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Bus Fleet Management Principles and Techniques

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EXECUTIVE SUMMARY

During World War II scientific teams, in the military of both Great Britain and the United States, experience outstanding success through the application of "systems approaches" to the management of the war effort. In post war years, these same systems approaches have been modified and applied to civilian industries, where they have offered similar efficiency improvements. The purpose of this monograph is to describe and to illustrate some of these approaches as they apply to transit bus fleet management. Experience has shown that bus fleet managers can often achieve dramatic performance improvements through the application of systematic approaches.

Overview. The text covers several fundamental techniques and principles of bus fleet management. Examples are derived from a detailed case study at the Wichita, Kansas Metropolitan Transit Authority. The examples taken from the Wichita transit system, and from other transit systems, are intended to help guide bus fleet managers when applying the management techniques described. Key elements of the Wichita case study are the development of standard maintenance task times (work measurement) and the calculation of a variety of bus fleet performance measures. The standard maintenance task times and plots of the performance measures for the Wichita transit system are included in appendices.

The first chapter describes the fundamental functions of management. These functions are then framed in a bus fleet management context. Five management functions are identified: planning, staffing, organizing, directing, and controlling. The chapter concentrates on the identification of good fleet management planning and controlling. Emphasis is placed on planning because all other management activities seek to achieve the objectives identified in the management plan and therefore, all other management functions are subordinate to planning. Several of the following chapters contain directions on the application of techniques which may be applied as part of the management plan. Emphasis is placed on controlling because controls are created to insure planned objectives are being achieved. The direct tie between planning and controlling produces a need to have controls which reflect planning. Many of the following chapters contain descriptions of methods for developing a meaningful set of controls and guidance on the efficient design of control data collection systems.

The second chapter covers the planning of maintenance management information systems. Whether maintenance data are kept on paper copies or by computer, it is important to properly plan the development of an information system. If the system is not planned to deliver the data required to calculate desired control measures, then the value of the system is diminshed. Therefore, it is necessary for the fleet manager to plan the system in advance so that it meets the fleet manager's expectation when the system is finally implemented. Planning is particularly crucial when a computer is involved because it is likely to be very expensive to correct computer programs to provide the information desired after the computer system is in operation.

To plan an information system, a simple graphical technique is proposed and illustrated with a Wichita Transit System example. The graphical technique uses only four symbols to represent data processing, data flows, data stores, and data sources. This system bridges the gap between a written performance description of an information system's operation and the technical description of a computer programmer's flow chart. Because the technique is graphical and non-technical, all the potential information system users can participate in planning.

The third chapter covers data collection systems and highlights the development of a work measurement system. Work measurement includes the development of time standards and then using the standards in maintenance management decision-making and planning. Usually time standards are used as a yardstick in comparison to actual times required to complete tasks or a number of tasks. By making comparisons, the fleet manager can determine the relative productivity of maintenance workers and attempt to alleviate the deficiencies found. In maintenance work, the implementation of work measurement has resulted in significant productivity gains.

Most conventional methods of developing time standards (e.g., using stop watches to measure the time it takes to perform activities) are costly and they are suited for production environments where individuals repetitively perform the same task under identical environmental conditions. On the contrary, maintenance work is not repetitive and conditions change from job to job. Because of the special conditions in a maintenance environment, a non-conventional technique, time slotting, is suggested and illustrated. Time slotting is a low cost means for developing time standards which realistically reflects the likely variability of job durations. Time standards are developed for all bus maintenance tasks performed and reported by the Wichita transit system during a seven month period.

Chapter Four defines the use of performance measurement (controlling) in fleet management. Fleet performance measures are divided into six fundamental areas; fleet reliability indicators, fleet maintainability indicators, fleet availability indicators, maintenance work quality indicators, maintenance work productivity indicators, and maintenance control indicators. Several indicators for all of the six areas are calculated monthly for the Wichita transit system over a seven month period. The Wichita indicators provide an illustration of the use of selected performance indicators.

As part of the work on performance measurement, a questionnaire was also distributed to bus fleet managers at transit agencies throughout the United States. The results are presented in Chapter Four and they show that there is little commonality in the performance indicators that fleet managers prefer. In general, fleet managers found simple performance indicators (i.e., average miles between roadcall) most useful.

The fifth Chapter covers many of the practical aspects of life cycle costing, both in making bus replacement decisions and in bus procurement decisions. Standard engineering economy techniques are illustrated for the analysis of equipment cash flows over the life of the asset. These standard techniques are applied to equipment retirement and replacement decisions.

Life cycle costing for bus procurement decision making has been tried by several transit agencies with mixed results. Some agencies have had their procurement procedures challenged, and bus purchases delay. Other transit agencies have been very satisfied with life cycle cost base procurement and they have felt that the process rewards manufacturers with more durable design. The difference between good and bad experiences generally is related to the thoroughness of the bidding and bid selection procedures. More successful life cycle cost based procurements are often more thorough and specifically identify the information requested from the bidder. Chapter Five covers several practical aspects which may assist in the development of a successful life cycle cost based procurement.

The final chapter discusses a forum for the exchange of bus maintenance data, information, and knowledge. The concept of greater exchange between industry members if one which has received much discussion by bus maintenance professionals. The sharing of maintenance experience, reliability, maintainability and availability data, and performance information through a national exchange is an attractive concept. The same concept has been promoted by related industries; public works fleet managers have considered and attempted to exchange computerized equipment maintenance through a national data base and trucking fleet managers have exchanged information through their national association. The Department of Defense and the National Aeronautics and Space Administration even requires many of their contractors to contribute a national equipment data and information exchange.

Chapter Six discusses the types of exchange that should take place within the transit industry and proposes objectives for an exchange. The majority of the transit industry's fleet management experts agree that a bus fleet data, information, and knowledge exchange would be extremely beneficial. However, if the exchange is to meet the expectations it must be given long-term financial support.

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There were several transit system staff who provided data used in the case studies and in the evaluation of fleet performance measures. Their assistance greatly enhanced the practicality of the monograph. Principally the support of the Wichita, Kansas Metropolitan Transit Authority (MTA) is gratefully acknowledged and the help of the MTA's General Manager and Equipment Maintenance Supervisor, David Smith and Raymond Amsler. In addition, the following individuals are acknowledged for their support and guidance: Don Drassen, Chief of Maintenance, Central Oklahoma Transportation and Parking Authority; Dennis J. Belknap, Manager of Operations and Maintenance, Transit Service of Fort Worth, Texas; Richard Golembiewski, formerly the Manager of Maintenance, Regional Transit, Sacramento, California; Joe Escobeda, Operations Manager, Corpus Christi Transit Authority, Texas; S.B. "Sam" Cox, Equipment Manager, Dallas Transit System, Texas; Lucas Montoya, formerly the General Manager of the Transit Division, City of Albuquerque, New Mexico; Rich Davis, Director of Maintenance and Equipment, Southern California Transit District, Downey, California.

Finally, Bus Fleet Management Principles and Techniques was ably word-processed by Betty Craig, a proficient technical text process at the University of Oklahoma. Joan Howeth of the Univeristy's Office of Grants and Contracts was responsible for the financial record-keeping.

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CHAPTER I

PRINCIPLES OF BUS FLEET MANAGEMENT

The purpose of this monograph is to demonstrate methods that should permit the better management of bus fleets through the systematic use of maintenance records and data. Making better use of maintenance data requires: 1) The identification of the goals and objectives of the transit maintenance department; 2) The identification of performance indicators to measure the achievement of these objectives; 3) The information required to develop performance standards and support the collection of performance indicator data; 4) The identification of the data flow and points in the flow where data are most easily collected; and 5) The determination of the most effective methods of converting data into useful management information and knowledge.

The materials presented here are intended to assist the fleet manager in creating a firm structure to plan, evaluate, and control fleet maintenance performance. This chapter reviews the principles of management and their applications to bus fleet management. Chapters II and III discuss the techniques of maintenance data collection and interpretation. An in-depth case study application derived from an analysis of maintenance operations at the Metropolitan Transit Authority of Wichita, Kansas, is presented to illustrate these techniques.

Maintenance performance indicators are discussed in Chapter IV and recommendations are presented which are based on a questionnaire survey of fleet managers. Administrators who attempt to manage without knowledge of management theory and without well-structured maintenance performance indicators must place their trust in luck, intuition, or past experience. With knowledge the fleet manager has a far better opportunity to design a workable and sound solution to managerial problems. The report concludes with chapters on life cycle costing applications and a discussion of the exchange of bus maintenance data and management information and knowledge between transit systems.

MANAGEMENT BY OBJECTIVES

Koontz and O'Donnell (2) 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 fleet manager's responsibility to select the series of actions which the transit agency should take to achieve a set of maintenance goals or objectives determined in advance. This is called "Management by Objectives" (MBO).

A Management by Objectives program starts with the development of a comprehensive set of goals or objectives which defines 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.

Management, however, is an inexact science and management actions do not always achieve the objectives desired. Therefore, since 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 which 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 his 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 him with a procedure which will, in all likelihood, move the organization towards its objective.

An MBO program must include a management strategy for achieving objectives, and this includes the development of work rules, procedures, and forms. Finally, an MBO program should include the development of policy guidelines for management which can be used to solve problems as they arise and simplify daily decision making. This makes maintenance management more efficient in moving the transit agency towards its objectives.

Determining objectives, policies, procedures and a strategy 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" must be established to guide the implementation of the plan. Controlling is the function which measures the agency's progress towards 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. Since 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 the making of agency objectives, the setting of policies and rules, and developing programs. The budgeting and staffing implications of all this must also be considered when developing a management plan.

The first step of planning is to develop objectives. All of the other aspects mentioned above are then designed to achieve the established objectives. Each of these planning elements is discussed in the following paragraphs and illustrated in Figure 1-1.

Objectives

Objectives or goals are the driving element 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 three attributes:

1. Quantification. Objectives should be clearly defined and, if possible, quantified. The following are examples of well-defined objectives:

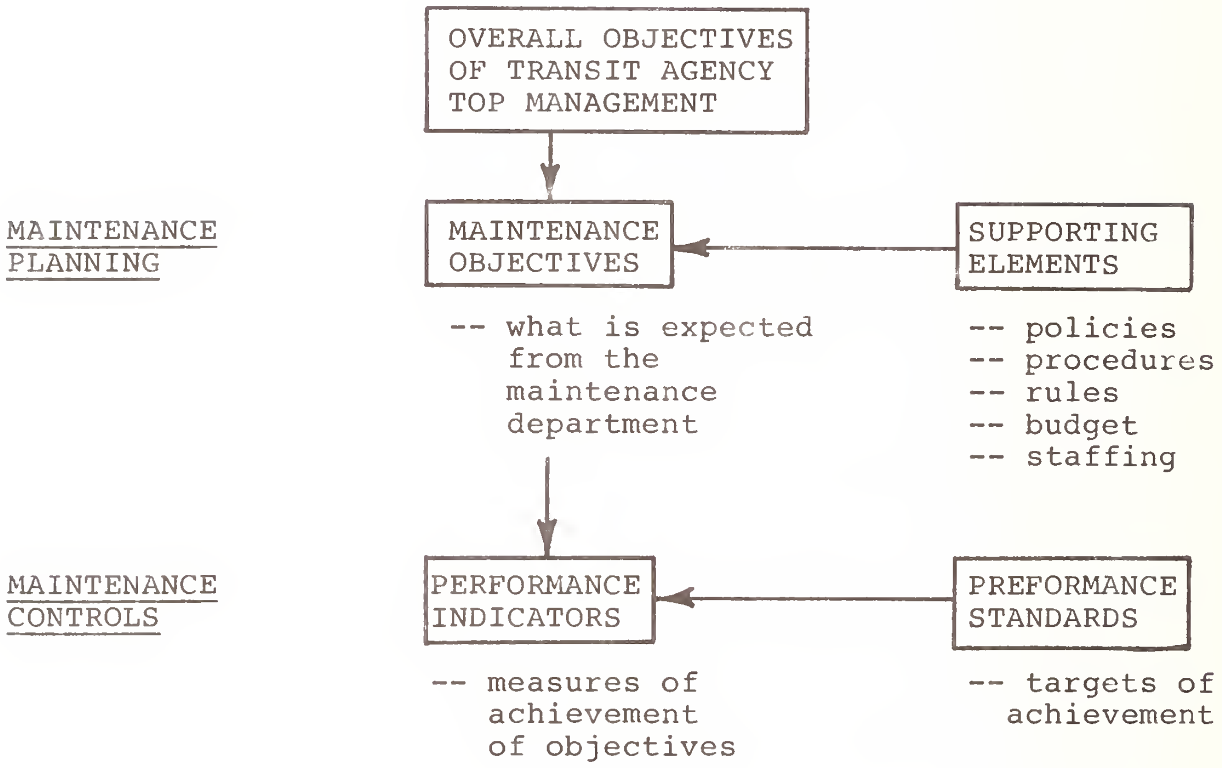
- -- Keep average maintenance costs to $0.50 per vehicle-mile or less.
- -- Maintain an average of 7,000 revenue miles or more between road calls for mechanical and electrical problems.

The latter objective above assumes that road calls are defined as service interruptions in transit agency procedures but do not include items not under the control of the maintenance department, e.g., a sick passenger.

2. Time Limits. Objectives often should include a time period or limit. For example, the two objectives cited above may pertain to the next budget year, or the next fiscal quarter.

FIGURE 1-1

MANAGEMENT BY OBJECTIVES



Without time references the motivation to accomplish the objectives may diminish and progress towards improving on these objectives may be retarded.

3. Appropriateness. Objectives must be scaled to meet the targeted level in the management hierarchy. For example, a meaningful objective for top management may be to cut the deficit per mile by ten percent in the next budget year while keeping fares constant. They may conclude that this objective can be achieved in part by increasing overall maintenance productivity. When the fleet manager delegates the responsibility of meeting this objective to the front-line equipment managers, e.g., 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 which 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 carried by ten percent, thus reducing the inventory overhead costs.

Trade-Offs Between Objectives

Some objectives may conflict with one another. 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 stock-outs do not increase while the inventory value is decreased. 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. Performance indicators can be useful in this regard, as will be explained in Chapter IV.

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 miles 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 (2) state: "Objectives are end points of planning, while policies channel decisions along the way to these ends." Consider a policy to promote 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 which 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 miles. The set of actions to be taken during this inspection is a procedure. Procedures are a mandatory set of ordered steps.

Foerster, et al. (1) 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, that 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 which, in turn, should move the transit agency towards its objectives of reducing road calls and minimizing maintenance expenditures.

Rules

Rules are simple, required planned actions which 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 RTS buses in the early 1980s that they established a rule which stated that RTS buses with air conditioning problems were not to be put in service (3). As long as spare buses were available, no exceptions were permitted, even if the RTS bus had windows which could be opened.

Programs

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

Budgets

Typically, a program which requires a high level of effort will need a budget and a staffing plan. 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. Since 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 1-1. 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 controlling can be.

The Control Process

Managerial controlling involves three steps:

1. Establishing performance indicators. By far, establishing a performance measurement system is the most difficult step in controlling. Once the system is established, the other

steps merely follow through with the required actions to maintain the plan's objectives. Thus the other two steps are subordinate.

2. 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. The development of work measurement standards is discussed in Chapter III.

3. 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 and/or the control must be redesigned.

A flow diagram of the control process is depicted in Figure 1-2. The process begins with planning and the determination of objectives. Next the controls (performance indicators) are designed based on these objectives. Finally, the plan and controls are applied to fleet operations through management direction. If the fleet's performance indicators are satisfactory, the process flow takes the path indicated in Figure 1-2 by the far right hand loop. If the performance indicators do not meet the standards, then the fleet manager must decide whether the deviation from the standard can be corrected or if the plan and/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 and/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 Chapter IV of this report typical candidate 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

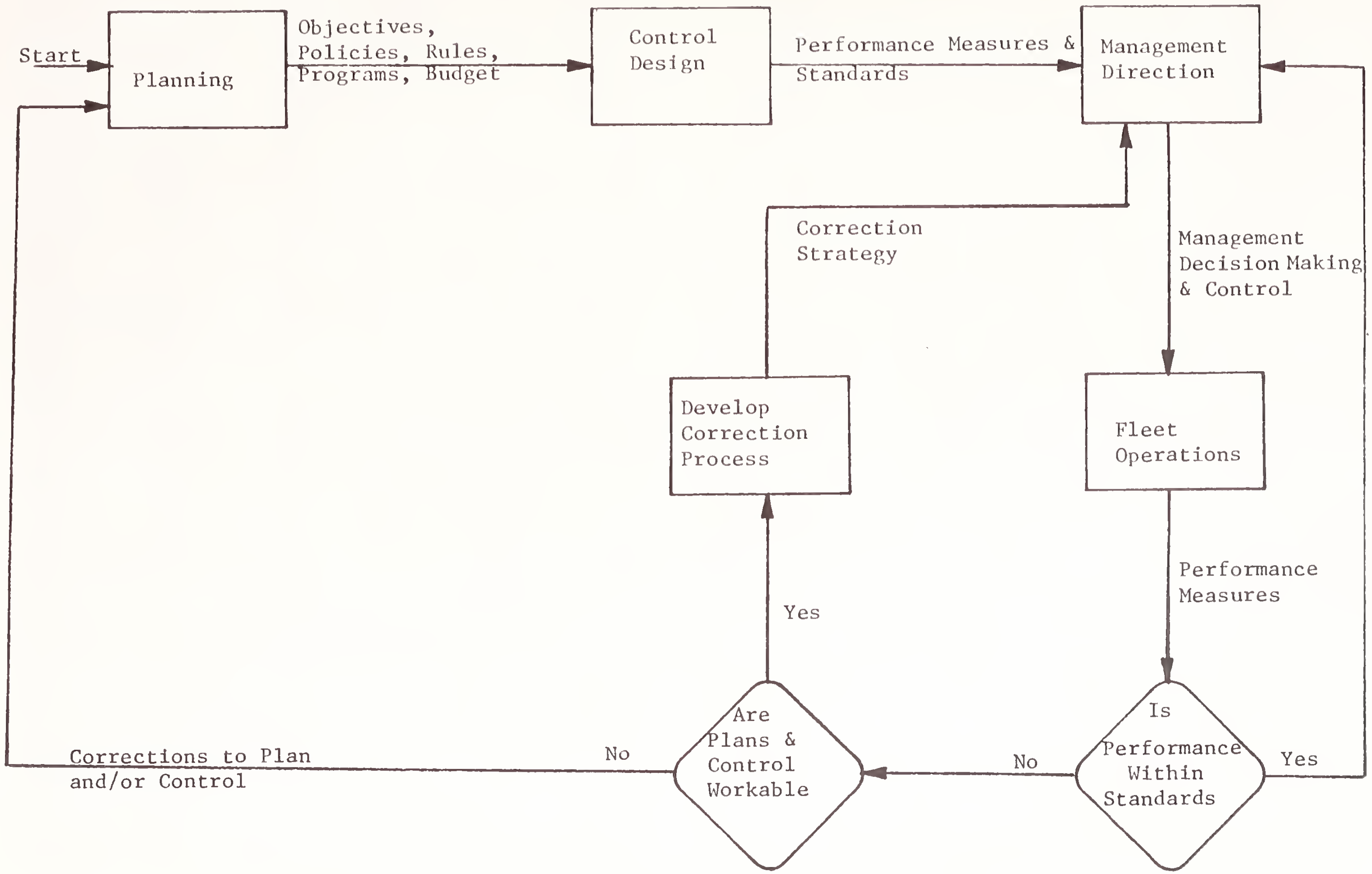


Figure 1-2 Flow Chart of the Controlling Process

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 (quarts or gallons per mile) should be monitored frequently, preferably every day and reported the next day. Other performance indicators, e.g., miles between road calls, will be timely even if they are collected less frequently (i.e., weekly, monthly, or even annually). Whatever the time period, for the performance indicator to be useful in management decision-making, it should be management's 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. A rise in the number of open work orders may bear little significance to the performance of the maintenance department. A rise 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 indicate 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 when a performance measurement 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 repeats or misdiagnosed. Subjective and judgmental measures 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 collection must have clear and accurate definitions. This is particularly true if measures 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, where 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 the control measures should be easily identified. Measures that are based on complex formulas, advanced mathematics, or sophisticated theories may fail to communicate their meaning to front-line management. Direct measures and simple ratios are the most readily understood.

Applications of Performance Indicators

This report covers two areas of application of fleet management control: 1) Individual vehicle mechanical and cost performance indicators (e.g., vehicle reliability, maintainability, and availability), and 2) Performance indicators for the maintenance system (e.g., work effectiveness, worker productivity, and management control). These two areas, vehicle performance and maintenance system performance, are interdependent. For example, the introduction of buses which 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 of the maintenance system and vehicle performance also may be divided with regards to their application to short and long-run management decision making. The distinction between short and long-run is largely a matter of their scope. The short-run covers decisions that assume the fleet composition will remain fixed, while the long-run spans a period where vehicles will be replaced and/or the fleet will be expanded.

Short-Run Applications. In the short-run, the fleet manager can use vehicle and maintenance performance indicators to guide the application of management actions on a daily, weekly, monthly, or yearly basis. The manager should use these indicators like a navigator uses a compass. When the navigator's compass indicates that the vessel is not on course towards its objective, the navigator takes corrective actions. Similarly, the manager should monitor the performance indicators to determine if the maintenance department is deviating from its objectives and make corrections to redirect the course of the department.

Long-Run Applications. In the long-run, the fleet manager makes adjustments to the composition of the fleet, which involve capital expenditure decisions. Past information on vehicle operating and maintenance costs and cost projections are performance indicators to be used in making equipment capital expenditure decisions. Fleet capital expenditure decision-making rules generally follow economic common sense: replace old vehicles when their average total cost (capital plus operating cost per mile) exceeds the expected average cost of new or rehabilitated vehicles, and procure new vehicles that are the least expensive to purchase and operate. In a complex organization, distilling cost data down to the unit vehicle level, where it becomes useful information for capital expenditure decision making, may be complicated and difficult. However, the allocation of costs to individual vehicles and vehicle models provides an important performance indicator for long-run, fleet management decisions. Vehicle replacement analysis is reviewed in Chapter V of this monograph, "Life Cycle Costing."

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CHAPTER II

THE ANALYSIS OF MAINTENANCE MANAGEMENT INFORMATION

The primary purpose for collecting maintenance system information is to support management controlling. That is, control information is collected to determine whether or not planned objectives are being achieved. In this chapter the benefits of maintenance management controlling are examined. Controlling activities are generally found to provide significant cost savings.

Just as the control information itself is important, so too is the planning and development of control information collection systems. With a plan, the maintenance manager can map out the information system, either computer or paper-based, and engineering the system so that it is capable of providing the desired control information. Without a plan, the maintenance manager is placed in the imprudent position of trusting that the system will fit together with ad hoc guidance. A five stage process for developing an information collection system is presented in this chapter.

This chapter includes a demonstration of a graphical information system planning tool. This graphical tool acts like a road map of the desired information flows and uses a set of only four symbols to present information. Therefore, it is easily understood and even those who are not familiar with computers can participate in planning a computer-based information system. The chapter concludes with applications of this technique to an actual transit maintenance department.

MAINTENANCE CONTROLS

All collected maintenance information is part of the management control system. However, controls or performance indicators vary greatly in scope and objective. In this chapter controls are categorized with regard to scope. In Chapter IV performance indicators will be examined with regard to their objectives (e.g., measuring the mechanical reliability of buses or measuring the productivity of labor). There are two types of controls, direct and indirect, and they are described as follows.

Direct Controls

These are simple performance indicators which independently provide information regarding the maintenance system's performance. For example, 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 are often simple ratios or indexes; they are easy for management to interpret and therefore, they 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

These are data which are collected, summarized into statistics, and used in decision making. The summarized statistics can be used as performance indicators, but not the original data without some interpretation. For example, a maintenance manager should collect the failure mileage for each major bus component that fails, e.g., air compressors. Since failures are random events, the fact that one failure occurred 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 components have failed and the mean mileage between failure is calculated, the manager can use the mean miles between failures in management decision making. For example, if the mean mileage between failures of air compressors is unusually low, the maintenance manager should investigate the cause, to determine whether it arises from poor quality replacements, improper preventive maintenance, and so forth. 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.

Both types of controls are performance indicators which have a crucial role in promoting the success of a maintenance management plan. Using these controls requires that the appropriate data to support management plans are collected and stored. Collecting these data requires that the information system be planned to reflect these needs. For example, an information system (either paper-based or computerized) which does not provide information in sufficient detail may not be able to provide the level of controlling desired. The system which provides too much detail may be cumbersome and inconvenient to use in controlling.

THE VALUE OF MANAGEMENT INFORMATION

Information is the part of data which is used to increase knowledge of the maintenance system. Through the use of information in controlling, the manager gains sufficient knowledge of the system's status to permit periodic managerial adjustments. The key to conducting managerial control is the orderly and efficient collection and storage of data. It is not necessary that the data collection system be computerized to be useful. However, a computer reduces the labor costs associated with data collection, storage, and processing. Therefore, a computer's main contribution to management controlling is that it allows the manager to conduct analysis that would be uneconomical if done by hand.

Productivity Gains Using Direct Controls

No transit industry examples were found in the literature which documented the cost savings or productivity gains that are possible through implementation of a structured management information system. However, there are documented examples of cost savings in closely related organizations in similar settings. For example, Becker and Hayden (2) found that truck fleet maintenance operations experienced cost savings ranging from 15 to 45 percent of total maintenance costs when structured maintenance management control practices were instituted with the assistance of a well-designed management information system. In their study of equipment owned by state highway departments, Byrd, Tallamy, MacDonald and Lewis (12) found that the introduction of a structured management information system generally reduced the labor and material costs of highway equipment maintenance by ten and 25 percent, respectively. In both the trucking industry and the highway equipment examples, the authors were largely concerned with direct controls.

Productivity Gains Using Indirect Controls

There are a number of maintenance management procedures which require indirect control information which have the potential for even greater cost savings. These largely involve the use of systems techniques such as inventory theory, computerized forecasting, statistical failure analysis, and work measurement in maintenance decision making and controlling. In a work measurement/methods study by Haenisch and Miller at the Chicago Transit Authority (9), they were able to achieve labor productivity gains in excess of 30 percent through the introduction of time standards. The Canadian Transit Handbook (4) suggests that "the implementation of a work study system in the garage can reduce labor content from 15 to 25 percent, depending on initial conditions."

In another study which was based on computer simulation, Dutta, et al. (6), found that systems techniques can have dramatic impacts on maintenance system performance. For example, they found that the introduction of work load scheduling and simple maintenance job prioritization rules (based on the expected number of labor hours a maintenance job will require) can decrease the average number of buses out of service and waiting for maintenance work by as much as 20 percent.

There are similar examples in closely related areas of maintenance. For example, the American Public Works Association Equipment Management Manual (1) states that "a study of local equipment management practices by the APWA concluded that millions of dollars could be saved annually through the utilization of existing knowledge and the application of proven systems techniques." However, the key to applying any systems analysis techniques is the availability of quality information.

Summary

Clearly, the collection of information to support performance indicators for management control of maintenance systems is a beneficial activity which makes it possible to apply systems analysis techniques to maintenance management problems. However, the information collection system must be capable of providing the level of information detail required to control the maintenance system. In the development and evaluation of an information system it is important to systematically examine data collection procedures to determine how best to collect the desired control information.

INFORMATION SYSTEM DEVELOPMENT

The orderly development of any information system, paper or computer based, should go through five stages. The progress through these stages is generally more formal for the development of computerized systems because of the hardware and software costs, and the institutional agreements involved. For example, if a flaw is found in a paper-based collection system, the manager needs only to revise manual procedures or redesign the data collection forms. With a computerized system, however, a revision may require new hardware or expensive rewriting of computer programs.

Regardless of whether or not the information system includes a computer, system development should go through the following five stages:, which are adapted from Matthews (11):

1. Conceptualizing: This involves the determination of a set of objectives for the maintenance department, and, hence, what is expected of the information system. These objectives are first determined as part of the management plan. The management plan establishes the need for controlling and indicates what aspects of performance should be measured.

2. Planning: This is the determination of information needs and evaluation methods. Planning should result in a system performance specification.

3. Designing: This is the determination of the actual system to be used to collect information. When developing a paper-based system this should include the design of forms and record keeping procedures. When a computerized system is being developed, the design should include the determination of hardware and software required to meet the performance specifications. Issues considered during the design stage include the system organization, agency procedures, and staff training.

4. Implementation: During this stage the new information system is installed. Transit agency staff become operational

in its use and the "bugs" are worked out of the system.

5. Maintenance: This stage covers the life of the system after the system builders are done with implementation.

The Need to Plan Paper-Based Systems

Most transit systems which have utilized paper information systems have not systematically engineered the forms, record keeping systems, and procedures used to collect maintenance information using the five steps listed above. Paper-based systems have more often evolved in a piecemeal fashion over time. The greatest difficulty with a piecemeal approach is that it does not permit the comprehensive design of the paper flow and data collection. In investigations of some transit maintenance paper-based systems, the lack of an overall design was evidenced by collection systems which did not collect crucial information (e.g., labor times for mechanic tasks) or where data elements had been included in the system that are no longer used. Collecting unused data generally resulted in apathetic recordkeeping and slipshod records.

The primary reason for planning a paper-based information system is to develop a system which is engineered to provide the information necessary for controlling. Planning will also assist in identifying the points in the data flow where data are most easily collected. The planning of a paper-based system allows the maintenance manager to comprehensively and systematically develop and review the entire maintenance information system.

The Need for Planning Computerized Systems

It is crucial to design a computerized system which meets the needs of management for controlling information. Once a system is in place, it is quite expensive to revise the software system and/or purchase different computing equipment. In other words, it is vital that the system is clearly planned such that the control information needs are met.

During the first two stages of the system development (Conceptualizing and Planning), the maintenance manager must take a leading role. The reason for this is that computer experts and system salespersons do not understand the maintenance department's information needs as well as the maintenance manager. Conceptualizing should primarily focus on the objectives of the maintenance management plan which require controlling. Planning of the information system is carried out to develop a performance specification which produces the performance indicators identified in conceptualizing. In the three remaining stages (Design, Implementation and Maintenance) the computer experts can take a leading role with continuing guidance from the maintenance manager.

To further demonstrate why it is important for the maintenance manager to be involved at the very beginning, consider the cost of making computer system changes after the system has been installed. Figure 2-1 shows the relative cost of fixing computer information defects during each of the five stages. For example, an error found during the Planning stage may have a relative cost of 1.0 (say $100). To correct it later, in the Maintenance stage, this same error may have a relative cost of 16.0 to correct ($100 x 16 = $1,600). Therefore, it makes sense to identify the maintenance management controlling needs in the early stages of development. Once a system is implemented it may be too costly to change it to the way it should have been in the first place! In other words, transit agencies can't afford to wait for their staff to "see what they get" before they "know what they want."

INFORMATION SYSTEM PLANNING

Planning an information system begins by developing a functional specification. The functional specification should be developed independently of the design of specific functions or features. Planning should consider the inputs, outputs, processes, and data sets that will be included as part of the information system. The difficulty in developing the system specification lies in presenting information needs and desires in a format that can be easily understood.

In this section a graphical planning tool is demonstrated with application to an actual transit maintenance system. The technique, adapted from Gane and Sarson (7), uses diagrams rather than words to construct the specification. To understand why this graphical approach is much easier than a written description of all the specifications, suppose that the specifications for a building had to be written rather than charted with blueprints. It would take hundreds of pages of text to describe the dimensions and locations of each door, window, wall, column, joist, etc. A graphical plan can provide the same information much more succinctly. The same is true with information systems. As the old saying goes, "a picture is worth a thousand words."

Data Flow Diagrams

The data flow diagram has only four types of symbols, each representing an activity in the flow of data. To illustrate each one, consider a simple example:

A bus driver reports a mechanical problem on a bus and triggers a chain of events which eventually results in the bus getting fixed. For now, consider only what happens when the shop foreman receives the notice of the problem.

The driver submits a defect card at the end of the shift which notes "soft brakes." The defect card goes to the shop

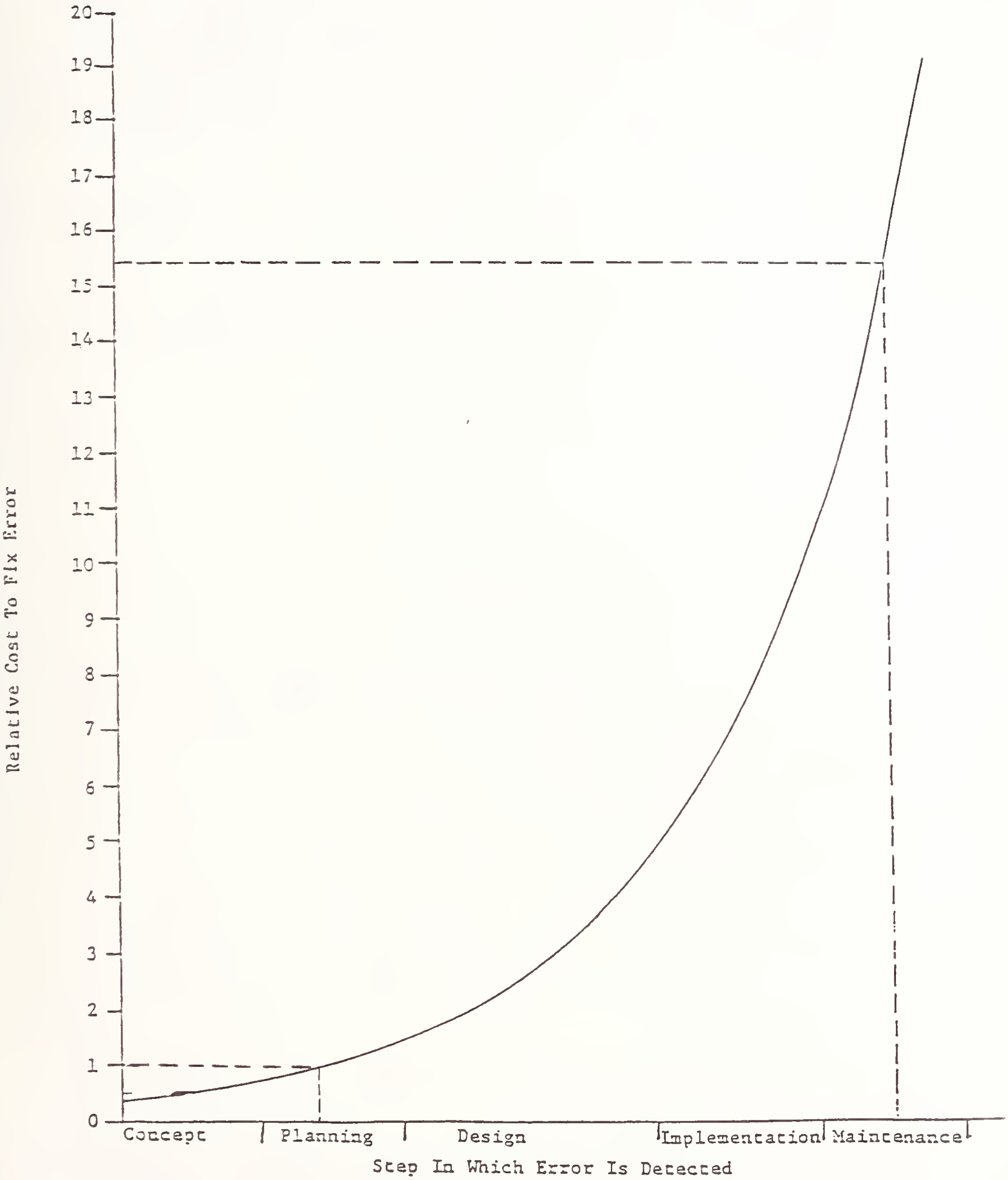


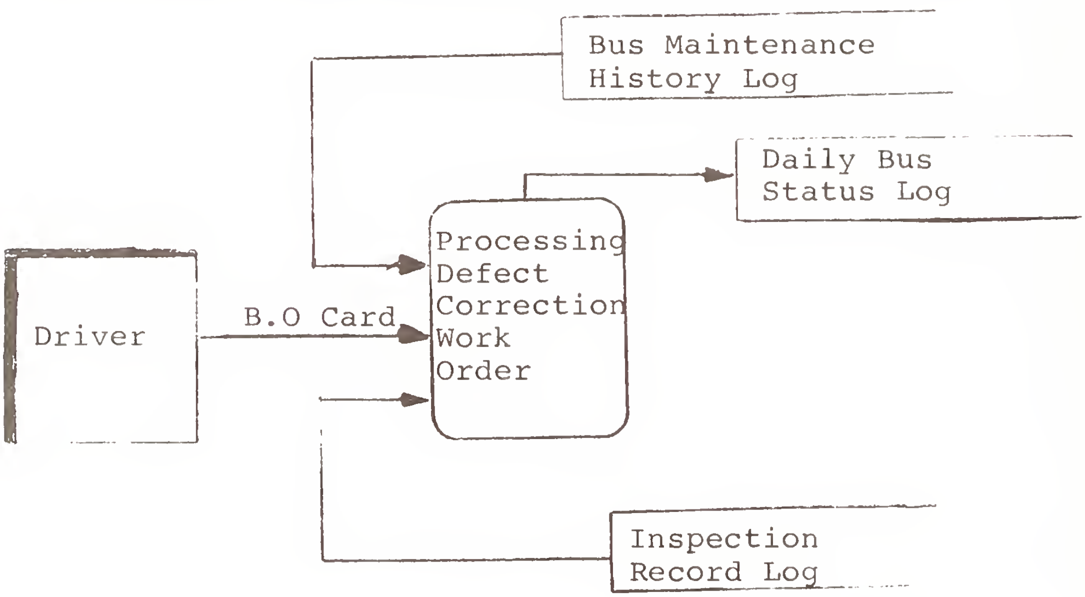
FIGURE 2-1

THE RELATIVE COST TO FIX AN ERROR AT EACH STAGE foreman (an "information flow"!) who must decide on a maintenance action. The shop foreman might check the bus's maintenance history to see when the brakes last were inspected or repaired, another information flow. Next, the foreman decides whether the bus should be taken out of service until it is repaired ("dead status") or if the bus can make tripper runs ("deferred status") while waiting for maintenance. The foreman changes the status of the bus and writes a work order indicating that the bus's brakes must be checked, two more information flows.

To diagram these information flows, it is first necessary to identify each flow and activity:

1. The defect card is generated by the driver.
2. The defect card goes (flows) to the shop foreman.
3. The foreman responds by checking the bus maintenance history and inspection log.
4. The foreman then posts a new status for the bus (dead, deferred or active).
5. The foreman submits a work order to the maintenance shop.

The diagram below shows this flow of information.



This diagram uses just four symbols. Their meanings are:

1. Double Square: The double square is an external source or destination of information. In this example the driver is considered to be external to the maintenance system but this was simply a matter of choice. Alternatively, drivers might be considered part of the maintenance system.

2. Arrow: The arrow represents a data flow. These can be identified in existing paper maintenance systems as forms which transmit information that is later recorded somewhere else. For example, the defect card or the work order are messages that are of temporary value and they only provide data about one bus. Later, the results of the action taken in response to the message are recorded or used somewhere else. A data flow may be the physical flow of information on paper forms or the flow of electronic messages in a computer system. For example, the parts inventory can be manually updated on filing cards by reading parts numbers off the work order or the inventory records can be automatically updated when work order data is key punched into computer terminals.

Arrow Data Flow (Message)

3. Rounded Rectangle: The rounded rectangle shows that the data is processed. In the example, the shop foreman gets the defect card and starts processing data by figuring out what should be done. While deciding what to do (processing), the foreman may look at other records, in this case bus inspection and maintenance records. The results of the foreman's process is a change in the status of the bus and a maintenance work order. Processing may also represent computerized action. For example, the daily recording of fuel consumption, posting fuel usage to vehicle records, and flagging exceptionally high fuel users could be a manual or computerized process.

Process Which Transforms Data

4. Open-Ended Rectangle: The open-ended rectangle stands for a data store. A data store is where information is kept. For example, the bus status log keeps data on several buses and even though it changes from one day to the next, it is a long term record of the work flow. The status log could be kept on a sheet of paper or stored on a magnetic computer disk file.

Open-ended Rectangle	Store of Data

The data flow diagram uses only these four symbols. In the Planning stage it is not necessary to translate these flows, processes, and data records into computer or manual procedures or functions. The diagram simply describes the relationship between the various functions of the system. Later, in the Design stage, the details can be figured out.

With the data flow diagram one need not worry about including procedures to double check for common mistakes which could be made when recording data. For example, on the defect card the driver may enter the wrong bus number. While processing the defect card, a check should be run to see if the driver was actually assigned to the indicated bus. Although these checks are important, they do not need to be considered at the data flow diagram stage

With data flow diagramming it is important to be cognizant of the level of the diagram. For example, when planning the collection of data and processing the data to develop maintenance performance indicators, high level data flow diagrams should deal in the specific details of the generation of each type of indicator (i.e., indicators of labor productivity equipment maintainability equipment, availability, etc.). Low level diagrams should be more broad in scope and may only show performance indicator reports being generated and going to management. On higher levels, the data flows should show more detail. The level of detail depends on the level of the diagram. The least detailed diagram should be drawn first and it should cover the entire system. For example, in the case study illustrated in the next two sections of this chapter, first a low level diagram is drawn which details all current maintenance data flows, later a higher level diagram is drawn which considers only maintenance job flow scheduling and appraisal of mechanical work completed.

Data flows and data stores also have levels of detail. In the above example, the defect card was shown flowing from the driver to the processing of defect correction work orders. The defect card will contain several pieces of information, such as the bus number, the symptoms of the defect (e.g., soft brakes), the driver's identification, the date, the time, and possibly other related information (e.g., the run the driver was assigned to). All these pieces of data are known as data elements. Similarly, the pieces of data in a data store are known as data elements. The elements that belong to each data flow and to each data store are defined in a data dictionary. Data dictionaries are discussed in the concluding section of this chapter.

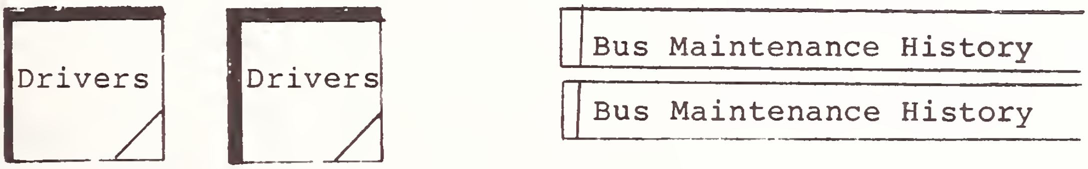
Guidelines for Drawing the Data Flow Diagram

To illustrate the drawing of a data flow diagram, an actual, small transit system (60 buses) is used as an example, the Metropolitan Transit Authority (MTA) of Wichita, Kansas. This example makes no attempt to approach the technical level of a computer programmer or a system analyst.

When drawing a data flow diagram, there are five conventions to always remember.

1. Do not cross data flow lines if possible.

2. In order to avoid crossing lines, it is acceptable to draw external entities and data stores twice or more. To indicate that the same external entity or data store appears more than once in the data flow diagram, draw a line in the corner of the external entity symbol and a line across the left end of the data store symbol as shown below.



3. To help identify a process put the title of the individual doing the process at the bottom of the rounded rectangle as shown below:

4. A minimum of three drafts of the data flow diagram should be made. After completing each draft of the diagram, one will find ways to improve it and find data flows that were overlooked.

5. Neatness does not count!

Starting the Data Flow Diagram

Where to start the designing of a data flow diagram largely depends on what is presently being done. Presumably, most transit agencies at least have a paper-based work order system. Therefore, most fleet managers have some kind of record keeping system to start with.

To provide an example, the paper-based information system at the Wichita MTA is used. The first level diagram covers the entire maintenance information system. Lower level diagrams illustrate generalizations of the information system segements (e.g. material and parts management). Higher level diagrams provide more detail on data flow and have corresponding data dictionaries which detail the data elements within the data flows and data stores.

To start the data flow diagramming process, all the forms used by the MTA maintenance department in its activities are first collected together. Using the paper forms, a description of the external entities, the data flows, and the data stores is developed.

External Entities. The external entities are easily defined because they are individuals who start the paper flow but are external to the maintenance system. A driver submitting a defect card may be considered an external entity. By submitting a defect card, the driver starts the paper information flow.

Sometimes it is not clear whether an entity is external or not. For example, the fuelers start a paper flow by submitting a fueling and fluids consumed report. Whether the fuelers are external or internal is simply a matter of definition. The external entities used for the MTA example are:

Drivers
Dispatcher
Fuelers
Maintenance and services contractors
Parts vendors
Transit system management

Data Flows. In a good paper information system, almost all data flows will be represented by a form or report. For example, the driver's defect card is a form that transmits data. However, even at the best managed transit properties not all data flows are formalized with their own form or report. For example, at the MTA the night fuelers occasionally spot a defect that a driver did not report. If the defect is minor, the fueler will fix the defect. If the defect is major, the fueler will change the status of the bus on the daily work sheet (a status log of the condition of each bus that is waiting for maintenance) and leave a note for the shop foreman. The next day the dispatcher sees that the status of the bus has been changed so it is not assigned to a driver. The shop foreman finds the note and writes a maintenance work order. Although information flowed from the fueler to the shop foreman, the MTA has no specific form or report for this information flow.

Another subtle example of data flow occurs during the requisition of a part. The mechanic asks the parts man for a specific part. This request is a data flow. In the next step the parts man "processes" the verbal request by looking up the part number and its availability. The second data flow is the availability or unavailability (stock-out) of the part. The next process is to get the part if it is available. Thus, the parts example illustrates two data flows that are verbal and have no forms: 1) the parts request and, 2) the availability or unavailability of the part.

To identify the data flows, start by identifying and classifying all of the paper forms. The following is a list and description of all the MTA forms and reports that are considered to act as data flows.

1. Driver's Bad Order (Defect Card. These are used by the driver to describe mechanical defects on their bus.

2. Notice of an Inspection Due. This is sent from the bookkeeper to the shop foreman and indicates that a bus is approaching the mileage level where another inspection will be required.

3. Notice of Inspection Completed. This is sent from the shop foreman to the bookkeeper and it indicates that the inspection has been completed. The bookkeeper starts accumulating miles until the next inspection.

4. Fueling Sheets. This report is generated by the nightly fuelers and contains the fuel and fluids (i.e., oil, coolant and transmission fluid) consumed by each bus. This report is given to the bookkeeper.

5. Bus Line Report. This report is generated by the nightly fuelers and identifies the location of each bus after fueling and cleaning. The report is given to the dispatcher.

6. Daily Mileage Report. The daily mileages accumulated by the bus are based on route miles. The dispatcher creates a report of all mileages accumulated by all the buses and the report is given to the bookkeeper.

7. Work Orders. Work orders are the heart of any maintenance information system, paper or computerized. A work order is a written history of each individual maintenance action. From the work order, information is later collected as in-

puts to summary reports. At the MTA, work orders are used to transmit data in a number of ways. Below are listed each of the distinct ways a work order is used to transmit information. In the data flow diagram each will appear as a separate data flow.

a. The work order is used to tell the maintenance department to process a bus inspection.

b. The maintenance department uses the work order to tell the shop foreman that the inspection was completed and that the bus is okay or that further maintenance work is needed.

c. The work order is used to tell the maintenance department to correct a bus defect.

d. The work order is used to tell the shop foreman that a bus's defect was corrected and what was done to correct the defect.

e. A work order is used to tell a maintenance contractor to perform a service (e.g., rebuild a transmission or dispatch a tow truck to a road call).

f. The work order is used to show the shop foreman that the maintenance contractor has completed his service.

g. The work order is used to transmit to the bookkeeper the direct costs (labor and material costs) of an inspection, maintenance task, defect repair, or contracted maintenance work.

8. Purchase Orders. These are used to purchase materials from vendors. Purchase orders provide several types of data flows. They are:

a. The purchase order requests the vendor to deliver material.

b. The returned purchase order tells the parts man to add the material to the inventory records and to create parts cards.

c. The purchase order is finally transmitted to the bookkeeper and the bookkeeper processes payment of the vendor.

9. Parts Cards. These are cards attached to each part in the inventory. The card lists the part number, cost, verbal description, the bus on which the part was used, and the date of its installation. Parts cards have two information flows. They are:

a. When the part is requisitioned, it goes with the work order while the defect is corrected.

b. When the work order is returned, after the defect has been corrected, the parts card supplies the part's direct cost information.

10. There are several end-of-the-month reports generated which provide management information. Each report is processed by the bookkeeper. These monthly reports are:

a. Fluids and fuel used per month and current inventory levels.

b. The monthly mileage, fuel and oil consumption quantities per bus and per mile.

c. The total monthly fuel, oil, parts, and maintenance labor cost, miles and cost per mile by the entire fleet, by bus model type, and by bus.

d. Parts purchased and parts cost by purchase order or contract.

There are several more data flows other than those represented by forms. These are general verbal data flows or flows from a data store to a process. For example, when the shop foreman receives a card from a driver reporting a defect (e.g., slipping transmission), the foreman will probably look the bus up in the maintenance history. The information found in the history log is a data flow. Such data flows will become obvious when drawing the data flow diagram.

Data Stores. Data stores can be easily identified because they contain information gathered from several individual data flows. For example, the bus maintenance history ledger summarizes the results of numerous work orders. The data stores identified at the MTA are:

1. Daily Work Sheets. This sheet lists the status of buses that currently require maintenance. As buses require maintenance work they are added to the list and when repaired they are taken off the list. The list also defines the status of a bus. For example, a bus with a cracked tail light cover can be used in service but eventually needs to be brought in for repair. Such buses are given tripper status which means that the dispatcher can assign the bus to tripper runs, thus making the bus available for the majority of the day. Buses with more serious defects are assigned dead status, thus stopping the dispatcher from assigning the bus to any run. Buses that are not repaired during that day are transferred to the next day's work sheet.

2. Parts Card File. In this file there is a card for each part. The card lists when parts are received and disbursed, how many are on hand, the vendor and the part cost.

3. Daily and Monthly Miles, Inspection and Fuel. This is an accumulative log of the fuel and fluid each bus has consumed each month and the miles each bus has accumulated since the beginning of the month, and since the last inspection. At the end of the month the miles since the last inspection are carried over to the next month.

4. Bus Maintenance History Ledger. Once a work order has been processed, component and major part replacements are posted to the bus maintenance history ledger. The information on the ledger is the date of the repair, the mileage of the bus and serial number of reusable parts and components.

5. Inspection Record Log. When the shop foreman receives an inspection notice the receipt of the notice is added to the inspection record log. This record is used to determine which type of inspection should be done next (e.g., 3,000, 6,000, 12,000 mile inspections).

6. Annual Cost Ledger. This ledger contains all of the monthly sums of parts, labor, fluid, fuel and contract service costs per bus (direct maintenance and operation costs). The total costs are produced on an annual basis from this ledger.

Drawing the Data Flow Diagram

The next step in preparing to draw a first level data flow diagram is to list out each of the data flows and determine what process, data store or external entity the data flows links together. Specifically, on both ends of the data flow arrow there must be a process, data store or external entity. The MTA's list is shown in Table 2-1.

With this information collected the data flow diagram can be drawn. Find a big sheet of paper, a table, and pencil. Then start with an external entity and start tracing the data flows. The second draft is shown in Figure 2-2 and a final draft (drawn with drafting tools) is shown in Figure 2-3.

Drawing the data flow diagram was simply a matter of connecting the processes and data stores with data flows. Now that the data flow diagram has been drawn, it is wise to have others check it over for accuracy and make the necessary corrections. Spend a few minutes inspecting the diagram and see if it looks like the data flow at your maintenance system.

TABLE 2-1

LIST OF DATA FLOWS FOR THE MTA

Generates Data Flow	Data Flow	Receives Data Flow
Driver	Driver's bad order card	Shop foreman processing defect correction work orders
Bookkeeper Processing monthly miles and inspection records	Notice of inspection	Shop foreman processing inspection work order
Shop foreman processing inspection completed work orders	Notice of inspection completed	Bookkeeper processing monthly miles and inspection records
Fuelers	Fueling sheets	Bookkeeper processing monthly miles and inspection records
Fuelers	Bus line report	Dispatcher
Dispatcher	Daily mileage report	Bookkeeper processing monthly miles and inspection records
Foreman processing inspection work orders	Work order initiating inspection	Maintenance personnel processing inspections
Maintenance personnel processing inspection	Work order for completion of inspection	Shop foreman processing inspection completion work orders
Shop foreman processing all completed work orders	Work order initiating correction of defect	Maintenance personnel processing defect corrections
Maintenance personnel processing defect corrections	Work order indicating correction completed	Shop foreman processing defect correction work orders

(continued)

TABLE 2-1 (continued)

Generates Data Flow	Data Flow	Receives Data Flow
Shop foreman processing contract work orders	Work order indicating required contract services	Maintenance contractor
Maintenance contractor	Work order indicating completion of contract service	Shop foreman processing completion of contract work orders
Shop foreman all work order completion processes	Work order used to transmit direct costs	Bookkeeper processing monthly cost reports
Parts man processing requisition from vendor	Purchase order to vendor	Vendor
Vendor	Purchase order material received	Parts man processing inventory update
Parts man processing inventory update (entering new parts in card file and creating parts card)	Purchase order for payment	Bookkeeper processing payment and posting to monthly reports
Parts man processing parts requisition	Parts card assignment to defect correction	Maintenance personnel processing defection correction
Maintenance personnel processing defect correction	Parts card with completed work order	Shop foreman processing defect correction work orders
Bookkeeper processing monthly reports	Monthly reports	Management

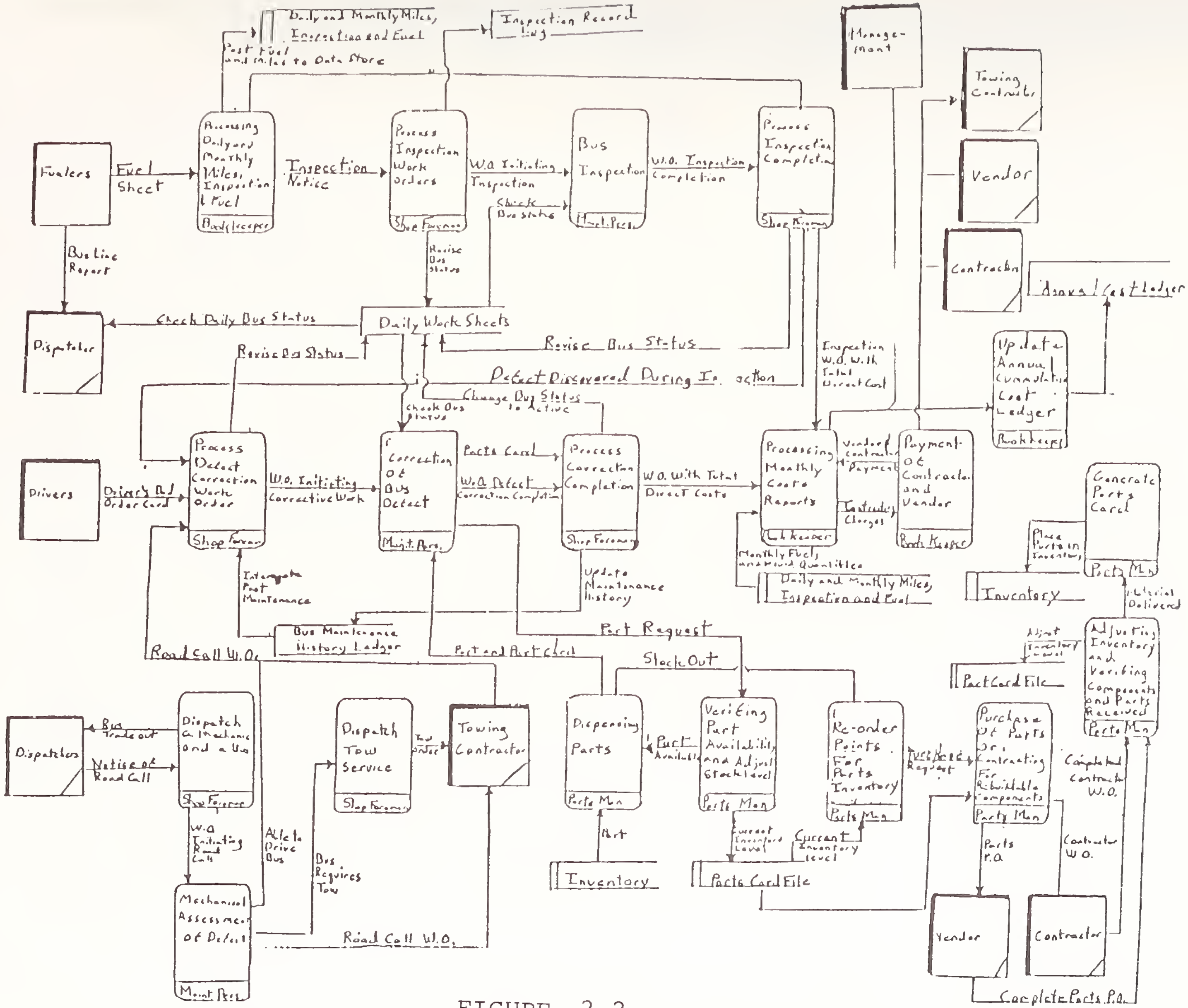


FIGURE 2-2

SECOND DRAFT OF THE DATA FLOW DIAGRAM

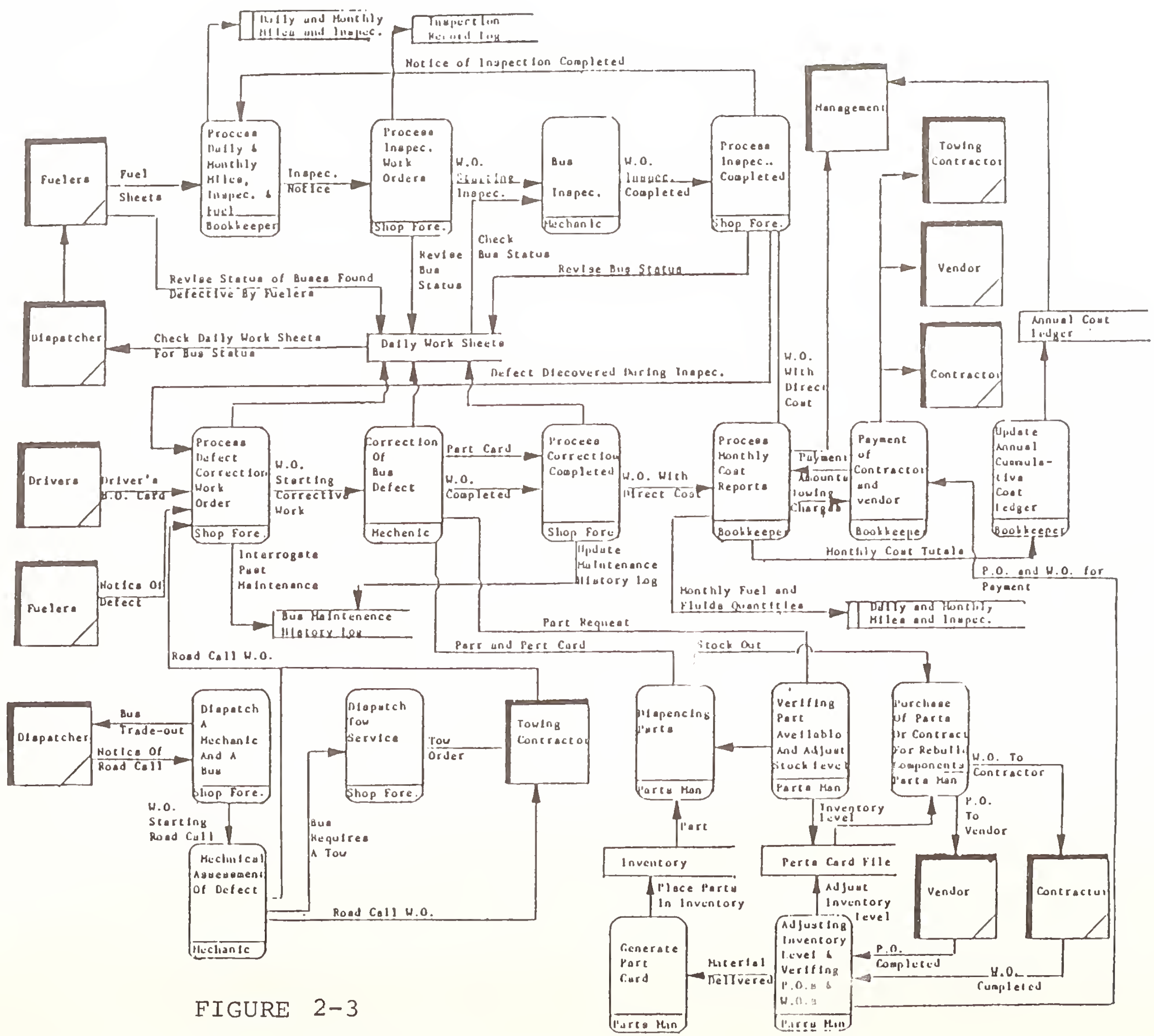


FIGURE 2-3

THIRD DRAFT OF THE DATA FLOW DIAGRAM

PLANNING NEW INFORMATION SYSTEM CAPABILITIES

Now that the old system has been diagrammed, it can be used as a basis for planning system improvements. To serve as an illustration, suppose that corrective work management and corrective work flow scheduling have been identified as areas for potential improvements and cost savings. Planning these improvements includes developing procedures related to the processing of corrective maintenance work orders. Examples of methods to support processing of work include the use of job time standards, systematic job scheduling based on job labor content, and the review and appraisal of individual jobs to facilitate the identification of training problems and work method problems. However, the application of any of these methods is dependent on better information.

Planning the new information system will require a higher level data flow diagram covering the corrective work flow management segment of the comprehensive diagram. As a first step in diagramming this segment, a list should be made of the new desired processes. Later, the new data flows and data stores will be determined. The new processes include:

1. Scheduling of work based on labor content of the jobs and available resources (labor, materials, and facilities).

2. Appraisal of the individual jobs in comparison to performance standards.

To be able to conduct both of these processes it is necessary to create some support systems for each process as described below.

Scheduling

To be able to schedule, the scheduler requires three inputs: 1) the labor content of the job being scheduled and the labor content of other jobs not currently assigned to a mechanic, 2) the amount of available resources (labor and facility resources), and 3) the priority for scheduling jobs to mechanics and mechanic assignment.

1. Measuring Job Labor Content. Making an estimate of the time duration of a job requires an accurate diagnosis of the defect and time standards for defect correction. Therefore, at least one new data store must be created, a list of time standards, and two new processes must be developed: defect inspection/job diagnosis, and the use of time standards to estimate job labor content, material and facility use estimates. The estimated labor content of each job must then be added to the content of jobs already waiting for corrective work and the labor content of scheduled preventive maintenance jobs. Therefore, there must be

third process which totals the amount of work in the backlog and categorizes it by job type (preventive or corrective), labor classification required to conduct the job (e.g., A, B, or C level mechanic), or other relevant categories.

2. Availability of Resources. Based on estimates of the labor content of already scheduled jobs in comparison to the amount of labor hours available, projections can be made of the future availability of labor and facilities to be scheduled to new jobs. This will necessitate at least one new process, the calculation of the likely future availability of resources. This calculation will require access to two data stores, the projected labor commitment to corrective maintenance jobs already assigned, and the labor commitments to current and scheduled preventive maintenance.

3. Job Prioritization and Assignment. The order that jobs are scheduled will depend on scheduling policy and current fleet status. For example, one scheduling policy could be to always placing a high priority on scheduled preventive maintenance. Thus, preventive maintenance always has priority over the use of resources (versus corrective maintenance) unless conditions warrant otherwise. Fleet status may drive schedule prioritization. For example, when a larger than normal number of buses are unavailable for service because they require corrective repairs, the buses that can be repaired most quickly should be scheduled for repair first.

   The prioritization and assignment of jobs will require two new processes: one which prioritizes jobs based on priority policies and fleet status, and one which assigns (schedules) jobs to mechanics based on job priority and the availability of labor by labor classification, and the availability of facilities. Prioritization and job assignment will also require access to a data store containing job scheduling prioirities.

Job Appraisal

The purpose of reviewing each job is to be able to document and identify an individual mechanic's performance for each job. Since the usefulness of the appraisal is dependent on the accuracy of the recorded work, a by-product of job appraisal is more accurate maintenance event information.

Once the direct costs (parts and labor) and material quantities have been totaled on the completed work order, the estimated job time (based on time standards) and diagnosed activities can be compared to the actual job times and maintenance tasks performed. Differences should be clarified, which sometimes requires additional clarification by the mechanic. Once all discrepancies have been clarified, the job performance can be appraised. Therefore, job appraisal requires two processes: 1) comparing and clarifying the differences between estimated and actual work, and 2) commenting on mechanic job performance.

Drawing a Second Level Data Flow Diagram

When drawing the existing system, it was easiest to start by listing out all data flows because they were represented by existing forms used to transmit data. However, when planning a new system it is easiest to start by conducting planning while developing the diagram. Before starting the drawing it is known that at least eight new processes and five new data stores are to be included. The new processes and data stores are listed in Table 2-2.

Figure 2-4 depicts the second draft of the corrective maintenance work flow management portion of the data flow diagram. The second draft is reviewed by the planner and others, and several more drafts typically are prepared and again reviewed. Once the revisions are completed, a final draft is drawn with drafting tools. The final draft is shown in Figure 2-5.

DATA DICTIONARY

The last step in information system planning is to create a data dictionary. In the case of a paper-based information system, the data dictionary describes the information that is to be placed on forms (data flows), and in ledgers, logs or record files (data stores). The data dictionary also may be expanded to include a description of the activities that take place during a process. For example, when describing the processing of daily fuel and fluids consumption data, the data dictionary might briefly describe the procedures used to update monthly cumulative records and procedures for flagging vehicles with an abnormal fuel, oil or other fluid consumption rate. The data dictionary then can be used to directly develop paper record keeping and data transmitting forms, ledgers, logs and files.

The data dictionary serves much the same purpose for computerized systems as it does for paper based systems. However, the planner must be more careful when developing the data dictionary for a computerized system because the operation of computers is much more structured. It is generally more difficult to add or delete space for a data element in a computer program than it is to add or delete space for written information on a paper form. Thus, the system planner must take care in accurately defining the data flows, data stores, and data processes before the computer system developer takes over.

Data Dictionary Development

The description of data may be broken down in a hierarchial fashion. The lowest level to be considered is the data element.

TABLE 2-2.

NEW PROCESS AND DATA STORES

New Activity	Process	Data Store
Measuring Job Labor Content	Detect Inspection/Job Diagnosis	
	Job Time Estimates Based On Time Standards	Time Standards
Availability of Resources	Calculating Mechanic Labor Hours In Backlog	Projected Labor Commitments To Assigned Corrective Maintenance Jobs
	Calculate Available Resources	Labor Committed to Scheduled and Assigned Preventive Maintenance
Job Prioritization and Assignment	Schedule Jobs	Scheduling Priorities
	Assign Jobs to Mechanics	
Job Appraisal	Comparing Estimated and Actual Work	Mechanic
	Comment on Job Performance	

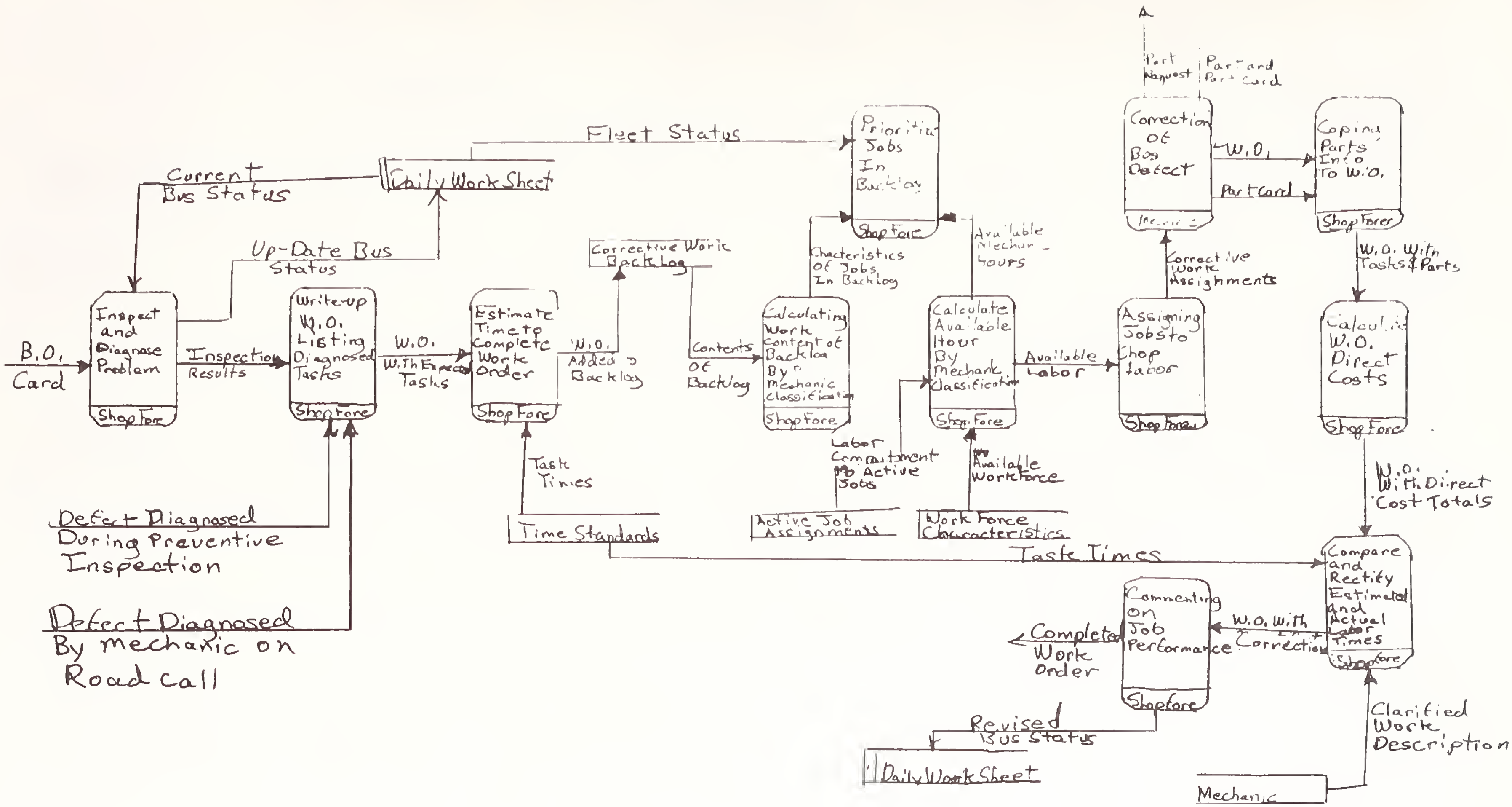


FIGURE 2-4
SECOND DRAFT OF MAINTENANCE WORK FLOW MANAGEMENT SYSTEM DATA FLOW

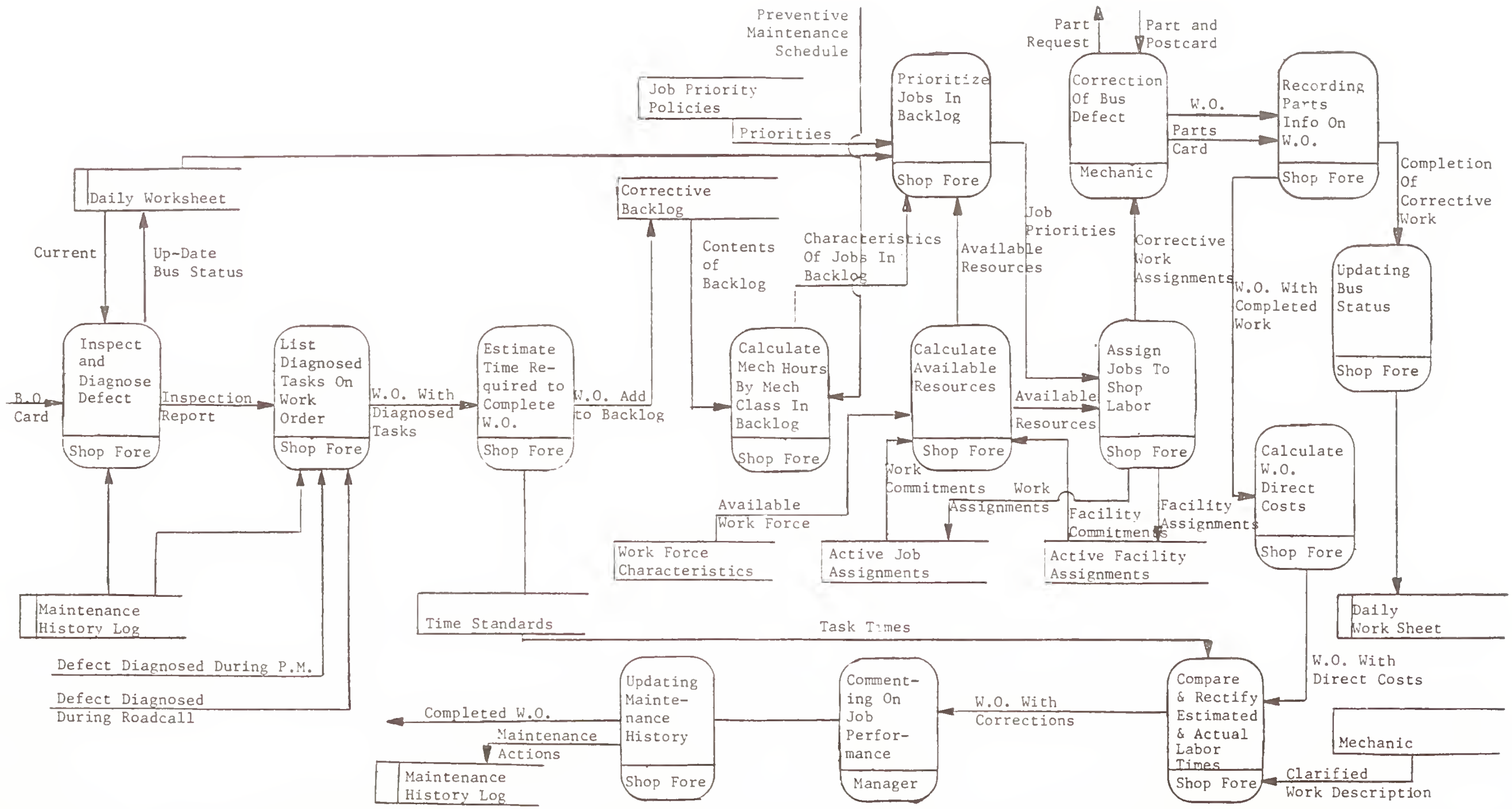


FIGURE 2-5
THIRD DRAFT OF MAINTENANCE WORK FLOW MANAGEMENT DATA FLOW

For example, a work order form should include information which identifies the job in the work flow and associates the job with a permanent maintenance record file. One element of the identifying data should be the bus identification number. Suppose that the bus number for a particular job is 8347. This number is one data element. Even though this data element may contain several associated pieces of information (e.g., the bus purchase date (1983), the model of the bus (GM-RTS II 04), and information describing the drive train and other units), the development of the data dictionary should only concern itself with the individual data element and not the other information that may be contained within the element.

The next level in the hierarchy is the data structure. For example, a work order typically includes several sections: 1) A section which identifies the job within the work flow; 2) A section identifying the tasks conducted during the job (e.g., removed and replaced air conditioner suction hose and serviced air conditioner); 3) A section covering the materials and parts used during the job; 4) A section used to calculate total job cost; and 5) A section for comments.

The functions of each section (a data structure) may be enhanced by including additional data elements. For example, suppose that the maintenance manager wishes to schedule jobs based on the estimated time required to complete the job and he wishes to calculate the time estimate directly on the work order form. The time estimate can be listed and totaled next to the required repairs found during inspection in the section describing the tasks conducted during the job.

The highest level in the hierarchy is the data store or data flow. Data structures and data elements are members of a data store or data flow.

Shown in Table 2-3 is a data dictionary for a work order. At the top is the title for the data flow, in this case, "work order." Beneath the data flow title are the five data structures, and under each data structure are listed the data elements. The data dictionary, as constructed in Table 2-3, could be used to design a work order form. Whether the system being planned is paper-based or computerized, all data flows and data stores should be similarly planned.

CONCLUSIONS

This chapter examined the importance of information to maintenance management. It was found that there are significant benefits that can be potentially accrued through the use of better information in management controlling, both paper-based and computerized systems. However, useful information systems require that the system be planned to reflect the management's needs for control information. The importance of proper planning is even more crucial when the information system is to be

TABLE 2-3

EXAMPLE DATA DICTIONARY FOR A WORK ORDER

WORK ORDER

JOB IDENTIFICATION

Work Order Number
Bus Number
Date When Work Order Was Opened
Date When Work Order Was Closed
Scheduling Priority (Emergency, As Soon As Possible, or Deferrable)
Inspector's Name
Mechanic's Name

WORK DESCRIPTION

Task Description (one for each task)
Job Code Number (one for each task)
Task Time Estimate (one for each task)
Actual Time Required (one for each task)

MATERIAL AND PARTS

Material and Parts Description (One for Each Item)
Material and Parts Codes (One for Each Item)
Material and Part Cost (One for Each Item)

TOTAL JOB COST

Estimated Time Required to Complete the Job
Total of the Actual Time Required to Complete the Job
Total Job Labor Cost
Total Parts Cost
Total Direct Cost for the Job

COMMENT SECTION

Explanations of Differences in Estimated and Actual Job Times
Appraisal of Mechanic's Performance

computerized. Generally, it is difficult to change computer programs and computer hardware when the system is found to be inadequate, unlike the relative ease of modifying and adapting a paper-based system.

To facilitate the development of an information system, an information system planning method, structured systems analysis, is recommended and illustrated using the existing maintenance data flows at the MTA transit system of Wichita, Kansas. Structured systems analysis also is illustrated in the planning of a new information system.

The chapter is concluded with an illustration of a data dictionary. A data dictionary describes the data elements that are to be included in the data flows and data stores.

The following chapter, Chapter III, describes the next step in the development of plans for information systems, the actual design of elements of a maintenance information system. Chapter III examines the development of a data store (time standards) and a maintenance information collection system (the work order and the organization and recording of information collected from the work order).

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CHAPTER III

DATA COLLECTION SYSTEMS

In Chapter One, the role of management planning and controlling was discussed. The activity of collecting control information is inseparable from management planning. As a result, when the quality of control information improves, it is possible to create more detailed plans that cover a longer duration. Detailed planning and higher-level decision-making uses of maintenance control data are where the most substantial payoffs can be accrued to an organization since they affect performance and cost of operation months and years into the future.

In this Chapter, two data collection systems are covered: 1) Work measurement systems; and 2) Maintenance event (e.g., failure base unit replacements, preventive inspections, preventive overhaul, etc.) collection systems. Work measurement systems provide both direct and indirect control information to better manage maintenance labor and to facilitate the identification of maintenance costs. Maintenance event collection systems provide both direct and indirect control information covering maintenance events and their frequencies. Information regarding the fluctuations in component/part failure frequencies throughout a bus fleet's life permits planning for surges in failures and the development of maintenance policies for component repair (e.g., deciding whether to maintain an item when it fails or replace it preventively before it fails). Together these two systems provide the backbone for an effective management control system, and they permit more detailed planning and provide inputs to higher-level decision-making.

WORK MEASUREMENT

Polk defines work measurement as the "time relation between worker and job component" (13). This involves the development of time standards for maintenance activities and the use of the time standards in decision-making and planning.

Often work measurement goes hand-in-hand with work methods analysis. Work methods analysis involves such things as the evaluation of work procedures and evaluation of methods used to conduct specific jobs. Later in this section the combined roles of both work measurement and work methods analysis will be discussed. The application of both work measurement and work methods analysis can lead to improved performance through a comprehensive work study. However, work methods analysis implies significant amounts of analyst time spent studying work methods. Such an effort may not be warranted at most small and medium sized bus transit systems. At small and medium transit systems a work measurement system can be established by itself and once high labor cost activities are identified through work measurement, work methods analysis can be applied incrementally starting with the highest cost jobs first.

Uses of Work Measurement Systems

Manion defines three uses for work time standards (8). Manion's list of uses can be further divided between direct uses, which involves day-to-day and week-to-week labor performance measurement and work flow analysis, and indirect uses, which involves the use of time standards in planning and projecting future labor resource requirements. Starting first with direct uses, Manion's applications for time standards are:

A. Providing a basis of strong management control over operations: This involves the direct use of time standards to exercise better control over labor, including:

1. Time comparisons. This is the comparison of times that maintenance actions should take based on time standard versus what they actually took. Some of the applications of time comparisons include:

    a. Comparisons of the time taken by individuals while conducting various tasks to a time standard for the same tasks. The comparison is intended to identify mechanics that are taking too much time to complete specific tasks. This information may be used to support claims that specific mechanics need additional training or as evidence of low employee performance in personnel actions.

    b. Comparing a time standard for a particular job to times actually required to complete the job can be used to identify work methods problems. If a job regularly takes longer than an accurate time standard, then the method used to conduct the job should be investigated to determine more efficient procedures.

    c. The sum of time standards for all the jobs completed during a week or a month in comparison to the cumulative time actually required to complete the same series of jobs provides a measure of overall productivity. This comparison may be used as an overall performance control or in a departmental incentive program.

2. Scheduling. Scheduling of the work flow requires estimates in advance of the labor content of jobs waiting to be processed. The uses of time standards in scheduling include:

    a. Jobs waiting to be assigned to a mechanic should be sequenced for assignment to mechanics. Unless specific circumstances warrant certain vehicles to be worked on first, maintenance work should be ordered with respect to the expected amount of labor time required to complete the job. The ordering of jobs can have significant impacts on the number of buses waiting for maintenance. To illustrate the importance of ordering, consider the San Juan Metropolitan Bus Authority which was troubled by having too many buses tied-up in the maintenance shop (10). Even though they had almost a 50 percent spare ratio, some runs were missed because of the unavailability of buses. Management discovered that the maintenance shop's throughput could be maximized when backlogged jobs which require the shortest time to complete are done first (2). Therefore, the shop supervisor assigned to mechanics, jobs from the backlog that appeared to require the least time to repair. Through the use of this simple scheduling rule and after three months, bus unavailability was decreased by nearly 50 percent. Dutta, et al. explored the results of the application of other simple job ordering rules and they provide guidance for the development of ordering rules (4).

b. The efficient assignment of jobs to individual mechanics may be facilitated through the use of time standards. Because time standards can be used to estimate in advance the time required to complete a job, the shop supervisor can plan the daily activities of mechanics by mapping out their daily work assignments.

B. <u>"Providing the ability to accurately project resource needs"</u>: Through the use of time standards, staffing needs can be projected that result from changes in the demand for maintenance. Since time standards are used to make staffing decision-making analysis, standards are being used as indirect controls. For example, suppose that top-management decides to expand service by ten percent. New maintenance staffing requirements can be estimated by determining the expanded number of times that maintenance activities will be conducted by each labor classification of mechanic and multiplying them by the time standard for each activity.

C. <u>"Providing the ability to accurately determine cost of alternative methods"</u>: There are several decisions that face maintenance managers involving different methods of achieving the same objective. In cases where time standards are used to assist in analyzing alternatives, they are being used as indirect controls. When evaluating methods, time standards will facilitate the estimation of accurate labor costs associated with maintenance method alternatives. Examples of the use of time standards to evaluate alternatives include:

1. <u>Maintenance Policy Making</u>. The maintenance manager

should decide on specific policies for the maintenance of components and subsystems. In general, there are three maintenance policies to choose from: 1) Conditioned based maintenance where maintenance is triggered based on a monitorable parameter which indicates fatigue and impending failure; 2) Fixed mileage maintenance where maintenance is performed preventively at fixed mileage intervals; and 3) Operate until failure where maintenance is performed when failure occurs. To set efficient maintenance policy choices requires that the manager have an accurate estimate of the cost of making repairs before and after failure, which necessitates an estimate of labor involved in making repairs.

2. Life Cycle Cost Based Decision-Making. Life cycle costing is a technique which is used to make decisions on equipment purchasing alternatives and equipment replacement timing. Decisions are based on purchase costs plus maintenance and operating costs. Examples of life cycle costing use include: 1) The analysis of the most economical time to replace a fleet of buses; 2) The analysis of the possible cost savings of contracting out maintenance work rather than doing it in-house, and; 3) The analysis of possible equipment procurement options to deterine which brand of bus is the least costly to own. All of these examples need accurate maintenance cost information which requires estimates of the labor time to conduct maintenance tasks. Time standards provide valuable information to assist in life cycle costing.

A recent National Cooperative Transit Research and Development Program (NCTRDP) study investigated the use of work measurement in maintenance departments at United States and Canadian transit systems (7). The investigators found several transit systems that used some kind of maintenance time standards, ranging from simple averages of the time spent repairing mechanical subsystems (e.g., the air conditioning system, electrical system, air system, etc.) to sophisticated time standards based on stop-watch studies combined with work methods analysis. Unfortunately, they found that time standard were used mostly for short-term, direct controlling.

The NCTRDP study found the primary uses for maintenance time standards were threefold: 1) The identification of low mechanic performance, which would trigger a corrective action by management (e.g., mechanic training, changes in work method, or a different mechanic work assignment); 2) The use of time standards to develop daily work assignment schedules; and 3) The use of time standards in personnel matters, generally related to employee discipline or termination. These three uses represent day-to-day or week-to-week controlling and thus indicate a lack of exploitation of work measurement systems in long-term management planning and in decision-making.

WORK MEASUREMENT SYSTEMS

Conventional work measurement systems were developed for production environments where the conditions from one job to the next are largely the same and workers conduct repetitive activities. Unlike a production environment, maintenance work tends to be non-repetitive and conditions vary from one job to the next. For example, even though maintenance problems may be diagnosed as needing the same type of repair, and the results of the maintenance activities are the same, the exact same method of repair can seldom be used. As an illustration, when diagnosing the need for the replacement of a part, it is not known if the bolts that must be removed to disassemble the part are rusted tight, or if they will come off smoothly. Depening on the state of the bolts, a different repair method should be chosen. Further, mechanics are often required to do a very broad variety of different jobs. For example, Haenisch and Miller estimated that Chicago Transit Authority bus mechanics regularly perform 1,800 different tasks (5). Thus, work conducted by bus maintenance workers tends to be diverse and non-repetitive, and work conditions are varied. The attributes of bus maintenance work are quite different than those of production work environments.

When jobs are repetitive and conditions are constant, times required by a qualified worker to complete a job tend to remain very stable. In industrial production environments where stable conditions exist, a time standard can be created which accurately represents the typical time required. However, in a maintenance environment, activities are more likely to take a broad distribution of times. For example, Figure 3-1 is a bar chart representing the data collected for time required to complete one job (3,000 mile preventive inspections). Times where collected for 171 inspections at the Wichita, Kansas transit system. The mean time to complete a 3,000 mile inspection was 2.29 hours and the standard deviation was roughly 1.0 hour. The important aspect that the bar chart in Figure 3-1 is the variation in the sample and the inaccuracy that would result if the time standard for this job were represented by a single number rather than a range of numbers.

Even though traditional time measurement methods tend to understate the variability of tasks, they have been used successfully in a few bus maintenance cases. Further because traditional methods generally provide a single accurate and well documented time estimate, they are essential in some cases. For example, it may be necessary to have time standards based on traditional methods to solve personnel problems because of the potential for disputes. A single estimate, based on objective traditional stopwatch measurements is widely accepted and understood, and is less likely to be questioned.

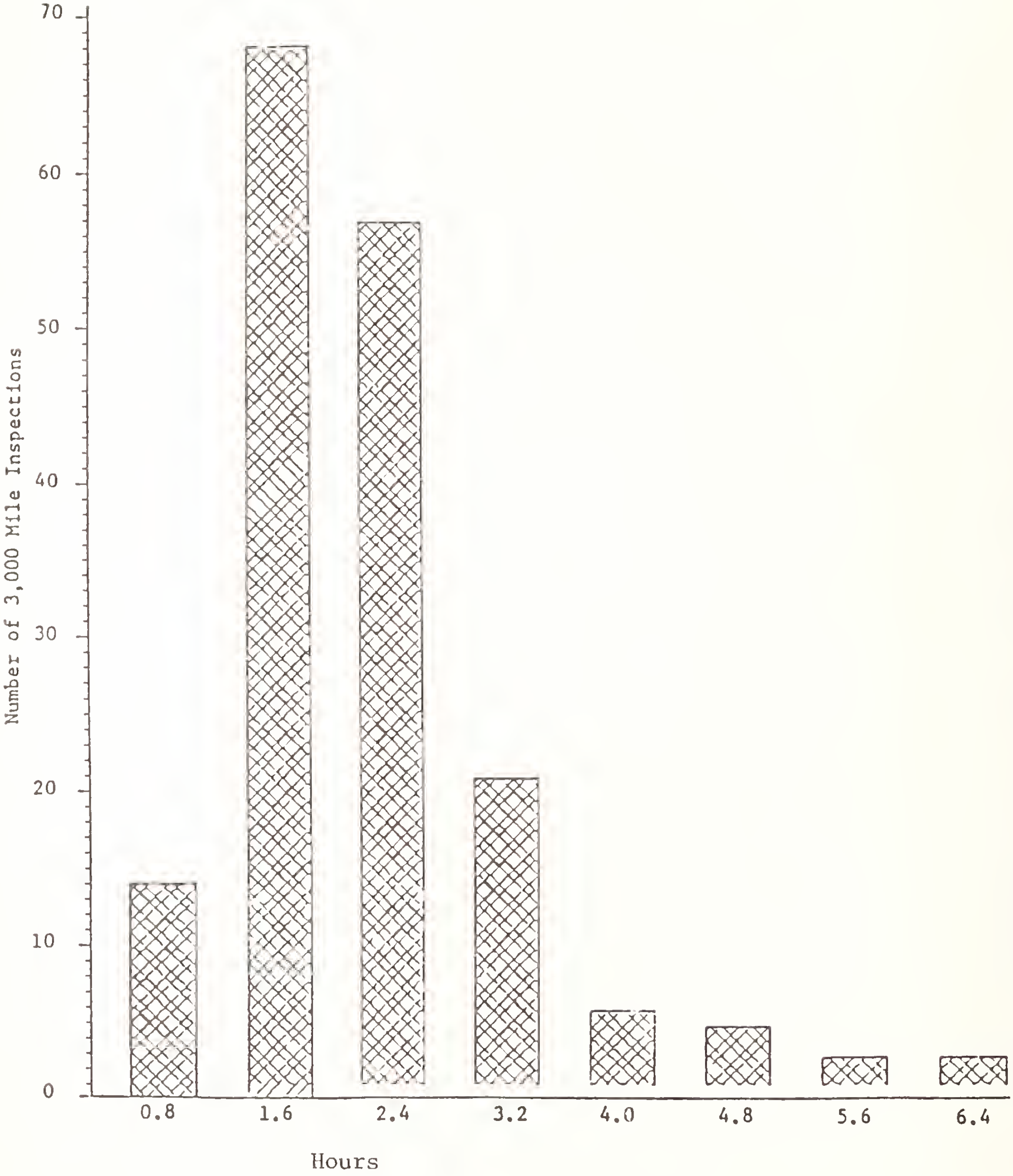

Figure 3-1 Time Taken To Complete 3,000 Mile Inspection

Traditional Methods

The Chicago Transit Authority's (CTA) work measurement system is a notable example of the application of traditional work measurement techniques to bus maintenance (5). At the CTA work measurement analysts conducted time studies using stopwatches to zmeasure the length of time required to conduct various jobs. The time study entailed measuring the job studied several times to serve as benchmarks and to insure that the times recorded are accurate and indicative of the actual performance.

Each job measured in a time study is broken down in basic divisions of accomplishment called elements. The sum of the times for each of these elements constitutes the total time in which the worker performs the job. Added to this total are personal and unavoidable allowances and a factor to account for fatigue which deters from the worker's ability to sustain productivity.

During the time study at the CTA the analysts also studied work methods. For each job studied a bulletin was produced which outlined the suggested methods to be used to perform the job. Though the work at the CTA, a productive gain in excess of 30 percent was achieved. However, the system's developers point out that each job studied required approximately 100 man hours for a qualified work measurement analyst to complete (including producing the bulletin) and they estimated that there were approximately 1,800 different jobs that they could study.

Job Flow Contents

In bus maintenance, or any kind of maintenance, generally the work flow consists of a large number of short jobs and a small number of lengthy jobs. Since the lengthy jobs consume the majority of the total labor hours, they are more important in terms of labor management. However, it may take just as long to develop a time standard for a short job as it may take for a more important long job. Therefore, because of the multiplicity of small jobs, during the development of time standards, the greatest amount of effort will be devoted to developing time standards for the majority of short jobs (less important jobs).

Wilkenson has noted the relationship between the number of maintenance jobs and the percentage of the total time to complete various jobs (15). He found that in general, 80 percent of the jobs consume 20 percent of the total time. In Figure 3-2 is shown the relationship between the percentage of the total labor hours and the percentage of the total jobs for the Wichita, Kansas transit system. Figure 3-2 illustrates that, for the case of the Wichita system, roughly 80 percent of the jobs account for about 36 percent of the total labor hours. The percentage of the total time taken by short jobs is greater than what Wilkenson found; however, it still demonstrates the same general trend. In

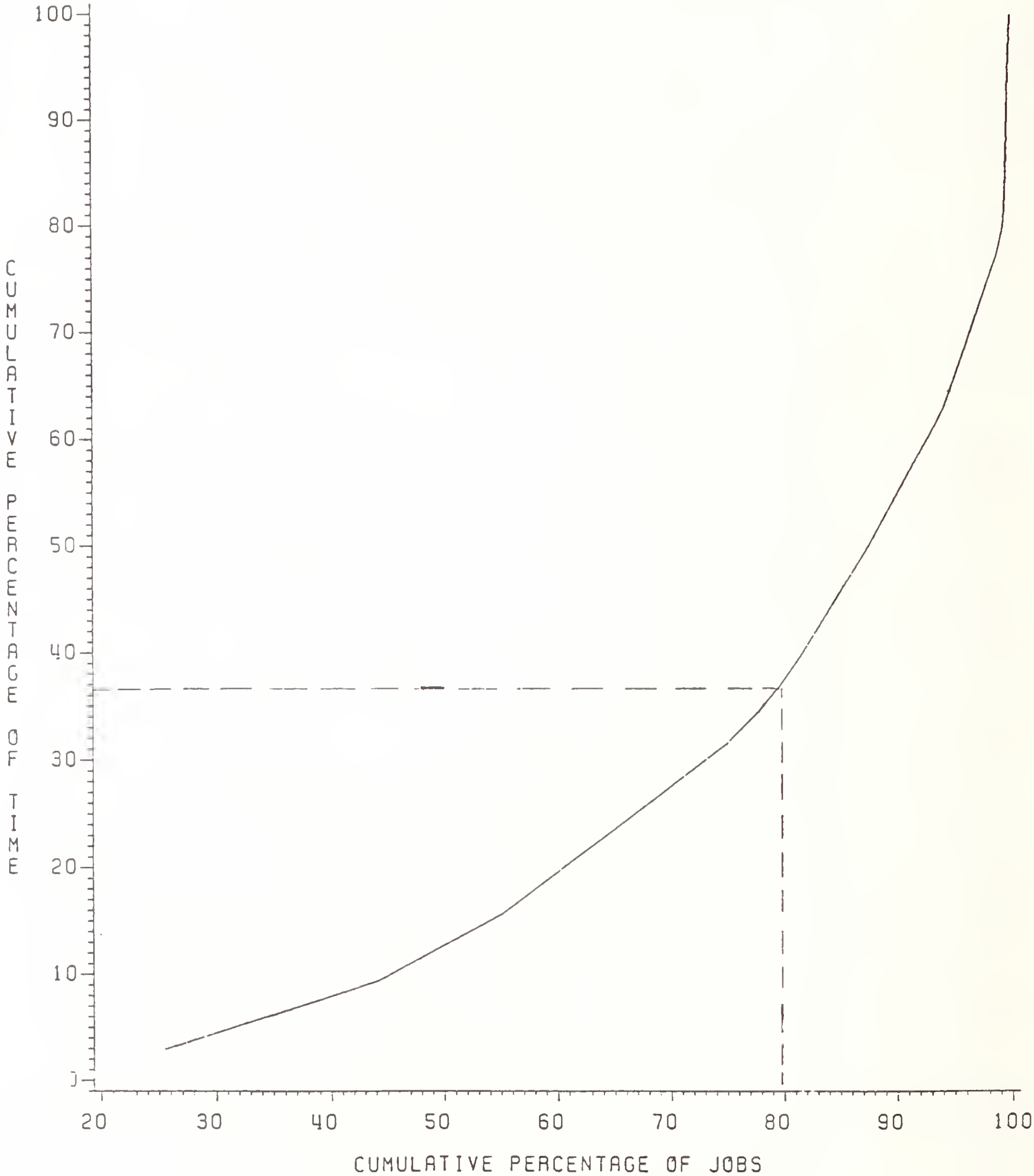

Figure 3-2 Percentage of the Total Time Consumed Versus the Percentage of the Total Jobs (Wichita MTA data).

general, it tends to be uneconomical to invest the effort required to develop time standards through traditional methods for the myriad of short maintenance jobs.

Despite the drawback of traditional work measurement techniques, through the work conducted at the CTA it can be readily seen that work methods and time standards studies can provide valuable improvements. However, the level of effort required to conduct such a study is likely to be prohibitive for most small and medium transit systems. Developing time standards using time studies require trained analysts and a discussion of how to conduct a time study is beyond the scope of this report. However, a discussion of a non-traditional work measurement technique, which does not require indepth knowledge of time study methods or significant investments of effort, is within the report's scope.

Non-Traditional Work Measurement

Time slotting is a non-traditional method of work measurement which has been successfully used in many maintenance applications. Time slotting recognizes that it is impractical and uneconomical to set up an accurate time standard for every maintenance job. Instead, each job is assigned to a time slot. For example, suppose that the time slots are 0.5 hours wide, where the first slot is 0.0 to 0.5 hours, the second slot is 0.5 to 1.0 hours, and so on. A slotting scheme is illustrated in Figure 3-3 where each of the slots is 0.5 hours wide. Every job that required between 0.5 hours and 1.0 hours should be assigned to the second slot and given a completion time of the average time of the slot, 0.75 hours. Because the pluses and minuses will eventually balance-out, the mean time will be sufficiently accurate for measuring maintenance work. For example, Mann found that the slotting technique will normally provide overall time estimates that are within 5 percent of what actually occurred (9).

In essence, a slotting system is representing a time standard as a range of values. The slots more accurately portray the variability of work times rather than representing them with a single value. In other words, when applied to maintenance the single values derived from traditional methods tend to overstate the accuracy of the time standard. Further, as conditions change which result in new work times (e.g., new tools, new facilities, better mechanic training, or new bus models), non-traditional methods do not have the sunken costs of traditional methods in stopwatch time studies.

The development of a slotting scheme assumes that there exists historical information on the time taken by mechanics to close work orders (completed maintenance jobs). In cases where such prior information does not exist or historical time data is of questionable accuracy, steps should be taken to institute the collection of the time required to complete individual jobs on maintenance work orders.

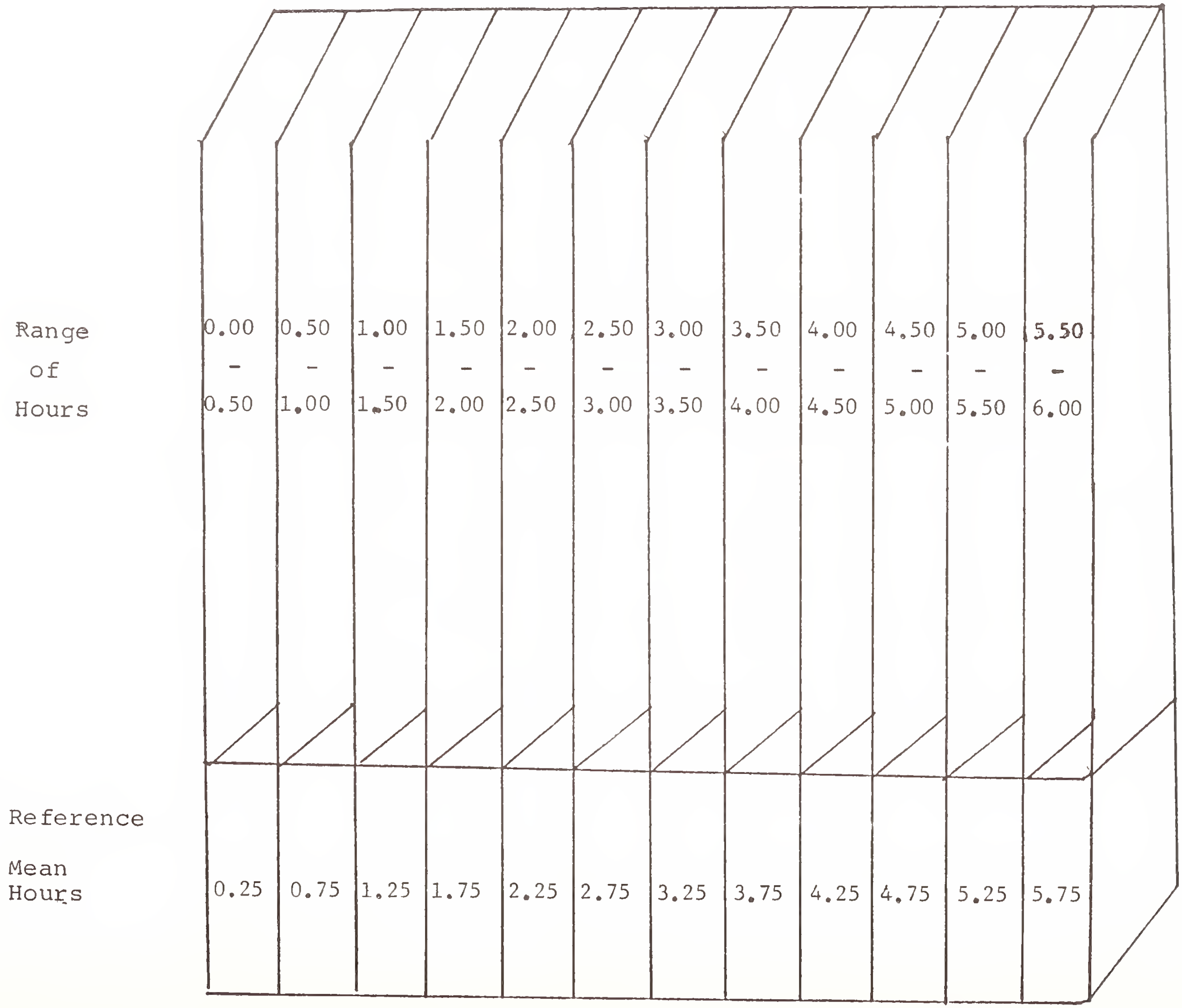

Figure 3-3 Example 0.50 Hour Time Slots

The use of time slotting will be illustrated in the next section, through a case study application to the Wichita, Kansas Transit system. Maintenance managers without sufficient historical data to develop their own slotting system may choose to use the system developed for Wichita. Once historical job times are available, the development of a time slotting scheme should follow four steps. They are:

1. Select a sample of completed maintenance jobs that is representative of the normal work flow. The sample should include approximately the same proportion of short and long duration jobs as is experienced in the total work flow. The jobs included in the sample will be used as benchmark jobs for further development of the slotting system.

2. Using the benchmark jobs, develop time standards for each job in the sample based on the average time required for a qualified mechanic to complete the job.

3. Determine each slot's time interval (for example, from 0.5 to 1.0) and its representative time (the average time). A system for developing an efficient slot interval is illustrated in the case study.

4. Place the slotting system into practice and assign new jobs to the appropriate slot as they occur in the normal work flow.

Slotting Case Study

During the spring of 1985 a slotting system was developed for Metropolitan Transit Authority of Wichita, Kansas. The first activity in the development of the slotting system was to prepare a representative sample of the normal work flow. This activity started by preparing a classification for bus maintenance jobs. The classification organizes the jobs into categories. The classification scheme used is modeled after a scheme outlined by the American Public Works Association and is contained in Table 3-1 (1). In Table 3-1, maintenance actions are divided into 8 groups and within each group are specific systems.

Closed work orders for an entire year were then examine for completed job time information. Often several jobs were conducted on one work order and only one time was given for the completion of the entire work order and a time could not be associated with any one specific job. Those work orders where jobs could be associated with a specific time were then categorized by group, system, and specific maintenance action. Mean times for job completion were estimated for those specific maintenance actions with large enough samples to provide statistically meaningful estimates (eighth or more events).

TABLE 3-1
MAINTENANCE JOB CODES

		Description
GROUP 0	BODY AND INSTRUMENTATION	
01	BUS FIXTURES	Mirror, reflectors, seats and stanchions
02	INSTRUMENTS and GAUGES	Driver's panel gauges, meters, warning devices and switches
03	GLASS	All windows and door glass
04	BODY	Bumpers, fenders, body insulation, panels, misc. body repair
05	DOORS	Door adjustment, door assembly, escape hatch
GROUP 1	CHASSIS	
11	AXLE - FRONT	Front end alignment, king-pin, upper and lower control arms, spindle
12	AXLE - REAR	Rear axle, differential, axle shafts and housing
13	BRAKES	Adjustments and repairs to brakes including replacing drums, cylinders, slack adjuster, lines, valves
14	FRAMES	Understructure, bumpers, frame assemblies, body mounts, motor mounts, and component mounts
15	STEERING	Bell crank, idler arm, tie rods, steering arms, steering gear, steering wheel and column
16	SUSPENSION	Bellows, shocks, shock bushings, stabilizer, radius rod
17	TIRES/WHEELS	Repair of tire, wheels and wheel bearings

TABLE 3-1 (Continued)

GROUPS 2	DRIVE TRAIN	
20	DRIVE SHAFTS	Drive shaft, universal joints, power take-off, and support bearings
21	TRANSMISSION CONTROLS	Shifter, transmission cable
22	TRANSMISSION	All transmission internal parts and case
23	TRANSMISSION FLUIDS	Hoses, gaskets, filters and fluids
GROUP 3	ELECTRICAL	
31	CHARGING SYSTEM	Voltage regulator, voltage equalizer, generator and related wiring
32	CRANKING SYSTEM	Starter and all necessary wires for cranking engine
33	LIGHTING SYSTEM	All wiring, bulbs, lights, fuses, relays and fixtures necessary to provide current to all lamps in or on equipment
34	BATTERY	The batteries
35	WIRING	Clean and reconnect wiring, troubleshoot circuit, and other activities necessary to recondition wiring
36	MISC. ELECTRICAL, RELAYS AND FUSES	Relay, fuses and all electrical units not found elsewhere
GROUP 4	ENGINE	
41	AIR INTAKE SYSTEM	Air intake blower, governor, and filters
42	COOLING SYSTEM	Radiator, surge tank, surge tank probe, shutters, fan drive, thermostat, hoses and water pump
43	EXHAUST SYSTEM	Exhaust pipe, muffler, and all gaskets, clamps and supports

TABLE 3-1 (Conintued)

44	FUEL SYSTEM	Fuel tank, pump, filters, throttle controls, idle control and fuel injectors
45	POWER PLANT	Adjustments, rebuilds or replacements to block or components of the block
GROUP 5	ACCESSORIES/ATTACHMENTS	
51	GENERAL ACCESSORIES	This code may be used for all items not included elsewhere, for example, seat belts, sun visor, passenger counter, etc.
52	FARE BOX	Adjusting fare box mechanism, fare box glass, and all repairs associated with the fare box
53	RADIO AND PUBLIC ADDRESS SYSTEM	All repairs and replacements made to radios and public address systems and all necessary wiring
GROUP 6	AIR AND HYDRAULIC SYSTEMS	
61	AIR COMPRESSOR	Repairs and replacements made to air compressor, compressor governor, pulleys and belts
62	AIR LINES CONTROLS AND TANKS	Air tank, air drier and valves, repair and adjustments
63	AIR POWERED DOOR SYSTEMS	Door engines, valves and electropneumatic door control system
64	BRAKE AIR SYSTEMS	Brake related valves and lines including brake application valve, parking brake control valves, air brake chamber, and quick release
65	WIPER SYSTEMS	Wiper motor, wiper blades, wind-shield washer, and hoses
66	AIR STARTER	Air starts, lines and valves
67	POWER STEERING	Power steering pump, hoses, lines, fluids and filters

TABLE 3-1 (Continued)

GROUP 7	CLIMATE CONTROL SYSTEM	
71	A/C	Compressor, belts, alternator, pulleys, hoses and condensor clutch
72	HEATER	Heat pump and heater core
73	VENTILATION	Heater and cooling blowers, vents, filter screens, and defroster blowers
74	CLIMATE CONTROL CONTROLS	Thermostat, A/C solenoid, climate control switches, and relay
GROUP 8	OTHER ACTIVITIES	
80	CLEANING/WASHING	Washing the outside and cleaning the inside
81	PAINTING	Painting of all or part of the exterior
82	TOWING AND ROAD SERVICES	All activities involved in maintaining or towing equipment off the garage site
83	DIAGNOSIS/ROAD TESTING	Include the time spent in diagnosing vehicle problems and in road testing the unit during or after the repairs are completed
84	LUBRICATION	Lubrication of a component, change of engine oil and/or filters, and change of transmission fluids and filters when not performed as part of PM inspection
85	3,000 MILE INSPECTION	Preventive maintenance performed at 3,000 mile intervals
86	6,000 MILE INSPECTION	Preventive maintentance performed at 6,000 mile intervals
87	12,000 MILE INSPECTION	Preventive maintenance performed at 7,000 mile intervals
88	CONTRACT MAINTENANCE	Unit rebuild contracts and service contracts

To determine the size of slot intervals, Niebel suggested that the benchmark times should be grouped into intervals of various sizes (e.g., 0.4, 0.5, 0.6., etc. hour intervals) and count the number of jobs falling into each interval, in each interval width (13). To understand how his is done, a small example is provided in Table 3-2. At the top of Table 3-2 are listed benchmark time standards for 38 jobs. Below are slotting schemes of 0.4, 0.5, and 0.6 hour width intervals. For each, time is divided into slots and jobs are allocated to the appropriate slot. In each of the slotting schemes, the slot's mean time is the time standard for all jobs placed in that slot. The number of jobs in each slot is simply the number of benchmark times that fell within each interval. In Table 3-2, the number of jobs in each slot lies at the bottom of each interval.

Niebel then suggests that the number of jobs in each slot should be charted in a bar chart where the height of the bar represents the number of jobs in each interval. Such a bar chart should be developed for each slotting interval tested. In Figure 3-4 is shown a bar chart using the Wichita MTA's benchmark jobs using a slot width of 0.3 hours. Niebel found that the best slotting interval is achieved when the bar chart has a ski slope shape like that of Figure 3-5. This shape is called a gamma distribution.

The bars in Figure 3-4 (0.3 hours slotting intervals) do tend to form a curve like the ski slope shaped curve in Figure 3-5. However, when the jobs are slotted into intervals of 0.6 hours, in Figure 3-6, they tend to form an even smoother ski slope shaped curve. Therefore, a slotting scheme of 0.6 hours appears to more closely represent the ski slope and is chosen for use with the MTA's data. The 0.6 hour width slotting scheme is shown in Figure 3-7.

Initially, all the benchmark jobs are placed in their appropriate slots. From that point on, the average time of the slot is used as the time standard for each job in the slot. For example, all jobs assigned to the slot containing jobs that take from 0.6 hours to 1.2 hours are assigned a time standard of 0.9 hours. Then as the shop foreman receives work orders with jobs that are not part of the set of benchmark jobs, he uses his experience to place the job into a slot. Thus the jobs in the slots are continually being updated to include new jobs. The time standards should be continually reviewed to make sure that each job is in the correct slot. For example, at the beginning of the Wichita case study a relatively inexperienced mechanic was performing a high proportion of the preventive inspections. As this mechanic became more proficient, the time he actually required to conduct inspections was consistently below the mean of the slot which initially included the inspections. Once the reduction in average time was found, inspections were dropped to slots with shorter average durations.

TABLE 3-2
EXAMPLE OF DIVIDING JOBS INTO SLOTS

Benchmark Time Standards (in Hours)

0.15, 0.21, 0.30, 0.32, 0.44, 0.61, 0.73, 0.85, 0.92, 1.01, 1.13, 1.21, 1.31, 1.42, 1.56, 1.75, 1.96, 2.05, 2.15, 2.24, 2.35, 2.44, 2.51, 2.83, 2.93, 2.10, 3.55, 4.10

0.4 Hour Slots											
Mean Time Interval	0.20 0.00-040	0.60 0.40-0.80	1.00 0.80-1.20	1.40 1.20-1.60	1.80 1.60-2.00	2.20 2.00-2.40	2.60 2.40-2.80	3.00 2.80-3.20	3.40 3.20-3.60	3.80 3.60-4.00	4.20 4.00-4.40
Job Times	0.15,0.21 0.36,0.32	0.44,0.61	0.85,0.92 1.01,1.13	1.21,1.31 1.42,156	1.75,1.96	2.05,2.15 2.24,2.35	2.44,2.51	2.85,2.95	3.55 3.10		4.10
Number in Slot	4	2	4	4	2	4	2	3	1	0	1
0.5 Hour Slots											
Mean Time Interval	0.25 0.00-0.50	0.75 0.50-1.00	1.25 1.00-1.50	1.75 1.50-2.00	2.25 2.00-2.50	2.75 2.50-3.00	3.25 3.00-3.50	3.75 3.50-4.00	4.25 4.00-4.50		
Job Times	0.15,0.21 0.30,0.32 0.44	0.61,0.85 0.92	1.01,1.31 1.21,1.31 1.42	1.56,1.75 1.96	2.05,2.15 2.24,2.35 2.44	2.51,2.85 2.95	3.10	3.55	4.10		
Number in Slot	5	3	5	3	5	3	1	1	1		
0.6 Hour Lots											
Mean Time Interval	0.30 0.00-0.60	0.90 0.60-1.20	1.50 1.20-1.80	2.10 1.80-2.40	2.60 2.40-2.80	3.00 2.80-3.20	3.50 3.20-3.80	4.10 3.80-4.40			
Job Times	0.15,0.21 0.30,0.32 0.44	0.61,0.85 0.92,1.01 1.13	1.21,1.31 1.42,1.56 1.75	1.96,2.05 2.15,2.24 2.35	2.44,2.51	2.85,2.95 3.10	3.55	4.10			
Number in Slot	5	5	5	5	2	3	1	1			

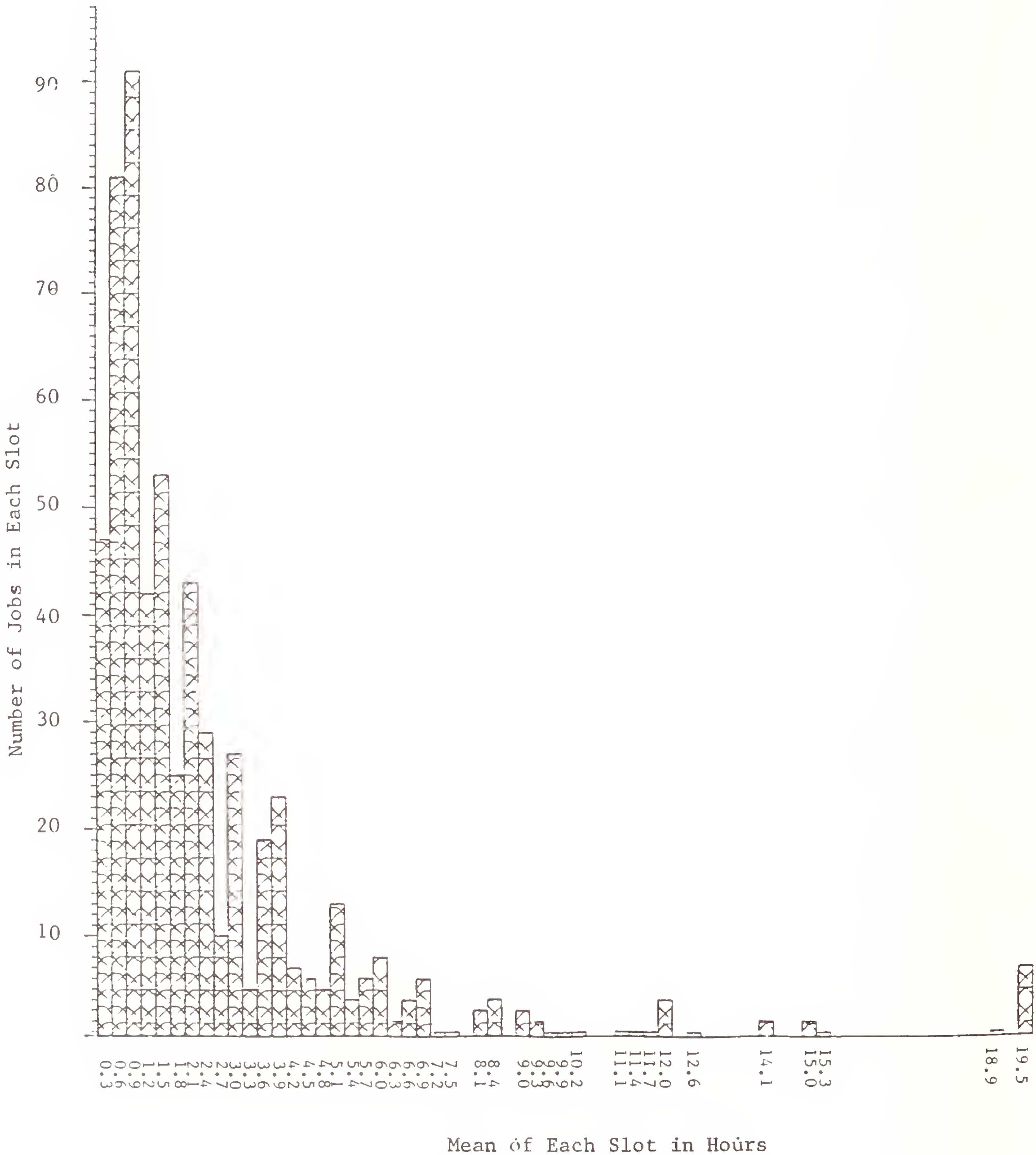

Figure 3-4 Jobs Per 0.3 Hour Time Slot (Wichita MTA data)

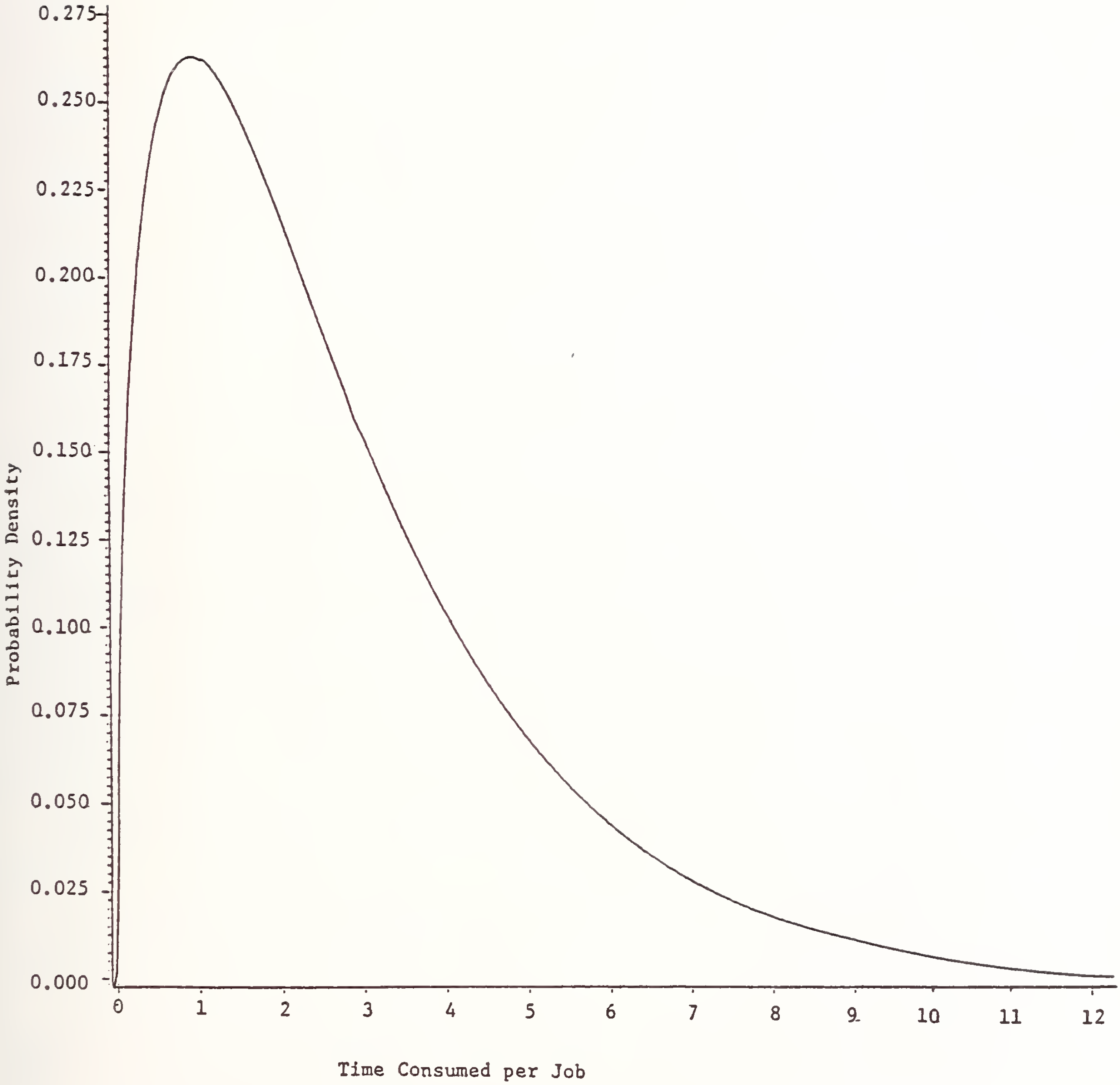

Figure 3-5 Characteristic Shape of the Gamma Distribution

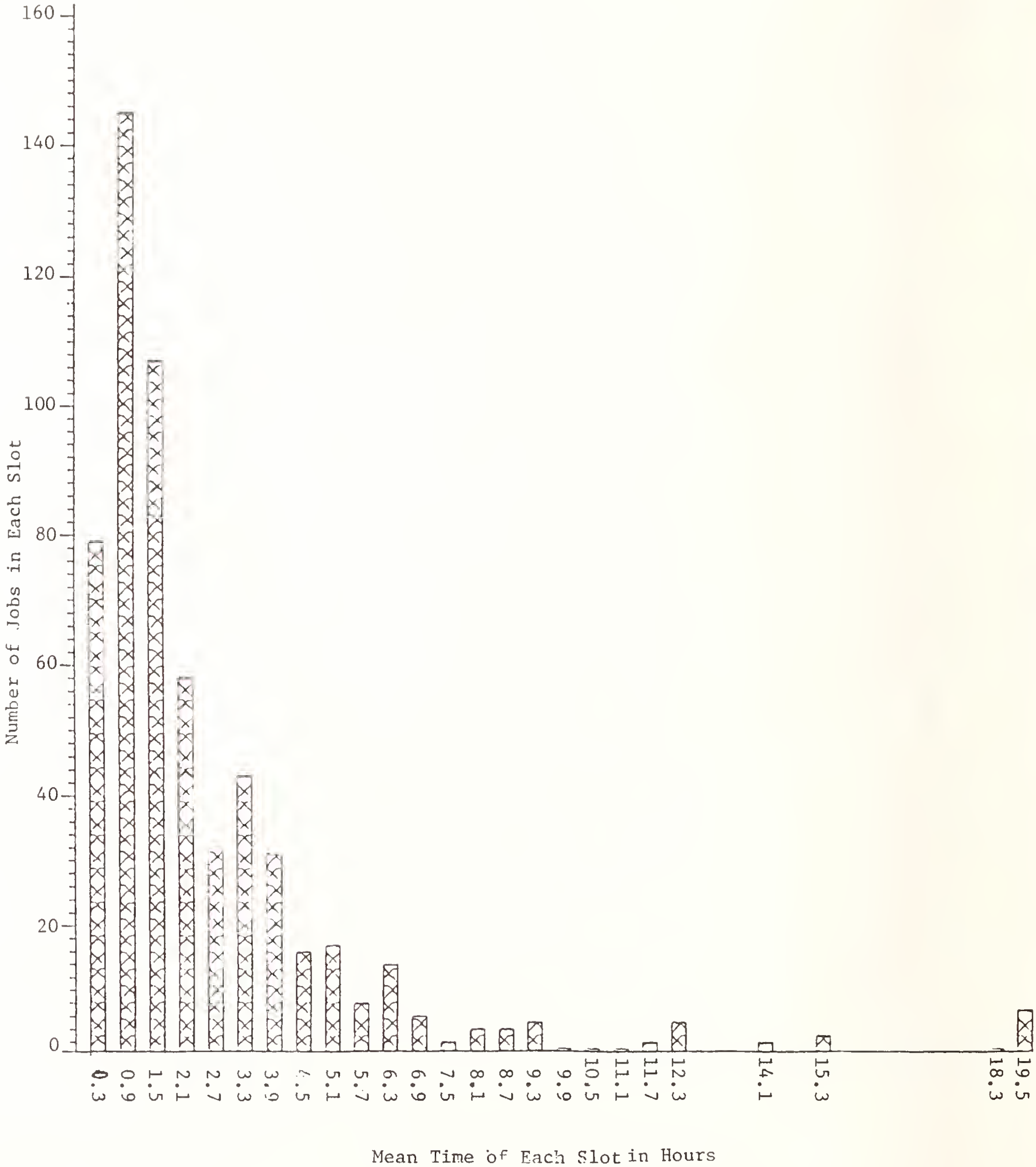

Figure 3-6 Jobs Per 0.6 Hour Time Slot (Wichita MTA data)

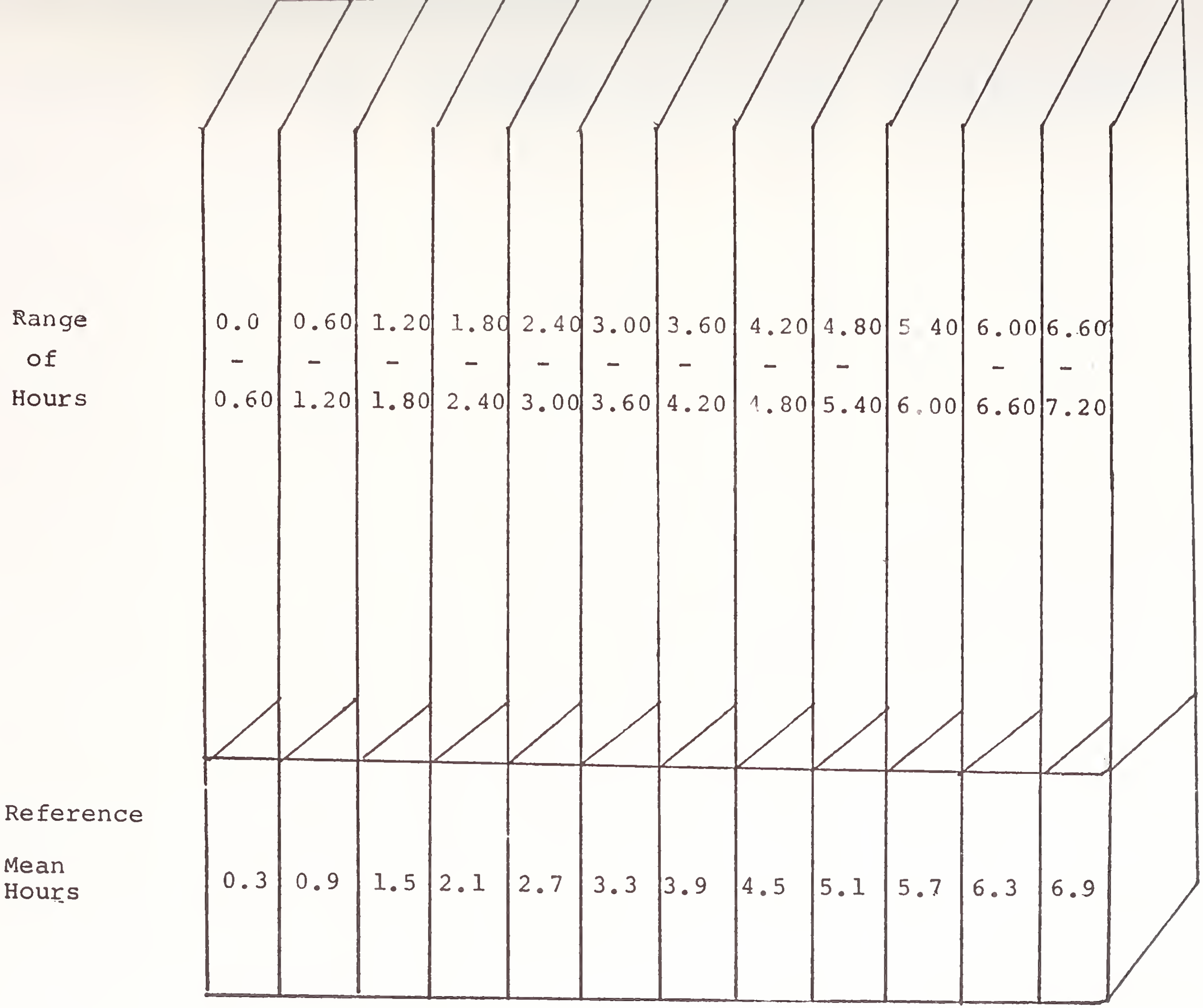

Figure 3-7 0.60 Hour Time Slots

In Appendix A are the time standards developed for the Wichita transit system. These were developed in the manner described, over a 7 month period. During this period about 370 time standards were developed at a very minimal cost.

Summary

Work measurement provides a valuable contribution to controlling maintenance. In several cases, work measurement has lead to significant productivity improvements. Traditional methods, involving time studies coupled with work methods analysis, are clearly the preferred system for developing a work measurement system. However, because of the extensive level of effort required, for small and medium transit system it may be uneconomical to develop a work measurement system using traditional methods. Further, slotting tends to more accurately portray the uncertainty and variability of maintenance labor times.

As an alternative to costly traditional methods, a slotting technique is suggested. Slotting has been successfully applied in plant maintenance and should work equally well in bus maintenance.

MAINTENANCE EVENT RECORD SYSTEMS

In this section maintenance event (e.g., preventive and corrective repair and inspection) record collection systems are discussed. Specifically, work orders systems and maintenance history logs are examined. These two record keeping devices form the backbone of a maintenance information system and derived from these two record keeping systems is the bulk of the information required to calculate most common maintenance performance measures. The importance of maintenance histories and, especially, work order systems is that they are the primary sources of maintenance information.

Although this discussion of maintenance event records covers only paper-based data collections systems, most computer based maintenance information systems require the same paper forms for the collection of original data. Even sophisticated computer information systems, which do not require paper forms (data are entered on-line), require computer systems which perform the same functions automatically as a work order system and a maintenance history log.

Maintenance information systems should be as simple as possible while collecting all the information necessary to control maintenance work. Because work order systems and maintenance history logs are primary collection devices for original information, if information is not collected through these systems it is lost and unavailable for future decision-making and controlling.

Work Orders

The work order is generally considered the heart of a maintenance management control system (9). The work order is the document that feeds original data to other record keeping devices. There are several expectable formats for work orders that have been used by transit systems and by equipment maintenance departments in other industries. For example, the American Public Works Association's, Equipment Management Manual contains suggested formates (1). Existing work order forms may be used as a model format for developing a new work order, but a new form should be designed for the unique functions of each management system to ensure that all data needs for management controlling are met. The following paragraphs list five common uses of maintenance data that should be considered while developing a work order system in addition to the special needs of a particular maintenance department.

1. Work Authorization. Because a work order form is used to initiate maintenance work, it provides a means of controlling the work flow. Work flow control may require certain planned procedures, such as requiring an inspection to diagnose work before it is assigned. Through the work flow control, work may be authorized through a fixed set of procedures and thus ensuring proper steps are followed and that the individuals in the authorization chain are held accountable.

2. Cost Accounting and Inventory Control. The work order should provide the original data necessary to classify cost (labor times and costs, and material costs), allocate costs to vehicle elements (i.e., costs classified by bus subsystem, component, bus model, etc.), and to update part inventory records. This information is not only important to cost accounting but it is crucial to most common maintenance performance measurement systems (performance measurement is covered in Chapter 4).

3. Repair Details. In his book on maintenance management, Herbaty defines three data elements that every work order should require for all repairs (6), they are: 1) The specific item that fails; 2) The reason for the failure (e.g., fatigue, rupture, wear, lack of lubrication, accident, etc.); and 3) The corrective action taken. This information is imperative for the investigation of critical, troublesome and/or repetitive repairs.

Herbaty also points out that in most cases there are few repairs that account for a large proportion of total maintenance costs. Herbaty's rule-of-thumb is that 10 percent of the maintenance jobs account for 90 percent of the labor time. The jobs which require the largest proportion of the mechanic labor time and/or account for the majority of maintenance repair cost are the most critical and should be investigated by management for possible reductions in maintenance costs. Improvements to reduce the cost of maintaining critical items could include new preventive maintenance procedures, more effective repair methods, redesign of equipment or retrofit of more durably designed units, and correcting driver abuse of equipment.

To identify high cost (critical) repairs, repairs are ranked according to the amount of direct mechanic time they require. Mechanic time may be used as a simple indicator of total repair cost. In Table 3-3 are listed ten maintenance jobs conducted by the Wichita, Kansas Metropolitan Transit Authority to their buses over a seven month period. The ten maintenance jobs listed in Table 3-3 consumed 51 percent of the total direct mechanic labor used to make repairs (this does not include mechanic labor time consumed while conducting preventive inspections). These ten repairs consume more mechanic repair time than the other 370 tasks that were conducted during the seven month period. Because these ten repairs are the most costly, they are therefore, the most critical and should receive the highest priority for improvement.

Other means of identifying critical problems may be to conduct a similar analysis, as that shown in Table 3-3, for roadcalls or downtime. For example, the causes of roadcalls could be ranked according to their frequency of occurrence. Those causes for roadcalls or those that are repeated reasons on the same bus should receive the most management attention.

Whether a critical maintenance problem is determined through the identification of high cost (or high labor time) repairs, high frequency causes for roadcalls, or through an analysis of repairs that cause the most days of downtime, the work order for these critical repairs should provide enough information to investigate the cause and method of repair. Investigations should result in improved practices and, because critical items are investigated first, they should maximize the impact of improvements.

4. <u>Work Planning and Scheduling</u>. Once a work order has been initiated and the maintenance work to be conducted has been estimated, job planning and scheduling can begin. Planning involves the act of matching the job with labor, materials, special tools (if required), and special facilities (if required). Scheduling involves the assignment of jobs to mechanics so that they may complete the work during a specific time interval.

Planning a component rebuild or remove/replacement job should include a review of prior maintenance work conducted to the vehicle. The review should determine if the length of the component's life was as expected and, if not, the investigation should determine why the component failed prematurely. An investigation which discovers a premature failure may lead to a review of such things as preventive maintenance practices, operator misusage, shoddy manufacturing, poor design, etc.

The work scheduler should have knowledge of currently open jobs, work backlogs, mechanic availability and skill, and job priorities. The scheduler should have time standards (similar to

TABLE 3-3 Example Repair Criticality Index

Criticality Index	Maintenance Job	Percentage Maintenance Repair Time
1	Refinish ouside of bus	23%
2	Reline rear brakes	8%
3	Trouble shooting electrical circuit	5%
4	Check and seal fan drive leaks	3%
5	Remove and replace transmission	2%
6	Service air conditioning	2%
7	Reline front brakes	2%
8	Remove and replace bellows	2%
9	Activate air conditioning	2%
10	Remove and replace ruptured air conditioning hose	2%
		51%

Preventive Maintenance	Percentage of Total Mechanic Time
6,000 mile Inspection	9%
3,000 mile Inspection	8%
12,000 mile Inspection	6%
	23%

Total Mechanic Time = Repair Time + Inspection Time those described in the first part of this chapter) to estimate the time required to complete the job. If time standards are not available, the scheduler should at least be familiar enough with the work that he or she can use experience to estimate the time involved in completing the job. Of course, estimating job durations with time standards is always preferable to using experience.

The work order should contain space for planning information (problem diagnosis and special tools or facilities required), and for scheduling information (expected time required to complete the job, the job's priority, class of mechanic required to complete the job, and mechanic assigned to the job).

5. Facilitate Control Over Productivity. Once the work order is closed, the shop floor supervisor should review the direct time required to complete the job. Any discrepancies between the estimated time and the actual time required should be clarified. An unexplained difference may be a result of a mechanic forgetting to document a task performed to the vehicle, or the conditions of the equipment which forced the job to take a longer time than expected. However, in some cases a discrepancy may indicate a productivity problem where a mechanic is simply taking too long to complete a job. For example, the United Parcel Service (UPS) has maintenance shop supervisors review, with the mechanic, any job that takes more than one hour longer than the corresponding time standard (14). Such a review may include an investigation of the work methods used by the mechanic. Of course, any effort to increase productivity should have a companion effort to make sure that quality of repairs does not suffer when the duration of repair times are decreased.

Maintenance History Log

It is important to design maintenance record keeping systems which are as streamlined as possible. This includes not asking for data which are never used and not requiring duplicate records. However, some duplication may be necessary. A maintenance history log is such a duplication. The log should contain summary information from the work order and provide a less cumbersome means of identifying maintenance actions without having to sort through work orders. In fact, a maintenance history log should provide the majority of necessary maintenance data for controlling and work orders should only be referred to when specific details are required. At a minimum, the maintenance history log should include the dates of preventive and corrective maintenance activities and a brief description of the work conducted.

When new corrective work is planned, the planner can use the log to determine when prior work was conducted on the vehicle. If necessary, the dates noted in the maintenance history log can be used to refer back to the work order for more specific details.

To understand why a log is necessary, suppose that each bus in a fleet generates an average of two corrective or preventive maintenance work orders per month. In a year each bus will generate an average of 24 work orders. If the bus is in service for 12 years, the vehicle will generate 288 work orders in its entire life. Now, suppose a major component fails on the bus after it has been inservice for several years. If the job planner does not have a maintenance history log to refer to, he will have to search through perhaps hundreds of work orders to determine what took place during prior repairs to the same component. Instead, a maintenance history log provides a quick cross reference point to assist in finding prior work on the item.

If the data entered to the maintenance history log for each maintenance event includes the cost, the mileage when the work was conducted, the cost of the maintenance work, the direct time taken by the mechanic to conduct the maintenance work, the estimated time to complete the maintenance work, the mechanic's name or identification number, and the length of time that the bus was tied-up in maintenance, the maintenance log can facilitate the calculation of several fleet performance measures, including:

1. The calculation of major component life statistics (the mean miles between failures and other failure statistics).

2. By presenting estimated and actual time required to complete jobs on maintenance logs, the logs can facilitate labor productivity measurement. This can be done monthly by stripping estimated (based on time standards) and actual mechanic times during that month from the logs and comparing the totals. If the sums of the actual times is much greater than the sum of the estimated times, then the maintenance department has a productivity problem. Productivity improvements should be based on comparisons of actual times in relation to time standards.

3. Recording the amount of time that a bus is tied-up in maintenance (downtime) permits the calculation of vehicle operationally availability. Availability is the ratio of downtime to the sum of downtime plus uptime (when the bus is operationally ready). Placing the duration of downtime on the maintenance history log and summing downtime over the entire month and over the entire fleet, permits the calculation of availability. Fleet availability can be useful in identifying maintenance productive problems, identifying an under-staffing problem (not enough maintenance personnel to keep vehicles operationally available), or for justification of spare fleet levels.

4. By associating cost data with specific maintenance descriptions, maintenance history logs simplify the task

of developing cost estimates (or labor times) of maintenance categories (e.g., the cost of all preventive maintenance, or the cost of maintenance work on a vehicle subsystem). For example, the costs of all air conditioning repairs for a model of bus over a one year period could be calculated by summing the costs of all air conditioning repairs recorded on the maintenance history log.

In addition to a maintenance history log, some maintenance departments track major components and subsystem through another log. The primary purpose of a major component and subsystem log is to facilitate the estimation of component life statistics and assist in predicting and planning for wear outs, preventive rebuilds, and likely failures. For example, one southwestern transit fleet manager that maintains buses, which operate in hot, dusty, and hilly conditions, preventively rebuilds transmissions at a specific mileage interval to avoid in service failures and/or catastrophic failures which might damage the unit. Therefore, the fleet manager must keep close track of the mileage accumulation of each bus's transmission since it was last rebuilt.

The Canadian Transit Handbook suggests a visual method for tracking major component and subsystem repairs, instead of using paper records (3). The Handbook suggests marking a Masonite board with numbers identifying each bus along one side. Along the board's other side, scaling-off the miles the buses are expected to travel over their entire life, or the remainder of the bus's life if it is not a new bus. Then place a pin with a colored head at the point where each component or subsystem is expected to fail, wear out, or at its desired rebuild interval. Each type of component or subsystem should have a different colored pin. For example, transmissions rebuilds could be blue and brake reline intervals could be red. Another colored pin would represent the current mileage accumulated by each bus. The mileage accumulated by each bus should be updated weekly.

The Handbook reports the advantages of the visual method are that "the maintenance chief can tell at a glance from the board approximately how many brake relines or component replacements and rebuilds are likely to come due in the next month or next year. Such a board can be useful in detecting unusually good or bad performance (i.e., abnormal component life), ensuring that the spare component allotment is satisfactory. It even helps to estimate the work load for the coming year when preparing the budget". Whether a visual method is used or major components and subsystems are tracked using a paper log, these records are known to result in better work flow management.

CONCLUSIONS

In this chapter, fundamental data collection systems were discussed. Work measurement and maintenance event record keeping system provide a strong base for maintenance data collection systems. Without such systems it is impossible to conduct comprehensive maintenance management controlling.

The next chapter covers maintenance performance measurement. The efficient use of performance measurement for management controlling can only be developed from a good maintenance management data collection system.

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CHAPTER IV

BUS MAINTENANCE PERFORMANCE MEASUREMENT

This chapter reviews the development of performance measures or performance indicators for the maintenance of bus fleets to support the policies of the transit agency. As indicated in Chapter I, performance indicators are expressions of transit agency objectives. Performance indicators include standards which measure the attainment of specific objectives.

This chapter therefore begins with a discussion of overall transit agency policies and how these must first be translated into policies for the bus maintenance department. General concepts for the development of maintenance objectives and their corresponding performance indicators are then presented.

The next section presents a series of candidate performance indicators. The indicators are categorized by the performance attribute they measure (attributes include labor force productivity, vehicle reliability, etc.). The value of each candidate 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 the systems, the performance indicators presented should provide fleet managers, who are designing or reviewing their performance indicators, with new candidate measures and a rating of the indicators utility at other transit systems. Further, the categorization of indicators by the performance attribute measured permits the manager who is designing a performance measurement system to select a group of indicators which comprehensively cover each attribute of bus maintenance performance.

In the last section a case study application of selected performance indicators is reported. The Metropolitan Transit Authority of Wichita, Kansas, was the site of the case study application.

MAINTENANCE POLICIES AND OBJECTIVES

Top Management Perspectives

Public transit agencies have obligations to the traveling public and to the government authorities which provide funding to subsidize transit service. These obligations can be translated into overall policies for top management. The first set of typical policies addresses the needs of the traveling public. Such policies include the provision of transit services at an acceptable level of service to the various transit constituencies: patrons without access to automobiles, the elderly and handicapped, work trip commuters, and so forth. Fielding, et al. (5) use the term, "effectiveness," to describe the set of objectives and performance indicators which correspond to the overall policy of providing adequate levels of transit service. Service indicators include system utilization (e.g., ridership, passenger miles, operating revenue), service quality (e.g., on-time performance, seat availability, reliability), and service accessibility (e.g., route coverage, bus stop location).

The second set of typical policies addresses the utilization of resources to provide these transit services. Fielding, et al. (5) use the term, "efficiency," to describe the set of objectives and performance indicators which measure transit service "output" in terms of resource "input." Service inputs include labor, capital, and fuel. Typical service outputs include vehicle hours of service, vehicle miles, and seat miles.

Fielding, et al. (6) illustrate these concepts of effectiveness and efficiency in the triangular diagram of Figure 4-1. They comment (5): "A useful way of clarifying these two terms is to say that efficiency is concerned with 'doing things right,' whereas effectiveness is concerned with 'doing the right things.'" Tomazinis in 1975 (12) declared that it was important to separate the use of resources (efficiency) from the quality of the service (effectiveness) in promoting transit ridership. Similarly, Fielding, et al. (6) caution against using a single performance indicator, e.g., total cost per vehicle mile, to assess transit performance. This is because a transit agency should have both efficiency and effectiveness indicators, an objective to minimize cost per mile may adversely affect service effectiveness.

Another perspective on the view of top management towards the role of maintenance, which includes example performance indicators, is to inspect the information required for UMTA's Section 15 reports (13). In the 1982 annual report three categories of maintenance statistics are reported: 1) Total number of road calls for mechanical and other reasons by transit system; 2) Total labor hours for vehicle inspection and maintenance; and 3) Number of light maintenance facilities (for inspecting and servicing buses). Based on Fig. 4-1, these are all "service inputs."

The Section 15 report provides three maintenance performance indicators for each transit system:

1. Total annual vehicle miles per dollar vehicle maintenance expense,

2. Total annual vehicle miles per road call, and

3. Total revenue vehicles (motor buses) per maintenance employee.

Based on the framework of Fig. 4-1, the first and third indicators are "cost-efficiency" indicators. The second indicator, miles per road call, is a "service-effectiveness" indicator.

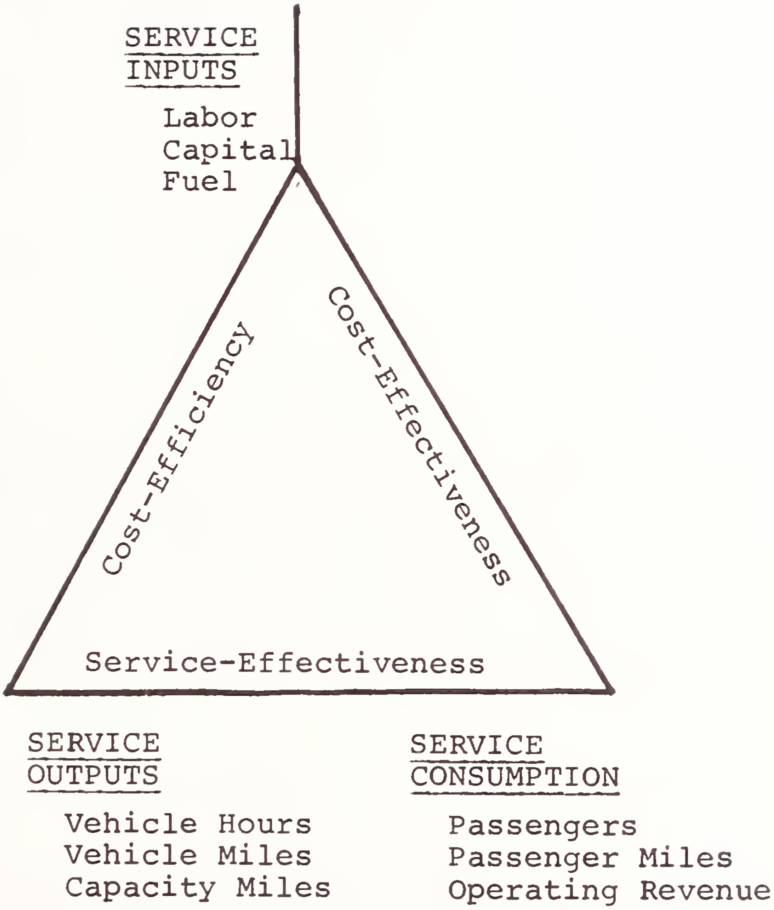

FIGURE 4-1

FRAMEWORK FOR TRANSIT PERFORMANCE INDICATORS
(Source: Reference 5, p. 75)

In the Section 15 report, performance of individual transit systems for each indicator can be compared with national averages for seven categories of bus fleet size as the "standard" of performance or performance goal. Among the problems of doing this comparison, however, are that averages are not necessarily an indication of acceptable performance and, since the average is of all systems, the performance of under-performing systems affects the average.

Of more concern to the maintenance manager, however, is that while these indicators may be of some use to top management, they are only superficial indicators of overall maintenance department performance. They are superficial because they fail to provide specific information on the maintenance operation's performance. In order to assess the performance of the maintenance department and provide management controls, the maintenance manager must develop an agency specific set of objectives and corresponding performance indicators which both conform to top management expectations and provide a plan of action for the maintenance department.

<u>Maintenance Manager Perspectives</u>

The transit maintenance manager has two primary concerns in developing performance indicators. The first is that indicators are needed which top management can use to evaluate the overall performance of the maintenance department. As noted above, vehicle miles per road call and maintenance costs per vehicle-mile are common overall indicators. The second concern of the manager, however, is for indicators which can be used to monitor the internal performance of the maintenance department. They should help the manager in evaluating internal productivity and alert the manager to practices and procedures that need refinement or correction.

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 which also reflects upon 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 Chapter IV.

PERFORMANCE INDICATOR QUESTIONNAIRE SURVEY

Transit maintenance managers throughout the United States were asked to evaluate the utility of 36 candidate performance indicators for the maintenance department. The indicators were selected in part from a pre-questionnaire sent to eight knowledgeable maintenance managers in February 1985 who were responsible for fleets of 50 to 3,000 buses. Interestingly, these managers preferred the "direct controls", as defined in Chapter II, over the "indirect controls" which would require some data analysis and interpretation first.

Based on this preliminary survey 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 to themselves and to top management. There were 92 questionnaires received out of about 120 sent out. The response rate was very 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:

1. Fleet Reliability Indicators. Reliability is the likelihood of the bus and its components operating properly at any given time. Common indicators of reliability include the average miles between road calls and the average age of major components.

2. 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 number of work orders per bus model are indicators of maintainability.

3. Fleet Availability Indicators. Availability is the likelihood of a given number of buses being 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.

4. Work Quality Indicators. Work quality is a measurement of the quality of the maintenance work performed. Quality corrective maintenance should completely restore a failed, worn out or malfunctioning component or part to its proper operating condition. Quality preventive maintenance should diagnose impending problems and correct them. Measures of work quality include repeat road calls, repeat repairs and the percent 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 quality work.

5. 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.

6. Maintenance Control Indicators. Maintenance control indicators measure the overall performance of the maintenance department and how well it 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 of periodic inspections 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 diagnosis of mechanical problems and preventive correction, as opposed to a later failure based repair, is related to quality of work conducted (category 4)

Value of Indicators to Maintenance Managers

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

5 = Vital
4 = Very Useful
3 = Useful
2 = Limited Value
1 = Worthless

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 score of each performance indicator is shown in Table 4-1 for their value to maintenance managers, themselves. Also, listed in Table 4-1 are the most frequent response (the mode) and the median response. Occasionally maintenance managers failed to indicate their opinion of a candidate indicator. Missing responses were very infrequent but they were treated as missing data and they are not figured into the statistics shown in Table 4-1. The candidate performance indicators are grouped by the six categories described above, and within each category they are ordered with respect to average score. The indicator which received the highest average score is listed first. The rankings extend from 1 to 36 regardless of the category.

TABLE 4-1

VALUE OF PERFORMANCE INDICATORS TO MAINTENANCE MANAGERS

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

(continued)

TABLE 4-1 (continued)

Rank	Performance Indicator	Most Frequent Answer	Average Score
35	Dollar Value of Parts in Inventory for Each Bus Subsystem	Useful	2.94
Fleet Availability Indicators:			
14	Current Number of Open Maintenance Work Orders	Vital	3.88
26	Average Daily Number of Maintenance Jobs in the Backlog	Very Useful	3.36
28	Average Miles Traveled Per Bus Model Versus the Total Fleet	Very Useful	3.33
30	Average Duration of Open Work Orders	Very Useful	3.20
Work Quality Indicators:			
3	Number of Repeat Repairs per Month	Very Useful	4.25
4	Number of Repeat Breakdowns in the Same Month	Very Useful	4.25
17	Corrective Maintenance Diagnosed During P.M. Inspections Versus Total Corrective Maintenance	Very Useful	3.70
21	Total Labor Hours Spent on P.M. Versus Total Labor Hours	Useful	3.61
Work Productivity Indicators:			
2	Total Regular and Overtime Maintenance Labor Hours per Month	Vital	4.25
15	Average Labor Time Taken to Perform Each Type of P.M. Inspection	Very Useful	3.80
23	Estimated Maintenance Labor Hours Required to Complete Maintenance Backlog	Very Useful	3.47
33	Average Daily Estimate of Maintenance Labor Hours Backlogged	Very Useful	3.08

(continued)

TABLE 4-1 (continued)

Rank	Performance Indicator	Most Frequent Answer	Average Score
34	Estimated Labor Hours to Complete Closed Work Orders (Based on Time Standards) Versus Actual Hours	Very Useful	3.07
Maintenance Control Indicators:			
8	Total Number of P.M. Inspections Scheduled Per Week Versus Inspections Actually Performed	Very Useful	4.03
9	Percent of P.M. Inspections Performed Within the Prescribed Interval	Very Useful	4.03
16	Average Labor Time Taken to Make Corrective Repairs	Very Useful	3.79
18	Of the P.M. Inspections Performed Past the Inspection Interval, the Average Miles Past the Interval	Very Useful	3.68
20	Number of Stock Outs During the Month	Very Useful	3.61
24	Parts Inventory Value Over Time	Useful	3.45
29	Actual Labor Hours to Complete Closed Work Orders Versus Total Labor Hours	Very Useful	3.30
36	Parts Room Overhead Cost Versus Value of Inventory	Useful	2.68

Interestingly, although no maintenance manager marked everything as being vital, all 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 37 indicators, but it was considered a vital indicator by 16 managers. Also, there were few indicators that were not considered worthless by one or more managers.

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, while Fleet Availability Indicators seemed of least interest. Maintenance Control Indicators also seemed of lesser interest to the managers.

The eight indicators that no maintenance manager considered worthless are:

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;
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 from required 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 seem to indicate that the most accepted indicators are those that are already commonly collected. Further, because there seems to be a broad variance in the responses (most indicators were considered worthless by some and vital by others), there seems to be little consensus among maintenance managers on what information is important.

Value of 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. The results are presented in Table 4-2. The maintenance managers considered Miles per Road Call the most valuable indicator for their use, but second to Maintenance Cost per Vehicle Mile in value to top management. The rankings of very few indicators differed substantially between Tables 4-1 and 4-2. One notable exception was "Parts Inventory Value Over Time" (a Maintenance 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 indicators were scored vital by at least a few respondents and all 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, Maintenance Cost per Vehicle, etc).

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 felt that top management understood maintenance "very well" or "perfectly" and only about 20% felt that top management understood maintenance "somewhat" or "not at all". Therefore, the majority of the maintenance managers seem to believe that their top management understands maintenance relatively well. However, eleven of the respondents did not answer this question, which may slightly bias the results.

TABLE 4-2

VALUE OF PERFORMANCE INDICATORS TO TOP MANAGEMENT

Rank	Performance Indicator	Most Frequent Answer	Average Score
Fleet Reliability Indicators:			
2	Miles Per Road Call	Vital	4.05
10	Road Calls Per Bus Per Month	Very Useful	3.30
21	Average Age of Major Components On Each Bus Model	Limited Value	2.89
Fleet Maintainability Indicators:			
1	Maintenance Cost Per Vehicle Mile	Vital	4.05
4	Maintenance Labor Cost Per Vehicle Mile	Very Useful	3.82
5	Maintenance Material Cost Per Vehicle Mile	Vital	3.73
6	Maintenance Cost Per Vehicle	Vital	3.72
8	Average Fuel and Oil Cost Per Bus Model Versus the Total Fleet	Useful	3.36
12	Maintenance Labor Cost Per Bus Model Versus the Total Fleet	Useful	3.21
14	Maintenance Cost Per Bus Mile Per Bus Versus the Total Fleet	Useful	3.16
17	Total Value of Parts Used Per Month Versus the Total Value of the Parts Inventory	Very Useful	3.05
19	Average Value of Parts Used by Each Model of Bus in the Fleet	Limited Value	2.93
26	Maintenance Labor Cost Versus Material Cost	Limited Value	2.83
29	Dollar Value of Parts in Inventory for Each Bus Subsystem	Useful	2.70

(continued)

TABLE 4-2 (continued)

Rank	Performance Indicator	Most Frequent Answer	Average Score
31	Maintenance Work Orders Per Bus Model Versus the Total Fleet	Useful	2.70
Fleet Availability Indicators:			
16	Current Number of Open Maintenance Work Orders	Limited Value	3.13
18	Average Miles Traveled Per Bus Model Versus the Total Fleet	Useful	3.03
30	Average Daily Number of Maintenance Jobs in the Backlog	Limited Value	2.70
36	Average Duration of Open Work Orders	Limited Value	2.47
Work Quality Indicators:			
9	Number of Repeat Breakdowns in the Same Month	Very Useful	3.30
11	Number of Repeat Repairs Per Month	Useful	3.21
20	Total Labor Hours Spent on P.M. Inspection Versus Total Labor Hours	Useful	2.90
32	Corrective Maintenance Diagnosed During P.M. Inspections Versus Total Corrective Maintenance	Limited Value	2.67
Work Productivity Indicators:			
3	Total Regular and Overtime Maintenance Labor Hours Per Month	Very Useful	3.93
24	Average Labor Time Taken to Perform Each Type of P.M. Inspection	Limited Value	2.86
27	Estimated Maintenance Labor Hours Required to Complete Maintenance Backlog	Limited Value	2.80
33	Estimated Labor Hours to Complete Closed Work Orders (Based on Time Standards) Versus Total Labor Hours	Limited Value	2.54

(continued)

TABLE 4-2 (continued)

Rank	Performance Indicator	Most Frequent Answer	Average Score
34	Average Daily Estimate of Maintenance Labor Hours Backlogged	Limited Value	2.52
Maintenance Control Indicators:			
7	Parts Inventory Value Over Time	Very Useful	3.61
13	Percent of P.M. Inspections Performed Within the Prescribed Interval	Very Useful	3.16
15	Total Number of Inspections Scheduled Per Week Versus Inspections Actually Performed	Very Useful	3.16
22	Of the P.M. Inspections Performed Past the Inspection Interval, the Average Mileage Past the Interval	Limited Value	2.89
23	Number of Stock Outs During the Month	Limited Value	2.89
25	Average Labor Time Taken to Make Corrective Repairs	Limited Value	2.83
28	Parts Room Overhead Cost Versus the Value of Inventory	Useful	2.76
35	Actual Labor Hours to Complete Work Orders Versus Total Labor Hours	Limited Value	2.49

Other Performance Indicators Suggested by Maintenance Managers

Table 4-3 contains a list of additional performance indicators that were suggested by the transit maintenance managers, grouped by the above six categories. Additional Fleet Reliability and Maintainability Indicators included those which 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 which detailed labor utilization and productivity.

Summary

The maintenance managers surveyed perceived the performance measures normally collected as part of Section 15 reporting requirements to be the most useful to them. There seems to be little consensus on the value of other performance indicators.

METROPOLITAN TRANSIT AUTHORITY OF WICHITA, KANSAS, CASE STUDY

During the spring and summer of 1985, University of Oklahoma researchers examined Wichita, Kansas, Metropolitan Transit Authority (MTA) maintenance data. The purpose of this case study was to demonstrate methods that would permit the better management of bus fleets through the systematic use of commonly collected maintenance data. The information that exists in the flow of such maintenance data can be structured to assist maintenance management in controlling their department and insuring that it is progressing towards its planned objectives.

The problem of making better use of this maintenance data lies in: 1) Identifying the information requirements to measure the maintenance department's progress towards its planned objectives; 2) Identifying the natural flow of data and points in the flow where the data is most easily collected; and 3) Determining the most efficient method of converting the data into useful management information. Thus, the specific objective of the MTA case study was to address each of these three points with particular emphasis on the latter two points.

Selected MTA Indicators

Table 4-4 contains a list of performance indicators as selected for the MTA case study analysis. They are grouped in the previously discussed six performance categories and are largely derived from the questionnaire of maintenance managers.

The intention of the case study was to use paper-based bus maintenance records to develop and test a set of meaningful maintenance performance indicators. The performance indicators should assist in better managing day-to-day activities as well as provide a useful set of life cycle cost information with which to

TABLE 4-3

OTHER PERFORMANCE INDICATORS SUGGESTED BY MAINTENANCE MANAGERS

Fleet Reliability Indicators:

Road Calls By System Failed

Road Calls by Type by Fleet Model

Mechanical versus Non-Mechanical Breakdowns

Percentage of Wheel Chair 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 Percent of the Fleet

Parts Inventory per Bus

High Cost Items (e.g., Tires, Fluids Other than Fuel, etc.) per Type of Bus versus the Fleet

Material Cost per 1,000 Miles

Tire Cost per 1,000 Miles

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

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(continued)

TABLE 4-3 (continued)

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

<u>Work Productivity Indicators:</u>

Percent of Total Fleet Cleaned Daily

<u>Maintenance Control Indicators:</u>

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

Percent of Fleet Without Visible Interior or Exterior Disorders (e.g., torn seats, leaks, body damage, etc.)

Percentage of Absentee Labor

Percentage of Labor Hours That are Overtime

Ratio of Mechanics to Buses

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

Average Number of Parts People per 50 Buses

Average Number of Mechanics per Work Shift

TABLE 4-4

CANDIDATE MTA PERFORMANCE INDICATORS

FLEET RELIABILITY INDICATORS

Selected Indicators:

- Road Calls per Vehicle
- Miles per Road Call

Other Indicators:

- Average Age of Major Components on Each Bus Model
- Road Calls by Type and by Bus Model
- Mechanical Versus Non-Mechanical Road Calls
- Number of Defects Reported by Operators

FLEET MAINTAINABILITY INDICATORS

Selected Indicators:

- Fuel and Oil Cost per Mile per Bus Model
- Total Maintenance and Fuel Cost per Mile per Bus Model
- Parts Cost per Mile per Bus Model
- Direct Mechanic Labor Hours per Bus per 1,000 Miles per Bus Model

Other Indicators:

- Mechanic Labor Cost per Vehicle Mile
- Dollar Value of Parts in Inventory for Each Bus Model
- Average Number of Maintenance Work for Each Bus Model
- Miles per Quantity of Fluids Other Than Fuel
- Number of Brake Relines Performed per Month as a Percentage of the Fleet
- Mean Miles Between Engine and Transmission Failures
- Tire Cost per 1,000 Miles

FLEET AVAILABILITY INDICATORS

Selected Indicators:

- Backlog, Average Number of Open Work Orders
- Backlogged Hours, Average Labor Hours to Complete Backlog
- Average Duration of Open Work Orders

Other Indicators:

- Percent of Active Fleet Waiting for Repairs - "Deadlines"
- Percentage of Air Conditioning Operable
- Percentage of Wheel Chair Lifts Operable
- Spare Ratio
- Actual Spare Ratio Versus Scheduled Spare Ratio

(continued)

TABLE 4-4 (continued)

WORK QUALITY INDICATORS

Selected Indicators:

- Repeat Road Calls for the Same Reason
- Repeat Repairs at the System Level
- Repeat Repairs at the Component Level

Other Indicators:

- Maintenance Required Within 15 Days of Preventive Inspection
- Total Hours spend Conducting Preventive Inspections Versus Total Labor Hours
- Corrective Maintenance Diagnosed During Preventive Inspections Versus Total Corrective Maintenance
- Breakdowns Versus the Number of Days Past Preventive Inspection

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WORK PRODUCTIVITY INDICATORS

Selected Indicators:

- Total Estimated Labor Hours to Complete Closed Work Orders Versus the Total Mechanic Pay Hours
- Average Time Taken to Complete Preventive Inspections
- Average Time Taken to Complete Corrective Repairs

Other Indicators:

- Maintenance Labor Hours Lost Due to Employee Absence per Month Versus Estimated Workload Hours per Month
- Percentage of Labor Hours That Are Overtime
- Ratio of Mechanics to Buses

MAINTENANCE CONTROL INDICATORS

Selected Indicators:

- Mechanic Labor Hours Clocked to Work Orders (Direct Labor) Versus the Total Mechanic Pay Hours

Other Indicators:

- Accomplishing Maintenance Training Goals
- Parts Inventory Value Overtime
- Percent of Preventive Inspections Performed Within the Prescribed Interval
- Total Number of Inspections Scheduled per Week Versus Inspections Actually Performed
- Of the Preventive Inspections Performed Past the Inspection Interval, the Average Mileage Past the Interval
- Percentage of Overtime Paid Due to Absences as Compared to Total Overtime
- Percentage of Absentee Labor

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base economic decisions. Because the goals and objectives of the research were not necessarily the same as those of the Wichita MTA when attempting to measure their own system's performance, the indicators selected varied somewhat from those used there and elsewhere. Also, because they were not members of the Wichita MTA, the researchers could not dictate the types of information collected. Therefore, the selected performance indicators were also designed to match the data the Wichita MTA was willing to provide.

Table 4-5 details the actual values of the selected indicators for the MTA from February through August, 1985, a period of seven months which includes most of the hot summer months of bus operation as well as spring preparations for summer operation. Note that many of the indicators are separately developed for the four types of bus models in the MTA fleet: New Look, RTS II, Flxible, and Chance.

Monthly variations of these performance indicators are generally difficult for outsiders to interpret. Their primary value is in their utility for the maintenance manager in monitoring on-going monthly performance when in close proximity to operations. The seven months of performance indicator values reported in Table 4-5 are graphed in Appendix B of this report.

As one example of these plots, "Monthly Mechanic Labor Hours" (a Maintenance Control Indicator) is depicted in Figure 4-2. The high levels in mechanic labor hours in February through April, in part, reflect maintenance preparations for hot summer operations, notably air conditioning preventive maintenance and tuning. Reduced labor hours in the summer months are accounted for in part by summer vacation schedules.

Figure 4-2 also illustrates the disparity between total reported labor hours and labor hours which can be accounted for on the work orders. The hours not clocked to work orders are presumably either unproductive time (time spent in clean-up, job preparation, maneuvering buses in and out of repair bay and other non-mechanical activities) or the time was spent conducting minor mechanical activities that do not warrant being recorded (i.e., bleeding air tanks). The amount of unaccounted for mechanic labor time (hours not clock on work orders) at the MTA appears alarming (between 18 and 44 percent of total mechanic hours were not clocked on work orders) but, in fact, the MTA's experience is not unusual. For example, the American Public Works Association has reported that mechanics at public works organizations spend only 50% of their total available time doing actual mechanical work (no similar statistics were available of bus maintenance operations) (1). The unaccounted mechanic labor time presents a tremendous problem because it represents a significant costs which cannot be allocated to a bus or a maintenance function.

TABLE 4-5

SEVEN MONTH TABULATIONS OF SELECTED MTA PERFORMANCE INDICATORS

1985:	February	March	April	May	June	July	August
Fleet Reliability Indicators:							
Road Calls per Vehicle	1.6	1.1	1.3	1.3	1.1	1.6	1.45
Miles per Road Call	1,647	2,674	2,254	2,348	2,619	1,847	2,032
Fleet Maintainability Indicators:							
Fuel and Oil Cost per Mile for New Look Buses	$0.24	$0.20	$0.20	$0.20	$0.17	$0.18	$0.18
Fuel and Oil Cost per Mile for RTS II Buses	$0.28	$0.26	$0.28	$0.29	$0.25	$0.25	$0.25
Fuel and Oil Cost per Mile for Chance Buses	$0.17	$0.15	$0.16	$0.16	$0.13	$0.13	$0.13
Fuel and Oil Cost per Mile for Flxible Buses	$0.24	$0.20	$0.22	$0.23	$0.19	$0.20	$0.20
Total Maintenance and Fuel Cost per Mile for New Look Buses	$0.41	$0.44	$0.37	$0.66	$0.32	$0.37	$0.48
Total Maintenance and Fuel Cost per Mile for RTS II Buses	$0.49	$0.68	$0.46	$0.45	$0.51	$0.77	$0.51

(continued)

TABLE 4-5 (continued)

1985:	February	March	April	May	June	July	August
Fleet Maintainability Indicators (continued):							
Total Maintenance and Fuel Cost per Mile for Chance Buses	$0.71	$0.77	$0.84	$1.48	$0.29	$0.43	$0.51
Total Maintenance and Fuel Cost per Mile for Flxible Buses	$0.33	$0.35	$0.35	$0.36	$0.31	$0.29	$0.31
Total Maintenance and Fuel Cost per Mile for Entire Fleet	$0.44	$0.53	$0.43	$0.49	$0.40	$0.49	$0.44
Parts Cost per Mile for New Look Buses	$0.07	$0.08	$0.07	$0.26	$0.07	$0.07	$0.18
Parts Cost per Mile for RTS II Buses	$0.14	$0.28	$0.10	$0.07	$0.16	$0.22	$0.15
Parts Cost per Mile for Chance Buses	$0.36	$0.07	$0.23	$1.07	$0.08	$0.18	$0.20
Parts Cost per Mile for Flxible Buses	$0.04	$0.08	$0.06	$0.08	$0.06	$0.05	$0.05
Direct Mechanic Labor Hours per Bus per 1,000 Miles for New Look Buses	5.5	9.5	4.6	12.3	4.7	7.1	8.1
Direct Mechanic Labor Hours per Bus per 1,000 Miles for RTS II Buses	4.0	7.8	3.8	4.7	4.5	6.7	7.8

(continued)

TABLE 4-5 (continued)

1985:	February	March	April	May	June	July	August
Fleet Maintainability Indicators (continued):							
Direct Mechanic Labor Hours per Bus per 1,000 Miles for Chance Buses	11.2	3.0	28.0	15.6	4.9	7.6	6.7
Direct Mechanic Labor Hours per Bus per 1,000 Miles for Flxible Buses	4.0	3.4	3.5	3.1	3.1	2.4	3.6
Fleet Availability Indicators:							
Backlog (Average Number of Open Work Orders)	17.5	27.3	16	18.4	13.6	19.2	26.6
Backlogged Hours (Average Labor Hours to Complete Backlog)	114	312	98	153	74	128	280
Average Duration of Open Work Orders	2.86 days	4.16 days	3.85 days	3.41 days	2.46 days	3.34 days	3.45 days
Work Quality Indicators:							
Repeat Road Calls for the Same Reason	18	4	13	13	12	27	19
Repeat Repairs at the System Level	27	32	13	33	14	15	37

(continued)

TABLE 4-5 (continued)

1985:	February	March	April	May	June	July	August
Work Quality Indicators (continued):							
Repeat Repairs at the Component Level	10	12	3	13	7	5	8
Work Productivity Indicators:							
Average Time Taken to Complete 3,000 Mile Inspection	2.1 hrs	2.0 hrs	2.0 hrs	2.1 hrs	2.2 hrs	1.96 hrs	2.44 hrs
Average Time Taken to Complete 6,000 Mile Inspection	4.2 hrs	3.6 hrs	3.3 hrs	3.4 hrs	3.0 hrs	3.65 hrs	3.98 hrs
Average Time Taken to Complete 12,000 Mile Inspection	4.2 hrs	4.1 hrs	3.7 hrs	4.3 hrs	4.0 hrs	3.65 hrs	4.53 hrs
Average Time Taken to Complete Corrective Repairs	4.6 hrs	5.9 hrs	6.9 hrs	6.7 hrs	7.95 hrs	5.91 hrs	6.39 hrs
P.M. Inspections Scheduled / P.M. Inspections Performed	100%						
Maintenance Control Indicators:							
Total Mechanic Labor Hours Clocked on Work Order	1179.2	1,105.3	870.6	989.7	677.5	907.04	1133.6
Estimated Labor Hours / Clocked Labor Hours	0.83	0.82	0.91	0.82	0.75	0.69	0.71

(continued)

TABLE 4-5 (continued)

1985:	February	March	April	May	June	July	August
Maintenance Control Indicators (continued):							
Direct Labor Hours / Total Labor Hours	0.63	0.78	0.63	0.82	0.56	0.58	0.67
Miscellaneous:							
Average Miles Traveled for New Look Buses	1,160	1,228	1,388	1,301	1,141	1,304	1,174
Average Miles Traveled for RTS II Buses	3,182	3,512	3,763	3,673	3,101	3,051	3,259
Average Miles Traveled for Chance Buses	1,458	1,827	1,417	1,671	1,666	1,702	1,797
Average Miles Traveled for Flxible Buses	3,420	3,754	3,580	3,609	3,752	4,183	4,236

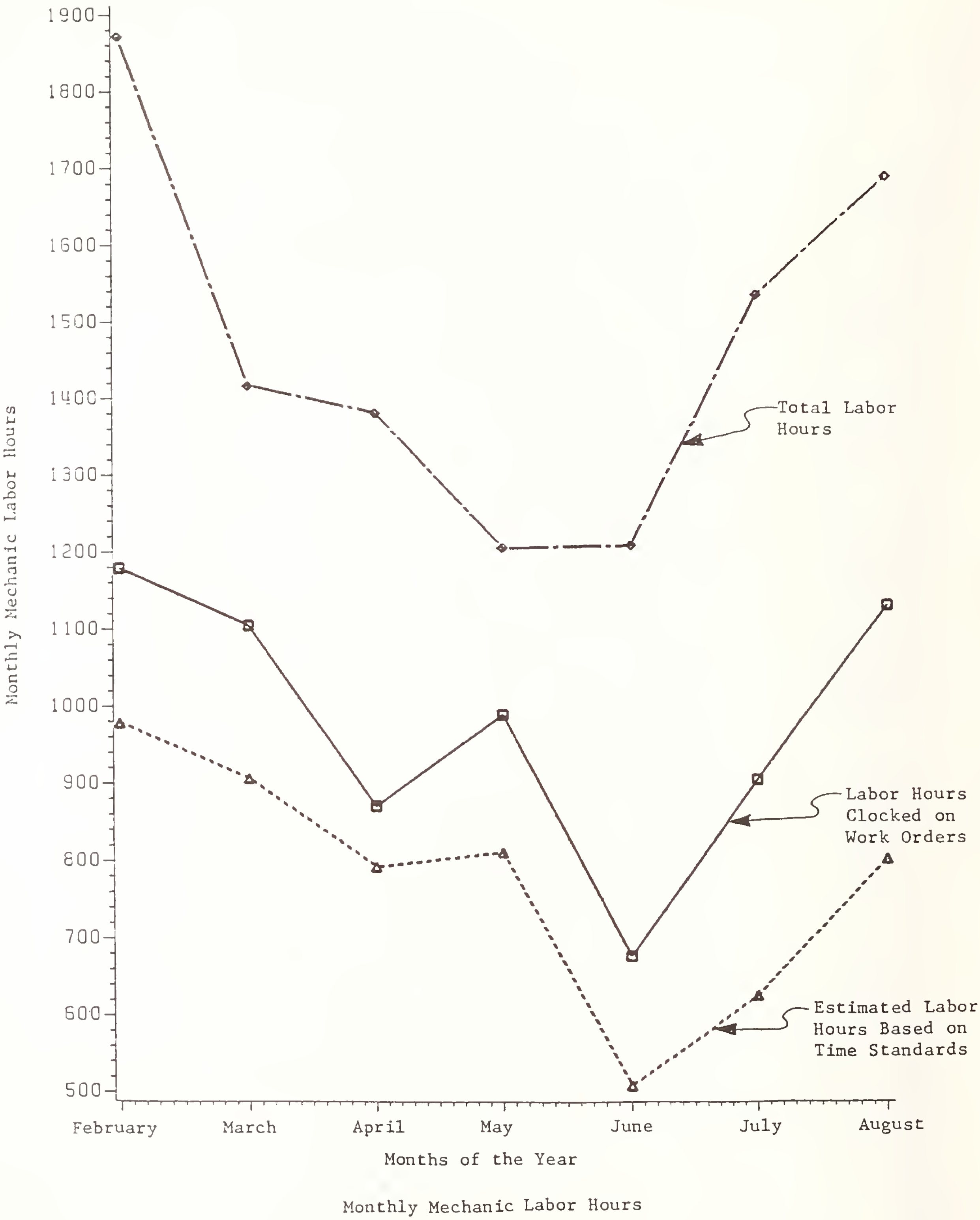

FIGURE 4-2

MONTHLY MECHANIC LABOR HOURS, WICHITA MTA, FEBRUARY TO AUGUST, 1985

CONCLUSIONS

This Chapter discussed the significance of maintenance performance indicators for maintenance managers. A questionnaire survey of 92 maintenance managers throughout the United States indicated that the most accepted indicators were those that were already collected. There were broad variations in their responses of how useful these indicators were to them, indicating a lack of consensus on what maintenance information is important.

Fleet Reliability (e.g., Miles per Road Call) and Maintainability (e.g., Maintenance Costs per Vehicle Mile) Indicators appeared to be valued the most, and Fleet Availability Indicators (e.g., Current Number of Open Work Orders) the least. When asked to identify more indicators, the managers suggested indicators which gave more details on road calls, component reliability, and costs.

The maintenance managers generally felt that these performance indicators were of more value to themselves than to top management. Most of the maintenance managers felt that top management understood maintenance at least "moderately well" or better.

Many of these performance indicators were monitored during a seven month period at the Wichita, Kansas, Metropolitan Transit Authority. Although no conclusions could be reached with this data, the case study served to demonstrate the practicality of the data collection effort as well as its utility in identifying maintenance data flows and how this information could be converted into useful management information.

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CHAPTER V

LIFE CYCLE COSTING

This chapter covers the development and use of life-cycle cost data. Life-cycle costing is an economic evaluation scheme that accounts for capital, operating, and maintenance costs during the usable life of an investment (e.g., a bus, maintenance equipment, or major unit within a bus, such as the engine). In other words, life-cycle costing takes into account the total costs associated with an investment when making decisions regarding the feasibility of procuring the item, the choices regarding the item's use and maintenance, and when the item should be replaced or removed from service.

In theory, life-cycle costing is both a common-sense approach to equipment management decision-making and a well-established evaluation procedure in engineering economics. Most private equipment investment, operation, maintenance, and replacement decisions instinctively incorporate at least a recognition, if not a formal accounting, of life-cycle costing. In practice, the difficulty involved in the application of life-cycle costing relates to obtaining data which can be applied to the theoretical model.

In this chapter, the use and the pitfalls of life-cycle costing in only two areas are discussed. The applications covered are: 1) The use of life-cycle costing in procurement decision-making and suggested procedures for the development of data to be input into the bus model and manufacturer selection process; and 2) The development of life-cycle costing data and its application to vehicle life and replacement decision-making. There are several other applications for life-cycle costing and they are listed by Maze, Cook and Dutta (12). However, before discussing specific applications of life-cycle costing, the next section reviews the economics of life-cycle costing.

ECONOMICS OF LIFE-CYCLE COSTING

The conscientious bus fleet manager will at least intuitively consider the total cost implication of all equipment decisions. Even the informal consideration of total cost indicates the management objective of life-cycle costing's use in decision-making. Described in this section are some of the tools which assist in the formal use of life-cycle costs in equipment decision-making. Fundamental aspects of formalizing the life-cycle costing process include:

1. Separation of objective and subjective measures of feasibility.

2. Use of money's time value.

3. The depreciation of equipment's value should be allocated to time periods during its life.

4. Whenever possible, all items should be given a monetary value so that they may be considered within the formal structure of life-cycle cost analysis.

5. Past costs are immaterial in the analysis except where they effect future costs.

Separation of Objective and Subjective Measures

There are certain aspects of any decision that cannot be measured in economic terms. Sometimes an alternative may be the best solution from an economic standpoint, but it may be unacceptable from a political standpoint. For example, suppose the economics of rebuilding major units (e.g., transmission, engine, compressors, etc.) through a contract is found to be financially attractive but the mechanic's union is strongly against service contracting. In such cases, even though contracting may be economically attractive, it may not be desirable, from a political point of view, because it offends the mechanic's union. Considerations that may not be reduced to a dollar value are called "irreducibles" (5, p. 16).

When performing life-cycle cost analysis, irreducibles should not be brought into the analysis. The life-cycle cost analysis should select the best alternative based solely on quantifiable economic criteria. Once alternatives have been evaluated in an objective context, a final selection can be made which includes irreducibles. If irreducibles dictate the final decision, then the decision-maker will have had the opportunity to weigh the irreducibles against known dollar amounts.

The Time Value of Money

When conducting life-cycle costing analysis it is often the case that the alternatives analyzed involve expenditures at different periods in time. Since money has a time value (interest), dollars spent during different periods are not the same value (or worth). As an example of the differences in worth, suppose an individual is offered two opportunities: 1) One thousand dollars today; or 2) One thousand dollars in one year. If the individual accepts the thousand dollars immediately rather than waiting, then he or she has the opportunity to place the money in the bank and draw interest on the money for one year, or put the money to some other productive use. If the individual accepts the alternative of receiving one thousand dollars in one year, then he or she loses the ability to use the money for one year. Clearly, receiving one thousand dollars today is worth more than receiving one thousand dollars in one year. Thus, money in the future has a lower worth than the same number of dollars at present. Accounting for the differences of money's worth at different times and making them equivalent is known as "discounting".

One form of discounting is known as "present worth analysis." Present worth analysis equates all future sums to present dollars. For example, receiving one thousand dollars today is worth more than receiving one thousand dollars in one year. Therefore, one thousand dollars in the future is worth less than one thousand dollars at present. To determine the present worth of future dollars, a factor is used to equate future dollars to present dollars. This factor is called a "present worth factor" and, because future dollars are always worth less than present dollars, the present worth factor is always less than or equal to one. The formula used to determine the present worth factor is shown below:

$$PWF = 1 / (1 + i)^n$$

Where: PWF = Single payment "present worth factor"

i = The discounting rate (interest) expressed as a decimal (e.g., i = 0.10 for 10 percent per year discount rate)

n = The number of years in the future

For example, if the discount rate is 10 percent and n = one year, then PWF = 0.9091. Therefore, with a discount rate of 10 percent per year, one thousand dollars one year in the future has a present worth of $909.10 ($1,000 x 0.9091 = $909.10). Values for PWF are typically found in tables of engineering economic textbooks or they can be computed using most scientific or financial applications pocket calculators (3,8).

The discount rate, i, reflects the prevalent economic interest rates as well as the degree of uncertainty in estimates of future cash flows. The examples used in this chapter will use a discounting rate of 10 percent. Most public agencies choose to either use the current discounting rate selected by the federal government for transportation investments or a discount rate which reflects local conditions. In most cases the agency's financial administrator will be able to recommend a discount rate.

Table 5-1 shows an illustration of the use of present worth analysis to equate future dollars spent on fuel over the life of a bus to their present worth. Shown in column 2 of Table 5-1 are the expected future miles the bus will travel per year. Column 3 contains the expected cost per mile. Notice that in column 3, future costs are not increased to account for inflation. The reason inflation is not included in the analysis is two-fold: 1) The rate of inflation in recent years has been quite unpredictable and hence any factor used for inflation may tend to be unreliable; and 2) All future expenditures will be made with dollars that were made less valuable through inflation, and thus, the reduced worth of future dollars tends to counteract inflation driven increases in future prices. In other words, the cost of inflation and the reduced worth of inflated future dollars tends

TABLE 5-1
PRESENT WORTH CALCULATIONS FUEL COSTS

Bus Age (Years) (1)	Mileage Per Year (2)		Cost Per Mile (3)		Total Annual Cost (4)		Present Worth Factor* (5)		Present Worth (6)
1	47,500	x	$0.249	=	$11,828	x	0.9091	=	$10,753
2	47,500	x	$0.249	=	$11,828	x	0.8264	=	$ 9,775
3	47,500	x	$0.249	=	$11,828	x	0.7513	=	$ 8,886
4	47,500	x	$0.249	=	$11,828	x	0.6830	=	$ 8,079
5	47,500	x	$0.249	=	$11,828	x	0.6209	=	$ 7,344
6	40,000	x	$0.249	=	$ 9,960	x	0.5645	=	$ 5,622
7	40,000	x	$0.249	=	$ 9,960	x	0.5132	=	$ 5,111
8	40,000	x	$0.249	=	$ 9,960	x	0.4665	=	$ 4,646
9	40,000	x	$0.249	=	$ 9,960	x	0.4241	=	$ 4,224
10	40,000	x	$0.249	=	$ 9,960	x	0.3855	=	$ 3,840
11	35,000	x	$0.249	=	$ 8,715	x	0.3505	=	$ 3,055
11	35,000	x	$0.249	=	$ 8,715	x	0.3186	=	$ 2,777
					Total Present Worth				$74,112

* Assumes 10 percent discount rate

to cancel each other. Column 4 contains the total cost per year which is multiplied by the present worth factor in column 5.

Note that the present worth factor in column 5 becomes smaller in the future. For example, the present worth factor for two years in the future is 0.8264, while the present worth factor for ten years in the future is 0.3855. The decrease in present worth factors means that costs in the near future have more present value than costs in the distant future. The product of column 4 and 5 for each year is the present worth of each year's estimated fuel cost and it is listed in column 6. Column 6 is then totaled and the total can be used to compare the expected fuel costs of this particular bus model to the fuel costs of another bus model. However, it must always be remembered that all comparisons using present worth analysis should be for items with the same life. If the numbers in Table 5-1 are to be used in a comparison, then they must be compared to a bus model with the same twelve year, assumed life.

Sometimes it may be the case that comparisons have to be made between alternatives that do not have equal lives. In such cases the time value of money is brought into the analysis through another method which equates costs to a uniform payment series. For example, when money is borrowed from a bank, the repayment is generally based on a constant (uniform) series of payments that are paid over a specific number of periods (the life of the loan). Thus the series of payments are equivalent to the amount borrowed plus the interest on the money while the money is being used by the borrower. Similarly, when analyzing an equipment expenditure, lump-sums may be broken into an equivalent uniform series over the life of the equipment and the periodic payment for one asset (such as a bus) may be compared to the periodic cost of alternative assets. In most cases, the analysis is based on an annual series of payments (payments made once-a-year). The number used to reduce a present cost to an annual uniform series is called the "capital recovery factor" and the formula for the capital recovery factor is shown below:

$$\text{capital recover factor (crf-i-n)} = \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

Where: n = number of periods

i = discount rate per period expressed as a decimal, e.g., 0.10 for 10 percent

Table 5-2 provides capital recovery factors for a uniform annual series of payments at a discount rate of 10 percent per year for an investment lasting from one to twelve years. Values for the capital recovery factor are typically found in tables of engineering economy textbooks or they can be computed using most scientific or busness applications pocket calculators (3, 8).

TABLE 5-2
CAPITAL RECOVERY FACTORS FOR i = 10 PERCENT

Bus Age, n	Capital Recover Factor*
1	1.10000
2	0.57619
3	0.40211
4	0.31547
5	0.26380
6	0.22961
7	0.20541
8	0.18744
9	0.17364
10	0.16275
11	0.15396
12	0.14676

* Capital recovery factor, (drf - i - n)

$$= \frac{i\ (1+i)^n}{(1+i)^n - 1}$$

As an illustration of the use of capital recovery factors, suppose that two alternatives are being compared: 1) The purchase of new buses; and 2) The rehabilitation of old buses. Further, suppose that new buses will cost $150,000 per bus and last for 12 years, and the rehabilitation being examined is a moderate rehabilitation which will extend the life of the buses for 6 years and costs $75,000. Both options (buy new or rehabilitation) are assumed to have no value at the end of their lives.

In a comparison of these two options, the analysis should consider the capital (purchase), operating, and maintenance costs, and perhaps include factors for performance (for example, expected costs of roadcalls). For simplicity sake, in this analysis only capital costs are considered. To derive the annual uniform series for each alternative, the formula below is used:

annual uniform series = (P - S) x (crf-i-n) + S(i)

Where: P = the present worth or purchase price of the bus

S = the salvage value of the bus at the end of n years

i = the discount rate expressed as a decimal

n = remaining bus life in years

In the example, the new bus option is assumed to be worth $3,000 at the end of its life (salvage value = $3,000) and the rehabilitated bus has no salvage value. The uniform series for each option is determined below:

1. Rehabilitation with 6 Year Life and 10 Percent Discount Rate;
   ($75,000) x (0.22961) = $17,221 per year

2. New Bus with 12 Year Life and 10 Percent Discount Rate;
   ($150,000 - $3,000) x (0.14676) + $3,000 (0.10) = $22,014 per year

The calculations above show that the annualized capital costs for the rehabilitated buses are less than those of the new buses. Thus, the use of a uniform annual series provides a method for comparison of alternatives with unequal lives and it permits the annualization of lump sum costs.

Although the example analysis is not a complete comparison of the life-cycle costs of rehabilitation versus buying new buses (for an example of a more complete analysis see 12, pp. 230-235), it does tend to demonstrate the economic appeal of rehabilitated buses. Rehabilitation of transit buses has grown substantially since the late 1970's, in part following national trends of remanufacturing transportation vehicles and other expensive capital investments. Also, it has seemed attractive to rehabilitate the old, but reliable, and familiar "New Look" buses which long have dominated transit fleets instead of investing in the more expensive advanced design buses (ADB) now being manufactured.

A 1983 UMTA report, Economic Comparison of New Buses Versus Rehabilitated Buses, found that rehabilitated buses were distinctively less expensive to purchase, they were perhaps just as reliable as new buses in terms of roadcall performance, and they achieved 25 to 35 percent more miles per gallon of fuel than new advanced design buses (13). The UMTA survey found that no transit agency which had purchased rehabilitated buses had done a comprehensive life-cycle cost analysis, in large part, because of the uncertainty of operating and maintenance data for rehabilitated buses as well as their projected life. Capital costs per rehabilitated bus ranged from $22,000 to $85,000 (1979-1982 figures) with corresponding extensions of 3 to 10 years in bus life depending on the extent of the remanufacturing.

Depreciation

Although the Federal government does not permit depreciation accounting of Federally-granted funds, this should not prevent the transit agency from including depreciation in its economic analysis of bus life-cycle cost. Through depreciation analysis, the original capital costs of buses are allocated to individual years over the bus's life. If capital costs are not included, a vehicle replacement analysis will indicate that new buses should be replaced every year because of the low initial maintenance costs. Thus, the use of depreciation relates to the economic analysis of the vehicle, not transit agency finances or budget computations.

There are several different definitions of depreciation (8). However, the one that relates best to the use of depreciation in analysis of life-cycle costs defines depreciation as the loss in value of an asset (such as a bus) between two dates. The value at the later date is subtracted from the value at the earlier data and the difference between the two is the depreciation. The depreciation that takes place during each period of time (usually per year) is a cost associated with the ownership and use of the bus during that year. Therefore, when estimating the life cycle costs of a bus, it is important to know the depreciation cost for each year.

One way of calculating depreciation is to determine the drop in market value in each year. This can be done for items that are easily priced through the market. For example, the current value of a used automobile could be easily determined through the National Automotive Dealers Association Used Car Guide or through current local prices for similar cars (10). However, no similar and easily accessible sources exist for determining the current value of a transit bus at each year within its life.

Determining the market value of assets through time is a problem which is shared by many other industries which do not have a wide spread market for their assets. In these cases, formulas are used to approximate the loss of an asset's value through time.

One method used to calculate depreciation is the straight line method. The straight line method is the easiest method available for estimating depreciation. The equation used to determine the depreciation for each year is shown below. The depreciation allocated is the same every year.

$$D = \frac{P - S}{n}$$

Where: D = the depreciation assigned to each year

P = the present worth or purchase price of the bus

S = the salvage value of the bus at the end of n years

n = remaining bus life in years

To illustrate the use of straight line depreciation, suppose that a bus has an initial purchase price of \$150,000, a life of 12 years, and an expected salvage value in 12 years of \$3,000. The straight line depreciation per year is \$12,250 ((\$150,000 - \$3,000)/12 = \$12,250). In other words, the projected loss in value in each year is \$12,250. The initial purchase price minus the cumulative depreciation is the book value. For example, the book value at the end of the first year is \$137,750 (\$150,000 - \$12,250 = \$137,750), the book value at the end of the second year is \$125,500 (\$137,750 - \$12,250 = \$125,500) and so on. In Figure 5-1, the book value using straight line depreciation is plotted against the years in the solid line.

Although straight line depreciation is simple to use, it often does not accurately represent the loss of an asset's value. Most assets tend to drop in value (depreciate) very quickly during the first few years of the asset's life and then they tend to depreciate very slowly towards the end of the asset's life. Accelerated depreciation early in the asset's life and a slower rate of depreciation later, cause a drop in the book value which more accurately represents actual conditions. Change in book value over time which more accurately reflects true market conditions, is represented by the dashed line in Figure 5-1. The dashed line represents depreciation found by using the declining balance method.

The declining balance method uses a depreciation rate which is calculated by the equation below:

$$k = 1 - \left(\frac{S}{P}\right)^{\frac{1}{n}}$$

Where: k = the depreciation rate

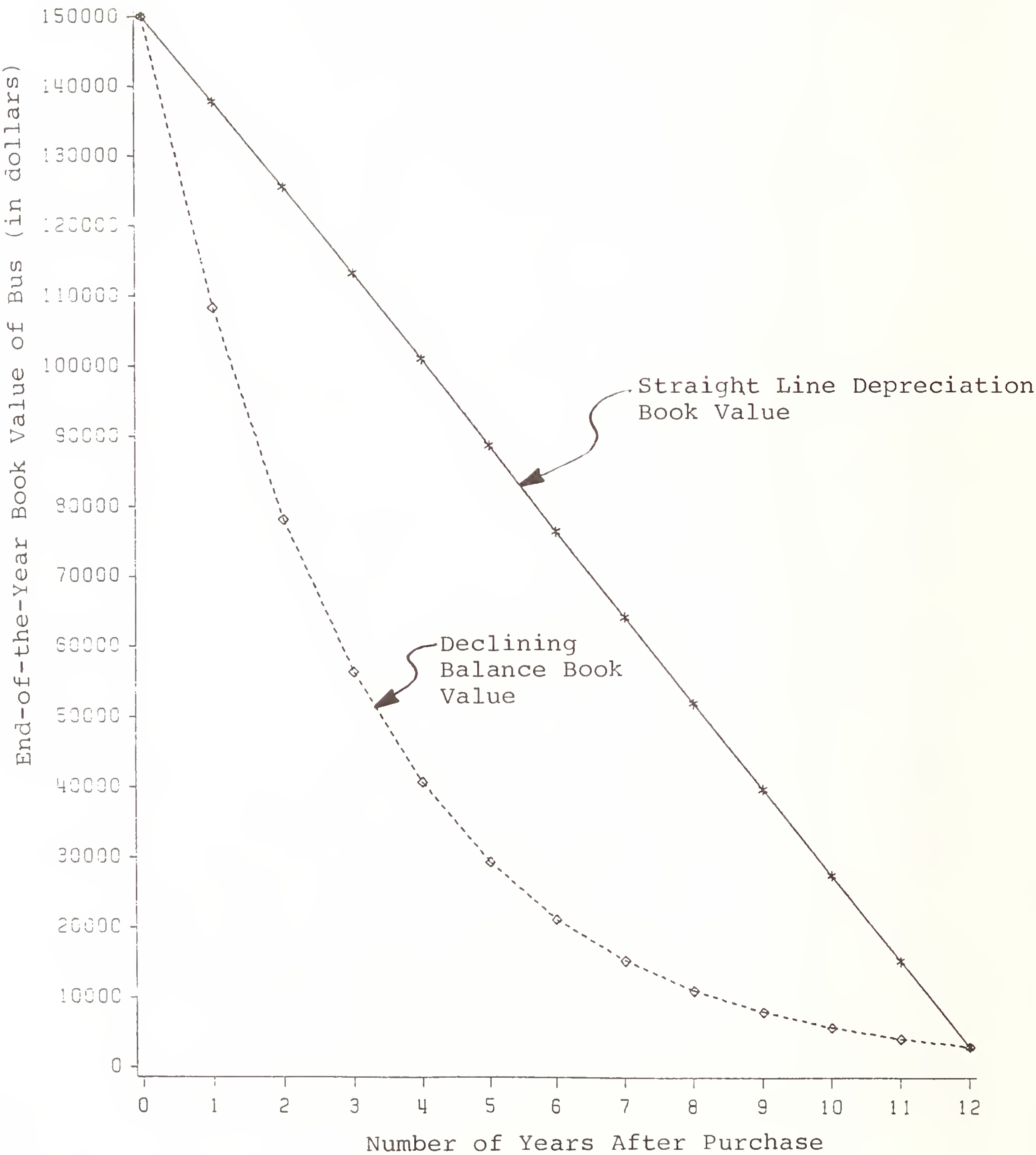

Figure 5-1 Decline in Book Value Under Straight Line and Declining Balance Depreciation

p = the present worth or purchase price of the bus

S = the salvage value of the bus at the end of n years

n = remaining bus life in years

Using the previous example, the depreciation rate is 0.2468 ($k = 1 - (3{,}000/150{,}000))^{1/12} = 0.2782$). The depreciation for the first year is then computed as follows:

$$D_1 = P \times k$$

Where: D_1 = the depreciation in the first year

In the example, the purchase price of the bus is \$150,000. The depreciation in the first year is \$150,000 x 0.2782 = \$41,730. The depreciation is placed in column 3 of Table 5-3. In column 2 is the book value at the beginning of each year and in column 4 is the book value at the end of each year.

In following years the depreciation is computed using the formula below:

$$D_n = (BV_{n-1}) \times k$$

Where: n = bus age in years

D_n = depreciation during year n

BV_{n-1} = the book value at the end of year n-1 (the previous year)

In the example, the depreciation for the second year is:

$$D_2 = \$108{,}270 \times 0.2782 = \$30{,}121$$

$$BV_{3 - 1} = \$108{,}270 - \$30{,}121 = \$78{,}149$$

In the third year:

$$D_3 = \$78{,}149 \times 0.2782 = \$21{,}741$$

$$BV_{4 - 1} = \$78{,}149 - \$21{,}741 = \$56{,}408$$

Depreciation costs are calculated in a like manner through year 12. After that the bus is considered fully depreciated. The complete allocation of depreciation to each of the 12 years is shown in Table 5-3. The book value, using the declining balance depreciation method, for each year is plotted with a dashed line in Figure 5-1. The acceleration in depreciation during the early years of the bus's life can be clearly seen.

TABLE 5-3
DECLINING BALANCE DEPRECIATION

Bus Age (Years) (1)	Book Value Beginning of Year (2)		Annual Depreciation (3)		Book Value End of Year (4)
1	$150,000	-	$41,730	=	$108,270
2	$108,270	-	$30,121	=	$ 78,149
3	$ 78,149	-	$21,741	=	$ 56,408
4	$ 56,408	-	$15,693	=	$ 40,715
5	$ 40,715	-	$11,327	=	$ 29,388
6	$29,338	-	$ 8,176	=	$ 21,212
7	$21,212	-	$ 5,901	=	$ 15,311
8	$15,311	-	$ 4,250	=	$ 11,051
9	$11,051	-	$ 3,074	=	$ 7,977
10	$ 7,977	-	$ 2,219	=	$ 5,758
11	$ 5,758	-	$ 1,602	=	$ 4,156
12	$ 4,156	-	$ 1,156	=	$ 3,000

There are other methods used to allocate depreciation to specific years and they are discussed in most engineering economy text books (3, 8). However, it is felt that declining balance is appropriate for most life-cycle costing problems.

Assigning a Money Value to Items

The objective of life-cycle costing is to analyze alternatives and programs based on their total cost. This implies that the system is being evaluated with the use of monetary values. However, often times factors related to the performance of a system do not have set dollar values. For example, suppose life-cycle costing analysis is being used to analyze the replacement of a subfleet of buses. The buses considered for replacement are old and thus they are more prone to roadcalls. Newer vehicles may be reliable and less likely to experience roadcalls. The difference in roadcall performance should be a consideration in the replacement analysis but, unlike the value of the bus, roadcall performance does not have a market value.

In cases were there are no market values for performance differences, a value should be assigned. For example, a roadcall often causes a service disruption, disgruntled patrons, unscheduled maintenance activities, etc. All these events can be associated with a cost penalty. Once an equitable cost penalty has been derived, then cost differences can be analyzed using objective life-cycle costing criteria.

In the past, some transit agencies have been quite innovative in quantifying performance differences and thus permitting the inclusion in life-cycle costing analysis. Transit agencies that have used life-cycle costing, have quantified, in economic terms, such items as new vehicle mainufacturer's delivery time performance, performance of the air conditioning system, maneuverability of the bus, parts service, engineering support, mechanic training, and the quality and availability of technical manuals (7).

Past Costs In Life-Cycle-Cost Analysis

Past costs are costs that have already been expended. Since they represent money which has already been spent that cannot be recovered, they should be disregarded except where they affect future costs. Money spent overhauling an engine, for example, cannot be recovered but it certainly affects the future maintenance and operating costs of a bus.

As an example of where past costs should not be considered, suppose an agency operates a fleet of paratransit vans. The vans are standard 16 passenger vans without wheelchair lifts. Based on past historical cost data and through the use of replacement analysis, the transit agency adopts a policy of replacing these vehicles every five years. Early in the fourth year of one van's life, its transmission fails and is rebuilt. During the remainder of the fourth year unexpected work is conducted to other components of the van's driveline. Towards the end of the fourth year, a major engine failure occurs (suppose that a rod is thrown) and, to become operable, the van's engine must be replace or rebuilt. The fleet manager must now decide whether to repair or replace the van. The expenditures made in the recent past to maintain the vehicle are totally immaterial to the replacement decision. Thus life-cycle cost analysis should only include the cost of repairing the engine and other expected future operating and maintenance costs.

In the use of life-cycle costing to analyze equipment options, the prediction of future life-cycle costs is the most difficult activity. Thus the predominate role for past costs should be to serve as a guide for the prediction of future costs.

LIFE-CYCLE COSTING IN PROCUREMENT

The use of life-cycle costing in procurement has been promoted as an innovative alternative to equipment procurement based on minimum initial capital cost, the "lowest bid" (11). Life-cycle cost based procurement selects the winning bidder based on the minimum total of capital, operating, and maintenance costs. Thus, the selected equipment will provide the minimum costs of ownership over its entire life. The federal government has used life-cycle cycle costing for military procurement by the Department of Defense since the 1960's. It also is used by the General Services Administration for the purchase of standard items such as typewriters and office supplies.

The application of life-cycle costing to procurement decisions does, unfortunately, bear a cost to the user. Accumulating life-cycle cost data, generating procedures for life-cycle cost bidding, evaluating life-cycle cost bids, and selecting the winning bidder are far more complicated and time consuming than selection of the low bidder based on initial capital costs alone. Because of the costs involved in applying life-cycle costing to procurement decisions, it is only efficient to apply life-cycle costing to cases where possible benefits of life-cycle costing's use exceeds its additional cost. A predominate characteristic of procurements where life-cycle costing is justified is the existence of post-purchase costs (maintenance and operating costs) (2). Examples of items that have no post-purchase costs, and hence, life-cycle cost based procurement is not justified, include paper clips, pencils and safety pins.

The higher the post-purchase costs in comparison to the initial cost, the more beneficial life-cycle cost base procurement becomes. Further, when the cumulative post-purchase costs over the expected life of the item become greater than the initial cost, the post-purchase costs should be more important to the purchase decision than the initial costs. In such cases, consideration of the post-purchase costs plus the initial costs through life-cycle costing is clearly warranted. Such is the case of transit bus procurement. For example, in 1983 the cost per bus per year for fuel, oil, and maintenance averaged roughly $27,000 for all federally subsidized transit systems (15). Over an expected 12-year life, the cumulative maintenance and operating costs are more than double the initial capital costs of a new bus. Because the post-purchase costs of transit buses are much greater than the initial cost, in theory the application of life-cycle costing to bus procurement decisions is clearly justified.

In practice, the application of life-cycle costing to transit bus procurements has received mixed responses from transit agencies. In a U.S. General Accounting Office (GAO) survey of transit agencies that have used life-cycle costing, when asked if the agency had difficulty with the life-cycle costing process, the transit agencies reported responses shown below (16) (for a detailed discussion of the survey of life-cycle costing practice see (4)):

Response	Percentage of Agencies
Little or no difficulty	31.0%
Moderate difficulty	25.9%
Great difficulty	20.7%
Very great difficulty or impossible	22.4%

In many cases the difficulty found in the use of life-cycle costing created confusion in the bidding process, resulted in delays in the delivery of equipment, and in a few cases it resulted in litigation. However, in most cases where difficulties have been encountered, they were a result of inadequate preparation of life-cycle costing procedures and a lack of spelling-out methods to be used in the development of manufacturer's cost estimates. Other agencies that have followed well development life-cycle cost based bidding procedures have found life-cycle costing efficient, that it greatly increases procurement flexibility, and it rewards manufacturers with durable designs.

This section will define many of the pitfalls that have been encountered in the use of life-cycle cost based procurement and suggests steps to help avoid problems in the future. "Cook book" like guidelines already exist that spell-out the theoretical method for the development and evaluation of life-cycle cost bids (12). The guidelines contain worksheets to facilitate the process and they incorporate sound economic principles into the analysis. These guidelines are not duplicated in this monograph. The transit fleet manager wishing to use life-cycle costing in procurement should consult these guidelines for proper economic analysis procedures, consult other transit agencies which have successfully applied life-cycle costing to bus procurement, and avoid the pitfalls of past procurements by considering the recommendations listed in the remainder of this section.

Life-Cycle Cost Based Procurement Procedures

The U.S. Urban Mass Transportation Administration (UMTA), in response to Congressional dictates, first required life-cycle cost based bidding for the purchase of transit vehicles in 1982 (7). Later, in 1983, UMTA made life-cycle cost based bidding optional. The 1982 guidelines said that transit agencies should select as "cost drivers" those items which account for 75 percent or more of operating and maintenance costs during the life of the bus. Typical cost drivers include preventive maintenance and major component repairs. The post-procurement portion of the life-cycle cost bid should be based on the projected costs associated with the cost drivers.

Cost Drivers. A limited number of items are used as cost drivers, rather than attempting to project costs to all items, because buses simply include too many items to project costs for each possible maintenance activity. In theory, buses with durable items that are included as cost drivers should similarly have durable items which are not cost drivers.

The cost driver concept is sound in theory but not in practice. The costs associated with maintaining a bus tend to be spread across a large number of maintenance activities and thus it is impossible for a few cost drivers (at most 10 cost drivers) to account for 75 percent of the total post-purchase costs. For example, a recent National Cooperative Transit Research and Development Program study of maintenance manpower planning found that 42 percent of total bus maintenance labor time, and presumable a similar proportion total maintenance costs, is devoted to servicing/cleaning and body work (6). Both of these activities include several different subactivities, that individually do not account for a significant share of maintenance costs. Therefore, rarely are either service/cleaning or bodywork included as cost drivers. Without including servicing/ cleaning and bodywork as cost drivers, it is unlikely that life-cycle cost bids actually account for 75 percent of the total post-purchase costs.

Tables 5-4 and 5-5 further illustrate the problems of the use of cost drivers. The numbers in the tables were taken from actual life-cycle cost bids. Note that fuel accounts for between 80.5 and 93.4 percent of the total life cost estimates. However, based on UMTA Section 15 reporting statistics, fuel only accounts for about one-third of the operating and maintenance costs attributed to the vehicle (15). Table 5-6 further demonstrates the variance between actual life costs and those bid by manufacturers. It presents actual costs experience by the Central Oklahoma Transportation and Parking Authority with RTS II 04 model buses in the third year of operation. Note that fuel accounts for less than half of the operating costs. As the buses age and major components begin to fail, the cost of maintenance is expected to grow and fuel will become a smaller proportion of total operating costs.

It is clear that the current life-cycle costing process does not take into consideration 75 percent of the total post-purchase costs. The existing process tends to overstate the importance of fuel costs in comparison to other post-purchase costs.

The fallacy of the cost driver concept is that it attempts to account for as much of the total post-purchase costs as is possible. On the other hand, when evaluating life-cycle cost bids, the comprehensiveness of the cost measures are not as important as measuring the differences in post-purchase costs between competing manufacturers. For example, even though cleaning/servicing may consume a large portion of the post-purchase cost, if all the bus models bid by manufacturers tend to require the same amount of cleaning/servicing, then cleaning/-servicing is a neutral cost and should not be included as a cost driver in the evaluation. Therefore, only items which are believed to vary in their cost performance from one manufacturer to the next should be included as cost drivers.

The careful selection of appropriate cost drivers, and specifically documenting how the costs associated with a cost driver are to be measured, are key elements to the success of life-cycle cost based procurement. As an illustration of poor selection and evaluation of cost drivers, an UMTA sponsored study of life-cycle cost base procurement found agencies that had received bids from different bus manufacturers that included the same brand component and the manufacturers had bid different overhaul intervals for identical components (14). Unless there is some reason to believe that common component performs differently in different bus models, common components should not be used as a cost driver.

Transit agencies which accept such unrealistic differences only tend to reward manufacturers that provide optimistic (or exaggerated) estimates of component life. Further, transit agencies should always reserve the right to modify mistakes in manufacturers' bids when sufficient information is available to correct the mistake. If the agency does not have enough cost information to correct a bid, then the agency should reserve the right to throw out an entire cost driver so that other bidders are not damaged by the mistakes of one bidder.

<u>Selection of Cost Drivers</u>. Cost drivers used in the life-cycle cost analysis of bids by competing manufacturers should cover those items which are likely to significantly vary from one manufacturer to the next. To determine quantitative difference between potential bidders requires cost performance data for each potential bus model. However, a data base containing the cost performance of competing manufacturers' buses does

TABLE 5-4
LIFE CYCLE OPERATING COST ESTIMATES PER BUS*

Transit System	Bidder	Fuel	Percent	All other Costs	Percent	Total
Houston, TX	GMC	$139,860	84.8	$25,069	15.2	$164,929
	GFC	135,722	83.1	27,587	16.9	163,309
	Neoplan	147,059	81.6	33,068	18.4	180.127
Dallas, TX	GMC	142,045	81.9	31,438	18.1	173,483
	GFC	137,665	82.8	28,586	17.2	166,251
Spokane, WA	GMC	150,102	80.5	36,414	19.5	186,516
	GFC	141,632	80.5	34,354	19.5	175,986
Columbus, OH	GFC	121,093	91.7	10,931	8.3	132,024
	GMC	129,563	93.4	9,214	6.6	138,777

TABLE 5-5
PERCENT OF INDIVIDUAL FACTOR COST
TO TOTAL LIFE CYCLE OPERATING COST *

Transit System	Bidder	Fuel	Oil	Brakes	Air Condi-tioning	Preventive Maintenance	Trans-mission	Engine
Houston, TX	GMC	84.8	0.5	4.4	0.7	4.0	1.8	3.6
	GFC	83.1	0.5	4.6	0.8	5.1	1.8	4.1
	Neoplan	81.6	0.4	4.9	1.8	6.1	1.9	3.3
Dallas, TX	GMC	81.9	0.4	9.2	0.7	2.7	1.6	3.5
	GFC	82.8	0.4	7.6	0.8	2.9	2.0	3.5
Spokane, WA	GMC	80.5	0.6	5.6	0.7	3.2	5.5	3.9
	GFC	80.5	0.6	4.3	0.9	3.7	5.9	4.1
Columbus, OH	GFC	91.7	-	-	0.8	7.4	0.1	-
	GMC	93.4	-	-	1.0	5.5	0.1	-

* Source: Genral Accounting Office (15)

TABLE 5-6
OPERATING COST DATA FOR RTS II 04 MODEL COACHES*

Cost Factors	Third Year's Cost Fleet Total	Average Cost per Bus	Percent of Total Cost
Preventive Maintenance	$ 7,463	$ 339	2.2%
Electrical	23,507	1,069	7.1
Brakes	24,807	1,128	7.5
Filters	8,964	407	2.7
Air Cond.	22,624	1,028	6.8
Transmission	4,087	186	1.2
Engine	7,680	349	2.3
Steering	1,160	53	0.4
Misc.	66,207	3,009	20.0
Fuel	165,137	7,506	49.8
Total	$331,636	$15,074	100.0%

Avg. Miles Per Bus = 35,322

* Source: Central Oklahoma Transportation and Parking Authority

not yet exist (such a data exchange is the subject of the next chapter). Instead, fleet managers must rely on their experience, contact with fleet managers from other transit systems, and their own cost records to determine what are the most important cost drivers. In many cases, cost drivers have been formulated by simply trying to account for the greatest portion of the total cost with a handfull of items. Hopefully the items that consume the greatest share of the cost will account for the greatest differences between manufacturers. Identifying the highest cost items can be conducted in a similar manner as the development of the criticality index in Table 3-3.

In Table 5-7 are listed the cost drivers used in 28 different life-cycle cost base requests for bids. The second column lists the frequency of each cost driver's used. The third column lists the number of times each cost driver was eliminated from the final evaluation. Elimination of cost drivers was primarily due to either: 1) The transit agency's failure to accurately and scientifically identify how the cost driver was to be calculated which resulted in suspect information from competitors; or 2) The transit agency requesting cost information for drivers without established histories and hence the manufacturer could only provide unsubstantiated cost data.

Table 5-7 shows that several transit agencies chose to include standardization and performance as cost drivers. Standardization deals with similarity or interchangeability of bus components of the bus being bid with buses currently being operated by the transit agency. For example, one agency defined a bidder's bus as being standard if 90 percent or more of the parts for the bidder's bus were interchangeable or the same as those used by buses already in the fleet. Other items covered under standardization included the spare parts inventory that would have to be added to accommodate new buses, new special tools, the cost of training mechanics to work on non-standard systems, and the cost of new facilities required for the maintenance of new non-standard buses. In general, most manufacturers have been able to accurately estimate the costs associated with non-standardized buses.

Performance cost drivers included items that were largely qualitative and difficult-to-quantify. Transit agencies include items under performance that covered three categories, 1) bidder's performance, 2) post-delivery support, and 3) performance of the vehicle. Items considered in "bidder's performance" included the financial resources of the manufacturer, the bidder's compliance with the specification, and the projected delivery date. "Post-delivery" support items included parts support, engineering service support, mechanic training support, and the availability and quality of technical manuals for the bus. "Vehicle performance" items included the bus's crashworthiness, the mechanical reliability (as measured by roadcall experience), ride and handling, anticorrosion protection, air conditioning performance, and turning radius (for articulated buses).

TABLE 5-7
FREQUENCY OF USE OF COST DRIVERS IN 28 PROCUREMENTS*

Cost Driver	Frequency of Use	Frequency of Elimination from Final Evaluation
Fuel Consumption	23	8
Oil	14	4
Repairs and Overhauls		
Brakes	23	10
Engine	19	6
Heating, Ventalation and Air Conditioning	17	4
Transmission	21	7
Electrical	9	2
Preventive Maintenance	21	8
Standardization	17	5
Performance	10	0

* Source: U.S. Department of Transportation, Urban Mass Transportation Administration (14)

The primary difficulty with the inclusion of performance cost drivers is in the development of a dollar value scale to reward good performance or dollar penalties for poor performance. In general, performance factors can be and should be included in a life-cycle cost bid only if the method used to measure performance is unbiased and thoroughly spelled-out in advance.

Cost Driver Identification and Calculation. In many cases, difficulties with life-cycle cost based procurement have been a result of the transit agency's failure to specifically identify cost drivers and calculation procedures for cost driver estimation. For example, Table 5-7 indicated that eight times fuel consumption was eliminated as a cost driver in 23 different procurements. Seven of the eight times fuel was eliminated because the consumption estimates were viewed as "unrealistic" and/or "not verifiable." In several other cases, methods used to calculate fuel consumption rates varied from manufacturer to manufacturer which further added inaccuracies to the analysis. Had the transit agency defined a specific fuel test methodology, a representative operating profile, and a requirement that the bus tested is identical to the bus being bid, the difficulties found in the use of fuel consumption as a cost driver would not have occurred.

Another cost driver that has commonly caused confusion in the development of cost estimates was preventive maintenance. Unless the transit agency specifically spelled-out the preventive maintenance actions and the frequency of each action, the manufacturers developed preventive maintenance programs which varied significantly.

To clearly delineate what is required for the estimation of preventive maintenance costs, the Central Oklahoma Transportation and Parking Authority (COTPA) of Oklahoma City, Oklahoma, developed worksheets to assist manufacturers in generating cost estimates. COTPA's preventative maintenance form is shown in Table 5-8. The material costs used in Table 5-8 are to be based on original equipment manufacturers parts cost, including shipping costs, and delivered to the transit system. The labor costs are to be based on the prevailing mechanic's wage, and the factor is the number of times each preventive maintenance activity is to be performed during a 500,000 mile bus life cycle. COTPA reviews the manufacturer's worksheets for accuracy and modifies estimates that differed from the property's maintenance practice or do not reflect the transit system's local experience.

Worksheets similar to the one in Table 5-8 should be used and developed wherever possible for the estimation of costs by bidders. For example, a similar worksheet should be developed for the estimation of the costs of major component overhauls.

Summary

Even though the use of life-cycle costing is no longer

TABLE 5-8
EXAMPLE WORKSHEET FOR COST DRIVER CALCULATION*

Submitted By: ______________________________
(Company Name)

____
(Company Representative)

MANUFACTURERS ESTIMATES
PREVENTIVE MAINTENANCE

Item	Material Cost	Labor (Hrs/$Amt)	Expected Interval (in miles)	Factor	Expected Cost
Engine:					
-Oil Change					
-Change oil filter(s)					
Full Flow					
By-pass					
-Clean engine air filter					
-Replace engine air filter					
-Tune-up					
Transmission:					
-Drain & refill					
-Change filter(s)					
External					
Internal					
Air Conditioning:					
-Clean return air filter					
-Replace return air filter					
-Adjust belt tension					
-Replace belt					
Chassis:					
-Complete lubrication					
Differential:					
-Drain and refill					
Brakes:					
-Adjust slack adjusters					
Shocks:					
-Remove and replace					
TOTAL					

* Source: Central Oklahoma Transportation and Parking Authority

required by UMTA, many transit agencies still favor its use. For example, a survey of 181 transit agencies found that 57 percent of the respondents either favor the use of life-cycle cost based procurement or they were not opposed to its use (4). Further, the greatest number of complaints with the use of life-cycle cost base procurement appears to be related to the lack of guidance provided by UMTA on the application of life-cycle costing methods (9). Lack of guidance is fortunately a problem that experience with the process will be overcome, and time and training will overcome methodological difficulties. However, a more troublesome problem is the lack of historical equipment cost data sources to assist in the development of verifiable estimates for cost drivers. Such a data resource would require the gathering of cost records from multiple transit systems.

Life-cycle cost based procurement is a rational economic approach to the selection of transit vehicles. To decrease the potential of encountering the pitfalls uncovered in previous procurements, the development of a request for life-cycle cost based bids should adhere to the following general recommendations:

1. Clearly describe and define cost drivers and methods to be used during the estimation of cost drivers.

2. Reserve the right to modify bids which include mistakes, or bids that contain unverifiable or questionable estimates.

3. Evaluate bids using sound economic principles and discount cost drivers over the life of the bus.

4. When tests are required to evaluate a cost driver, use clearly defined, objective engineering tests.

5. Examine the experiences of other transit agencies that have used life-cycle cost based bidding successfully.

6. Whenever possible, verify reasonableness of cost driver estimates using existing data.

VEHICLE LIFE AND REPLACEMENT

The long-term management of vehicles and planning for the retirement and replacement of buses is one of the most important functions of fleet management. The procurement and replacement process of vehicles requires planning much in advance of the actual replacement of fleet members because of the long lead time required for: 1) The budgeting and grant processes; 2) The bid package development, advertising the request for bids, manufacturer's bid development, and bid award; and 3) Vehicle manufacturing and delivery. Not planning the replacement of buses far enough in advance may require making expensive repairs to unreliable vehicles that are past their efficient life.

The long-term management of vehicles involves two related problems. The first involves the planning for the retirement of buses currently in the vehicle fleet and this is the replacement problem. The second problem involves the planning for future bus replacements and this is the economic-life problem. The replacement problem involves a bus that has already consumed a portion of its life and has a history of past costs. However, because economic analysis only concerns itself with future costs, the past costs are ignored and only costs within the likely future replacement period are considered (the next one to two years in the future). The economic-life problem only deals with future purchases and hence considers all future costs from the beginning of a bus's life until its expected retirement.

The economic analysis of vehicle fleets requires thorough historical cost records. Although past costs are not used in the analysis, it is from past experience that future costs are forecasted. In other words, past cost experience should be used to develop estimates of cost trends in the future so that wise decisions can be made regarding equipment replacement in advance of the best economic replacement point.

In the remaining sections of this chapter, the economic-life problem will be covered followed by a discussion of the replacement problem. Lastly, the solution approaches to the two problems will be tied together as input to the replacement decision.

The Economic-Life Problem

For a transit agency, a bus has only one relevant life. This is the duration that the agency operates the bus. However, for the purpose of economic analysis, a bus has three lives.

1. Depreciation Life. This is the anticipated life of the bus. The depreciation life is developed solely for accounting purposes; to aid in allocating the future annual loss in value of the bus to a specific set of years. Conventional practice in the transit industry is to use a depreciation life of 12 years for a standard transit coach. Note that after 12 years the bus may still have useful life and be kept in operation by the transit agency.

2. Economic Life. This is the length of ownership over which the average annual cost per unit of production (usually miles of travel) is minimized. This life should only be used in planning decisions regarding buses not currently owned. The economic life may or may not correspond to the anticipated depreciation life.

3. Physical Life. This is the life up to where the bus is exhausted and it can no longer be used. The physical life is clearly the longest of the three lives. It is largely a theoretical life since buses are generally replaced or rebuilt for economic reasons before they reach their physical life.

In Table 5-9 are listed hypothetical costs for a bus over a twenty year period. The depreciation costs are those calculated in Table 5-3 using declining balance for a bus which was initially purchased for $150,000 and has a salvage value of $3,000 at the end of 12 years. The total annual costs are summed in column 5 (depreciation plus fuel plus maintenance costs) and the total annual costs are cumulatively totaled in column 6. The cumulative annual costs (column 6) are then divided by the cumulative mileage (column 8) to derive the total average cost per mile for each year in column 9.

Note that the cost per mile is high in the early years of the bus's life. This is because of the high depreciation costs in the first few years. Later, the average costs decline as the depreciation is spread across more miles of travel. Towards the end of the twenty year period, average costs increase as maintenance begin to grow.

The average cost per mile is plotted in Figure 5-2. The average total cost reaches a minimum in years fourteen and fifteen at roughly $0.87 per mile. The period where the average total cost is at a minimum (fourteen to fifteen years) is the economic life. This is the life that provides the minimum cost per mile of ownership and use. This analysis does not account for performance factors such as the reliability of older buses. In an actual analysis, performance maybe taken into account by penalizing for downtime or for service disruptions, both tend to increase with age (for an example of the use of other factors see (1)).

The economic life and the minimum average cost should be used only for planning future actions. For example, the economic-life could be used for the planning of future replacement cycles of vehicles.

The Replacement Problem

The decision to replace existing equipment should be based on the expected costs of the existing bus in the next one to two years. In other words, costs encountered in previous portions of the bus's life should not be considered. Costs should be considered which are likely to be accrued during the period between when a decision is reached to replace the bus and when it is actually replaced (one to two years in the future). The expected costs of existing buses should be compared to minimum average costs of alternatives (for example, rehabilitate or purchase a new bus).

To illustrate the information required for replacement analysis, the hypothetical data in Table 5-9 is used in Table 5-10 to generate annual average cost per mile. The average costs developed in Table 5-10 are the average costs of each year and not the average costs accumulated up to that point in the bus's life. The averages from both Tables 5-9 and 5-10 are plotted in Figure 5-2.

TABLE 5-9

CALCULATION OF TOTAL AVERAGE COST PER MILE OF HYPOTHETICAL BUS

Year (1)	Depreciation Cost (2)	Annual Fuel Cost (3)	Annual Maintenance Cost (4)	Total Annual Cost (5)	Cumulative Cost (6)	Annual Mileage (7)	Cumulative Mileage (8)	Total Average Cost Per Mile (6) ÷ (8) = (9)
1	$41,730	$13,350	$ 5,300	$60,380	$ 60,380	47,500	47,500	$1.271
2	30,121	13,350	9,170	52,641	113,021	47,500	95,000	1.140
3	21,741	13,350	11,050	46,141	154,162	47,500	142,500	1.117
4	15,693	13,350	14,900	43,943	203,105	47,500	190,000	1.069
5	11,327	13,350	15,850	40,527	243,632	47,500	237,500	1.026
6	8,176	12,700	14,500	35,176	278,808	42,500	280,000	0.996
7	5,901	12,700	15,100	33,701	312,509	42,500	322,500	0.969
8	4,260	12,700	16,800	33,760	346,264	42,500	365,000	0.949
9	3,074	12,700	15,700	31,475	377,744	42,500	407,500	0.927
10	2,219	12,700	16,200	31,119	408,863	42,500	450,000	0.904
11	1,602	12,000	13,000	26,602	435,465	37,500	487,500	0.893
12	1,156	12,000	13,400	26,552	462,021	37,500	525,000	0.880
13	0	12,000	16,800	28,800	490,821	37,500	562,500	0.873
14	0	12,000	18,100	30,100	520,921	37,500	600,000	0.868
15	0	12,000	21,300	33,300	554,221	37,500	367,500	0.869
16	0	11,300	22,650	33,950	558,171	32,500	670,000	0.878
17	0	11,300	26,100	37,500	625,571	32,500	702,500	0.890
18	0	11,300	25,950	37,250	662,821	32,500	735,000	0.902
19	0	11,300	28,300	39,600	702,421	32,500	767,500	0.915
20	0	11,300	27,650	38,950	741,371	32,500	800,000	0.927

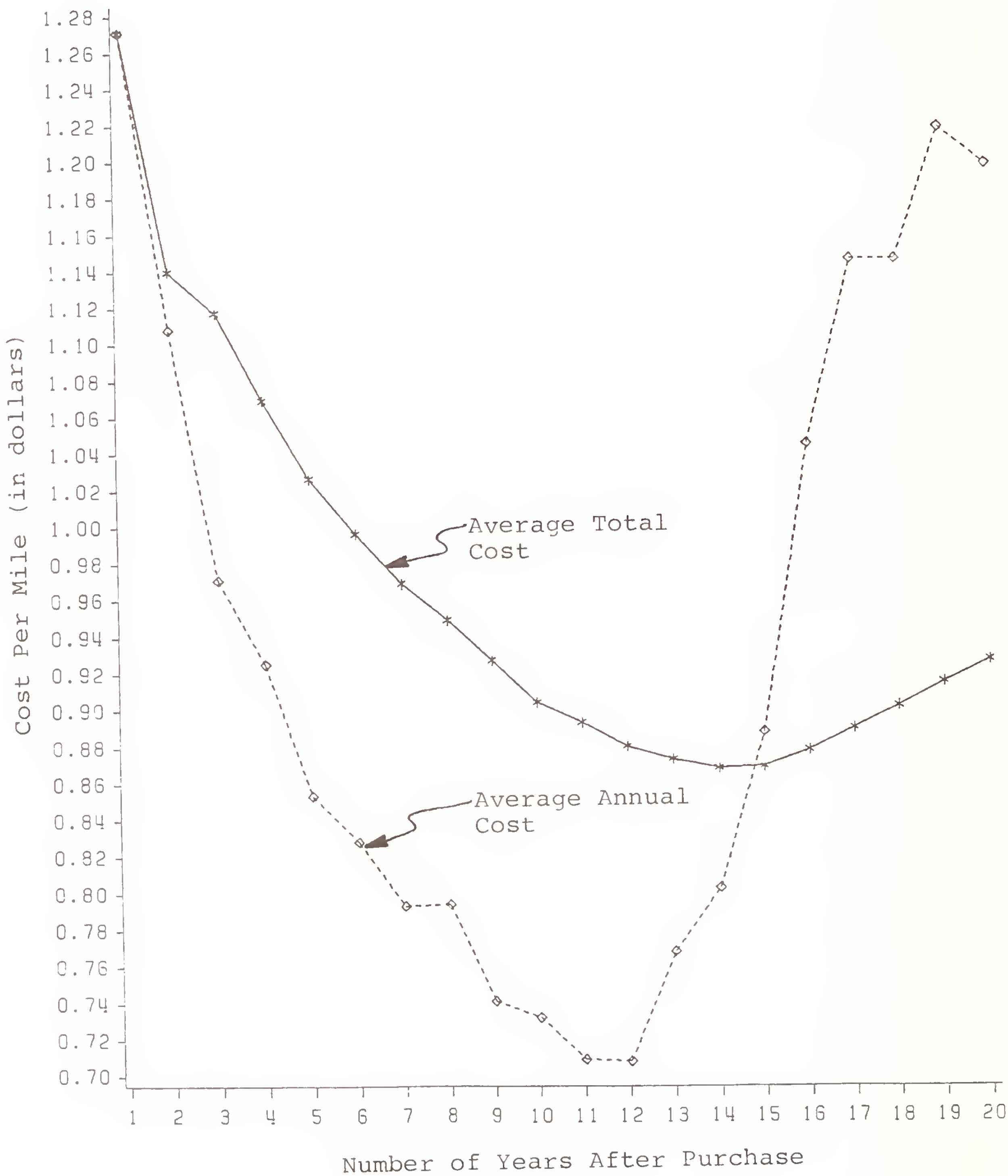

Figure 5-2 Average Annual Cost Versus Average Total Cost

TABLE 5-10
CALCULATION OF ANNUAL AVERAGE COST
PER MILE OF HYPOTHETICAL BUS

Year (1)	Depreciation Cost (2)	Annual Fuel Cost (3)	Annual Main. Cost (4)	Total Annual Cost (5)	Annual Mileage (6)	Average Annual Cost per Mile (5) ÷ (6) = (7)
1	$41,730	$13,350	$ 5,300	$60,380	47,500	1.271
2	30,121	13,350	9,170	52,641	47,500	1.108
3	21,741	13,350	11,050	46,141	47,500	0.971
4	15,693	13,350	14,900	43,943	47,500	0.925
5	11,327	13,350	15,850	40,527	47,500	0.853
6	8,176	12,700	14,300	35,176	42,500	0.828
7	5,901	12,700	15,100	33,701	42,500	0.793
8	4,260	12,700	16,800	33,760	42,500	0.794
9	3,074	12,700	15,700	31,475	42,500	0.741
10	2,219	12,700	16,200	31,110	42,500	0.732
11	1,602	12,000	13,000	26,602	37,500	0.709
12	1,152	12,000	13,400	26,552	37,500	0.708
13	0	12,000	16,800	28,800	37,500	0.768
14	0	12,000	18,100	30,100	37,500	0.803
15	0	12,000	21,300	33,300	37,500	0.888
16	0	11,300	22,650	33,950	32,500	1.045
17	0	11,300	26,100	37,400	32,500	1.146
18	0	11,300	25,950	37,250	32,500	1.146
19	0	11,300	28,300	39,600	32,500	1.218
20	0	11,300	27,650	38,950	32,500	1.198

To determine if a vehicle should be replaced, the average annual cost per mile for the next year should be compared to the minimum total average cost of a replacement. If the replacement's cost is less, the bus should be replaced.

Replacement Decision Making

Consider a subfleet of buses which are 12 years old and have accumulated more than 500,000 miles of service. The fleet manager anticipates that the buses in the subfleet will need an average of about $23,000 in maintenance work in the coming year, including routine maintenance and some major component overhauls. The buses have incurred high maintenance costs in the past and high costs are expected to continue in the future. Recent fuel consumption records indicate that the subfleet averages 3.9 miles/gallon and the subfleet averages 1,200 miles between roadcalls. The buses in the subfleet have been generally relegated to tripper status and thus they will operate around 25,000 miles in the coming year. Is it time to replace the buses in this subfleet?

The alternative to keeping the buses one more year is to purchase an equal number of new buses as replacement (rehabilitation could also be an alternative). The costs of the alternative must be based on the minimum expected average cost per mile over the entire life of the alternative (the economic-life). Since the comparison is based on one year of cost of the existing buses, all capital costs of the alternative must be reduced to annual costs. The reduction will be conducted through the use of capital recovery factors. The existing buses are assumed to be completely depreciated and thus they have no capital costs.

To include a cost factor for the unreliability of the existing buses, a cost penalty of $300 per roadcall is assumed. The $300 is intended to cover the potential maintenance costs associated with roadcalls and the ridership inconvenience and delay. The annual cost per bus of roadcalls for the existing buses are:

$$\frac{25{,}000 \text{ miles/year}}{1{,}200 \text{ miles/roadcall}} \times \$300\text{/roadcall} = \$6{,}250$$

The average total annual cost of keeping the existing buses one more year is:

Annual fuel cost:	$ 6,750	($0.27 per mile)
Annual maint. cost	23,000	
Annual roadcall cost	6,250	
Total annual cost	$36,000	

Annual average cost per mile $1.44

The new buses have a capital cost of $150,000 and a salvage value of $5,000 at the end of 12 years. The new buses are expected to have an annual maintenance cost of $18,000 per year and experience a roadcall performance of 4,500 miles per roadcall. The new buses are expected to average 42,000 miles per year and have an annual fuel cost of $11,000.

The annual capital cost of the new buses can be determined by using the capital recovery factors listed in Table 5-2 (using a 10 percent discount rate). The equivalent average annual capital cost of the new buses is:

Annual cost =

(initial cost - salvage) x (crf-i-n) + i x (salvage)

$21,780 = ($150,000 - $5,000) x (0.14676) + 0.10 x ($5,000)

The average annual cost of roadcalls for the new buses is:

$$\$2,800 = \frac{42,000 \text{ miles/year}}{4,500 \text{ miles/roadcall}} \times \$300/\text{roadcall}$$

The average annual total cost of the alternative is:

Annual fuel cost	$11,000
Annual maint. cost	18,000
Annual roadcall cost	2,800
Annual capital cost	21,780
Total annual cost	$53,580

Annual cost per mile $1.28

In an economic analysis it is difficult to account for all factors. For example, in the analysis roadcalls were included as a factor. However, there may be many other performance factors that should have been included in the analysis that should be taken into account. Other factors, like passenger comfort and appeal of new bus designs, may be irreducibles and left for consideration in subjective analysis by decision-makers.

SUMMARY

Replacement and retirement analysis is an important activity in fleet management. Without conducting replacement and retirement analysis to assist in fleet management, the fleet manager is left in the imprudent position of either: 1) Using arbitrary rules-of-thumb for bus replacement intervals (e.g., replacing coaches after 12 years) which may be inapplicable to the manager's particular circumstance; or 2) Simply waiting until the maintenance costs of buses begin to significantly rise and they become mechanically unreliable before beginning a retirement and replacement campaign. Either of these two approaches do not take advantage of the cost efficiencies that are possible by retiring and replacing buses when it is most cost effective.

Replacement and retirement techniques are well-established in the engineering economy literature. Their proper application is a commonly accepted practice in most industries that own costly assets. To aid in the proper application of replacement and retirement analysis, the following general recommendations are offered:

1. Use standard depreciation technique and use discounting formulas.

2. Compute summaries of cost data for vehicles and vehicle subfleets on a regular basis. These data can be used in cost graphs to determine cost trends (such as the determination of the economic life of a bus) and to assist in the projection of future costs.

3. Initiate plans for the retirement and replacement of equipment at the time of purchase using the economic life as the projected retirement age. Adjust the planned retirement age as more is known about the cost performance of the vehicle.

4. Never base equipment retirement decisions on past costs unless they are expected to effect costs in the future.

5. Always base replacement decisions on a comparison of the cost of owning and operating existing equipment versus the same costs of new or rehabilitated buses. A decision to replace old buses should not be made simply because the operating and ownership costs of old buses are rising. The cost of operating and ownership must increase beyond the total average costs of new or rehabilitated buses before it is economical to replace old buses.

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CHAPTER VI

DATA, INFORMATION AND KNOWLEDGE EXCHANGE

To this point, the monograph's chapters have presented guidelines for the application of standard management principles, procedures, and techniques to transit bus maintenance and bus fleet management. This chapter represents a departure from the general theme of the previous chapters and it attempts to cast new light on an issue currently facing bus fleet management professionals.

The issue addressed is to determine the appropriate forum or forums for the exchange of bus maintenance and bus life cost data, information, and knowledge. There are significant differences in the attributes of data, information, and knowledge. They are defined as (the definitions follow those found in (8)):

1. Data: Data are simply the relationship between some measurable attribute and a specific event. For example, data on failures of a specific bus component (e.g., transmissions) will consist of miles traveled or hours of use (a measurable attribute) until each component failure (the event). Such failure data may be derived by reviewing work orders or vehicle maintenance history logs. Data are the lowest level of maintenance and vehicle life cost communication.

2. Information: Information is processed data and it reduces the uncertainty of future events. For example, if statistical analysis is performed on component failure data, the statistics (i.e., the mean miles between failures, the standard deviation of miles between failure, and other statistical parameters) would help to determine when to expect future failures of the same component. Statistical information may be derived by conducting hand or computerized calculations on failure data. Statistical information reduces uncertainty because it aids in the making of forecasts of future failures.

3. Knowledge: Knowledge is highly processed data and the creation of knowledge from data required independent judgement and interpretation of data analysis. For example, if failure data and repair cost data were analyzed it may be possible to specify a component's minimum cost replacement or overhaul interval (e.g., overhaul engines every 250,000 miles or at failure). Procedures for determining the optimal interval between component overhauls are knowledge. Procedures are one form of knowledge. Other forms involve factual and judgemental knowledge. Factual knowledge requires the study of data sets to derive facts. For example, Duffy, Foerster, and Puente compared the use of pre-run inspections by transit systems and found that transit systems with more thorough pre-run inspection procedures tended to enjoy better maintenance system performance as indicated

by mechanic labor hours per mile (6). Judgemental knowledge is derived from observing data without the use of formal analysis of data. For example, during Duffy, Foerster, and Puente's study of pre-run inspections they found that, in the judgement of most maintenance managers, the use of pre-run inspections will improve maintenance performance.

The distinction between data, information, and knowledge is quite important. The value of a bus maintenance and bus life cost exchange will be largely a function of the format, structure, and level of exchange (i.e., data, information, or knowledge). For example, if only raw data is exchanged, then for the exchange to be valuable to the participants, each participant must have the capability of processing raw data into either information or knowledge. Some sophisticated transit agencies may find a raw data exchange beneficial. However, many others, without data processing skills, are not likely to find raw data worthwhile. Thus it is apparent that the utility and success of an exchange will be dependent upon the data, information, and knowledge that flows into and through the exchange and dependent upon matching the level of exchange (i.e., data, information or knowledge) to the requirements of exchange users. The planning of an exchange must consider both the data, information, and knowledge that is needed to meet the exchange's objectives and ability of the users to apply exchange flows to the management of their own bus fleets and to their own bus maintenance management problems.

MOTIVATION FOR AN EXCHANGE

In 1982 the Transportation Research Board organized a conference on "Bus Maintenance" (11). One of the charges of the conference was to recommend activities that offered the potential of improving the performance of bus maintenance. A highly recommended management tool was the creation of "A national information network for sharing data on major component specific defects (11)." A second bus maintenance conference was organized by the Transportation Research Board in 1984 (12). During the second conference the attendees indicated that the single most important issue facing bus maintenance managers was the creation of an "Improved Information Exchange."

Since the 1984 TRB conference, there have been several efforts to improve exchange of bus maintenance and bus operating information. The American Public Transit Association (APTA) has taken a key role in the promotion of data, information, and knowledge exchange and APTA has organized workshops on "Bus Equipment and Maintenance," and periodically APTA devotes a section of its weekly newspaper (Passenger Transport) to bus maintenance topics ("Bus Tech"). The Urban Mass Transportation Administration and other organizations (i.e., regional or state transit associations) have also attempted to promote exchange in various fashions ranging from highly structured exchanges of computerized maintenance data to informal discussions of garage level problems. However, all these efforts are clearly changing with time and they will evolve to different forms and improve in the future.

A discussion of these transitory exchange efforts is, however, outside of the scope of this monograph. Many current forms of exchange are likely to change shortly after publication of this monograph and thus minimizing the discussion's value. However, the current efforts to promote exchange does indicate the industry's recognition of the importance and value of exchange. Further, the value of an exchange has been proven by other industries. For example, the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) have found that equipment data exchange is so valuable that the Navy sponsors an extensive exchange. Since the early 1970s many DOD-NASA organizations and contractors have been required to submit data and reports from technical studies which document the costs, reliability, and maintainability of equipment to the "Government-Industry Data Exchange Program." Although the Navy does not have an exact mechanism for estimating the benefits of their data exchange system, annually users are surveyed and asked to estimate the costs they avoided due the exchange. In 1985 over $61 million in savings were reported by the system's users, while the operating cost of the exchange was roughly $3 million per year (9). These results have led the Navy to conclude that the savings and cost avoidance accrued through the use of the exchange far exceed the exchange's operating costs and the exchange member's cost for their use of the system.

TYPE OF EXCHANGE

Current methods of bus operating and maintenance data, information, and knowledge exchange are relatively diffused and they take very different directions in attacking the exchange problem. For example, APTA's Conferences on "Bus Equipment and Maintenance" are largely devoted to the exchange of judgemental knowledge (informal analysis derived from experience) while UMTA has promoted, through a demonstration project, the exchange of statistical information through a centralized computerized data base containing computer maintenance data records from several transit agencies (2). Each of these represent an exchange of maintenance data processed to different levels (process to become information or highly processed to become knowledge). The usefulness of each level depends on the user's ability to interpret the materials being exchanged. For example, knowledge would require little interpretation before it can be applied, while pure data may require a good deal of analysis and interpretation. The relative popularity of APTA's conferences, as witnessed by their increasing attendance, leads to the conclusion that many bus maintenance managers find exchange at the knowledge level (particularly judgemental knowledge) quite useful (3).

Contrasting the varied methods of exchange illustrates that not one single means of exchange is appropriate for all users all of the time. Sophisticated users often may require only access to a data bank and then they can perform their analysis on the data to develop information or knowledge. While others may find data processed to the information level more useful, or even data that is highly processed to the knowledge level. Further, some topics of exchange may be more appropriately exchanged at only one of the three levels. For an exchange to be of universal utility it should contain all levels of exchange.

MANAGEMENT PLANNING OF EXCHANGE

The management of a data, information, and knowledge exchange should follow the same fundamental activities as the management of all other systems. In the first chapter of this monograph, planning was defined as the most fundamental function of management. Planning includes the development of objectives, rules, procedures, programs, and budgets. Clearly, it is premature to propose operating rules, procedures, programs, and budgets for an exchange in this monograph. However, it is reasonable to suggest general objectives for a bus maintenance and life cycle cost exchange.

PROPOSED OBJECTIVES

Proposed objectives for an exchange are categorized by their time frame. Some are continuous objectives to be accomplished throughout the life of the exchange. Some objectives can be accomplished with a relatively small amount of historical data and they are short-term objectives. Some can only be accomplished with several years of historical data and they are mid-term objectives. Other objectives can be accomplished when historical data are available over a long enough period to gain a maintenance data profile over a bus's life and they are long-term objectives.

Proposed Continuous Objectives

Clearly there are non-technical, fundamental goals that should be common to any system, such as deriving the greatest costs savings for the system's users, attract a large number of regular users, and other standard goals. However, technical continuous objectives for a bus maintenance exchange should include:

The Development of Standards: Most transit systems have institutional and environmental differences which, to some extent, make maintenance and operating data from different agencies inconsistent. For example, a transit agency may have mechanics which are more qualified than other agencies, which in turn, makes the performance of the agency's maintenance system superior. Differences in mechanic performance may be due to factors that are under the maintenance managers control (such as, mechanic recruitment and training programs). Differences may be also due to institutional factors outside of the maintenance manager's control, such as the inability to offer wages that will attract competent mechanics, or environments factors such as, a lack of competent diesel mechanics in the local labor pool. The extent of inconsistencies grows even more serious when a comparison is made of local data collection methods, definitions, and data accuracy. Uniformity is further diminished by differences in maintenance procedures, policies, rules, and practices. Comparability is also made even more difficult by variations in uncontrollable factors such as, duty cycles, fleet age, the terrain covered by routes, weather, ridership levels, etc.

Because of the variations between agencies, an exchange should strive to develop standard procedures for data definitions and data collection. By minimizing the institutional variations in data definitions and data collection, the exchange can increase the comparability between the maintenance operations of individual exchange users. Thus a continuous objective of the exchange should be to strive for standard data definitions and standard data collection procedures. A first step in the path towards uniformity would be the adoption of a job code system for transit buses, in a fashion similar to the American Trucking Association's development of "Vehicle Maintenance Reporting Standards" for trucks (5).

Comprehensive Coverage of Levels of Exchange: UMTA's experimentation with a national computerized bus maintenance database and information exchange provides an illustration of the need for comprehensive coverage of all levels of exchange. The primary purpose of UMTA's system was to be able to take data from individual transit systems, merge the data, and derive summary statistics on a national basis (i.e., cost per repair, labor per repair, total maintenance costs, etc.) and possibly even identify specific model defects that exist in the fleets of data contributors. An individual system could then use the summary statistics to make comparisons to its own performance.

During the demonstration project of UMTA's computerized database and information exchange system, a Liaison Board of knowledgeable transit professionals was asked to evaluate the exchange. Members of the Liaison Board from large transit systems, with sophisticated maintenance management information systems and detailed data bases, failed to see the value of having access to a national data base since they already had their own detailed performance statistics (2). Generally, a data base with more detail will have a greater number of maintenance job codes thus permitting greater accuracy in identifying specific maintenance jobs. When detailed data sets are merged with less detailed data sets, the detailed data sets will be condensed and job codes are aggregated thus losing information through the aggregation process. Liaison Board Members from large transit systems felt that their own sophisticated information systems were likely to provide more detail than would a national data base because of aggregation problems.

The specific reason for large systems being unattracted to

UMTA's exchange is probably because the system only exchanged information at one level. The UMTA system only provided summary statistics that are similar to those commonly produced by individual maintenance management information systems but using a national basis.

A comprehensive exchange should provide data, information, and knowledge that one system could not derive on its own. For example, a national exchange should be able to provide a transfer of knowledge through: 1) Research conducted on the data base; 2) The exchange of transit technological innovation; 3) The exchange of technological innovations from related industries; and 4) Technical, engineering, and management training. Thus, the exchange should strive to comprehensively exchange data, information and knowledge.

Proposed Short-Term Objectives

Short-term objectives are generally those that can be achieved with modest amounts of maintenance data from individual contributors. Proposed short-term objectives include:

Identifying Model Specific Defects: The identification of model specific defect was identified as a primary purpose for the development of a national data base in the 1982 TRB conference on "Bus Maintenance" (11). Generally a defect is identified by premature failures and possibly other performance attributes (e.g., high fuel consumption) that would indicate a flaw in design or manufacturing. By identifying flaws, pressure can be brought to bear on manufacturers to correct and modify equipment. Agencies owing the equipment can be made aware of the defect, its special conditions, and means to design-out the defect can be developed and/or distributed (e.g., retrofits).

An exchange could identify specific defects with modest amounts of data. As an example, studies could be conducted that are similar to the Transportation Systems Center's (TSC) study of the V730 transmission in 1982. The TSC study successfully identified the poor reliability of early models of the V730 transmission with only transmission life data from a few large transit systems (6).

Tools, Diagnostic Equipment and Tests: Methods of conducting maintenance are constantly improving through the use of special tools, diagnostic equipment, and special test procedures. Sessions at APTA's "Bus Equipment and Maintenance" conference are often devoted to improved methods. Knowledge covering these methods should be reported and disseminated through an exchange. The exchange should stress the importance of reporting improvements in standard formats with data which provides evidence of the method's effectiveness and cost savings.

Training: The exchange should seek to facilitate training at all levels; including maintenance labor, front line supervisors, and maintenance management training. Training can be facilitated through an exchange of training materials, organizing workshops, and preparation of training materials.

Performance Data: Chapter IV pointed out that there has been little conformity across the transit industry in measures used to define maintenance and vehicle performance. In the short-term, data from transit properties could be collected to calculate performance measures. The performance measures could act as a means to compare the productivity of individual systems to national averages. Of course, individual transit agencies must realize that national performance measure averages may not be comparable to their own system depending on their system's uniqueness.

The idea of creating national averages (standards) for performance is an attractive notion and efforts to create national maintenance performance standards have been attempted in the past. In 1951 the American Transit Association established a panel of operating company executives to develop a set of "Transit Pars" for transit industry performance (including maintenance) (4). The pars were in fact standards for performance measurements and they were designed to help management test the efficiency of their own transit system.

Proposed Mid-term Objectives

Mid-term objectives are generally those that can be achieved within one to two years. Mid-term objectives may involve the analysis of maintenance system performance of individual data contributors to derive information and knowledge covering the desirability of management practices of individual agencies. Proposed mid-term objective includes:

Management Procedures: Maintenance management practices tend to vary dramatically from one transit system to another. For example, the preventive maintenance activities that are conducted and the frequency of preventive inspections vary dramatically, even between transit agencies with similar duty cycles and similar equipment. For example, the frequency of preventive inspections has been commonly observed to vary from 2,000 miles between inspections to 8,000 miles between inspections. Presumably there must be significant differences in the cost of preventive and corrective maintenance, and the reliability of equipment when inspections frequencies vary widely from one transit system to the next. However, there exists little information in the literature which, through empirical data, identifies the trade-offs and advantages of various preventive maintenance strategies.

A mid-term time frame study (between one to three years) of maintenance data and the corresponding practices of individual maintenance data contributors could identify the trade-offs and advantages of management strategies and policies that are practiced by transit fleet managers. Besides studying preventive maintenance practices, studies could cover: 1) Management control systems used by various transit agencies to better control labor time allocation, material dispersal and consumable dispersal (i.e., fuel, oil, etc.); 2) Maintenance staffing levels and skill distribution, and the effectiveness of training programs to update and improve skill levels; 3) The effectiveness of conducting maintenance functions inhouse versus contracting them out for fleets of various sizes, inhouse maintenance labor skill levels, and maintenance facility and maintenance equipment resources; and 4) Studies of other maintenance management practices that either tend to vary from one system to the next or practices that appear innovative and timely.

Equipment Innovation: There are issues concerning bus equipment innovation and equipment design that are being researched by individual transit systems. For example, a summer 1987 issue of "Bus Tech" in Passenger Transport report that thirteen transit systems were experimenting or considering experimenting with alternative fuel systems (i.e., methanol fuel, compressed natural gas, and propane gas) (1). Other areas of equipment innovation include the use of new non-asbestos brake blocks, drive line retarders, and emission control equipment. The exchange could set standards for the reporting of experimentation results and the exchange could provide engineering analysis of experiments that appear to provide a high level of effectiveness.

Proposed Long-term Objectives

Long-term objectives are those that may not be achievable without several years of data (five years or more). Long-term objectives may involve the analysis of maintenance and cost data from contributors over the life of buses to derive information related to their life cost and life performance. Proposed long-term objectives include:

Life Cycle Cost Analysis: Because buses have minimum lives that span several years, it is difficult to gain information on life cycle cost and life performance data (i.e., reliability, maintainability, and availability) over a bus's entire life without a long-term data collection effort. The long-term collection of life costs and life performance data would be of tremendous assistance in the selection and specification of equipment, replacement and bus rehabilitation decision making, and budgeting for future maintenance and capital costs. Knowledge of equipment performance over its life is essential for the setting of the most cost effective spare ratio policies. Of course, all cost data must be tempered by the environmental conditions, the bus's duty cycle, and other factors that are unique to the transit systems of the data contributors.

CONCLUSIONS

For an exchange to be of the greatest value it should strive to provide exchange at all levels data, information, and knowledge. This is not an easy task and requires that a significant effort be devoted to the exchange and that there is a long-term commitment to funding the exchange. The performance of the Navy's "Government-Industry Data Exchange Program" illustrates the benefits of an exchange. However, its roughly 15 year existence and its approximately $3 million per year operating budget illustrates the significance of the support required to achieve the benefits that are possible through an exchange.

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APPENDIX A

MAINTENANCE TASK TIME STANDARDS

This appendix contains the maintenance task time standards developed for the Metropolitan Transit Authority of Wichita, Kansas. The time standards were developed using the time slotting technique described in Chapter III. The time standards are stratified by the maintenance job codes listed in Table 3-1.

GROUP O BODY AND INSTRUMENTATION

01 Bus Fixtures

Repair Type Code	Repair Code	Description	Time
01	0001	Remove and Replace Outside Mirror	0.3
01	0002	Remove and Replace License Door Assembly	0.3
01	0003	Remove and Replace Lens Cover or Reflector	0.3
01	0004	Adjust Drivers Control Panel	0.3
01	0005	Remove and Replace Stanchion	0.3
01	0300	Remove and Replace Drivers Control Panel	3.0

02 Instruments, Switches and Gauges

Repair Type Code	Repair Code	Description	Time
02	0001	Remove and Replace Speedometer Drive Gear	0.3
02	0002	Remove and Replace A/C Low Pressure Switch	0.3
02	0003	Remove and Replace Low Coolant Light	0.3
02	0004	Remove and Replace Brake Light Switch	0.3
02	0005	Remove and Replace Engine Compartment Starter Switch	0.3
02	0006	Remove and Replace Dimmer Switch	0.3
02	0007	Remove and Replace Emergency Shutdown Switch	0.3
02	0008	Remove and Replace Water Temperature Gauge	0.3
02	0060	Remove and Replace Turn Signal Switch and Boot	0.9

02	0061	Remove and Replace Door Control Switch	0.9
02	0062	Remove and Replace Speedometer Drive Shaft Adaptor	0.9
02	0063	Remove and Replace Master Switch	0.9
02	0120	Remove and Replace Horn Switch Assembly	1.5
02	0240	Remove and Replace Speedometer Cable	2.70

03 Glass

Repair Type Code	Repair Code	Description	Time
03	0001	Misc. Window Repairs	0.3
03	0002	Remove and Replace Door Glass	C.3
03	0240	Remove and Replace Half of Windshield	2.7

04 Body

Repair Type Code	Repair Code	Description	Time
04	0001	Remove and Replace Radiator Door	0.3
04	0060	Reseal Engine Access Door	0.9
04	0061	Remove and Replace Engine Door Latch	0.9
04	0062	Remove and Replace Wheel Housing Panel	0.9
04	0063	Remove and Replace Body Panel	0.9
04	0120	Remove and Replace Engine Shroud on RTS	1.5
04	0360	Misc. Body Work to Bumper	3.9

05 Doors

Repair Type Code	Repair Code	Description	Time
05	0001	Adjust Safety Hatch Door	0.3
05	0002	Remove and Replace Exit Door Brackets	0.3
05	0060	Remove and Replace Front Door	0.9
05	0061	Adjust Exit Door	0.9
05	0062	Adjust Front Door	0.9
05	0120	Remove and Replace Half of Door Assembly	1.5

GROUP 1 CHASSIS

11 Axle - Front

Repair Type Code	Repair Code	Description	Time
11	0001	Check Control Arm Boshings	0.3
11	0002	Remove and Replace Control Arm Bolt	0.3
11	0060	Check and Adjust Front Wheel Alignment	0.9
11	0180	Remove and Replace Control Arm Rod	2.1
11	0240	Remove and Replace Lower Control Arm Bushings	2.7
11	0300	Remove and Replace Upper Control Arm Bushings	3.3
11	0360	Remove and Replace King Pin	3.9
11	0361	Remove and Replace Spindle	3.9
11	0480	Remove and Replace King Pin Housing Bushing	5.1
11	0540	Rebush Front Axle, One Side	5.7

12 Axle - Rear

Repair Type Code	Repair Code	Description	Time
12	0130	Remove and Replace Pinion Seal	1.5
12	0131	Check and Seal Rear Axle	1.5
12	0300	Check and Seal Differential Leaks	3.3

13 Brakes

Repair Type Code	Repair Code	Description	Time
13	0001	Check Brakes	0.3
13	0060	Remove and Replace Emergency Brake Yoke	0.9
13	0061	Install Parking Brake Kit	0.9
13	0130	Remove and Replace Brake Adjuster	1.5
13	0420	Front Brake Reline	4.5
13	0780	Reline Rear Brakes	8.1

14 Frames

Repair Type Code	Repair Code	Description	Time
14	0180	Remove and Replace Motor Mounts	2.1
14	0240	Remove and Replace Transmission Supports	2.7

15 Steering

Repair Type Code	Repair Code	Description	Time
15	0001	Check for Steering Gear Box Leaks	0.3
15	0002	Repair Steering Column Lock	0.3

15	0060	Remove and Replace Tie Rod	0.9
15	0120	Remove and Replace Upper or Lower Steering Column Bears	1.5
15	0121	Remove and Replace Bell Crank Bushings	1.5
15	0180	Remove and Replace Idler Arm Bushings	2.1
15	0300	Seal Steering Gear Box	3.3
15	0360	Remove and Replace Steering Column Support Assembly	3.9
15	0361	Remove and Replace Steering Gear Assembly	3.9

16 Suspension

Repair Type Code	Repair Code	Description	Time
16	0001	Check Carrier Bearings	0.3
16	0002	Check Suspension	0.3
16	0003	Remove and Replace Stabilizer Link	0.3
16	0004	Check Shock Bushings	0.3
16	0060	Remove and Replace Shock Bushings	0.9
16	0061	Remove and Replace Stabilizer	0.9
16	0062	Remove and Replace Safety Wire	0.9
16	0120	Remove and Replace Rear Shocks on New Look Buses	1.5
16	0121	Remove and Replace Rear Shocks on RTS Buses	1.5
16	0180	Remove and Replace Front Shocks	2.1
16	0181	Remove and Replace Bellows	2.1
16	0182	Remove and Replace Stabilizer Bushings	2.1

16	0240	Remove and Replace Upper Radius Rod	2.7
16	0241	Remove and Replace Lower Radius Rod	2.7
16	0242	Remove and Replace Upper Radius Rod Bushings	2.7
16	0243	Remove and Replace Lower Radius Rod Bushings	2.7
16	0244	Remove and Replace Trunion Bushings	2.7
16	0360	Remove and Replace Rear Radius Rod	3.9
16	0361	Repair Shock Mount	3.9
16	0362	Remove and Replace Upper and Lower Radius Rod Bushings	3.9
16	0480	Remove and Replace Rear Shocks on Flex Bus	5.7

17 Tire/Wheels

Repair Type Code	Repair Code	Description	Time
17	0001	Clean Threads on Wheel and Replace Studs	0.3
17	0060	Change Front Tires	0.9
17	0061	Check and Adjust Wheel Bearings	0.9
17	0062	Remove and Replace Rear Wheel on One Side	0.9
17	0120	Remove and Replace Front Outer Wheel Bearings	1.5
17	0121	Remove and Replace Tire on Street	1.5
17	0180	Check and Balance Wheels and Reinstall	2.1
17	0181	Remove and Check Wheel Bearings, Cones, and Cups, and repack	2.1

17	0360	Remove and Replace Inner/Outer Wheel Bearings	3.9
17	0480	Remove and Clean up Wheels, Axle, Brakes, etc., and reseal	5.1

20 Drive Shaft

Repair Type Code	Repair Code	Description	Time
20	0001	Check Drive Shaft for Wear	0.3
20	0120	Remove and Replace Drive Shaft	1.5
20	0180	Remove and Replace Rear U-Joint	2.1

21 Transmission Controls

Repair Type Code	Repair Code	Description	Time
21	0001	Adjust and Lube Shifter	0.3
21	0002	Adjust Transmission Cable	0.3
21	0003	Remove and Replace Transmission Low Oil Switch	0.3
21	0004	Remove and Replace Transmission Solenoid	0.3
21	0005	Remove and Replace Neutral Switch	0.3
21	0006	Remove and Replace Air Shifter	0.3
21	0060	Remove and Replace Shifter	0.9
21	0180	Remove and Replace Transmission Cable	2.1

22 Transmission

Repair Type Code	Repair Code	Description	Time
22	0060	Remove and Replace Transmission Fluid Pan	0.9

22	0120	Remove and Replace Shift Governor	1.5
22	1200	Remove and Replace Transmission	12.0
22	1600	Remove and Replace Bell Housing	16.0

23 Transmission Fluids

Repair Type Code	Repair Code	Description	Time
23	0060	Check and Repair Transmission Fluid Leads	0.9
23	0061	Change Transmission Fluid and Filters.	0.9
23	0120	Repair Transmission Hose Fluid Leak	1.5

31 Charging System

Repair Type Code	Repair Code	Description	Time
31	0001	Remove and Replace Generator Relay	0.3
31	0002	Remove and Replace Electrical System Equalizer	0.3
31	0003	Remove and Replace 12 Volt Regulator	0.3
31	0004	Remove and Replace Generator Cable	0.3
31	0060	Check Charging System	0.9
31	0240	Remove and Replace Generator	2.7

32 Cranking System

Repair Type Code	Repair Code	Description	Time
32	0060	Starter Rework	0.9
32	0060	Remove and Replace Starter	0.9

32	0120	Remove and Replace Air Starter Solinoid	1.5
32	0180	Remove and Replace Starter Control Relay	2.1

33 Lighting System

Repair Type Code	Repair Code	Description	Time
33	0001	Remove and Replace Turn Signal Flasher	0.3
33	0002	Remove and Replace Interior Light Relay	0.3
33	0003	Remove and Replace Light Switch	0.3
33	0004	Remove and Replace Exterior Light Relay	0.3
33	0005	Remove and Replace Circuit Breaker	0.3
33	0006	Remove and Replace Door Stop Light	0.3
33	0007	Remove and Replace Turn Signal Light	0.3
33	0008	Remove and Replace Dome Light	0.3
33	0009	Remove and Replace Step Light	0.3
33	0010	Remove and Replace Interior Light	0.3
33	0011	Remove and Replace Brake Lamp Assembly	0.3
33	0012	Remove and Replace Headlight	0.3
33	0013	Remove and Replace Headsign Light Inverter	0.3
33	0014	Remove and Replace Panel Light	0.3
33	0015	Remove and Replace Shift Lights	0.3
33	0016	Remove and Replace Marker/ Tail Light	0.3

Repair Type Code	Repair Code	Description	Time
33	0017	Remove and Replace Side Sign Light	0.3
33	0060	Remove and Replace Interior Light Socket	0.9
33	0061	Repair Tail Light Assembly	0.9
33	0210	Remove and Replace Rear Travis Beam Assembly on Chance Bus	2.4

34 Battery

Repair Type Code	Repair Code	Description	Time
34	0001	Remove and Replace Battery	0.3

35 Wiring

Repair Type Code	Repair Code	Description	Time
35	0060	Clean and Reconnect Wiring Contacts	0.9
35	0061	Relocate and Rework Ground Cable	0.9
35	0780	Trouble Shoot Electrical Circuit	8.1

36 Miscellaneous Electrical

Repair Type Code	Repair Code	Description	Time
36	0001	Remove and Replace Fuel Pressure Switch	0.3
36	0002	Remove and Replace Backup Horn	0.3
36	0003	Remove and Replace Engine Run Relay	0.3
36	0005	Remove and Replace Exit Door Relay	0.3

36	0006	Remove and Replace Wheel Chair Relay	0.3
36	0007	Remove and Replace Engine Shutdown Solenoid	0.3
36	0008	Remove and Replace Oil Sending Switch	0.3
36	0009	Remove and Replace Limiter Fuse	0.3
36	0060	Remove and Replace Horn	0.9
36	0061	Remove and Replace Surge Tank Switch	0.9
36	0120	Passenger Chime	1.5
36	0122	Remove and Replace Engine Temperature Switch	1.5

41 Air Intake System

Repair Type Code	Repair Code	Description	Time
41	0001	Remove and Replace Air Cleaner/ Filter	0.3
41	0060	Remove and Replace Blower Shaft	0.9

42 Cooling System

Repair Type Code	Repair Code	Description	Time
42	0001	Check Water Pump Seals	0.3
42	0002	Check Fan Speed	0.3
42	0003	Remove and Replace Drain Lock	0.3
42	0004	Remove and Replace Water Hose	0.3
42	0060	Service Radiator	0.9
42	0061	Remove and Replace Radiator	0.9
42	0120	Check for Leaks and Tighten Clamps	1.5

42	0121	Seal Leaks at Radiator	1.5
42	0180	Remove and Replace Engine Thermostat	2.1
42	0181	Remove and Replace RTS Water Pump Seal	2.1
42	0182	Remove and Replace Fan Drive Seal	2.1
42	0240	Remove and Replace Seal and Impeller Kit	2.7
42	0300	Shutter Assembly, Shutter Stat Changed	3.3
42	0360	Remove and Replace Fan Blade	3.9
42	0780	Remove and Replace Fan Drive	8.1
42	0780	Check Fan Drive and Seal Leaks	8.1

43 Exhaust System

Repair Type Code	Repair Code	Description	Time
43	0001	Check and Seal Exhaust Leaks	0.3

44 Fuel System

Repair Type Code	Repair Code	Description	Time
44	0001	Adjust Idle	0.3
44	0002	Change Fuel Filter	0.3
44	0003	Remove and Replace Throttle Cylinder	0.3
44	0004	Install Slave Throttle Kit	0.3
44	0060	Change Fuel Filter and Water Separator	0.9
44	0061	Exterior Fuel Line Leak and Tighten Fittings	0.9

44	0120	Check for Leak and Adjust Governor and Slave Throttle Linkages	1.5
44	0180	Check and Repair Fast Idle	2.1
44	0181	Interior Fuel Line Leak, Tighten Fittings	2.1
44	0182	Remove and Replace Injectors	2.1
44	0240	Remove and Replace Accelerator Interlock	1.7
44	0300	Remove and Replace Throttle Cable	3.3
44	0300	Rebuild Governor	3.3
44	0360	Remove and Replace Fuel Pump	3.9

45 Power Plant

Repair Type Code	Repair Code	Description	Time
45	0001	Check and Seal Oil Leaks	0.3
45	0002	Remove and Replace Oil Dip Stick	0.3
45	0003	Check Head for Leaks	0.3
45	0004	Remove and Replace Engine Breather Hose	0.3
45	0005	Remove and Replace Oil Sending Unit	0.3
45	0060	Remove and Replace Engine Oil Pan	0.9
45	0061	Remove and Replace Oil Cooler Gasket	0.9
45	0120	Remove and Replace Upper and Lower Engine Oil Gaskets	1.5
45	0180	Remove and Replace Lower Head	2.1
45	0181	Hot Engine Shut Down, Full of Oil and Water	2.1

45	0182	Remove and Replace Generator Gasket	2.1
45	0360	Tune Engine	3.9
45	0361	Remove and Replace Cam Shaft Seal	3.9
45	0362	Remove and Replace Oil Pump	3.9
45	0363	Adjust Valves on Chance Bus	3.9
45	1080	Reseal Crank Shaft	11.1

61 Air Compressor

Repair Type Code	Repair Code	Description	Time
61	0001	Check Air Compressor for Oil Leaks	0.3
61	0002	Remove and Replace Air Compressor Governor	0.3
61	0300	Remove and Replace Compressor Fly Wheel Seal	3.3
61	0301	Remove and Replace Air Compressor Drive Hub	3.3

62 Air Lines, Controls, and Tanks

Repair Type Code	Repair Code	Description	Time
62	0001	Check for Air Leaks	0.3
62	0002	Repair Leveling Valve Leaks	0.3
62	0003	Thaw and Drain Air Tanks	0.3
62	0004	Remove and Replace Air Line Valve	0.3
62	0005	Remove and Replace Air Tank Drain Tank	0.3
62	0060	Repair Airline Leak, Tighten Fitting, or Fix Rupture	0.9

62	0120	Remove and Replace Air Drier	1.5
62	0121	Remove and Replace Air Drier and Bad Airline	1.5
62	0180	Remove and Replace Leveling Valve	2.1
62	0181	Clear Airline Restriction	2.1

63 Air Power Door Systems

Repair Type Code	Repair Code	Description	Time
63	0001	Check and Adjust Door Engine	0.3
63	0002	Remove and Replace Door Solenoid	0.3
63	0120	Remove and Replace Door Engine Hose	1.5
63	0121	Remove and Replace Door Engine Cylinder	1.5
63	0122	Remove and Replace Door Engine	1.5
63	0180	Remove and Replace Exit Door Control Arm	2.1

64 Brake Air Systems

Repair Type Code	Repair Code	Description	Time
64	0001	Rebuild Brake Air Pressure Regulator	0.3
64	0060	Remove and Replace Brake Diaphram	0.9
64	0061	Remove and Replace Brake Interlock	0.9
64	0062	Remove and Replace Parking Brake Chamber	0.9
64	0120	Remove and Replace Parking Brake Valve	1.5

65 Wiper System

Repair Type Code	Repair Code	Description	Time
65	0001	Remove and Replace Windshield Wiper Blade	0.3
65	0002	Remove and Replace Windshield Washer Hose	0.3
65	0003	Remove and Replace Windshield Wiper Arm	0.3
65	0004	Clean and Service Windshield Washer	0.3
65	0005	Remove and Replace Windshield Washer Pump	0.3
65	0120	Remove and Replace Windshield Washer Valve	1.5
65	0180	Remove and Replace Windshield Wiper Motor	2.1

66 Air Starter

Repair Type Code	Repair Code	Description	Time
66	0060	Remove and Replace Starter Tank Check Valve	0.9

67 Power Steering System

Repair Type Code	Repair Code	Description	Time
67	0001	Check Power Steering for Fluid Leaks and Proper Operation	0.3
67	0002	Remove and Replace Power Steering Fluid Line	0.3
67	0003	Remove and Replace Power Steering Fluid Filter	0.3
67	0004	Bleed Air Out of Power Steering System	0.3

67	0120	Remove and Replace Power Steering Pump	1.5

71 Air Conditioning

Repair Type Code	Repair Code	Description	Time
71	0001	Remove and Replace A/C Cutoff	0.3
71	0002	Remove and Replace A/C Drier	0.3
71	0003	Check A/C Compressor Leaks	0.3
71	0004	Tighten A/C Alternator Belt	0.3
71	0005	Check and Tighten A/C Lines	0.3
71	0006	Check A/C Pressure	0.3
71	0007	Remove and Replace A/C Clutch Cylinder	0.3
71	0060	Service A/C	0.9
71	0061	Remove and Replace A/C Belt	0.9
71	0062	Remove and Replace Evaporator Fan Motor	0.9
71	0063	Remove and Replace Idler Pulley	0.9
71	0064	Remove and Replace A/C Alternator	0.9
71	0065	Remove and Replace A/C Charge Over Valve	0.9
71	0120	Remove and Replace Ruptured A/C Hose	1.5
71	0121	Remove and Replace A/C Compressor Seal	1.5
71	0122	Remove and Replace A/C Compressor Yoke	1.5
71	0180	Check and Seal A/C Compressor Oil Leak	2.1
71	0240	Remove and Replace Clutch Coil	2.7

71	0480	Activate A/C on Newlooks	5.1
71	0481	Remove and Replace A/C Fan Belt Hub	5.1
71	0540	Remove and Replace A/C Compressor	5.7
71	0600	Remove Radiator to Repair A/C Line, Replace Radiator	6.3
71	0601	Remove and Replace A/C Condensor	6.3

72 Heater

Repair Type Code	Repair Code	Description	Time
72	0001	Check Heating System	0.3
72	0002	Remove and Replace Heater Valve on Chance Bus	0.3
72	0060	Remove and Replace Heat Pump Modulator Valve	0.9
72	0120	Repair Leak in Heater Core on Flex Bus	1.5
72	0180	Remove and Replace Heater Pump Motor	2.1
72	0300	Remove and Replace Heater Core	3.3

73 Ventilation

Repair Type Code	Repair Code	Description	Time
73	0001	Change A/C Filter Screens	0.3
73	0060	Remove and Replace A/C Blower Motor on RTS	0.9
73	0120	Misc. Defroster Repairs	1.5
73	0121	Remove and Replace A/C Blower on New Look	1.5

73	0180	Remove and Replace Defroster Motor	2.1
73	0181	Remove and Replace Defroster Motor Bushing	2.1
73	0182	Remove and Replace A/C Blower Motor Bushings	2.1

74 Climate Control Controls and Climiate Control Systems Switches and Relays

Repair Type Code	Repair Code	Description	Time
74	0001	Remove and Replace A/C Diode	0.3
74	0002	Remove and Replace Climate Control Thermostat on RTS Bus	0.3
74	0003	Remove and Replace A/C Relay	0.3
74	0060	Check Climate Control	0.9
74	0120	Remove and Replace Heat Pump Relay	1.5
74	0060	Remove and Replace A/C Solenoid	1.5
74	0061	Remove and Replace A/C Terminal Control Board	1.5
74	0190	Remove and Remplace Climate Control Relay	2.1
74	0191	Remove and Replace A/C Generator Relay	2.1
74	0360	Remove and Replace Blower Switch	3.9
74	0361	Remove and Replace Heater Relay	3.9

80 Cleaning and Washing

Repair Type Code	Repair Code	Description	Time

81 Painting

Repair Type Code	Repair Code	Description	Time
81	8000	Refinish Outside of RTS Bus	80

82 Towing and Road Service

Repair Type Code	Repair Code	Description	Time

83 Diagnosis/Road Testing

Repair Type Code	Repair Code	Description	Time

84 Lubrication

Repair Type Code	Repair Code	Description	Time
84	0060	Change Transmission Fluids and Filters	0.9
84	0061	Change All Oil Filters and Oil, and Take Samples	0.9

85 Preventative Maintenance

Repair Type Code	Repair Code	Description	Time
85	0180	3,000 Mile Inspection	2.1
85	0181	15,000 Mile Valve Adjustment	2.1
85	0360	6,000 Mile Inspection	3.9
85	0361	12,000 Mile Inspection	3.9

88 Contract Maintenance

Repair Type Code	Repair Code	Description	Time
88	0001	Tow Bus to Garage	

88	0002	Check Engine
88	0003	Check and Service Transmission
88	0004	Reseal Crankshaft
88	0005	Rebuild Transmission
88	0006	Valve Job
88	0007	Bell Housing Rework
88	0008	Remove and Replace Fan Drive
88	0009	Realign Front End
88	0010	Remove and Replace Engine
88	0011	Remove and Replace Lower Control Arm
88	0013	In Cradle Engine Overhaul

APPENDIX B

WICHITA, KANSAS METROPOLITAN TRANSIT AUTHORITY FLEET AND MAINTENANCE MANAGEMENT PERFORMANCE MEASURE PLOTS

This appendix contains plots of the performance measures listed in Table 4-5. These are meant to illustrate measures that can be collected through a rudimentary maintenance record keeping system. Much of the interpretation of shifts in the monthly values of performance measures are of significance to the internal operation of the Wichita transit system. However, if these measures are collected over the long-run, they have significant value in determining the performance and life-cycle costs of equipment.

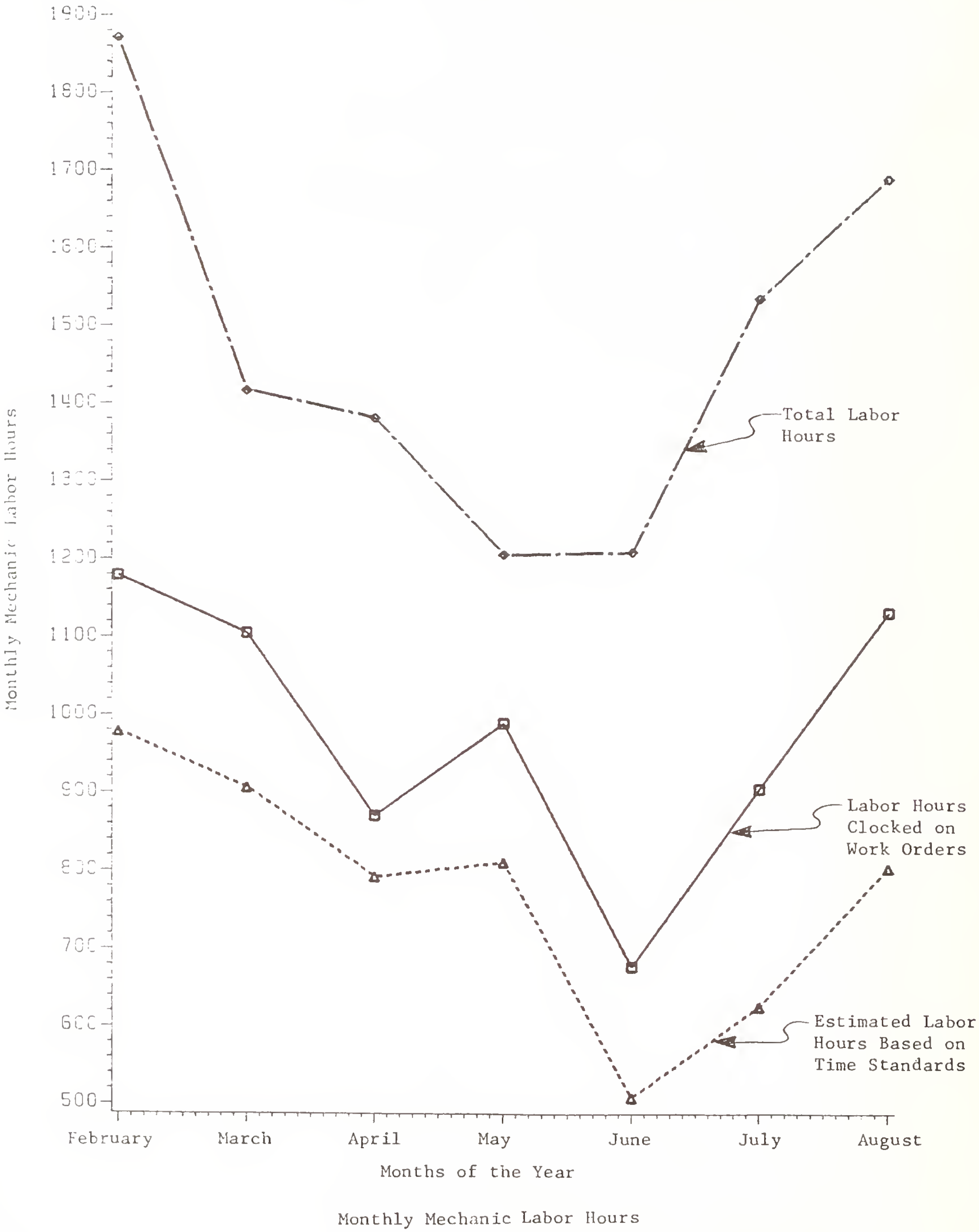


FIGURE B-1

MONTHLY MECHANIC LABOR HOURS,
WICHITA MTA, FEBRUARY TO AUGUST, 1985

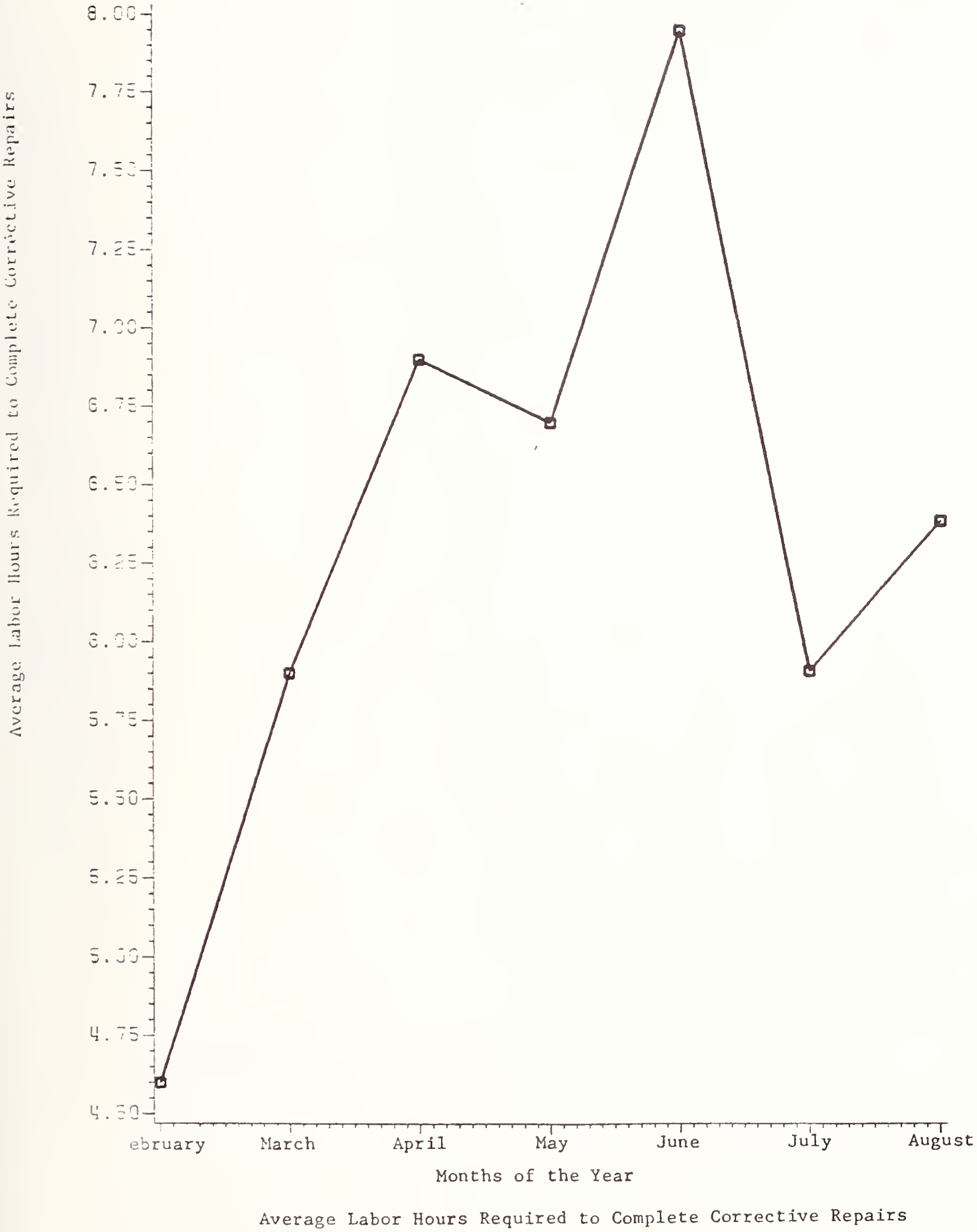


FIGURE B-2

AVERAGE LABOR HOURS REQUIRED TO COMPLETE CORRECTIVE REPAIRS, WICHITA MTA, FEBRUARY TO AUGUST, 1985

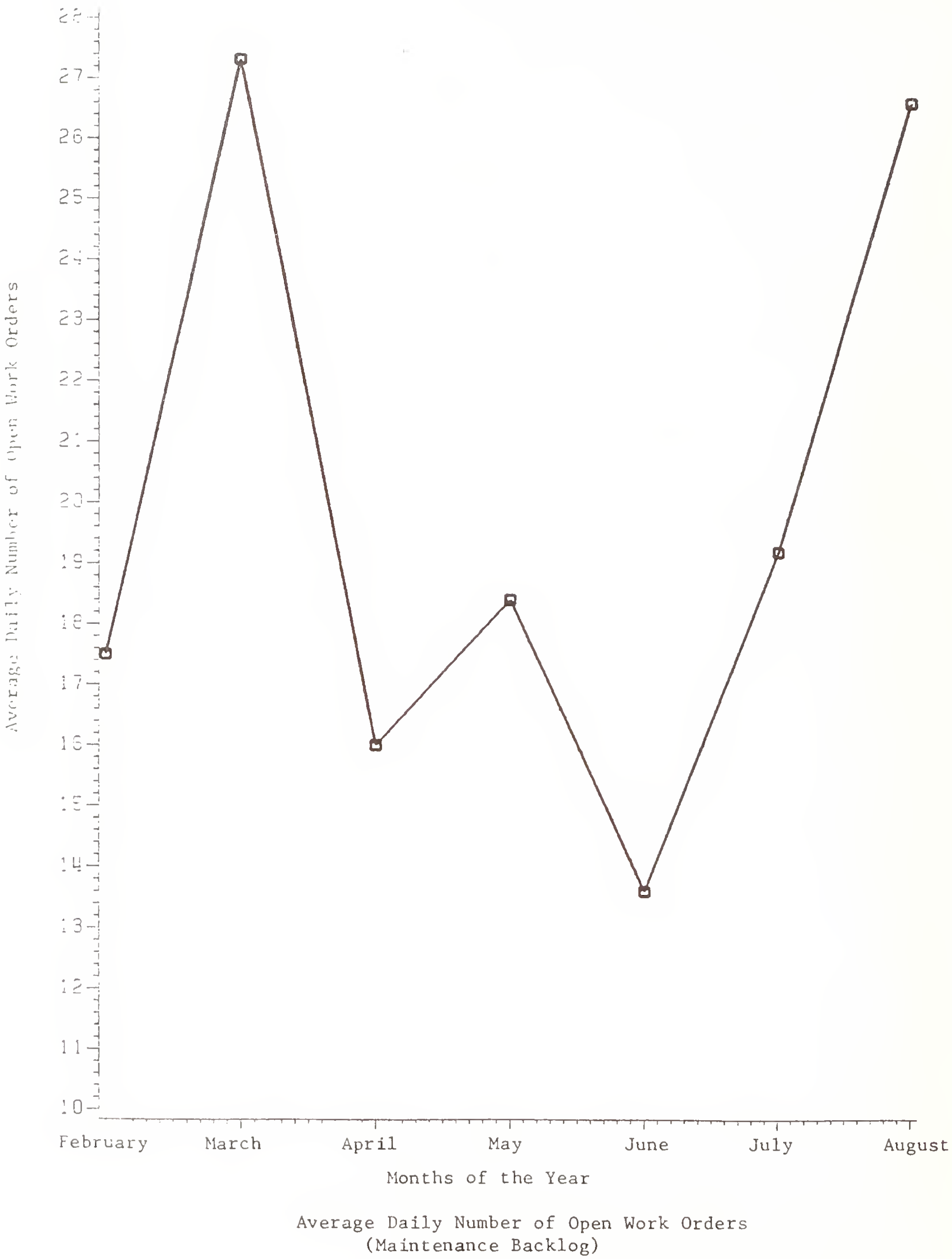


FIGURE B-3

AVERAGE DAILY NUMBER OF OPEN WORK ORDERS, (MAINTENANCE BACKLOG), WICHITA MTA, FEBRUARY TO AUGUST, 1985

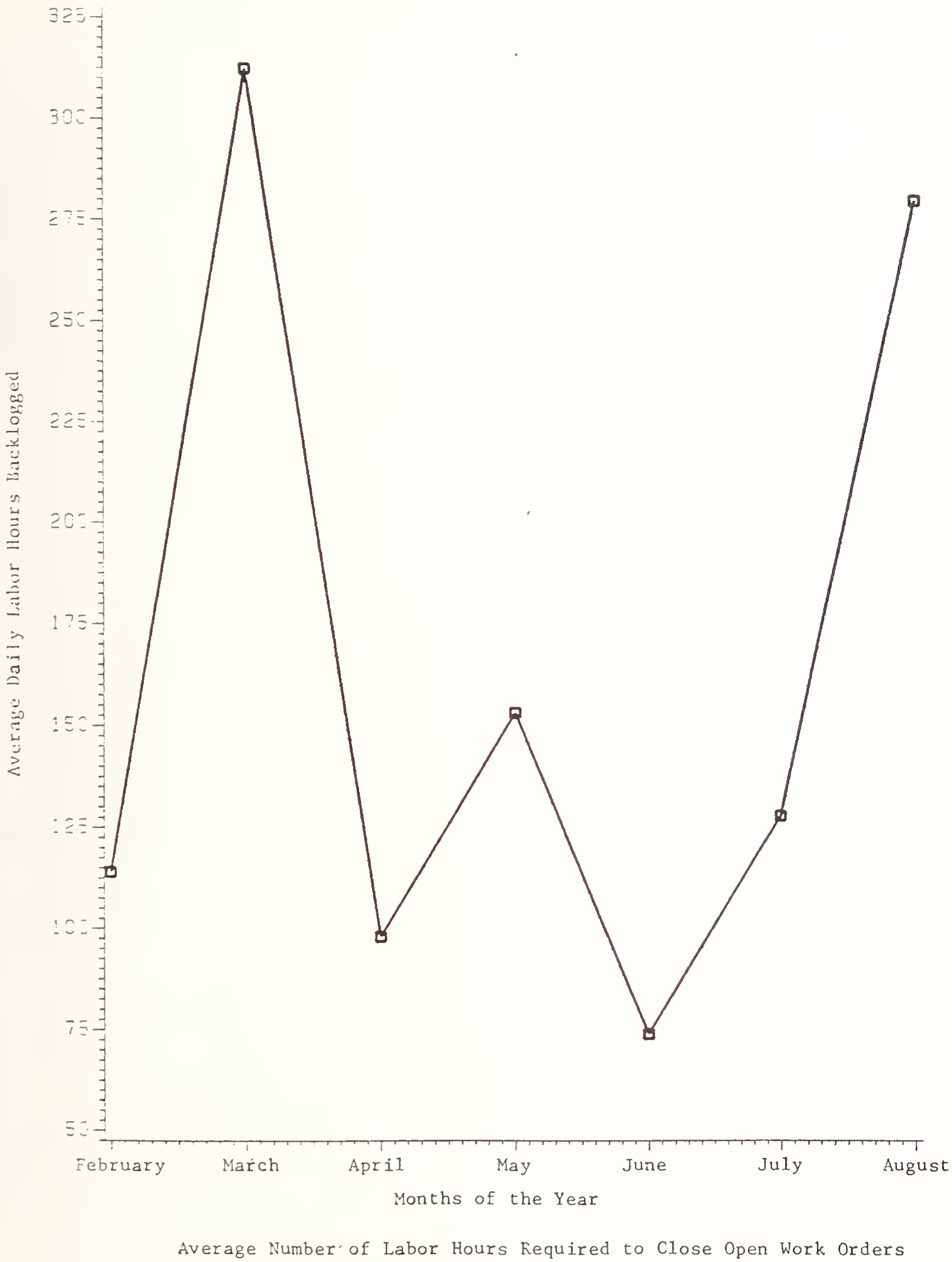


FIGURE B-4

AVERAGE NUMBER OF LABOR HOURS REQUIRED TO CLOSE OPEN WORK ORDERS, WICHITA MTA, FEBRUARY TO AUGUST, 1985

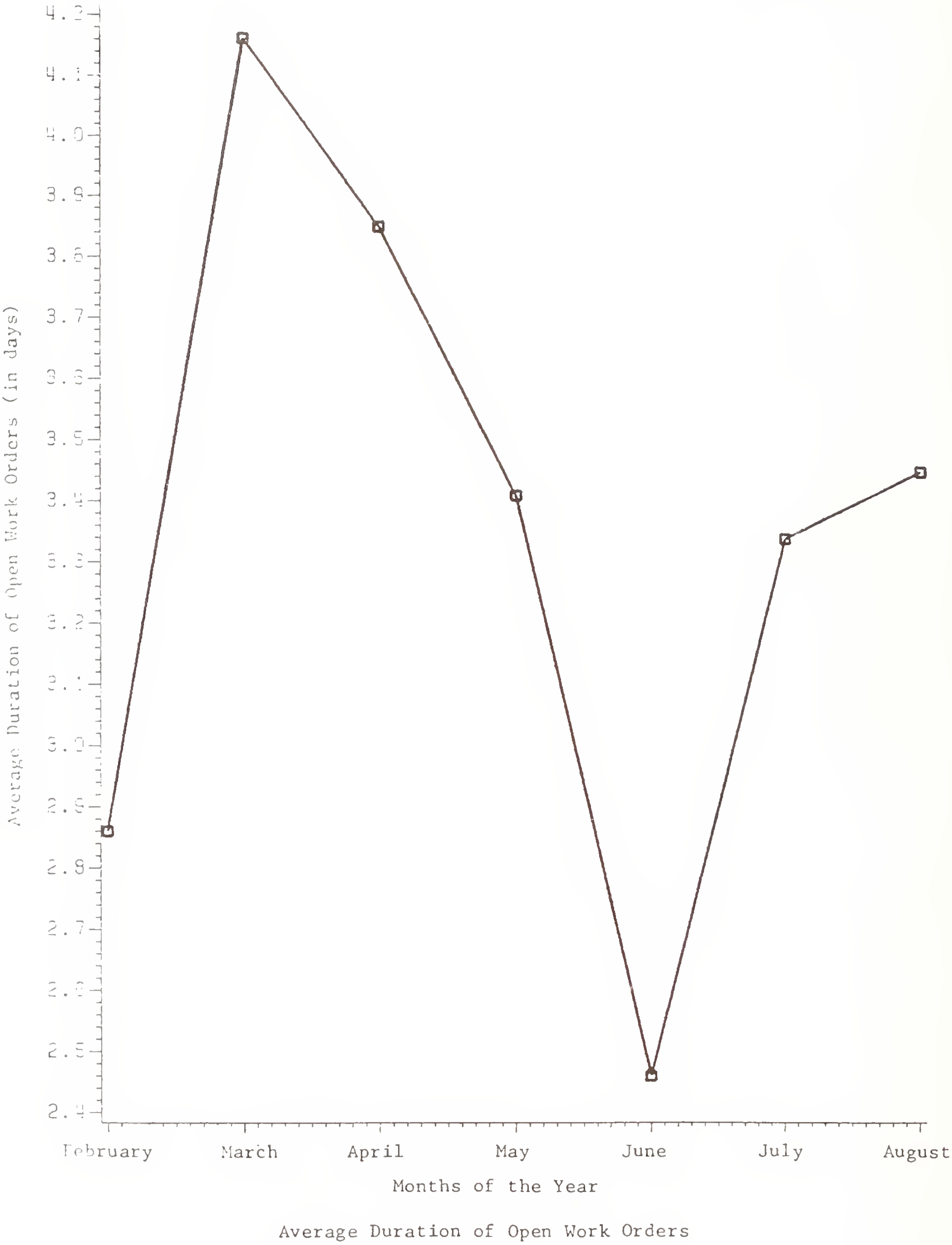


FIGURE B-5

AVERAGE DURATION OF OPEN WORK ORDERS,
WICHITA MTA, FEBRUARY TO AUGUST, 1985

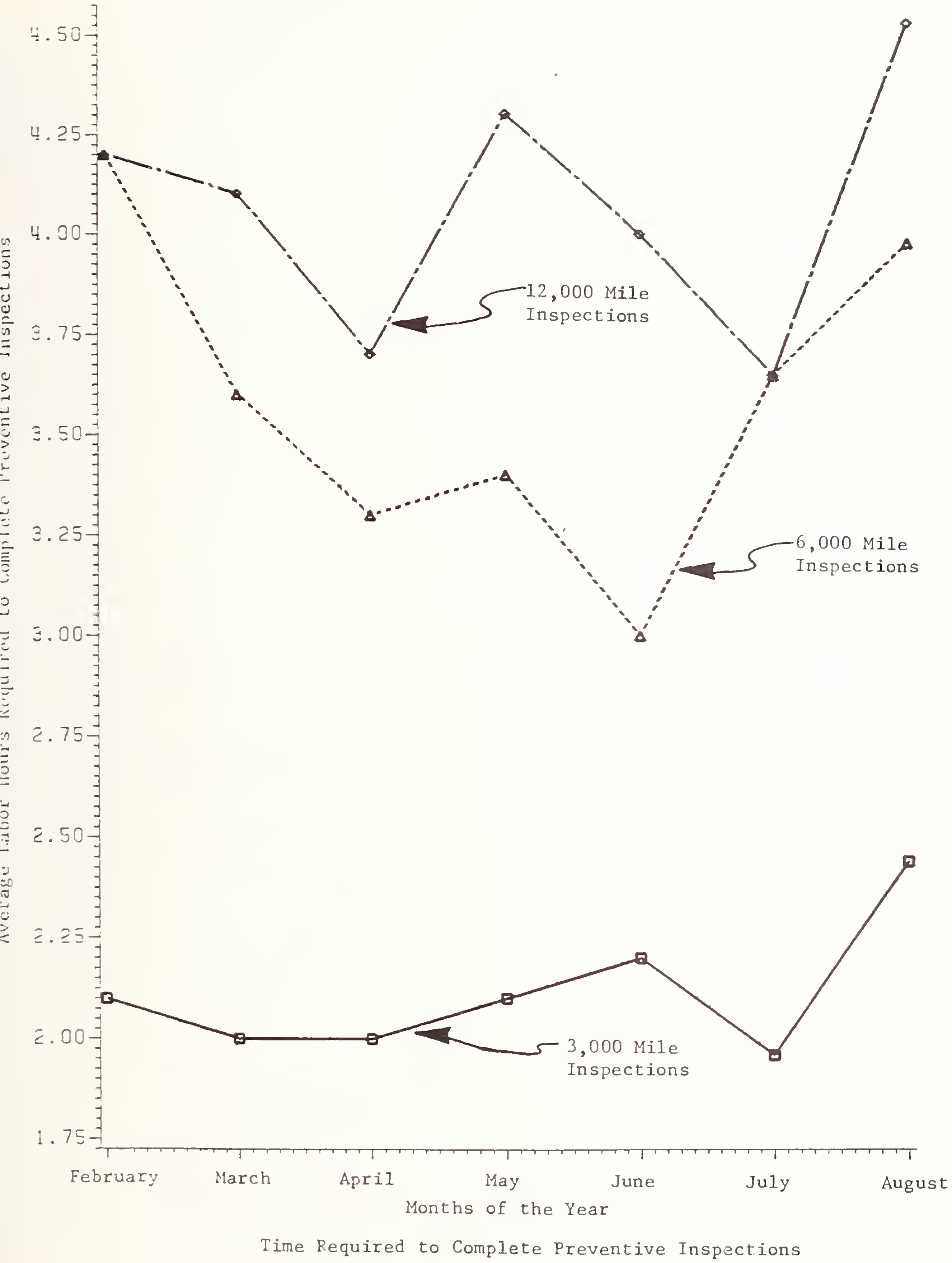


FIGURE B-6

TIME REQUIRED TO COMPLETE PREVENTATIVE INSPECTION
WICHITA MTA, FEBRUARY TO AUGUST, 1985

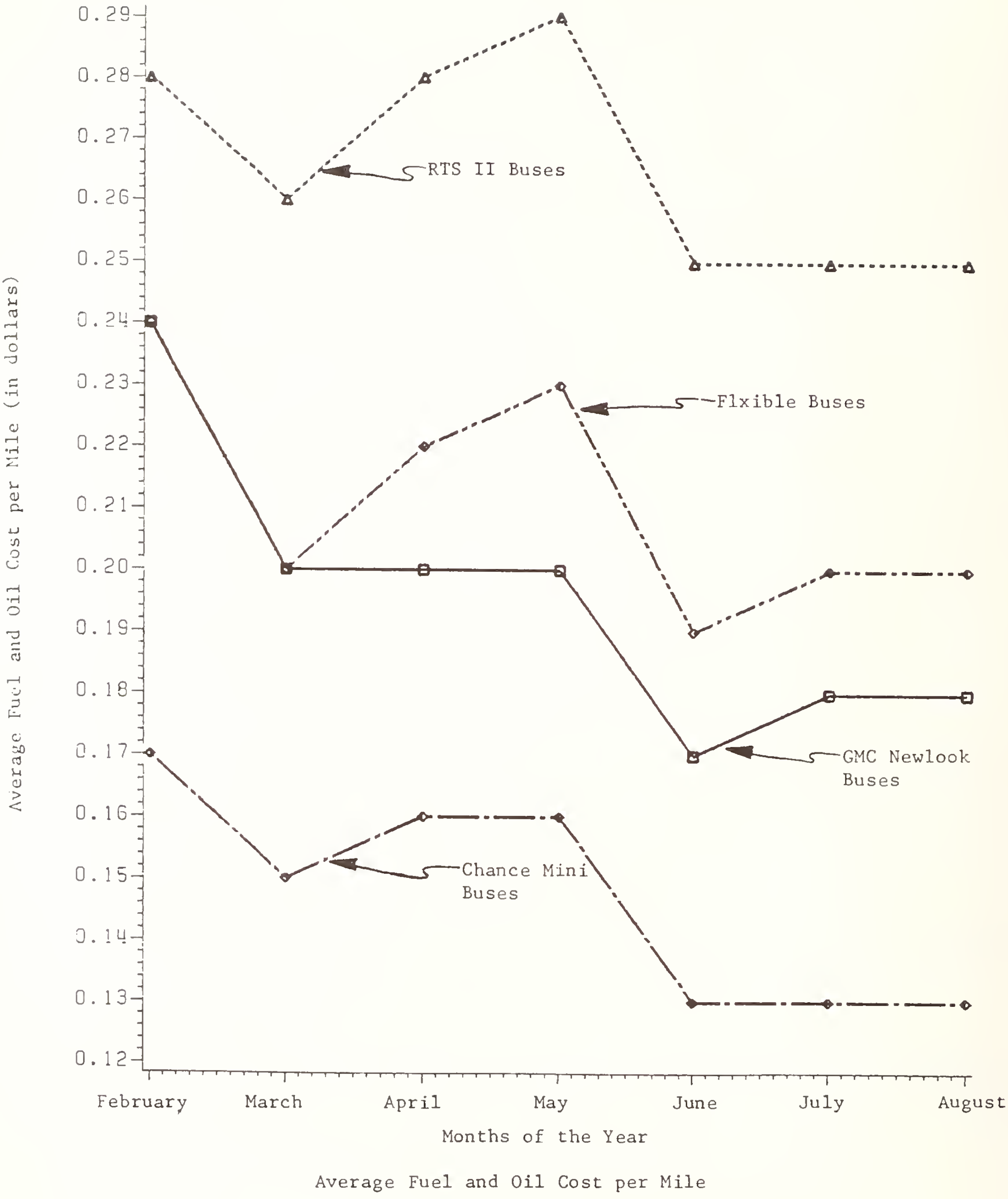


FIGURE B-7

AVERAGE FUEL AND OIL COST PER MILE
WICHITA MTA, FEBRUARY TO AUGUST, 1985

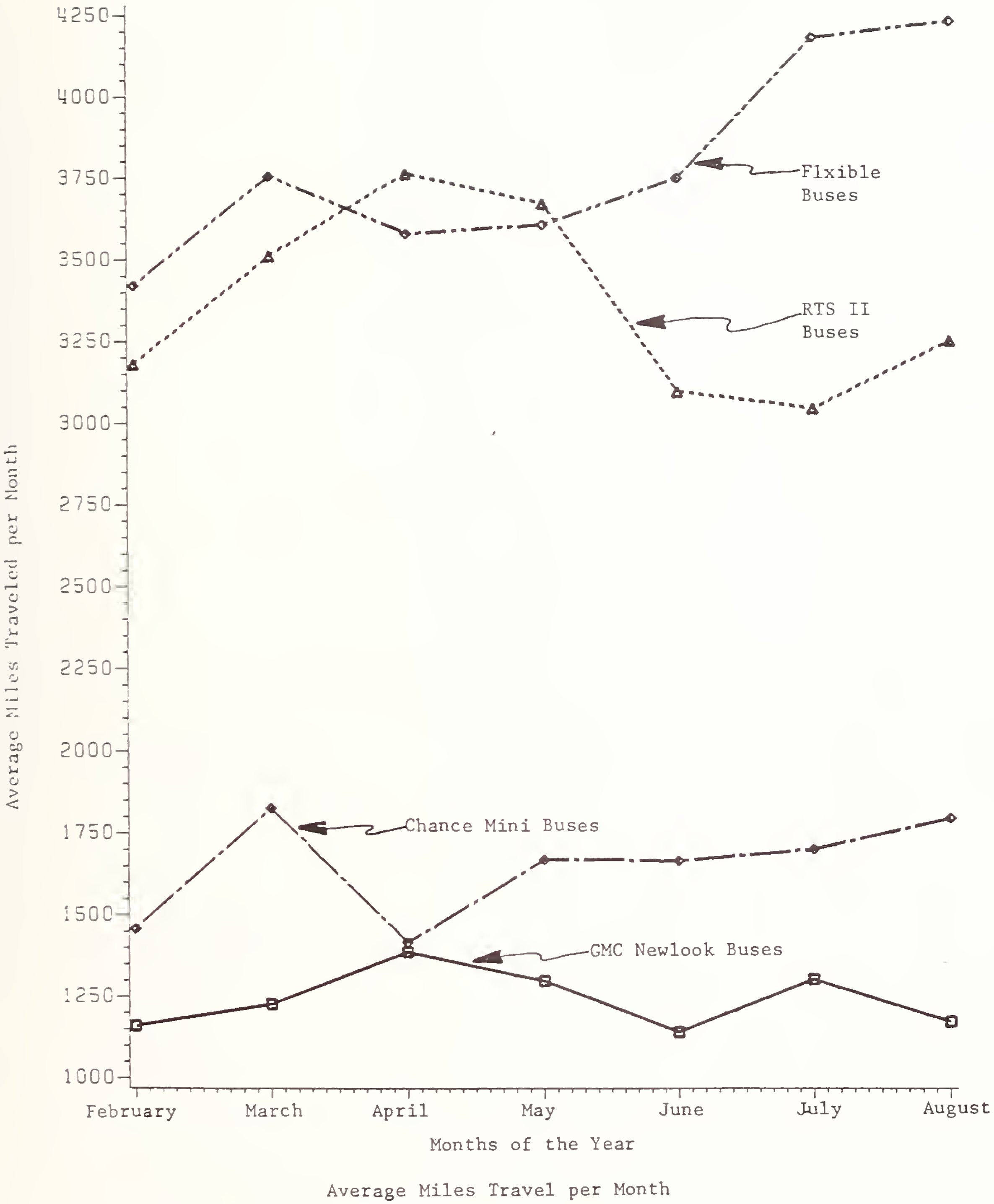


FIGURE B-8

AVERAGE MILES TRAVELED PER MONTH
WICHITA MTA, FEBRUARY TO AUGUST, 1985

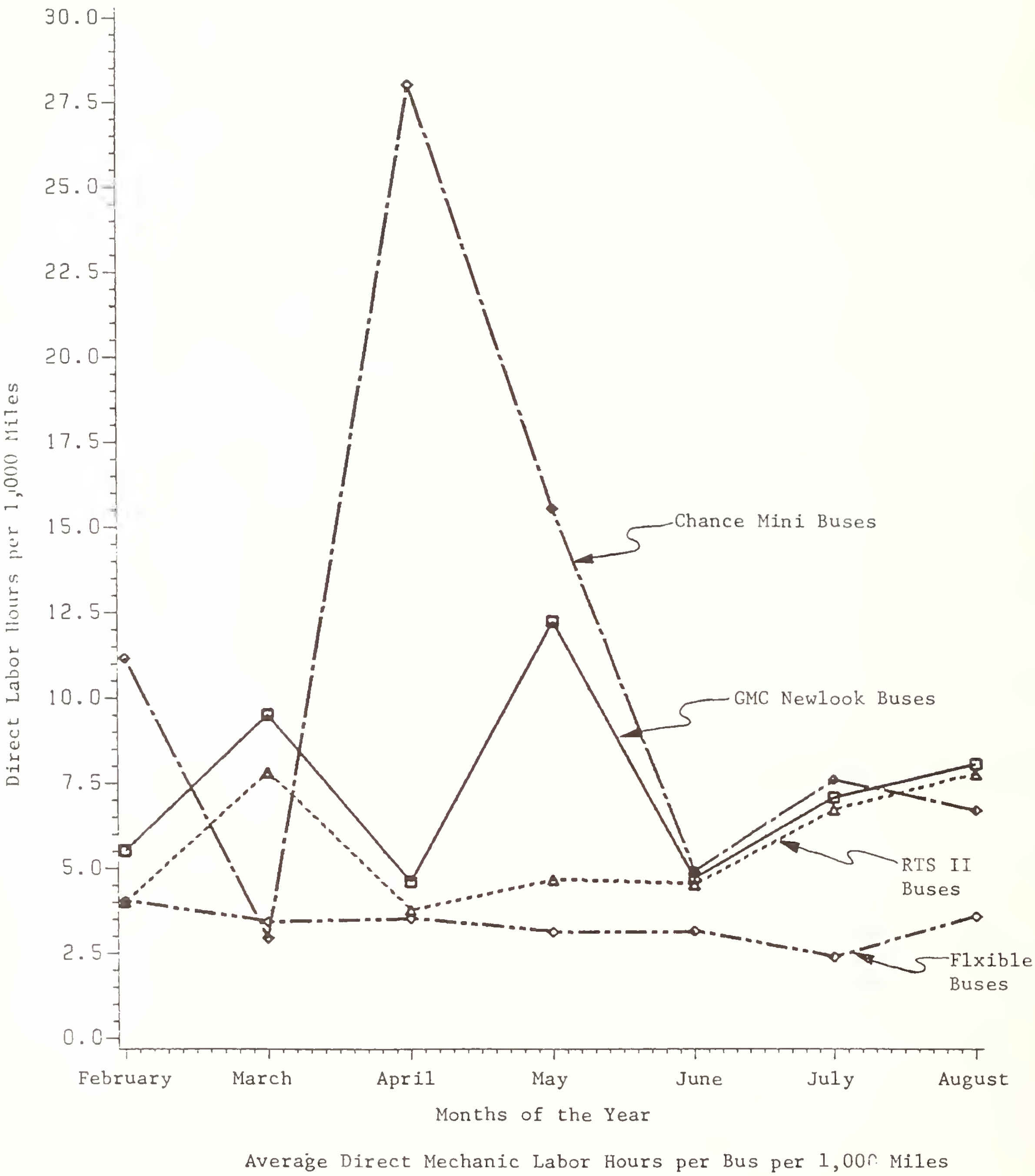


FIGURE B-9

AVERAGE DIRECT MECHANIC LABOR HOURS PER BUS PER 1,000 MILES
WICHITA MTA, FEBRUARY TO AUGUST, 1985

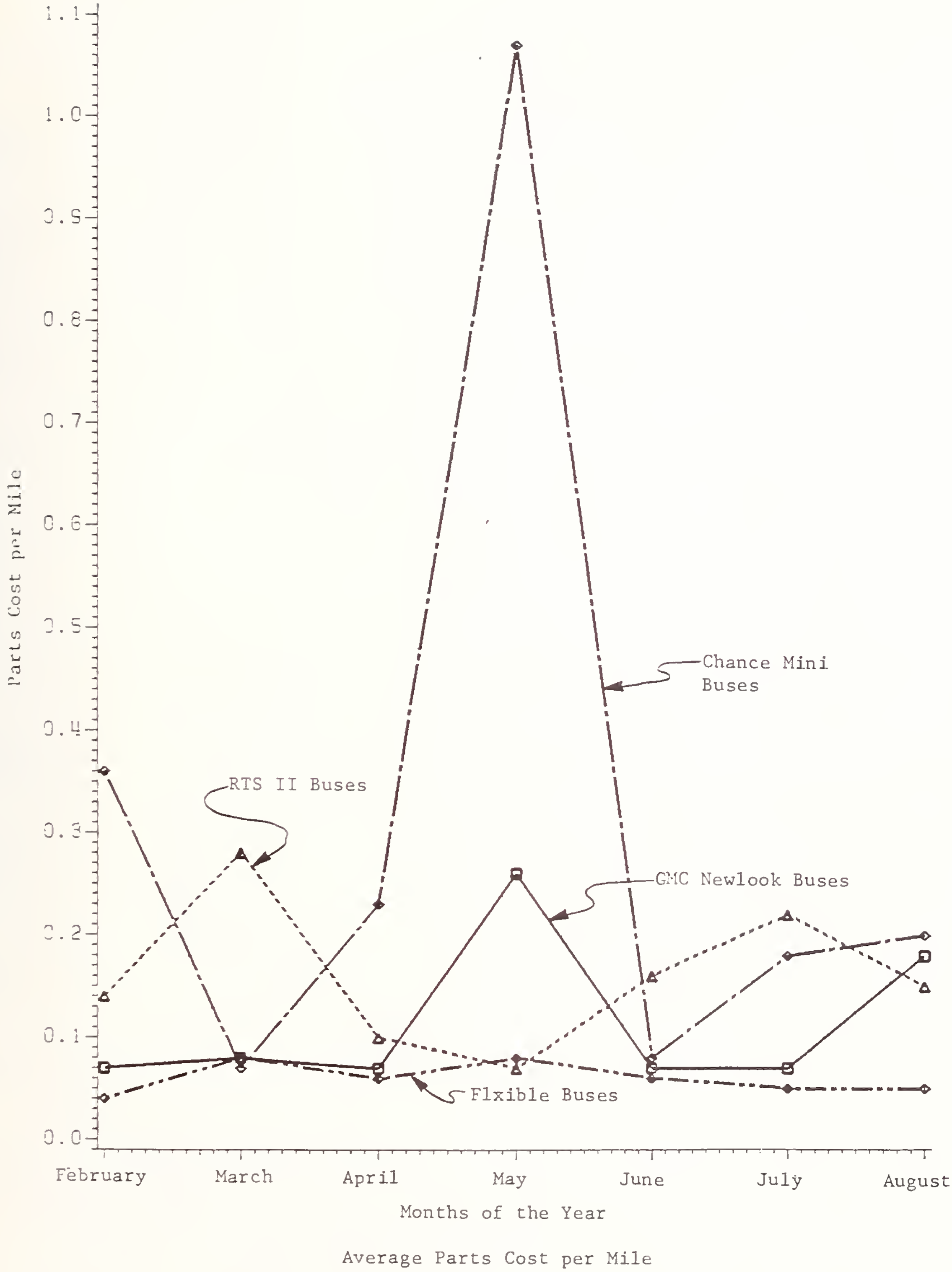


FIGURE B-10

AVERAGE PARTS COST PER MILE
WICHITA MTA, FEBRUARY TO AUGUST, 1985

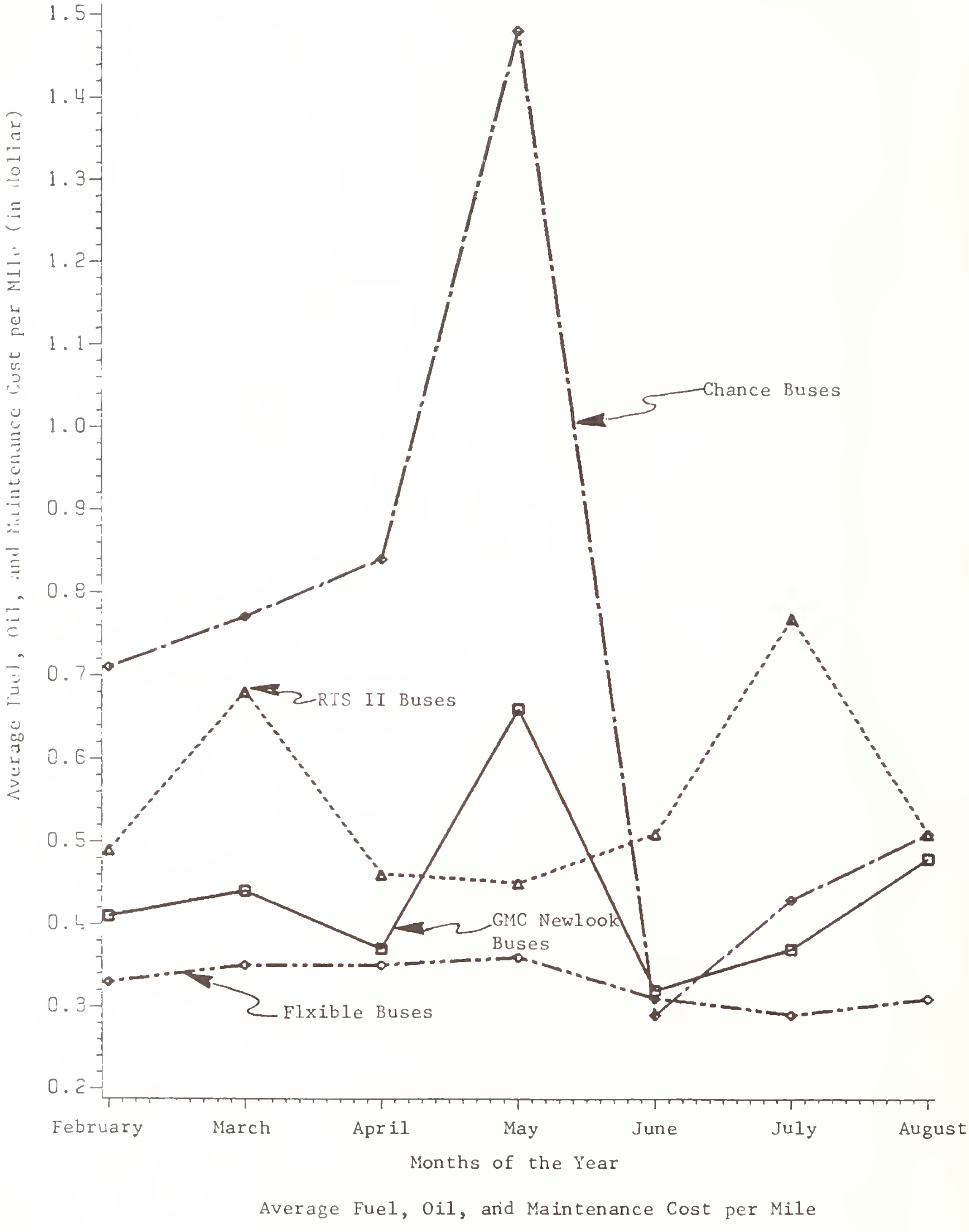


FIGURE B-11

AVERAGE FUEL, OIL, AND MAINTENANCE COST PER MILE
WICHITA MTA, FEBRUARY TO AUGUST, 1985

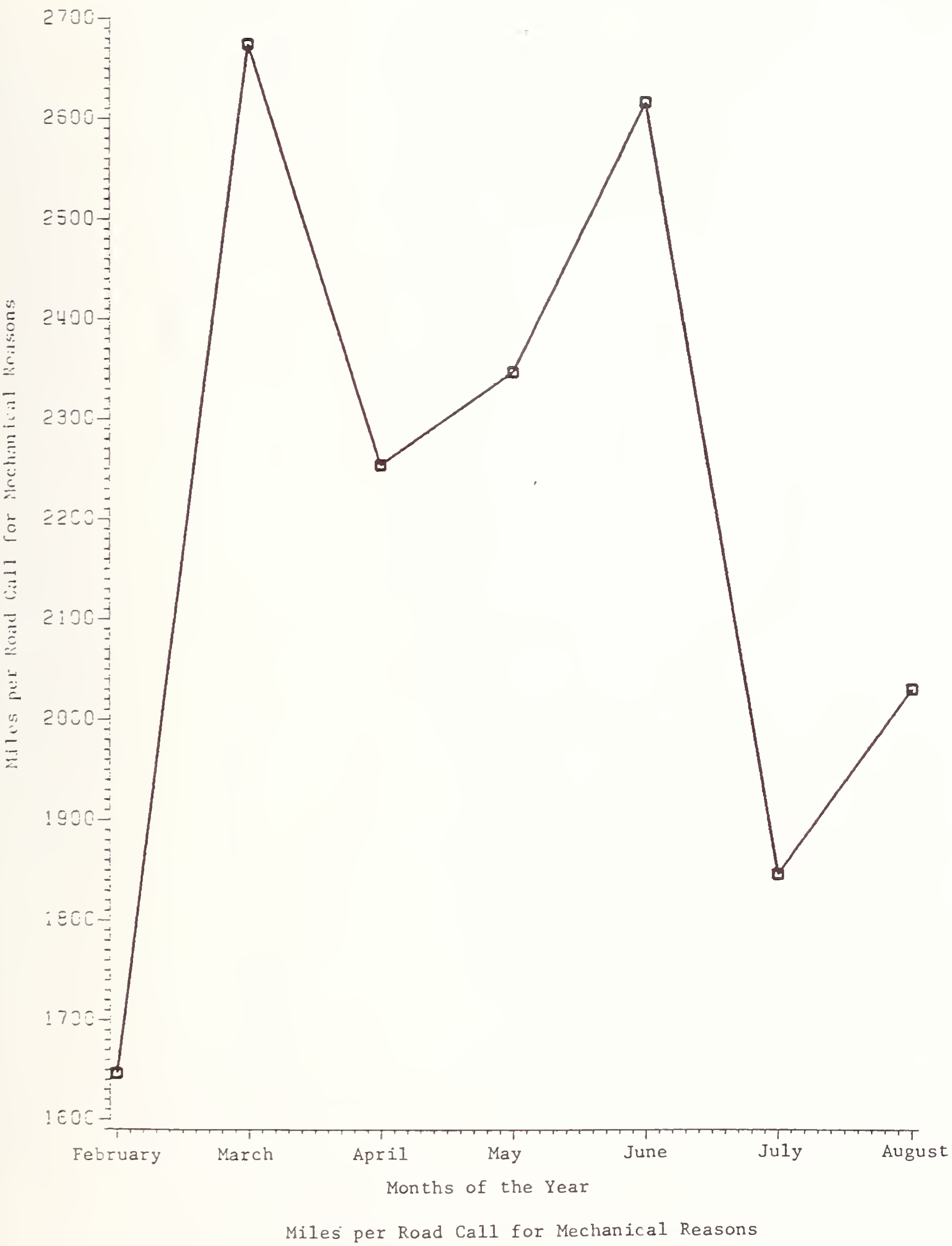


FIGURE B-12

MILES PER ROAD CALL FOR MECHANICAL REASONS
WICHITA MTA, FEBRUARY TO AUGUST, 1985

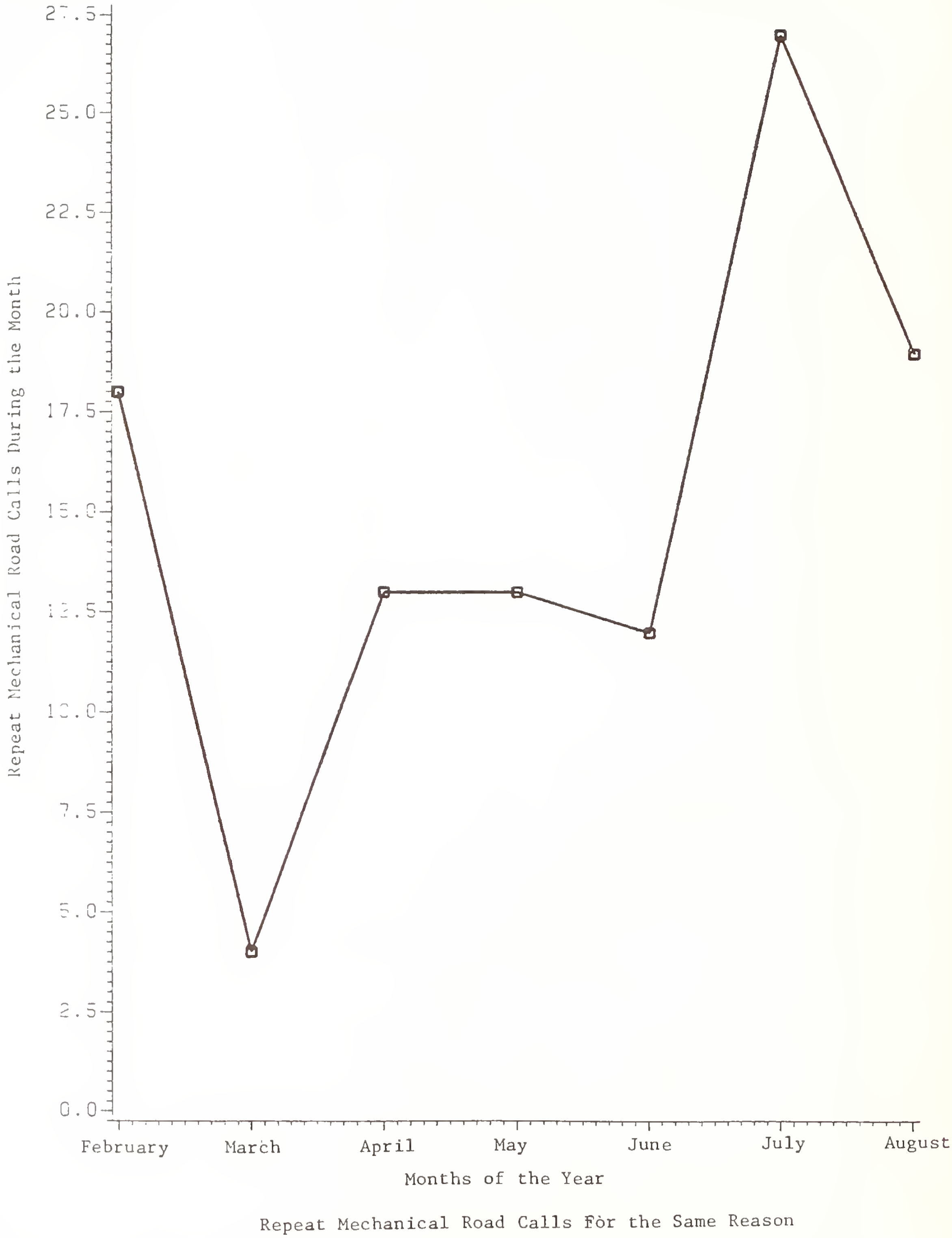
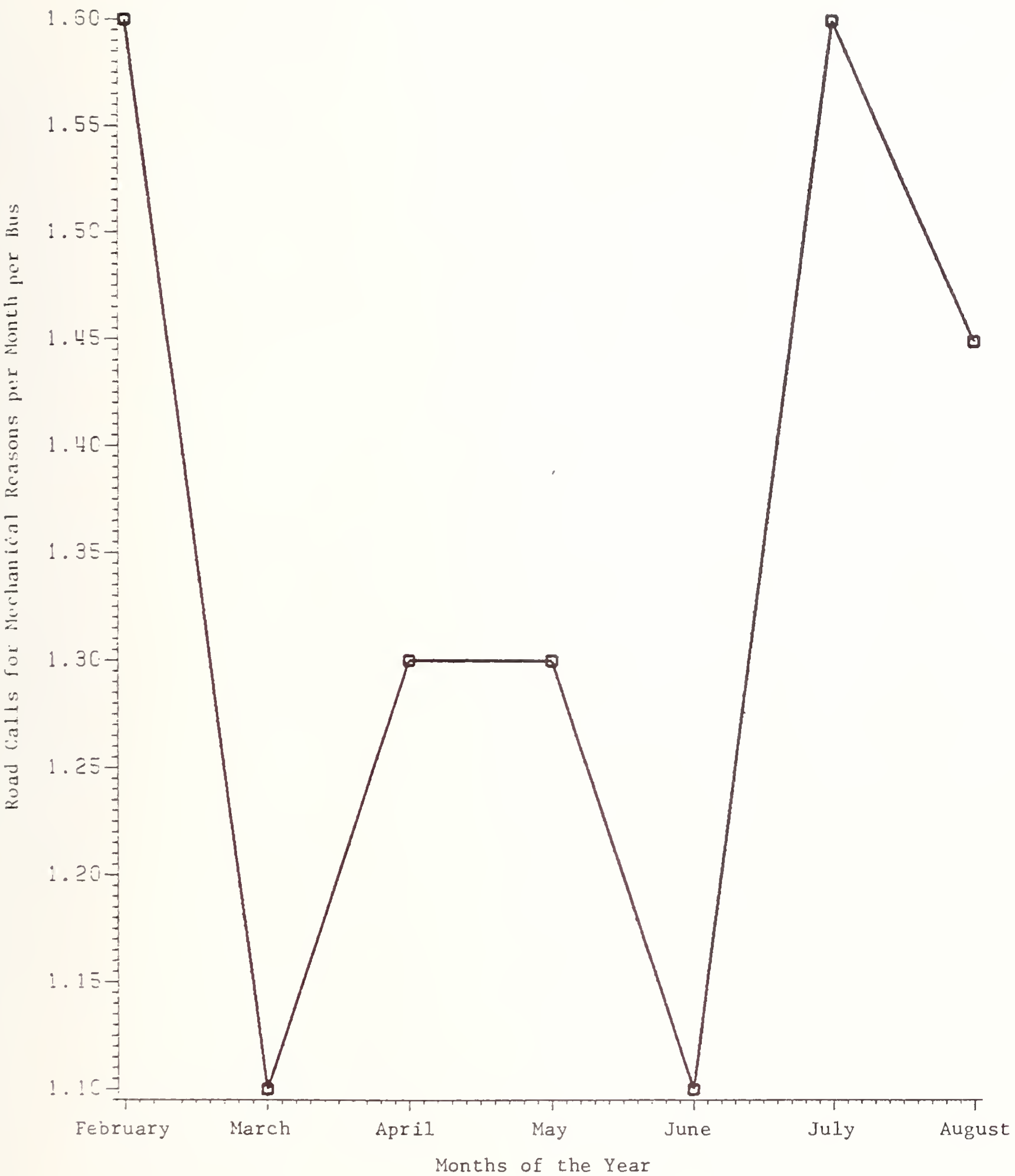


FIGURE B-13

REPEAT MECHANICAL ROAD CALLS FOR THE SAME REASON
WICHITA MTA, FEBRUARY TO AUGUST, 1985



Road Calls for Mechanical Reasons per Month per Bus

FIGURE B-14

ROAD CALLS FOR MECHANICAL REASONS PER MONTH PER BUS
WICHITA MTA, FEBRUARY TO AUGUST, 1985

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