Evaluation of Bus Maintenance Operations

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ABSTRACT

A generalized framework is developed to view the transit bus maintenance operation. Environmental and policy factors that influence and constrain the maintenance organization are shown, and then the maintenance function is defined as a set of eight component activities, which include work assignment, maintenance scheduling, workforce development, labor allocation, inventory management, equipment management, information systems, and monitoring and evaluation. Each activity is conceptualized as a spectrum that represents a scale of increasing sophistication and, ultimately, cost. The external factors and maintenance activities are synthesized to represent a composite profile of a bus system's maintenance department. This descriptive framework is used to demonstrate that different levels of activities are appropriate for different sets of external factors. Finally, applications of the framework at the transit-agency level are discussed.

An organized method for defining and reviewing bus maintenance operations of small and medium-sized transit agencies is provided. The framework is intended to assist researchers in identifying areas of maintenance and associated strategies that can be used to improve the effectiveness of bus transit maintenance organization and delivery systems. It also presents transit executives and public officials with a reference framework for discussing ways to allocate limited resources to make their organization's maintenance program more effective than at present.

BACKGROUND

Transit bus maintenance is by nature a highly complicated and irregular activity that often is scheduled around, and determined by, the needs of the entire organization. Because of the basic, fundamental dependence on the maintenance department by other divisions within the transit agency (e.g., operations, marketing, and administration) the maintenance function often must be responsive to immediate needs of the agency.

Although the role of maintenance has always been important to the welfare of the entire transit organization, recently this role has grown in importance. Certain factors account for this growing importance:

- Maintenance activities have been shown to absorb more than 20 percent of annual transit operating expenses, and the proportion appears to be growing (1);
- Federal operating subsidies are diminishing, thereby intensifying the need to control maintenance expenses; and
- Market-oriented trends in bus design have placed a growing burden on the task of maintenance.

Growing awareness and interest in these problems have spurred some recent research, but many needs remain to be addressed. Often maintenance research has been addressed from the viewpoint of maintenance labor--the enumeration of tasks and the description of their proper execution. This approach is exemplified by the many procedural manuals that are available within the industry.

In this paper the maintenance department is first differentiated from other units within a transit agency, and then the key activities of maintenance management are illustrated. Finally, a general model for the analysis of bus maintenance operations is presented.

LITERATURE REVIEW

Recent years have seen an upturn in maintenance research, and as a result, better, more productive maintenance methods should evolve. The body of maintenance research can be characterized by chief subjects of study. Some research (2-4) has been concerned with disseminating exemplary forms and interval schedules for reference. Other studies (5,6) have conducted questionnaire surveys of preferred maintenance practice. Still other studies (7,8, paper by Foerster et al. in this Record) have focused on the intriguing prospects of regression performance models. Perhaps the greatest interest has been directed to analysis of the optimum establishment of intervals and scheduling (9-15). These and other recent studies have done much to improve the status of available literature on maintenance. Generally, a particular subject of interest in maintenance has been isolated and examined in detail.

Unfortunately, although many of the findings have proved to be interesting, there has been difficulty in bridging the gap from research findings to practical implementation. Even if the recommendations are justified, the findings seldom appear easy to incorporate into industry practice. A classic case is the frequent recommendation for agencies to maintain detailed parts histories. This idea appears perfectly sensible to researchers but prohibitively demanding to the industry.

Furthermore, the literature review reveals that bus maintenance research may have neglected to address the need for general education in the industry. In the following cases--an administrator newly arrived to the responsibilities of maintenance, a board member or upper-level administrator who is unfamiliar with the concepts of maintenance, or

maintenance laborers who are being trained to view the overall picture of maintenance--the individual in each case should benefit from a general document reviewing maintenance management and placing it in a meaningful context. Scant literature exists to provide a simple, comprehensive overview of the maintenance department and the associated management activities that can be brought to bear on it. This discussion thus proceeds from a perception of a need for such a general document.

INTRODUCTION OF FRAMEWORK

This project is restricted to small to medium-sized agencies, ranging in size from 15 to 500 vehicles. The omission of very small and very large agencies preserves the general applicability of the model, because the extreme sizes frequently employ exceptional administrative arrangements.

In constructing a general maintenance model, the first challenge is to provide a simple, convenient conceptual framework. This framework should assist in placing the maintenance department in the broad context of the transit organization. Second, a useful model should outline key management opportunities--those areas that management can control to achieve maintenance objectives.

The first step of the approach, then, must be the placing of the maintenance department in its context. Maintenance exists alongside other departments. These departments exist within an organization, and this organization is itself contained within a larger community.

Figure 1 demonstrates these contextual relationships. It provides a broad, conceptual flowchart that traces the production of service output through the organizational process. Figure 1 identifies not only the maintenance department and other departments but also those conditions that set the stage for the operations of these departments.

Many important limiting conditions are set before the transit agency ever makes its first decisions. Figure 1 identifies these limiting conditions as community-external constraints. These constraints, which arise outside the maintenance department and outside the transit agency as well, are as follows:

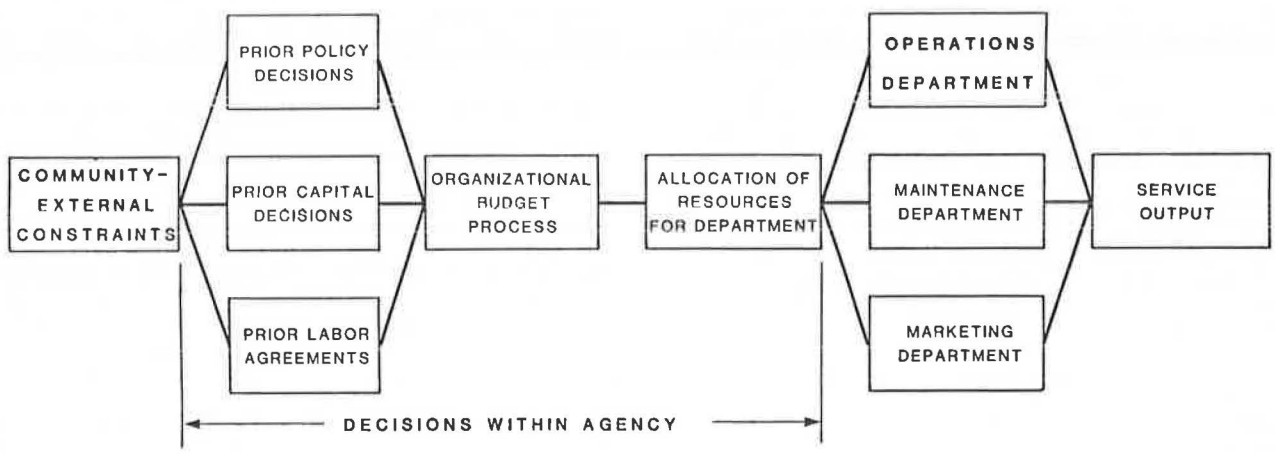
- Community size,
- Community density,
- Community values (transit use, local funding),
- Terrain (flat or hilly),
- Climate (cold or hot, moderate or variable),
- Street conditions (potholes, narrow streets), and
- Local labor market (union climate, high or low wage rates).

Proceeding through Figure 1, many important limits are further set by the decisions of upper transit management. These decisions are made outside the maintenance department but inside the transit agencies. They are as follows:

- Organizational objectives,
- Hours of revenue service,
- Fleet size,
- Fleet composition (type of vehicle, homogeneity of fleet),
- Physical layout of facilities,
- Labor agreements (vague levels, work rules, promotion system, shift restrictions), and
- Budgeting allocations.

For instance, an agency might be described as follows:

- Small community (50,000 population);
- Dispersed community;
- Light transit reliance;
- Flat terrain;
- Warm, moderate climate;
- Inexpensive labor market;
- New road surfaces;
- Fleet of 15 buses;
- Revenue service per week, 72 hr;



*Community-external Conditions (Outside the Agency)
Community Size
Community Density
Community Values (transit use, local funding)
Terrain (flat or hilly)
Climate (cold or hot, moderate or variable)
Street Conditions (potholes, narrow streets)
Local Labor Market (union climate, high or low wage rates)

**Decisions within the Agency (Outside the Maintenance Department)
Organizational Objectives
Hours of Revenue Service
Fleet Size
Fleet Composition (type of vehicle, homogeneity of fleet)
Physical Layout of Facilities
Labor Agreements (vague Levels, work rules, promotion system, shift restrictions)
Budgeting Allocations

FIGURE 1 Determining factors for transit service output.

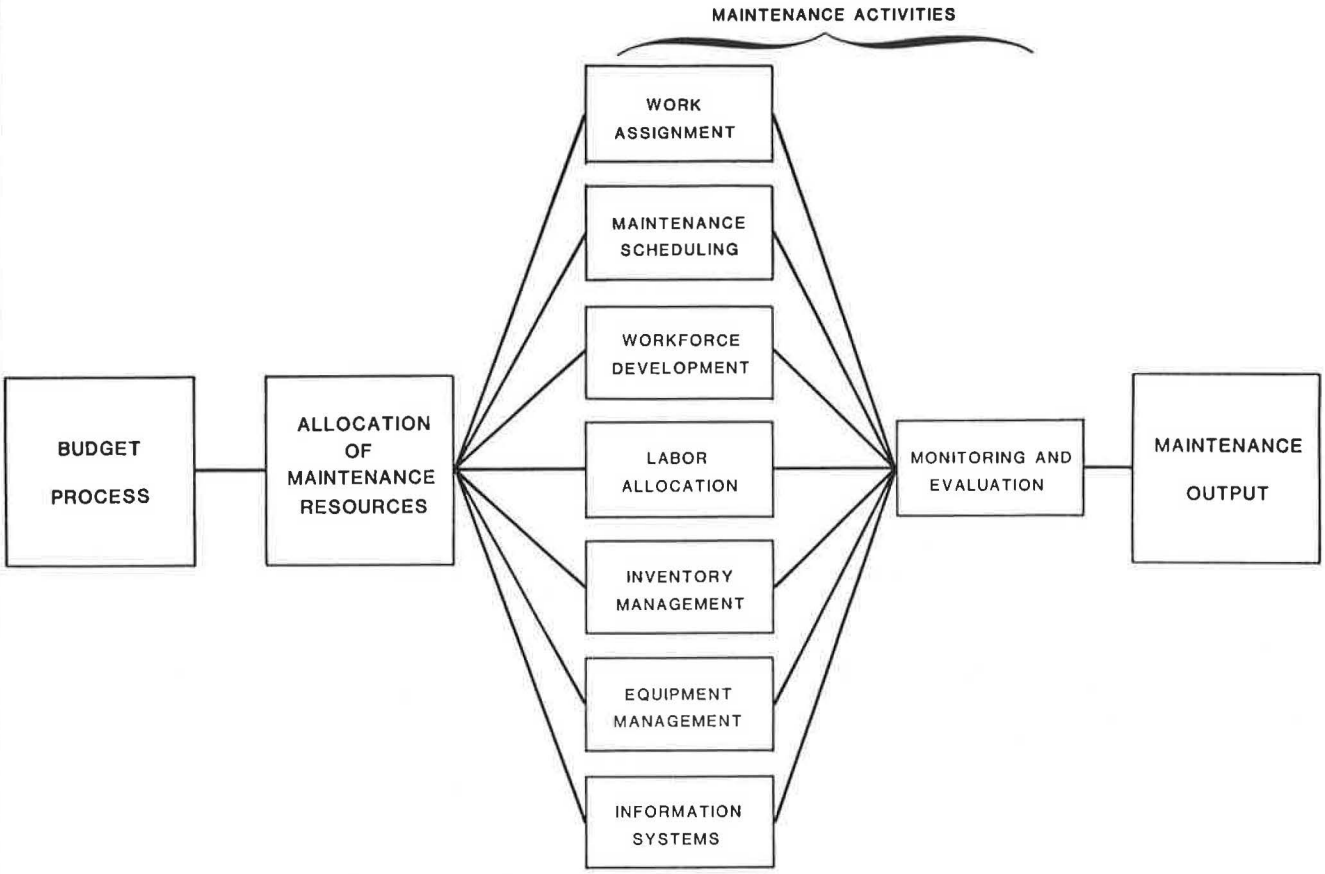


FIGURE 2 Operating activities of the maintenance department.

- Homogeneous fleet;
- Abundant capacity in facility;
- Nonunionized workforce.

None of the foregoing items is under the direct control of the maintenance department, and yet they will play a significant part in the performance of the maintenance department (8).

After a broad organizational overview, it is appropriate to focus on a more detailed analysis of the maintenance department. In Figure 2 this step is outlined by expanding a section of Figure 1. Maintenance is elaborated as a collection of eight activities. It should be noted that in this study the maintenance department is described as a collection of management activities as opposed to the functional description often observed in maintenance (servicing, inspection, repair, etc.). The activities include the following:

- Work assignment
- Maintenance scheduling
- Work force development
- Labor allocation
- Inventory management
- Equipment management
- Information systems
- Monitoring and evaluation

Together, the foregoing activities encompass the total maintenance effort. They can be further broken down into subactivities as will be demonstrated later.

From this preliminary development, a general model begins to suggest itself as shown in Figure 3. By breaking an agency down to key characteristics, it can be neatly summarized into a framework where external factors are set along the left column of a matrix and the different management activities are set along the top row. Given a specific bus system, it and its circumstances can be described in the first column, and the particular strategies of its maintenance department can be entered into the remaining columns.

A number of objectives should be achieved by this framework.

- A convenient method of summarizing different maintenance departments should follow. Such a summary should help to describe an agency quickly, and its format should help to promote comparability among agencies.
- It should be possible to illustrate the relationship of one maintenance activity to another maintenance activity.
- It should be possible to illustrate how different strategies are appropriate for different circumstances.
- A linkage between choice of strategy and output should be demonstrated. The last column of the framework should observe performance measurements. A specific maintenance department should generate its own performance values, and this performance in turn should be related to the strategies chosen in each activity. Although the linkage will not be direct enough to be termed a "predictive" model, it might be termed a "resource performance" model.

EXAMINATION OF ACTIVITIES

The basic framework has now been introduced and the

Descriptors	Work Assignment	Maintenance Scheduling	Workforce Development	Labor Allocation	Inventory Management	Equipment Management	Information Systems	Monitoring & Evaluation
Descriptors of Property A								
Descriptors of Property B								

FIGURE 3 General maintenance evaluation model.

next step is to show how the values are assigned to the different cells. Figures 4-10 follow a two-step format: a recitation of key subactivities and the presentation of the subactivities as a spectrum of strategies. The first seven activities are presented in this format of strategic choice; however, the last activity, monitoring and evaluation, will be presented in the following discussion as a recitation of key measures. (No strategic alternatives are presented for this activity because it will be used to reflect on the other management activities.)

It should be noted that each spectrum is presented as a progression, from a simple case to progressively more complex, developed cases. The strategies are keyed as A, B, C, and D; movement through the alphabet signifies increasing complexity. Thus the letter coding should provide instant identification. When the letter D occurs in a chart, it should instantly communicate a highly developed strategy, even before the reader matches the letter key to its particular strategy on the spectrum.

Monitoring and evaluation departs from the spectrum format of presentation. The following measures are all appropriate for monitoring maintenance:

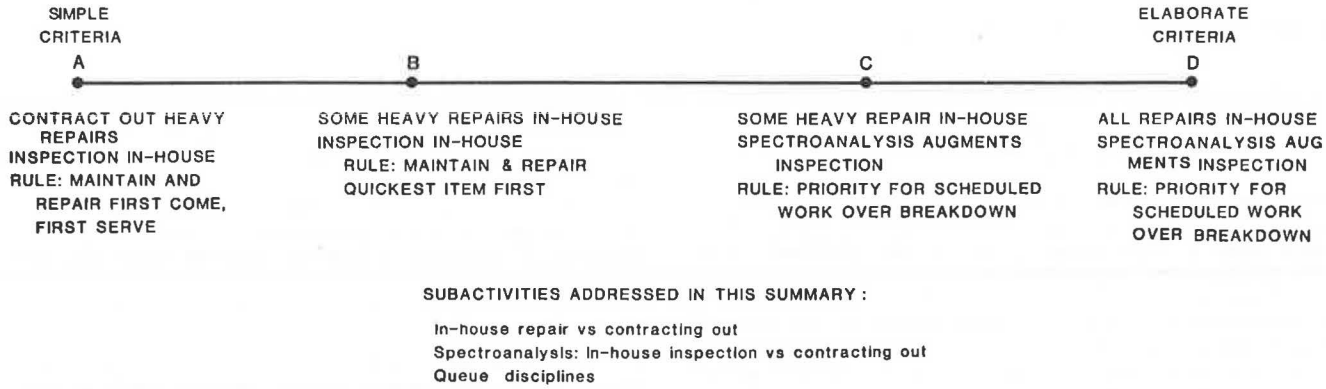


FIGURE 4 Strategic alternatives for work assignment.

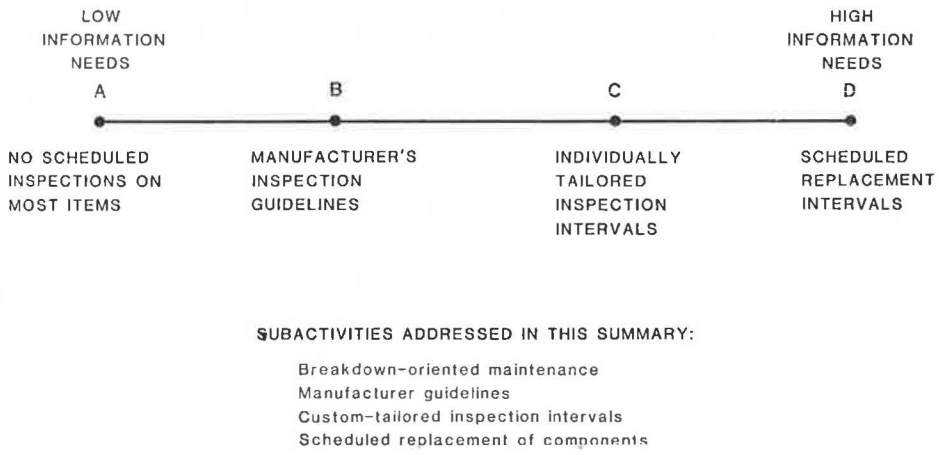


FIGURE 5 Strategic alternatives for maintenance scheduling.

- Roadcalls
- Missed runs
- Late outs
- Inactive buses
- Spare-to-peak-requirement ratio
- Labor-hour productivities
- Life mileage
- Fuel and lubricant use
- Accidents
- Cost of maintenance per mile

However, the measures possess different capabilities. Some reflect only one or a few activities, whereas others reflect the aggregate performance of the department. In this paper two simple measures are ultimately suggested to promote the easiest evaluation of a department: roadcalls and maintenance cost per mile. These are selected primarily on the basis of an adequate quick sketch of departmental performance and availability in Section 15 data, which promotes comparison with other agencies.

USING THE FRAMEWORK

The material necessary to fill the framework is now

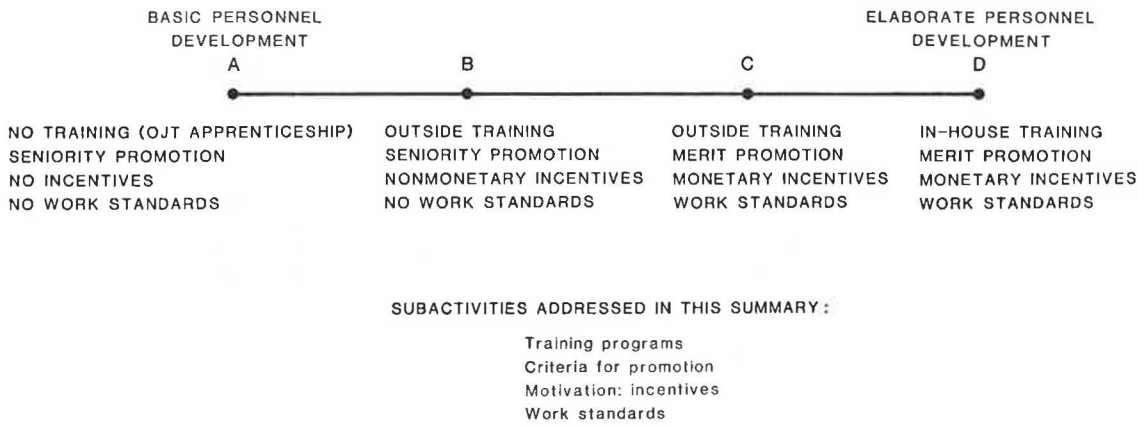


FIGURE 6 Strategic alternatives for workforce development.

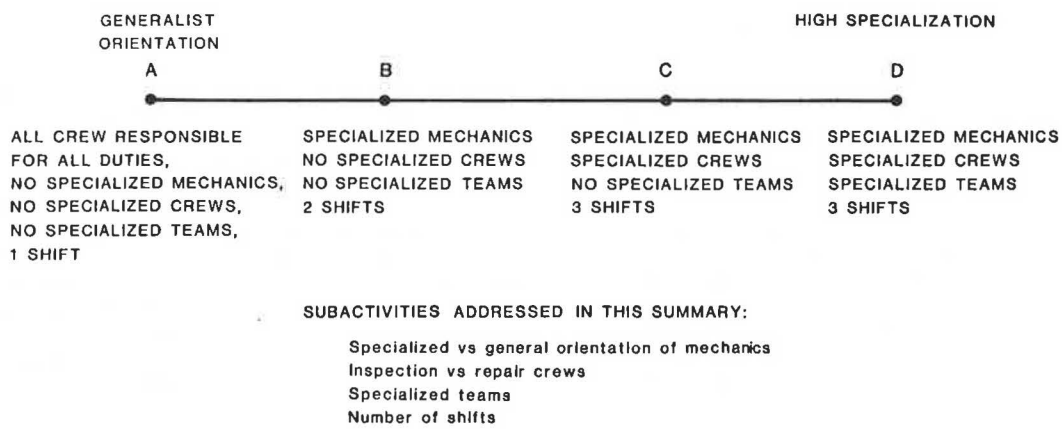


FIGURE 7 Strategic alternatives for labor allocation.

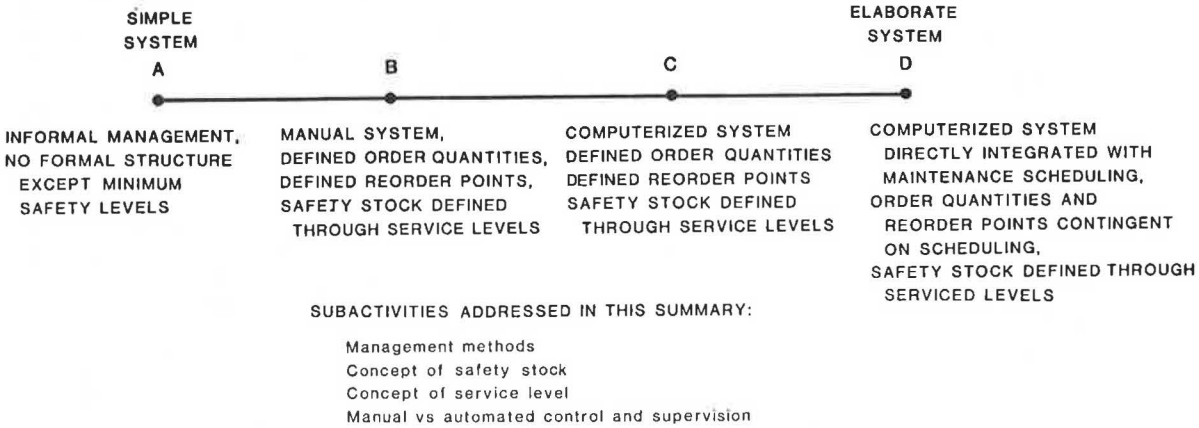


FIGURE 8 Strategic alternatives for inventory management.

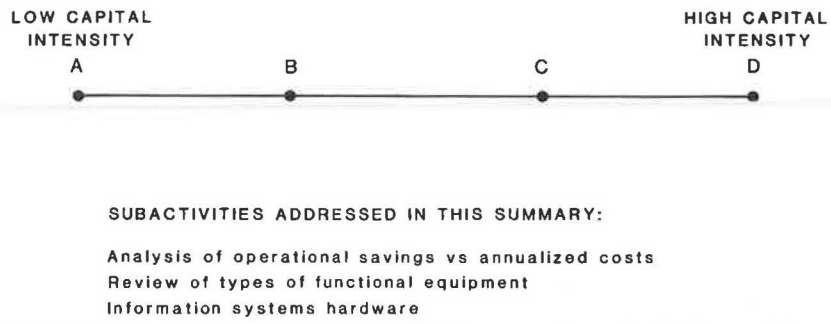


FIGURE 9 Strategic alternatives for equipment management.

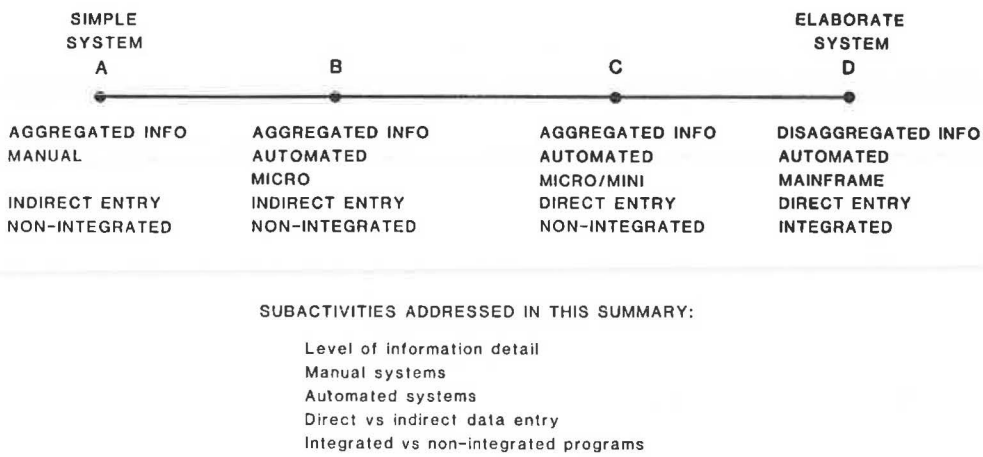


FIGURE 10 Strategic alternatives for information systems.

sufficiently introduced. When external factors (Figure 1) and management activities (Figures 4-10) are combined, they in fact provide a composite profile of a bus agency's maintenance department. Table 1 provides some highly generalized examples of maintenance departments.

Table 1 also provides an opportunity to discuss the framework in its completed form. The external factors describe the particular circumstances of a transit agency. Given a description of an agency's situation, an appropriate selection of strategies (from Figures 4-10) can be lined up. Reading across the row from the description of circumstances, the strategies are explicitly matched to those circumstances. A maintenance department can thus be rendered A-A-A-B-A-C-A or D-C-C-B-C-C-D or B-B-A-B-B-C-C, and so on.

In its complete form, the framework suggests at a glance that some strategies for an activity are consistent with circumstances, and others are not. It stands to reason, for instance, that a large agency with 400 buses would not be a likely situation for A-level strategies, but that it might be suitable for C-level and D-level strategies.

Table 1 also suggests that strategies can be consistent among themselves, or they can be inconsistent. For instance, an orderly arrangement of all A strategies appears consistent internally, but an arrangement of A-A-A-A-A-A-D would appear to support an inconsistent information system strategy.

In these examples, the framework only intends to suggest relationships; further inspection should follow, of course, if action is to be taken by management.

In Table 1, the most visible determinant for the development of a management system is the size of the property--the number of vehicles to be maintained. It is suggested in Table 1 that a small agency with 15 vehicles warrants the simple A-A-A-A-A-A-A configuration, that a moderately small agency with 40 vehicles warrants a B-B-B-B-B-B-B configuration, that a medium-to-large property of 200 vehicles warrants C-C-C-C-C-C-C, and that a large property of 450 vehicles warrants D-D-D-D-D-D-D.

These four general types of departments, then, may provide a basic skeletal reference for this analytical framework--all-A, all-B, all-C, and all-D departments. However, this framework is designed for flexibility, and thus particular details can be incorporated into the analysis, yielding far more than four basic configurations. For example, one might consider how one small change in the description of the base case--say, a hilly operating environment--would alter the proper strategy configuration. Hilly terrain exacts exceptional stress on some components and thus calls for more developed strategies for maintenance scheduling and inventory management. Theoretically, in fact, given four alternatives for each of seven variables, there is a possibility of 16,384 different configurations of strategies--from A-A-A-A-A-A-A to A-A-A-A-A-A-B to A-A-A-A-A-B-B, and so on.

But not all such configurations are valid. In fact, it is the contention of this exercise that some configurations can be recognized as theoretically possible but inherently inconsistent. For instance, the theoretical configuration of A-A-A-A-A-A-D is not practical, because a department with reactive scheduling and minimal information needs for its labor, materials, and equipment management would have no cause to support highly detailed, automated, mainframe integrated information systems.

As a last step in the analysis, some performance evaluation should be applied to the department after

TABLE 1 Composite Profiles of Maintenance Departments

Description (External Factor)	Maintenance Strategy by Management Activity						
	Work Assignment	Maintenance Scheduling	Workforce Development	Labor Allocation	Inventory Management	Equipment Management	Information Systems
[a]Small community (50,000); dispersed community; light transit reliance; flat terrain; warm, moderate climate; inexpensive labor market; new road surfaces; 15-bus fleet; 72 hr of revenue service per week; homogeneous fleet; abundant capacity in facility; nonunionized workforce	A	A or B	A or B	A	A	A	A
Moderately small community (120,000); dense community; moderate transit reliance; flat terrain; moderate climate; expensive labor market; new road surfaces; 40-bus fleet; 90 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	B	B	B	B or C	B or C	B	B
Moderately large community (500,000); dense community; moderate transit dependence; flat terrain; warm, moderate climate; expensive labor market; new road surfaces; 200-bus fleet; 105 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	C	B or C	C	C	C	C	C
Large community (1,000,000); dense community; moderate transit reliance; flat terrain; warm, moderate climate; expensive labor market; new road surfaces; 450-bus fleet; 120 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	D	C or D	D	D	D	D	D

[a]Base case.

it has been entered into the matrix. This study recommends the application of output measures--maintenance cost per vehicle mile and vehicle miles per roadcall--because they provide quick aggregate assessment and facilitate comparability with other agencies. These measures can be compared with Section 15 data, which provide a convenient reference. If the measures appear troublesome (assume that the department's performance is below the average performance for Section 15 agencies in its size bracket), the analyst can direct attention to the configuration of strategies. Irregularities in the configuration may assist in identifying potential causes of poor performance.

The maintenance framework, as exhibited by Table 1, addresses the objectives of this paper. It demonstrates the relationship between diverse elements of the maintenance operation. It underscores the relationship among maintenance strategies and between maintenance strategies and external factors. Last, the framework associates performance measurements with maintenance department profiles. Furthermore, all these objectives can be achieved through easy application.

APPLICATION

A preliminary case study has been conducted as part of the development of the project (16). The maintenance department of an actual transit agency was selected as the subject of the study, and the evaluative framework described in this paper was applied to it. The study method consisted of site visits by the authors, interviews, and the completion of an evaluation form developed from the framework.

The outcome of the study confirmed the utility of the method. The results were consistent with expectations, and the framework was found to greatly assist in the collection of information as well as assist in the analysis of information. Furthermore, the case study data have now been expressed in a format that is readily comparable with that of other transit maintenance departments.

As a result of this application, it is recommended that further case studies be executed so as to develop a basis for comparison among maintenance departments.

CONCLUSIONS

The maintenance management model presented in this paper is recommended for application at the transit agency level. In such application, the model may be employed in many alternative ways. The framework can be used as an introductory descriptive device, or it may be used as an instrument for evaluation of department performance. Furthermore, the framework is adaptable to many procedural approaches. In the simplest form, a quick-response review may be executed by agency personnel. In its most developed form, a formal departmental audit may be conducted by independent experts, relying on evaluation forms, interviews, and site visits.

This effort is seen as one of the early attempts to provide an organized view of the institutional structure through which bus transit maintenance is delivered. There is much opportunity for work in the future to mathematize and computerize the model into a simulation methodology. For example, areas of applied probability and statistics such as regression analysis and reliability models can be employed to show cause-and-effect relationships. Further extensions may include an "expert systems" program for configuring maintenance organizations given certain levels of resources and constraints.

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