator Questionnaire Survey

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

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

Categories of Performance Indicators

The 36 performance indicators were grouped into six categories.

Fleet Reliability Indicators

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

Fleet Maintainability Indicators

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

Fleet Availability Indicators

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

Work Quality Indicators

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

Work Productivity Indicators

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

Maintenance Management Control Indicators

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

Value of Candidate Indicators to Maintenance Managers

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

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

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

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

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

TABLE 1 VALUES TO MAINTENANCE MANAGERS OF CANDIDATE PERFORMANCE INDICATORS

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

TABLE 1 *continued*

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

TABLE 1 *continued*

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

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

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

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

The eight indicators that no maintenance manager considered worthless were

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

Of these eight performance indicators, only two cannot be calculated through performance reporting data required by the U.S. government of all transit systems receiving federal operating assistance (Section 15 data). Of those two (number of

repeat repairs in the same month, and average fuel and oil cost per bus model versus the total fleet), fuel and oil cost is almost uniformly kept by all transit systems and only the repeat repairs indicator is unusual.

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

Value of Candidate Indicators to Top Management

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

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

Top Management's Understanding of Maintenance

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

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

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

Other Performance Indicators Suggested by Maintenance Managers

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

Fleet Reliability Indicators

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

Fleet Maintainability Indicators

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

Fleet Availability Indicators

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

Work Quality Indicators

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

Work Productivity Indicators

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

Maintenance Management Control Indicators

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

CONCLUSIONS

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

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

ACKNOWLEDGMENT

The preparation of this paper was made possible by a grant to the University of Oklahoma from the UMTA University Research and Training Program (OK–11–0005).

REFERENCES

1. G. List and M. Lowen. Performance Indicators and Desirable First Line, Supervisor Skills for Bus Maintenance. Presented at the American Public Transit Association Bus Maintenance Workshop, Oakland, Calif., March 2–5, 1986.
2. G. J. Fielding, R. E. Glauthier, and C. A. Lave. Performance Indicators for Transit Management. *Transportation*, Vol. 7, 1978, pp. 365–379.
3. A. R. Tomazinis. *Productivity, Efficiency, and Quality in Urban Systems*. Lexington Books, Lexington, Mass., 1975.
4. H. Koontz and C. O'Donnell. *Principles of Management: An Analysis of Managerial Functions*. 4th ed., McGraw-Hill, New York, 1968.
5. J. F. Foerster, C. McKnight, and M. Kosinski. Impact of System and Management Factors on Bus Maintenance. In *Transportation Research Record 1019*, TRB, National Research Council, Washington, D.C., 1985, pp. 69–76.
6. C. McKnight. *Madison Metro Transit System: Bus Maintenance Case Study*. UMTA, U.S. Department of Transportation, 1984.
7. T. H. Maze. *Bus Fleet Management Principles and Techniques*. UMTA, U.S. Department of Transportation, 1987.
8. K. Inaba. Allocation of Time for Transit Bus Maintenance Functions. *National Cooperative Transit Research and Development Program*. Report 4. TRB, National Research Council, Washington, D.C., 1984.