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Responsible Senior Program Officer: Christopher W Jenks

Leveraging Information for Better Transit Maintenance

This TCRP Digest summarizes the findings of TCRP Project E-1, "Innovative Maintenance Procedures for Transit Buses," prepared by RAND, Santa Monica, California.

INTRODUCTION

Problem Statement and Project Objectives

Transit operators typically expend one-fifth of their operating budget on vehicle maintenance. With subsidies being reduced for transit, managers are looking for ways to minimize this expense without compromising reliability. Governmental agencies are increasingly under pressure to be more innovative in how they manage the public's money and deliver their vitally needed services to their customers; many governmental entities are looking at private firms to see if cutting-edge practices emerging in the business world are applicable to transit.

The objectives of TCRP Project E-1 were to survey innovative maintenance practices being used in transit agencies or in transportation-related private firms, to evaluate their applicability to the population of transit agencies in the United States, and to develop recommendations and strategies for implementation.

No specific area of focus was specified at the onset of the project. Work was executed in two phases: the first was a general survey of candidate new practices; the second was a more detailed study of several candidates identified in the first phase of research. The candidate innovations were grouped into three resource areas--capital, labor, and information.

PHASE I RESULTS

Following a literature review and site visits to leading transit agencies and private transportation firms where innovative strategies and practices have been successfully implemented, a series of hypotheses about innovative strategies was generated. (See Appendix A for additional information on the site visit process.) These hypotheses were presented as potential candidates for Phase II work and are discussed below.

Capital Issues

Spares Ratios

A low spares ratio may not increase maintenance costs. Initial research led to the hypothesis that agencies that are innovative in the way they maintain their fleets are able to operate with lower spares ratios, with resulting lower capital and maintenance costs, without detriment to their service output.

Inventory Management

A well-controlled inventory will lead to smaller inventories (more turns, lower costs, and fewer obsolete parts), less parts unavailability, and exploration of alternatives to on-hand inventory for meeting parts needs. Inventory stock purchase accounts for a substantial part of

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maintenance costs; there are also personnel costs for inventory management and purchasing. In addition, running out of needed parts has a cost in both maintenance productivity and in providing spare vehicles to cover those awaiting parts.

Labor Issues

Specialists Versus Generalists

There are differences among agencies as to the level of specialization of the maintenance workforce and differing conclusions as to costs and benefits of specialization. Agencies that emphasize a generalist workforce (one where most mechanics can work on any of a bus' subsystems) may require less maintenance manpower and show more flexibility in accomplishing a wider range of work. It may also allow a more even spread of capability across workshifts and ease the process of on-the-job training for new mechanics as they work with more experienced mechanics on a wide range of jobs. Finally, it may provide for more expertise in routine repairs (running repair) as senior mechanics are not promoted out of onvehicle repair to more specialized functions, such as component rebuild.

In-House Versus Contract-Out

Contracting-out certain classes of work is practiced by commercial transportation firms, based on careful tradeoffs of costs.
Some of these maintenance tasks that are performed on transit buses may be accomplished more efficiently by contracting out for them, rather than by doing them in-house.

Information Issues

Designed Experiments for Evaluating Maintenance Practices

Designed experiments can be a valuable tool for evaluating proposed process improvements. Agencies and organizations that use carefully designed experiments to evaluate alternatives will have reliable information with which to make decisions about adopting particular maintenance innovations.

Information Sharing

Transit bus maintenance would benefit from enhanced interagency communication. The public transit agencies observed differ in one striking fashion from the commercial organizations: they have limited contact with each other apart from professional meetings. In contrast, most commercial transportation firms claim to have a wide network of contacts (many of which are with direct competitors) with whom they share information fairly freely.

Process Information and Work Planning

Coordinating the basic set of process information with inventory information and work schedule planning can lead to greater maintenance efficiencies. Management of any operation requires information about the performance of its component processes. In particular, such data allow management to assess the costs of old and proposed new maintenance practices.

Upper Management Involvement

Upper management involvement in maintenance can be highly beneficial when certain guidelines are followed. Upper management attention to maintenance (in the form of easy and informal communication as well as a direct reporting structure) is associated with efficient maintenance operations. Many senior managers do not strive to understand maintenance. One result is that there is little contact with or knowledge of maintenance procedures. However, agencies identified as highperforming were distinguished by close (often informal) relations with upper management; the importance of maintenance to the agency's mission was transmitted by the highest levels, and rigorous performance measures were established and used to monitor performance.

FOCUS OF PHASE II

Phase II of the project focused on one particular resource input, better exploitation of information, and three of the hypotheses, with their associated work plans, were selected for more intensive study:

- Information sharing,
- Exploiting maintenance information for managing operations, and
- Designing experiments for evaluating maintenance practices.

The results of these work plans are summarized below.

Information as a Tool in Maintenance Management

Objectives and Conclusions

Phase II targeted information usage as one of the most rapidly growing and changing areas of the maintenance function. There are three factors in this revolution:

- Increasing spread and power of computer technology,
- Expanding capabilities for quickly processing data into report formats, and
- Growing computer networks with concomitant capability to expand communication electronically.

It is a conclusion of this report that information, one of the three resource inputs for maintenance, should be a primary lever for maximizing the efficient use of labor and capital resources.

The report presents analysis of and strategies for using information in the following areas:

1. Maximizing the spread of ideas through electronic communication,
2. Improving the use of data to manage and diagnose the maintenance operation, and
3. Validating the benefit of innovations through controlled testing.

The three areas are linked. Evaluating the effect of changed maintenance procedures requires more effective use of information systems, including combining and presenting data in new ways to uncover hidden patterns. Dissemination of and discussion about new ideas through electronic communication within the maintenance community are needed final tests for any new idea to become a new standard in the industry.

SPREADING IDEAS THROUGH ELECTRONIC COMMUNICATION

Introduction and Overview

One of the critical means for improving performance of any operation is through access to information. The primary source of knowledge on most effective transit maintenance practices is found less in research studies or even maintenance manuals than it is in the collective experience of its practitioners--the body of maintenance managers, supervisors, foremen, and mechanics.

Yet there are too few means for this community to share the benefits of its experiences. Neither industry meetings, nor other forms of industry organizations, nor available publications serve to quickly transmit lessons learned in maintenance. The result is that the abundant knowledge of ideas and innovations being discovered on a daily basis remains limited to a few individuals.

The idea proposed in this section is to use emerging information technology to expand the reach of maintenance personnel networks as well as increase the speed of information dissemination. As described below, the most promising means for doing so is via electronic forms of communication.

Communication Constraints in Transit Maintenance

When the 1984 Bus Maintenance Productivity Workshop completed its sessions in Cleveland, Ohio, participants were asked to name and rank the 12 most important issues raised there. The top priority was an improved information network; the second priority (of 11 issues ranked) was establishment of a maintenance council, an early goal of which was to establish an effective information database and exchange network. Workshop participants had reason to wish for more effective information sharing with their colleagues, and believed that "current methods used to collect, summarize, and disseminate relevant bus maintenance information [were] inadequate" and "significant improvements to information exchange can be made easily by applying present technologies in computer hardware and telecommunication." They also believed that such improvements could be made without great expense or lengthy implementation[1].

Because many of the properties have neither the resources nor the management support to participate in developing the tool, the situation has not improved much since then.

When asked what their main source of information and advice was, most maintenance managers interviewed cited small groups of fellow maintenance managers (with most contacts via telephone); others noted the importance of meetings, such as the American Public Transit Association's (APTA) Bus Operations and Technology Conferences. The limitations of both sources are apparent. Most telephone networks are small, no more than five to ten managers. While association meetings afford attendees greater exposure to their counterparts, the expense and difficulty of traveling limits access for the majority of maintenance personnel. The dependence on meetings for sharing information especially disadvantages small agencies and individuals below the level of maintenance manager. In addition, the relative infrequency of such meetings makes them less effective for quick dissemination of new ideas and information.

Transit is at a disadvantage when compared with the private sector, where private firm maintenance managers highly valued and sought out exchanges with their counterparts from other firms, even to the extent of trading tips (e.g., best parts suppliers). The density and frequency of communications appeared, at least qualitatively, to be greater than that found in transit. Significantly, private firm maintenance managers benefit from the sheer scale of many of their operations. The more prominent firms studied--UPS, FedEx, and Ryder--are national, indeed international in scope, and can tap employee knowledge worldwide. FedEx maintains a companywide e-mail system fulfilling many of the functions the researchers recommend the transit industry adopt; it offers an electronic means for a maintenance manager in any location to discuss issues with other maintenance managers anywhere in the world. It even allows them to send messages to the CEO.

Electronic Communication as an Additional Source for Communication

As a supplement to existing forms of communication and information sharing, electronic forms of communicating offer great promise to a dispersely structured industry like public transit. These exchanges can run the gamut from casual encounters between two individuals to postings of substantial documents for a worldwide audience.

Electronic communication is a tool for linking members of a community with shared interests, by extending their access to all members of that community, and by greatly multiplying the kinds and complexity of information and knowledge they can share.

Maintenance personnel-principally but not exclusively maintenance managers-are such a community and have the issues in common such as:

- What should be known about special maintenance needs before purchasing a new type of vehicle?
- Which vendors stock the cheapest, most reliable parts?
- What's the effect of increasing mileage intervals between scheduled inspections?
- When should corrosion problems be expected in a particular climate?

In virtually every case, someone else involved in transit can answer the question. The issue is how to link the person with the question to the one with the answer.

In an organization like APTA, where a number of associate members are vendors, there will be sensitivity to the opinions expressed in a public forum. Some of the legal issues are discussed below, but it is worth noting that in a competitive enterprise, such as parts and equipment sales, all parties can benefit from the free exchange of information.

Electronic communication has value to the transit industry as a whole. While aggressive steps should be taken toward implementing electronic communication industrywide along the lines proposed in this section, an initial pilot implementation, such as one involving the transit maintenance community, offers the best odds for successful growth.

APPLYING A STRATEGY FOR INSTITUTIONALIZING ELECTRONIC COMMUNICATION IN TRANSIT MAINTENANCE

Building and Defining the Community

Advances in electronic communications are creating thousands, perhaps millions, of "cyberspace" communities around the world linked via computer. Through postings on the network, individuals and organizations determine whether the electronic environment offers something of value to them. But at the beginning, when the body of listings is still limited, early users may dismiss the value of this tool too quickly.

This problem is common with a farflung community like transit (or transit maintenance). A purely "bottom-up" strategy by which individuals build their own connections to others in the industry may not gain enough initial momentum to develop beyond a small group environment to encompass the potentially much larger interest group.

Yet a "top-down" strategy may be equally flawed. There have been several attempts by leading organizations in transit to create an electronic communication network from above, either by creating an electronic bulletin board or by creating home pages, which provide regulatory information and direction to other information sites. However, such strategies tend to benefit those already accustomed to using electronic communication and do little to bring in the rest of the potential community.

There have been few attempts to network an entire defined community, like transit maintenance. While Internet growth has followed the bottom-up path, an alternative strategy is possible, combining bottom-up and a top-down approaches to build the basis for an inclusive and networked community of transit personnel communicating frequently via electronic means.

General Outline of the Alternative Strategy

The strategy proposed here is based on combining both bottom-up and topdown approaches to propagating electronic communication capability and use. In order to initiate such a strategy, a framework for early use and recruitment and guidance of the early users needs to be executed by an organized body in order to overcome the "critical mass" problem and create a precedent and pattern for use of electronic communication.

As the voice and the reflection of the assembled transit community, APTA is best placed to play the role of guiding organization. In order to create a framework that gives individuals an incentive to use electronic communication, APTA subcommittees may serve as "nuclei" for a self-sustaining electronic communications system.

Rotation of individuals among different APTA committees will increase exposure to electronic communication and help make its use standard. APTA can also facilitate and encourage communication in order to guide users through the vast array of information sources and set standards for the quality of the information exchanged.

Finally, the principal point of entry into electronic communication for new users should be via e-mail (or aliases and mailgroups). These formats are easy to understand and use, operate without browsers and file servers, and are the best tool for passing information that relates to tasks needing execution.

"Bottom Up:" Creating a Critical Mass of Electronic Communication Users

The best way of encouraging new users to use electronic communication is to create a framework in which such use is vital to their functions. Users must have a reason to log on and check their e-mail, otherwise they will stop doing so.

APTA Subcommittees as Electronic Communication "Seed Groups"

APTA subcommittees have many characteristics that make them a valuable starting point for spreading electronic communication:

- Their members share common goals and common tasks, such as developing agendas for APTA conferences and creating guidelines for new practices for the transit community;

- The membership is geographically dispersed;
- Membership covers the extended transit community, including agency personnel, consultants, and vendor representatives; and
- Committee leaders have an obligation and an incentive to increase exchanges among the members.

APTA subcommittees also have the advantage of covering a wide range of agencies and vendors. A likely candidate for initial use of electronic communication might be one or more of the subcommittees that make up the Bus Equipment and Maintenance Committee (BEMC), as well as the overarching committee itself. In 1995, there were 137 individuals participating in one or more of the BEMC subcommittees. This included representatives from 44 agencies and 31 vendors, as well as 7 representing consultants, universities, government, and service providers.

Application of Electronic Communication to Subcommittee Tasks

Preparing agendas for upcoming APTA meetings is a regular task of APTA committees and subcommittees. This requires vetting papers, communicating with authors, and deciding on final candidates. Most of this effort takes place between committee meetings by telephone, fax, or other means. Electronic communication can expedite the discussion and decision processes. Abstracts or entire papers can be sent to all members of the group; individual comments can easily be sent back to the panel chair and to all members of the group.

Some committees have more demanding tasks. For example, the Procurement Task Force and the Procurement Steering Committee have as their charter overseeing the comprehensive revision of the procurement guidelines and technical specifications contained in the White Book. The Steering Committee consists of 25 representatives of transit agencies and vendor organizations that are dispersed geographically. The Committee's goal is to develop and publish a comprehensive set of procurement-process guidelines and standard terms and conditions for transit industry procurements. The committee will work with several consultants during the course of the work, as well as solicit industry members' feedback through questionnaires, and hold frequent meetings themselves.

Such a concentrated and goaloriented effort would overwhelm telephone and fax communication capabilities; this type of work is well suited to be handled by e-mail.

Mechanics of the Implementation

The idea of e-mail is becoming more familiar to many members of the transit industry. Almost 70 percent of transit agencies have networked PCs, with the capability of sending intraagency messages via e-mail; substantial numbers of agencies have external e-mail capability and subscribe to major commercial online providers of electronic communications. E-mail probably should serve as the first entry point for electronic communication and can familiarize a new user with the idea of electronic communication in a less technologically intimidating fashion. From there the user can advance to other capabilities such as browsing or file transfers.

The costs and management demands of implementing an e-mail networking of APTA committees should be fairly low. Initially, each member would need to establish an external e-mail connection. If the agency or organization does not already provide one, inexpensive accounts can be maintained with a commercial provider.

Alias maintenance. Once all members of a networked group have email addresses, participants can exchange messages with any number of addressees, from one to the entire group. For large mailings, using e-mail "aliases" is an efficient addressing convention. An alias links a simple set of characters to an expandable list of addressees. For example, an alias "psc" could refer to the entire membership of the APTA Procurement Steering Committee. By typing "psc" (and a few other symbols to be discussed below), an individual could send a message to the entire membership. The alias would need to be maintained; an appointed individual would need to establish the set of e-mail addresses underlying the alias, and make additions and subtractions to the list as the membership changed. The alias would reside on the host computer of the alias maintainer.

If, for example, the psc alias were maintained on the host computer at APTA (with an address like "apta.com"), anyone wishing to send a message to the entire Procurement Steering Committee membership would send the message to "psc@apta.com". According to e-mail addressing conventions, this would send the message to the computer called "apta" at APTA, and to an address inside APTA corresponding with the "psc" alias. At that location, the computer would be directed to disaggregate the names and addresses associated with the "psc" alias and retransmit the message to all members of the list, with the entire process taking usually seconds or minutes.

A host computer located at APTA and maintained by APTA personnel would seem the most reasonable home for group aliases. This would require the use of a reasonably capable PC (a Model 486 or better) with the requisite communication software, an external connectivity account (Internet connection or a commercial account), and one or more modems and phone lines. Alias maintenance would require a fairly small amount of time from one individual with moderate computer skills.

Costs. Assuming PCs are already available, cost should not be a prohibitive factor in making this system work; in fact, such an e-mail network is likely to lead to a reduction of costs for committee work. While prices change frequently, commercial provision of email capability tends to be fairly inexpensive. Communications software packages are relatively inexpensive, typically under $100.

Commercial accounts prices are not onerous either. A popular commercial provider of online services (extending well beyond e-mail) charges a baseline price of $9.95 per month including (in addition to online magazines and access to many bulletin boards) 100 e-mail messages per month of up to 100 lines each; additional messages would add to the cost. Another commercial service, which provides pure e-mail services, charges by the byte in a graduated fashion: the first 500 bytes costing $0.50, the next $0.10, and so on, with each 1000 bytes after the first 10,000 costing $0.05. If a normal line of text is approximately 50 bytes, most short messages (30 to 40 lines) would cost around $0.70. A long message, such as a 10-page document, would cost $2.00 to $2.50.

Such costs could replace long-distance telephone or fax machine charges. Thus, while there are some startup costs,[2] the overall expense of using e-mail connections is likely to be much less than with a telephone or fax machine, and e-mail offers ease and speed in communication.

Natural Growth of Electronic Communication Networks

Experiencing the ease of e-mail increases its use. As e-mail use gathers momentum inside the agencies, employees find it increasingly necessary to their daily operations; thus, interorganizational e-mail use builds its own energy. As members join and leave committees, many may wish to stay linked into committee message traffic whether or not they are official members. Others will want to build their own e-mail networks and their own aliases to link colleagues. APTA also might provide alias management capability for these more independent networks. When word of an interesting or useful group spreads, more individuals ask to join. Most will silently read, others will add energy to discussions. When discussion is lively, the problem is not too few members but too many; discussion overload and digression can become problems; the solution is to create new topical groups that parallel the original one.

At this stage, e-mail exchanges will become a standard means of communication in the industry. Enthusiastic users will spread the word about using browsing capability or file transfers. As that happens, the full range of electronic communication will be adopted by an increasing part of the community.

"Top Down": Managing Growth and Use of the Network

While electronic communication is best nurtured from below, a top-down component is needed to influence its development. Some of the early demands for top-down management have already been mentioned; they include establishing a clearinghouse for information to get the new user started; maintaining committee aliases; and installing a "switchboard" computer to move e-mail to the right destination. This subsection discusses some of the main functions of the "top-down manager."

APTA as a Top-Down Manager

APTA, as the voice of the transit community, is the natural candidate to facilitate electronic communication among its members and beyond. Because many of APTA's operations are aimed at increasing communication among its members (e.g., APTA conferences) or at disseminating information to the membership (e.g., the "Thursday mailings"), managing the growth of electronic communication is a natural extension of APTA's function.

Major Functions of Top-Down Management

There is a variety of services a manager should provide and the list will change as the technology of electronic communication changes.

Establishing nuclei involvement. APTA should encourage making electronic communication the standard means of communication among its subcommittees and other panels; it should provide technical expertise for new members; it should maintain the mailing aliases.

Maintaining directory services. As the number of users increases, one emerging difficulty is the lack of directory services. Directory services are still primitive on the Internet, and early attempts to create the equivalent of long-distance telephone directory assistance have been disappointing. The best way to get an e-mail address is still to ask the person for his or her address.

APTA can maintain a directory of e-mail addresses for members of the transit community and put them in an easily accessible format. Such a directory could be a relatively sophisticated searching mechanism (which could allow a search for the names and e-mail addresses of agency maintenance managers) or it could be an alphabetized list with e-mail addresses and titles of all members of the directory.

Managing aliases. APTA may choose to provide alias management services along the lines discussed earlier. If non-APTA related groups wish to establish a mailgroup alias, APTA may offer its services for maintaining the alias in its own computer and providing a routing service for messages. This would facilitate APTA's development of a transit e-mail directory.

Establishing and managing bulletin boards. While many of the electronic conversations will be "private" (read only by subscribers to the alias or the mailgroup), there is great value in having discussions that all can read or contribute to. This is one of the functions that electronic bulletin boards and newsgroups provide. It would be of particular value for APTA to establish and maintain some bulletin boards on a variety of topics; these could act as a continuous "town hall" for matters of interest to the transit community. One could imagine a bulletin board on the White Book revisions, providing feedback from the community at large to those making revisions, or discussions about desired aspects of the advanced technology bus, or the benefits of brake retarders, or specific intervals for preventive maintenance. The advantage of bulletin boards is that they are accessible to all and can be read at the individuals' convenience, without the postings overwhelming their electronic mailbox.

APTA, in managing these bulletin boards, could sponsor their startup, solicit ideas for topics and vote on whether they should be initiated[3].

Providing a clearinghouse for browser resources. One of the most frustrating things for new users is the formless, unedited nature of the Internet, especially the browser-accessed World Wide Web. There is no reliable guide to what exists in cyberspace nor is there a mechanism to guide the users. Perhaps one of the most valuable roles an organization like APTA can do for an emerging electronic community is to act as a guide to the information available. APTA can serve as a reference librarian to the resources that the community puts on the Internet. APTA might consider taking the following actions:

- Maintaining the APTA home page on the World Wide Web that, in addition to providing information about APTA itself, serves as a gateway to transit-related resources elsewhere in the Web. (An APTA home page has already been established and provides access to the kinds of transit information recommended here. It is accessible through the following address: http://www.apta.com).
- Encouraging other potentially interested parties to establish home pages; these might include vendors displaying information about current product lines, price lists, updates to technical bulletins and maintenance manuals and the like; agencies listing job opportunities or posting experiences with particular maintenance problems; or government agencies providing updates to regulations;
- Providing an organized way of accessing all of these resources via "onestop shopping" through the APTA gateway; and
- Providing annotations to guide users in searching the various home pages. However, such annotations would have to be updated fairly often.

Being a technical advisor of the last resort. Finally, APTA should strongly consider offering technical help to its members. Although using e-mail is becoming easier all the time, new users may still find themselves easily thwarted by startup problems. APTA might offer some of the following resources:

- Hard or soft copy information packages to help new users get started;
- An 800 telephone number for technical advice;
- Package information and costs; and
- Last-resort subsidies for member operating costs.

Conclusions and Steps for Implementation

For the transit community, the issue of joining the world of electronic information sharing is a question of "when" not "if." This section points out that the strategy for developing electronic communication can help or hinder its development. A useful implementation strategy is one based on creating seed groups exchanging e-mail to handle ongoing business among dispersed members of the transit community, aimed at familiarizing members with the benefits of electronic communication and enhancing its spread industrywide.

A top-down element is essential to this strategy, recognizing that some level of guidance is required to ensure quality standards for the information exchanged. APTA is positioned best to play this role.

For that implementation to succeed, several steps need to be taken:

- Volunteering specific committees or subcommittees to act as seed groups, including the agreement of all members to acquire connections, familiarize themselves with its operation, and commit to using the channel as the situation demands;
- Designating APTA personnel, hardware, and software necessary to support committee and subcommittee use of electronic links;
- Developing a larger and longerterm APTA plan to support electronic communications in the transit industry, including e-mail address directories, alias management, home-page coordination and annotation, and preparation of tutorial packages for new users;
- Disseminating APTA plans to the membership to facilitate independent efforts to develop electronic links in coordination with APTA efforts; and
- Soliciting vendor and governmental participation in electronic links, especially through home pages, for access through an APTA gateway.

As implementation proceeds, ongoing research by consultants or by APTA personnel can play a valuable role in analyzing emerging usage trends, evaluating network problems and weaknesses, and suggesting corrective actions.

In conclusion, it is important for the transit community to be proactive. The transit industry needs to lead rather than follow in adopting the electronic communication standard. The resulting product will be better suited to transit personnel use, and its adoption throughout the community will spread quickly.

USING INFORMATION TO SUPPORT MAINTENANCE DECISION MAKING

Maintenance Information and Data

When the collection of data on maintenance processes and maintenance information systems is discussed, the terms data and information are used interchangeably. For the purposes of this section, the following distinction between the two is made.

Data are the individual numbers, codes, text, and so on, selected by mechanics, hustlers, and managers to describe what they did or found during the course of a maintenance action. Among the transit agencies and other organizations visited in Phase I and Phase II site visits (Appendixes A and B summarize these site visits), there is general agreement on a common core of data elements that need to be collected for maintenance management. The computer hardware now commercially available has sufficient power and storage capacity to collect and retain this core data easily for most transit organizations (most have adequate computer capability, though their maintenance organization accessibility is limited). There have been advances in data capture devices: bar code readers, magnetic card swipes, ruggedized input devices (keyboards and touch screens), and computers on vehicles and individual components. Commercial attention has focused on the use of such devices to ensure the quality of collected data, particularly by eliminating errors that occur when paper forms are used for collection. There is increasing interest in data elements beyond the basic core, e.g., serial-number tracking of components for lifetime estimation and evaluation of suppliers, but the benefits of these elements are debated.

However, data are useless if they are simply stored and never looked at again. The purpose of data collection is to produce *information,* the combination and display of data to illuminate some aspect of maintenance practices, evaluate possible actions, or suggest alternatives. Both data collection and information production are critically dependent on the capabilities of computer technology and one's function is often confused with the other's.

Although there is a core of maintenance data elements, the combinations of those data and the information potentially available are infinite. Therefore, information production needs to be tailored to the circumstances and its particular problems to be useful. While fields such as statistics and graphical design can suggest methods of analyzing data to extract information, the value of information production can be judged only by information *use,* and the benefits of use can be assessed only through the experience of maintenance organizations. Ideas for information production need to be tested on real problems.

The use of post processors is an emerging strength of the more advanced management information systems. Post processors facilitate the manipulation of data for any desired purpose. Some systems even allow data to be downloaded for use onto other computer applications like spreadsheets. With these new capabilities, maintenance managers will be able to track, troubleshoot, and control their operations even more effectively than through advances being made in the areas of data collection or data coding.

Maintenance Information Usage in Commercial Firms

Phases I and II of the project included visits to facilities and offices of six commercial firms that operate transportation fleets: FedEx, Arkansas Best Freight (ABF), Laidlaw, American President Lines (APL), Ryder Leasing, and United Parcel Service (UPS). A summary of some of the innovations in the collection and use of maintenance information used by these firms follows, along with a comparison of those used in mass transit. First, the overall approach to maintenance data taken by these organizations is described, then the innovations of two of these firms in using information to develop their maintenance operations are examined.

All the firms visited were very large and had maintenance centers spread over a wide geographical area. Almost all the centers were the size of a moderate bus agency in terms of number of vehicles; the vehicles were somewhat less complex. The amount of control of the centers, particularly in maintenance policies, ranged from virtual autonomy at APL to detailed, centralized control at UPS. Maintenance was seen in each firm as a key part of their business because each had low spares ratios and operated on tight schedules with heavy demands.

All the commercial organizations considered their maintenance data an asset that helped them make their maintenance operations more costeffective. This was reflected in the belief that data collection was part of the job of mechanics and foremen, not a secondary task to "real work." With the exception of UPS, this realization had occurred fairly recently, and all the firms were in the process of upgrading both their maintenance data collection and the provision of information for maintenance management to mechanics, foremen and maintenance managers.[4] These organizations were similar to public transit agencies in terms of maintenance management until the early 1990s (in fact, some of the large transit agencies may have been ahead of them in terms of computerization). However, the resources that these firms command have allowed them to move rapidly in developing and installing state-of-the-art maintenance information systems. For example, Ryder went from a paper system at its maintenance centers to FastTrack[5] in 3 years.

There are two other differences in the use the commercial firms made of maintenance information. First, because of their size, most had decided to centralize analysis of their interregional data. This function was long standing at UPS; the other firms were considering this to benefit collection of local data (during our visits to the corporate headquarters of Ryder and FedEx, this development was presented as a key part of their maintenance information strategy).

Second, although the commercial firms planned to use their maintenance data to improve their maintenance practices, they all saw the biggest payoff to be more informed procurement decisions. In their view, the primary driver of maintenance costs is the design and manufacture of the vehicle, and they planned to aggressively use the maintenance data to pursue warranty claims, guide the development of engineering changes and purchase specifications, and evaluate the performance of different makes of vehicles and major components.

Although the commercial firms share similar views on the above issues, the researchers observed that there was a difference among the firms visited in how they were using maintenance information. One set of firms took a *diagnostic* approach to the use of maintenance information. Their information is focused on vehicles: keeping track of repairs, PM and safety inspection schedules, parts usage, and reporting this information to the maintenance manager and higher levels as needed. The management of the center is much less formalized, with managers and foremen using their own judgment to assign work and assess mechanic performance. Maintenance information is used primarily for the diagnosis of persistent problems with vehicles, and, to a lesser extent, with maintenance processes. The maintenance information system is important to day-to-day maintenance operations, but not vital. The firms in this group are FedEx, ABF, Laidlaw, and APL.

In contrast, Ryder and UPS have maintenance operations which are *information-organized.* In addition to using maintenance information in a diagnostic fashion, information about vehicles, mechanics, and schedules is used to make management decisions about running the maintenance operation. Both Ryder and UPS schedule maintenance jobs and assign mechanics based on job priorities, mechanic qualification and skills, and available space. The UPS system also insures that the correct parts will be on hand for scheduled PM and deferred maintenance before a vehicle is brought in for work. For these firms, the maintenance information system is critical to day-today operation.

Information-organized maintenance uses information to minimize work which is not direct repair work, whether mechanic or supervisor, particularly administrative paperwork. To get accurate information to do this, both firms have used computers to reduce the data collection burden, even when the initial cost for hardware and software development is high. Both Ryder and UPS have brought together all the resources required for the mechanic to do a repair job through completion without delay (Ryder has integrated its diagnostic equipment and is developing online technical manuals that can be accessed by a laptop computer as the mechanic works).

The success of both Ryder and UPS in their use of the information system in scheduling maintenance and moving administrative tasks, which ensures that all resources needed for a repair job are brought together at the right time, suggests that maintenance information use can be pushed beyond diagnosis to a more central role in managing maintenance.

Findings

No hard or fast rules exist for the use of information in maintenance management; the value of information is determined by the situation and the personal application; how it is manipulated and presented is similarly situation dependent.

The research conducted in this project indicates that the capabilities and much of the content of most maintenance management information systems in public and private organizations are similar. Computerization is the rule. The majority of agencies maintain vehicle work histories and are for the most part work-order based. Mileage, fluids consumption, and cost tracking (to some degree) are typical, and most agencies investigated can generate standard performance measures, such as miles between roadcalls and cost per mile.

There is a lack of standardization, especially in the area of codes. There is no equivalent in transit to the American Trucking Association's (ATA) Vehicle Maintenance Reporting Standards (VMRS). The ATA codes describe the vehicle, problems, action taken by whom and where, and at what cost.[6] Such a system, if modified to fit the characteristics of transit vehicles, could be of great use to transit maintenance managers. However, consideration of any type of industry standards for maintenance data must be preceded by consideration of how such data would be *used.*

The research revealed that many agencies collect subsystem, failure, and repair-coded information, and that these coding systems are undergoing substantial modification to enhance accessing data. However, we also found very limited use of many of these codes, especially failure and repair codes. Subsystem codes, on the other hand, were often profitably exploited, but there was great variation in their use across the agencies. In some cases, a failure code of special interest, such as the "No Trouble Found" code, was frequently included in performance measurement, but few if any other codes were so employed.

In opening the discussion of how best to use information to support maintenance management decision making, it was found that most agencies are already well-positioned to make good use of existing data resources without settling on an industry standard or pursuing expansion of data collection capabilities. The power of information exploitation flows as much from methods of *combining* and *presenting* data as from the volume of collected data itself.

To demonstrate this, a series of examples was presented based on current uses of data among agencies that illustrate ways of bringing together different data elements and presenting the results to answer questions, convey information, and support the maintenance decision maker in the simplest, clearest way.

In a comparison of public transit agencies and private transportationrelated firms, there were few differences found in data uses for diagnostic purposes. However, several firms studied are using data to create information-based maintenance operations that are very different from anything seen in transit. Organizations like UPS and Ryder are using information to schedule all aspects of the maintenance operation. Needed repairs are noted during inspection and set up for future repair. Mechanics are assigned, and their daily schedule laid out for this scheduled work, based on carefully maintained shop standards. Repair part requirements are determined during the inspection phase, orders are placed, and parts delivered within the time frame of the repair.

Maintenance work organized with such detail and close control generates benefits for these firms but clearly increases their dependence on computerbased management systems and the personnel who need to run them, generate the schedules, and coordinate the execution of all activities. The systems also require realistic shop standards to work efficiently. Adopting such systems would be a substantial undertaking for transit agencies but, if budget pressures continue, one worth considering.

TESTING INNOVATIONS THROUGH EXPERIMENTAL DESIGN

Purpose

Is an innovation in maintenance practice worthwhile? Will its potential benefits outweigh its costs? In most of the agencies visited, the procedure for evaluating changes to maintenance practices is based on informal tests. In contrast, in areas such as manufacturing, agriculture and medicine, evaluations are planned and executed through designed experiments that ensure valid results. These experiments are described in this section. The use of such experiments in the context of fleet maintenance can benefit the industry by speeding up evaluation and spreading the use of innovative practices. This section provides ideas about how experiments can be useful to transit maintenance and suggestions and references for further information.

Evaluation of New Maintenance Practices

There is increasing pressure in the transit industry for agencies to improve their performance in all areas, including maintenance. Agencies are expected to produce more with fewer resources and to increase their productivity and efficiency. Exploring new maintenance practices is a key tool.

Before adopting a new method for all vehicles, it is often tested in a pilot program. The reason for using a pilot program is to measure the amount of improvement gained. If the new technique has harmful effects, it is critical to discover these before the technique is applied to the entire fleet. If the new method is more costly than the old method, a manager needs to be confident that the improvement in maintenance performance will save more money than the cost of the technique.

Many innovations have been adopted by different agencies. These included brake retarders, the use of oil analysis, new tools for repairing and cleaning a bus, alternative fuels, and so on. However, these innovations have not diffused uniformly through the industry. In the cases of both brake retarders and oil analysis, some agencies insisted that these were valuable innovations that saved substantial resources, while other agencies insisted that the same techniques were not worth their cost. Similarly, it has often been pointed out[7] that preventive maintenance schedules differ widely among agencies, even when they have similar equipment and environments.

When asked how changes were evaluated, the answer was virtually the same from all agencies: new techniques were tried out on a small set of vehicles, and if there were no problems and the relevant performance was judged to have improved, the technique was adopted for the entire fleet. However, there was little recorded about how the vehicles were selected or how the performance was evaluated; experienced people picked the vehicles and "looked at" the results.

There are two problems with this evaluation procedure. First, there is inherent variability in measuring any performance metric: fuel mileage, oil usage, miles between roadcalls, all differ between vehicles for a variety of reasons including route, driver, bus make, and even characteristics of the particular bus. If vehicles are not selected to be representative of the overall fleet, and comparisons are not made carefully, this variability can either obscure the effect of a good idea, or indicate that a new procedure is beneficial when it has no effect. Second, the informal procedures for testing render the results from most tests suspect from one agency to the next: without a clear picture of what was done, concerns relevant to an agency considering the new technique could not be addressed without running separate tests at the new agency. However, industry has carefully designed and carried out such tests, though maintenance organizations in the transit industry have yet to avail themselves of their benefits. The adoption of these techniques for designed experiments provides an important tool for transit maintenance to evaluate accurately proposed changes in maintenance procedures.[8]

Designed Experiments

A designed experiment is a carefully structured test that uses statistical methods to estimate accurately the changes produced by the test. Such tests are particularly useful in situations where there is substantial inherent variability, that is, response is affected by a variety of factors. Designed experiments allow the two types of effects on test response to be separated and measured so that the effect under study can be accurately assessed.

Modern interest in designed experiments dates to the early twentieth century agricultural experimenters who needed to show the effect of new farming methods on crop yields, but had to contend with the variations of yield due to different fields, slight variations in planting practices, and other factors. These methods were picked up by manufacturing firms, particularly those in the food and petrochemical industries. After the end of World War II, the techniques were introduced into Japanese industry by the American statistician W.E. Deming and helped revolutionize Japanese manufacturing by applying designed experiments to virtually every proposed improvement in manufacturing methods. Similar techniques need to be employed in transit to help separate the variability introduced by seasonal temperatures, speeds, passenger loads, and age from the actual effect of changes to maintenance procedures.

Designed Experiments in Maintenance

Maintenance has lagged behind production in many parts of industry in the use of designed experiments. The reasons are not clear, but may include aversion to risk in carrying out tests on a significant portion of a fleet (this is a special concern in mass transit) and significantly more variability in the repair process (compounded with each repair) than in a manufacturing process. The result is that new methods in maintenance are evaluated by small, informal tests. However, such tests have a number of problems, which can obscure or distort the effect of significant improvements.

Basic Concepts of Experimentation

There are three basic concepts of experimentation that determine the design of experiments.

The first concept is *variability,* the differences in any measurement from vehicle to vehicle. For example, gas mileage or brake lining life varies from vehicle to vehicle or on the same vehicle over time. Some of the causes are known, such as size, route, or driver. But some of the causes are unknown or random (even with the same route and driver, mileage and brake life are not constant from measurement to measurement). The most important consequence of this concept is that tests need to be done on more than one vehicle. The actual number needed depends on the amount of variability; with more variability, tests on more vehicles are required to accurately estimate the effect of some change in maintenance. Designed experiments offer methods of determining the number of vehicles in the test so that the test will detect any meaningful effect from the maintenance innovations.

The second concept is *representativeness,* the extent to which the vehicles tested are like the other vehicles in the fleet. Eventually, the innovation under testing will be applied to the entire fleet. If the vehicles in the test differ significantly from those in the fleet (e.g., newer, older, on easy or challenging routes) it is much harder to argue that the results from the test can be applied to the fleet as a whole. In designed experiments, vehicles are randomly selected from the fleet to provide a set of test vehicles.

The third concept is *controls.* When a new method is tested on one or more transit buses, an improvement can only be measured relative to buses on which the method has not been tested. Further, the comparison buses must be like the tested buses, except for the application of the new maintenance method. For example, buses compared should be the same make, or maintained in the same garage, or run on similar routes, otherwise the effect of the new method can be confused with the effect of the difference in the vehicle or its environment. This is a fundamental point, but one which is ignored in many testing situations.

Experimental design is a set of methods, primarily statistical, which takes the effect of all three concepts into account and sets up a test that has good controls and enough test vehicles to accurately estimate the effect of a new maintenance innovation. Designed experiments can show how to select controls so that variability and the number of vehicles required is reduced, saving time and money on the test without sacrificing accuracy. Statisticians have developed these methods to address a wide range of practical situations.

Problems with Informal Testing

The problems with informal testing are listed below:

- The number of buses to test may not be sufficient to make an accurate quantitative assessment of the variability in effect to be expected or the size of improvement that needs to be detected.
- When improvement in the test fleet is assessed informally, the control group is rarely scientifically defined and the bus fleet may differ substantially from the test buses.
- Lack of randomization means that other factors affecting the improvement may have not have been adequately balanced between the test and controls.

The result is that whether an improvement is seen in the test buses or not, it is hard to defend the improvement (unless it is very dramatic) as a real effect. As noted above, this may explain why some innovations seem to take so long to diffuse through the transit industry; there are very few informal tests which have the credibility of designed experiments unless the effect is very large and easily observable.

Application to Transit Maintenance

The potential areas of application are almost endless: alternative fuel testing, maintenance of wheelchair lifts, brake retarders, different types of lubricants, analysis of air compressors. Maintenance aspects of each of these and many other innovations have been widely discussed but little tested.

But there are clearly a number of issues that need to be addressed. Design of experiments in the real world is a complicated task, one that requires assistance from someone with statistical or quality control training. Large agencies would find experimental design most useful because their size allows them to conduct a test on an adequate number of vehicles and they have the resources to get help with experimental design.

It might also be possible to conduct a cooperative experiment among a group of small agencies. It would require centralized coordination and planning to design and monitor the experiment. This is routinely done in medicine with multi-center clinical trials, in which trials of a proposed new therapy are carried out at several different sites under the guidance of one clinic. There is great interest lately in the statistics field in *meta-analysis* which uses statistical techniques to synthesize results quantitatively from a number of different experiments. Meta-analysis is seen as a cost-effective way to use data from many small experiments in lieu of mounting a single, expensive, centrally controlled experiment. The use of such a technique in transit could produce small-scale experiments from many different properties, yielding credible results that are applicable to the industry as a whole.

Conclusions and Suggested Research

Maintenance organizations in transit agencies are engaged in a variety of innovations in their maintenance policies and practices, for reasons ranging from economic pressures to improvement for its own sake. The use of designed experiments for such tests is virtually nonexistent in agencies. This is unfortunate, because designed experiments would allow agencies to get more precise results from their tests. Further, random selection of test vehicles would ensure that results could be generalized across the entire fleet. The investment in experiment design would more than pay for itself through the savings gained from innovations that demonstrate benefits and save money.

Use of designed experiments might also reverse the tendency for innovations to diffuse slowly through the industry. At the very least the expense of running duplicative and inconclusive tests of every proposed innovation at many different agencies might be avoided.

In order to prove the value of designed experiments, the industry (perhaps working through APTA and FTA) needs to sponsor carefully designed experiments at operating agencies. Such experiments would require aid particularly in the planning phase. These experiments could be done either individually or as multi-agency experiments. The latter is particularly attractive because it would allow the inclusion of small transit agencies, which do not have enough vehicles to have an adequate sample for a controlled experiment. However, many small agencies could participate in a multi-site experiment and pool their results. The design and administration of such trials would require coordination by entities like APTA or FTA.

SUMMARY: LEVERAGING INFORMATION FOR BETTER TRANSIT MAINTENANCE

This report has focused on three aspects of information in transit bus maintenance: the production of information (from designed experiments and collection of maintenance process data), the use of information (by analysis of maintenance process data), and the sharing of information between transit agencies (with electronic communication). At the present time, the third aspect is the most important; transit maintenance officials have many ideas to share, both in maintenance practice and in the use of maintenance information, but their opportunities to do so are limited by geographic dispersion and constrained travel budgets. Given previous failed attempts to build electronic communication in transit, the best strategy involves APTA committees pioneering electronic communication and makes use of APTA's role as the voice of the transit industry.

Electronic communication can also form the foundation of efforts to use maintenance information better. There are already many innovative uses of such information, from collection to methods of analysis and display. What is missing is the sharing of questions and ideas, something that electronic communication can remedy. Electronic access to people with analytical responsibilities in different-sized transit organizations would be an ideal way to pool resources and diagnose problems.

The increasing sophistication of computer-based maintenance information systems gives maintenance managers access to even more knowledge. The ability to archive data even on small computers (hard disk memories of a gigabyte and greater are commonplace), the greater ease in using data management tools such as spreadsheet programs, and the growing flexibility of report writers will give maintenance managers more freedom to understand and achieve higher levels of performance. Maintenance managers in agencies large and small should be encouraged to develop data systems and report styles that fit their own needs, and to keep abreast of methods being developed by their counterparts.

The proposal to use designed experiments in evaluating maintenance innovations stands apart from the first two recommendations. While the techniques have been used very effectively in areas of manufacturing, they have not made much headway in maintenance, whether public or private, although some of the commercial firms visited (particularly FedEx) were beginning to run some simple experiments. As in the electronic communication area, there is an important role for a coordinating agency such as APTA or FTA to play in encouraging the use of designed experiments and ensuring that adequate technical advice is procured. And there is an interaction potential between electronic communication and designed experiments; the information produced from experiments can be shared effectively via electronic communications.

Another common characteristic linking the three proposed strategies for exploiting information is the cultural change they call for. Maintenance managers, while retaining the skills they have brought to their present position, must also become symbolic analysts. They need to understand the importance of information and its manipulation in the execution of their jobs. In responding to demands for more flexible and efficient management, they must strive to be more analyst, experimenter, and communicator than they have been before. This is especially evident in the demand for broader and deeper communication, along the lines promised by electronic networking. If this form of communication becomes all-pervasive, it behooves maintenance managers to be proactive in adapting it to their needs rather than grudgingly accepting a tool designed by others for different reasons and purposes. This cultural change requires much closer interaction between maintenance management and top management, and between maintenance management and the workforce. The maintenance manager must impress upon the directors of the agency that increased connectivity, even down to the shop floor, is a vital necessity and no boon-doggle. Similarly, these agency leaders must give the maintenance manager the room and resources to incur short-term costs (through designed experiments) that promise substantial longer-term gains, or to use the analytical capacity of increasingly capable MMIS to investigate reasons for poor performance, and accept the findings with equaminity.

The "information age" is recasting the shape of work. Many fields, maintenance included, are discovering that they are "information intensive," and can use information more efficiently than they do to increase their productivity. This report has focused on information for maintenance management, but technical information such as manuals and repair updates are also important and are affected by electronic communication as well. While information is not a substitute for mechanical experience and hard work, it can play an important supporting role in ensuring that experience and work are effectively and efficiently applied in maintenance.

APPENDIX A

IDENTIFICATION OF EFFECTIVE PRACTICES FROM SITE VISITS

A major part of Phase I research was a series of site visits to public and private agencies and firms identified as "best performers" to determine if there were lessons in effective performance applicable to the transit industry as a whole. This appendix summarizes the lessons learned from those visits.

Public agencies were selected on the basis of expert recommendation (in part from the research panel input) and from a statistical analysis of Section 15 performance data, comparing agencies, within peer groups, on the basis of cost-per-unit output, spares ratio, labor input, roadcall mileage (weighted less to compensate in part for lack of standard definitions of roadcalls) and density of ridership.

The following public and private organizations were visited:

Public Transit Agencies

- Santa Monica Municipal Bus Lines, Santa Monica, CA
- Long Beach Transit, Long Beach, CA
- San Diego Transit, San Diego, CA
- Metropolitan Transit Commission, Minneapolis, MN
- Greater Richmond Transit Corporation, Richmond, VA
- VIA Metropolitan Transit, San Antonio, TX
- San Francisco Municipal Railway (MUNI), San Francisco, CA
- Bay Area Rapid Transit District (BART), Technical Support Services, Oakland, CA

Commercial Transport Firms

- Laidlaw Transit, Long Beach, CA
- Arkansas Best Freight (ABF), Pico Rivera, CA
- United Parcel Service (UPS), Cerritos Hub, Cerritos, CA
- American President Lines, Freight Terminal, San Pedro, CA
- Federal Express Indianapolis Hub, Indianapolis, IN
- Federal Express Corporate Headquarters, Memphis, TN
- Gillig Corporation, Hayward, CA

Synthesis of Site Visit Lessons

In analyzing the site visits, two points of divergence were noted. The first is commercial (for-profit) organizations versus public agencies. The performance of commercial organizations is often held up as a model for public agencies, and it is important to keep in mind the different environments in which these two groups operate. This is not to say that maintenance practices from commercial organizations are inapplicable to public agencies, nor even that the perspective of commercial organizations (e.g., toward capital investments) could not be applied in the public sector, but that such transfer needs to be tempered with knowledge of the special circumstances of public agencies.

The second divergence is at levels of performance. Site visits in this phase of the project were targeted to agencies that scored well in data analysis. However, even in this group there were clear differences in performance, which seemed closely related to their maintenance practices.

There is a range of performance levels and maintenance practices. These observations, detailed below, formed the basis for the research questions which were formulated for further study.

Capital Issues

Spares ratios

The first point is the difference in attitude toward spare vehicles. Public transit agencies which receive capital assistance from FTA are required to hold their spares ratios to no more than 20 percent.[9] However, commercial agencies and more efficient public agencies maintain ratios well below this figure. For the commercial agencies, the primary motivation is clear-cut numbers indicating the cost of such capital investment. Public agencies (for which the FTA pays 80 percent of the cost of new vehicles) do not have this visibility of cost. However, the more efficient public agencies have cut their ratios because of other expenses (e.g., parking space rental) associated with a large spare fleet. The result is that commercial firms and the more efficient public agencies operate with spares ratios of 8 to 14 percent, suggesting that the current uniform 20 percent rate for public transit agencies needs further research.

Inventory Management

A second area of difference is in inventory management. This area requires great care when comparing commercial organizations and public transit agencies because (1) the commercial organizations visited are doing simpler repairs (e.g., little or no component rebuilds) and virtually all of the parts they need are in wide commercial use. (The engines and transmissions in transit buses are quite similar to those used on trucks, but transit buses also have unique air conditioners, electronic signs, etc.) In general, comparing the efficient maintenance organizations (most of the commercial ones and the better public ones) with the others suggested that the better organizations turn their inventory substantially more often (4 or more turns compared to 1 to 2 for transit systems), and keep meticulous track of what was used to avoid repairs being halted for lack of parts. Interestingly, the methods used by the better organizations vary widely by complexity of the inventory, ranging from computerized parts lists linked to a national warehouse to a simple scheme by which mechanics who find a low stock condition drop a card on the stockman's desk. In contrast, the lower-performing organizations have little visibility of their inventory performance (significantly for many of the public agencies, inventory was not managed by maintenance).

Computerization of inventory management is fairly rare, and it is not clear whether this is due to lack of acceptable software or because it has not been essential for adequate operation. However, most firms actively wish to computerize inventory management.

Commercial firms are also aggressively pursuing other methods of parts stockage, ranging from quick delivery from local dealers to guaranteed overnight delivery from an in-house or vendor warehouse. Few of the public firms visited were considering this seriously. One reason is that most of them have significant in-house rebuild capacity, but another seemed to be that the U.S. bus manufacturing industry is considered too fragile to support the costs of regularly supplying repair parts on a fast-shipment basis. In addition, buying repair parts as part of a bus purchase is often subsidized by the FTA, reducing the incentive to look for new methods of parts supply.

Labor Issues

Specialists Versus Generalists/In-house Versus Contract-out

Two related issues were the specialization level of mechanics and the use of contracting out for certain tasks such as component rebuild. Commercial organizations tend to limit their scope of repair and value mechanics who can do any task done in the shop. Managers claim that this gives them flexibility in organizing and scheduling work, and allows them to get away from rebuild operations which are inefficient because of their small scale. In contrast, many public agencies foster specialization of mechanics and do most of their rebuild in-house, even components having wide commercial application such as engines and transmissions.

The question is complicated by issues of scale and commercial availability of parts. Very large transit agencies may be able to support specialist repair personnel and an extensive rebuild capacity, particularly for bus-specific components. However, given commercial experience, the question of what agency characteristics make such an approach worthwhile needs research.

Information Issues

Designed Experiments for Evaluating Maintenance Practices

While the use of designed experiments for evaluating process changes has wide acceptance in many industries, most of the sites visited professed not to use them. Instead, most relied on informal tests tried on a small scale and assessed the results qualitatively. However, one transportation company with a widely dispersed fleet of light vehicles did claim to use experimentation to evaluate a variety of new maintenance-related issues, including new components, maintenance products, and maintenance practices. In this company, experiments could be initiated at the local or corporate level, but had to be approved by the corporate fleet maintenance manager's office to ensure adequate design and to avoid duplication of effort.

Information Sharing

One of the questions asked at each site visit was how much communication each maintenance organization had with other maintenance shops in similar agencies. In the public transit agencies, the managers uniformly said that they had personal networks with other managers, but that these were used primarily when bus purchases were being considered, supplemented by informal conversations at annual meetings. Surprisingly, managers of commercial organizations reported discussions with peers of maintenance problems and the exchange of maintenance tips in a much wider variety of situations (social contacts, local maintenance lunches, and participation in national organizations such as the American Trucking Association's Truck Maintenance Council). This is true even of managers of companies in direct competition with each other; even under these conditions, much valuable information was shared.

Process Information and Work Planning

The computerization of inventory information is not the only automation initiative being considered by repair organizations: many of the efficient organizations are considering acquiring computer systems to track other aspects of the repair process, including parts usage and labor required for specific repair jobs, component lifetime monitoring (at least for complex components like engines, transmissions, and air-conditioning units), and complete repair histories. Many of the efficient agencies keep substantial paper records, and use them to set work standards, but they have found that detailed analysis requires a great deal of sifting through paper files.

Given that current technology allows the accumulation of extensive data on a vehicle fleet, it is necessary to decide what data are useful and feasible to record. How can such information be used in planning and executing vehicle fleet maintenance? Current practice varies widely, and some of the more computerized organizations are not the most efficient.

Upper Management Involvement

Another issue for maintenance management is the degree to which maintenance is a concern of upper management, that is, whether maintenance is considered a core capability of a transport organization. Commercial firms and the most efficient public agencies have a flat management structure, with the director of maintenance reporting directly to the general manager. Other public agencies have one or two levels of management between the maintenance manager and the top executive.

One of the case study questions for general managers was what information did they look for from maintenance to assess its job performance. The managers of flat organizations usually had a variety of formal and informal contacts with maintenance management; the others received a formal report at various intervals, which listed a few performance indicators such as roadcalls.

APPENDIX B

PHASE II CASE STUDIES

Selection of Case Studies

For the study on maintenance data and information, resources were budgeted to carry out five case studies/site visits. In line with the overall goal of the project to find innovative maintenance practices, selection was focused on finding agencies which were good at using maintenance information in the management of their maintenance processes. In particular, the complexity of an agency's computer system or the mere collection of voluminous data was not of primary interest. Although it would have also been interesting to visit agencies which had problems in the area of maintenance information, the success stories were more valuable in providing good ideas.

Because an intangible characteristic is of interest, namely whether an agency was good at using maintenance information, looking only at quantitative aspects of an agency's information systems would not be useful. Instead, the search began with a series of phone interviews with the members of the Maintenance Management subcommittee of APTA's Bus Equipment and Maintenance committee. Seventeen members were contacted and asked to nominate properties that were equally good in collecting maintenance data and in using the data to manage their maintenance function. They were also asked to recommend commercial fleet operators who made good use of maintenance information. To supplement the nominations from the Maintenance Management subcommittee, other contacts in the industry, used in Phase I, were also interviewed.

Almost all interviewees gave from two to five agencies that they thought were outstanding in using maintenance information. There were some overlaps, but the final list contained 30 agencies. Basic information on each agency (primarily size and passenger load) was obtained from the Section 15 database. This information was used to select 12 agencies ranging in size and location and carrying fairly heavy passenger loads in their size category.

The maintenance manager of each candidate agency was called and answered a short questionnaire that covered most of the details of maintenance data collection and use. Permission for a site visit was requested.

The final selection was based on the recommendations, the Section 15 data, and the telephone interviews. The selections were Reno Citifare (small, western); Orlando LYNX (medium, southern); San Antonio VIA (medium, southwestern); Toronto TTC (large, northeastern); and Ryder Truck Leasing (commercial fleet operator). A brief profile of each agency selected follows below, including basic statistics and their collection and use of maintenance information.

CASE STUDY ORGANIZATION

PROFILES

Reno

Basic statistics. RTC/Citifare is the Reno bus agency. It operates 63 buses in the Reno-Sparks, NV, area (covering about 58 sq mi) and has 20 mechanics at its single operating garage, which is in operation around the clock. The Regional Transportation Commission (RTC) is responsible for mass transit as well as street and highway planning and construction, paratransit (RTC/Citilift), and countywide transportation planning.

Maintenance information system. Citifare currently uses FleetMate, written by Multisystems of Boston, MA. It has been computerized, using FleetMate, since 1987, which gives it a fairly lengthy set of computerized maintenance records. The system is administered by the purchasing agent in charge of parts procurement.

Data collection and use. There are two primary instruments for data collection, both paper. The mechanic fills out a numbered repair order for each job performed, including the date, employee number, time used, and a code for the system/subsystem repaired (4-6 characters). As parts are needed, the mechanic turns in a material requisition at the parts desk, including the description and repair order number, and the part is provided by the parts clerk. Every day the system administrator enters both the repair order information and the parts information to update the inventory and keep track of hours. Repair orders are closed daily so that inventory is properly recorded as issued; jobs which take multiple days are recorded on multiple repair orders.

Fuel usage and mileage are recorded nightly for each bus and entered the following morning. Roadcalls are kept in a manual file by the shop foreman.

The automated system is used to generate five reports monthly: the vehicle performance report, the servicing report, the vehicle cost report, a labor report by mechanic, and an inventory on hand report. This is combined with information from the shop foreman on roadcalls and tire usage to produce a monthly statistical report which summarizes key performance indicators (road calls, parts cost/mile, overtime, etc.) and general statistics (revenue miles, tire mileage, etc.). Many entries include spaces for the same statistics for the prior month. This report is the fundamental tool for the maintenance manager to look at the maintenance operation and to report to general management. While most of the information is available from the automated system, the final entry onto the statistical report is done by hand and with some calculator work. Auxiliary reports are available for supporting detail and getting more information on suspect values.

Although the computer system can track serial-numbered components by bus, the small size of the Citifare fleet allows them to do this effectively with paper records. Citifare has not used job time information to establish formal standard times.

Innovations. Because of its small size, the Citifare maintenance automation structure is very lean. As noted above, the purchasing agent for parts does much of the data entry (which includes responsibility for data quality) and report running, while the shop supervisors ensure that the data is recorded by mechanics and hustlers. The foremen and purchasing agent are the analytic staff, together with the maintenance manager. In addition to using FleetMate, Citifare also makes some use of other graphical programs to do graphical displays for their data, although this is not in regular use in their monthly statistical report.

The coding scheme used to identify systems and subsystems has been refined by the shop foremen to reflect the work at Citifare and to minimize the data collection burden on the mechanic. One shop foreman estimated that each mechanic spent about 15 minutes at the end of a shift filling out workorders with time and system/subsystem information.

Citifare has the capability to do electronic mail on their computer system, but at the time of the visit it was not used. However, interest in electronic communication is growing since some parts of the RTC (e.g., planning) are not co-located with Citifare.

Future plans. Citifare is looking forward to Multisystems' promised improvements to FleetMate, particularly in support modules such as purchasing. There are features they would like to see in reporting formats, and they are considering the use of a report writer on the FleetMate database for customized reports. However, the leanness of the staff severely limits the time available to experiment with new reports and analyses, and RTC financial constraints restrict attendance at meetings.

Orlando LYNX

Basic statistics. LYNX operates approximately 200 buses in Orlando, FL, (a 370-sq-mi area) out of two maintenance facilities, one at its headquarters and a smaller facility for PMs only. LYNX employs 40 mechanics and 21 fueler/cleaners. Ridership is growing rapidly, and LYNX is expanding (current plans call for 300 to 500 buses by 2000) because Orlando's pre-1990 mass transit has been inadequate.

Maintenance information system. LYNX has been using FleetMate since 1986. The system is administered by the MIS department, along with other agency information systems.

Data collection and use. The primary data collection instrument for LYNX is a single numbered paper workorder form, which is organized into a set of jobs (numbered in sequence), each of which has an activity code and a system/subsystem code. The codes were redone a year ago to reflect current practice and usage. The mechanic fills this part of the form out, along with a record of labor time. A separate part of the form lists parts used by job number; the parts information is filled out by the parts clerk. The secretary to the maintenance manager is responsible for entering this data, as well as the mileage/fluids information collected overnight by the hustlers. Jobs are closed daily to record all parts as issued; multi-day jobs are recorded as a series of work orders.

Management routinely looks at tabular reports on labor performance by mechanic, a daily printout of closed workorders that includes work done and parts and labor costs, and a vehicle performance report summarizing current mileage, fluids usage, and cost/mile. A series of graphics covering longer periods summarizes roadcalls, inspections made, and miles driven. These reports are routinely used for monitoring maintenance performance, and are frequently supplemented by special analyses of specific areas of concern.

The work history is available to mechanics on terminals near the shop floor. A few mechanics have mastered the use of the system, and most of the others regularly turn to them for information, particularly when determining the details of a previous repair job (e.g., components replaced) on the vehicle they are working on.

Inventory is also managed exclusively by FleetMate, but there are gaps in its capabilities that the organization wants to fill. This includes the ability to have a real-time picture of the inventory; currently, the inventory is only updated in the morning when work orders are closed. Management is trying to assess the tradeoff between having inventory and maintenance integrated and using a supplementary system in inventory management to provide extra information.

Innovations. LYNX makes heavy use of its data, in tabular form, although graphics are common in its presentations. As a rapidly growing fleet with little opportunity to retire old buses, it sees maintenance as a key factor in keeping its vehicles running.

Unlike many other properties, LYNX tracks several different components by serial number, even when moved between vehicles, in order to remove the component before failure, reasoning that a rebuild or buy is cheaper than fixing a failed component such as an engine or transmission.

LYNX also emphasizes analysis of its data, particularly in maintenance, by naming one person to handle special analyses. They are embarking on a new program of intensive PMs for the fleet, and are using their maintenance data to estimate costs and benefits.

Future plans. The MIS department is hiring a part-time programmer to work with the new report writer, which will access the FleetMate database to produce custom reports. They plan to use this capability both on current data and on their archived data to look at long-term trends.

San Antonio VIA

Basic statistics. VIA serves the metropolitan San Antonio area (1200 sq mi). It has 529 transit buses and 156 paratransit vehicles (VIAtrans), all of which are maintained out of a single garage. The maintenance workforce (mechanics and support staff) number approximately 250. The transit fleet is RTS buses.

Maintenance information system. Until the early 1990s, the maintenance function at VIA relied on paper records for maintenance management, including maintenance histories of vehicles and timekeeping. This resulted in problems with anticipated response delays from sharing mainframe resources with administrative departments.) By 1994 some data were automated, and VIA was preparing to bring in a new comprehensive system which tied together work histories, time keeping, and parts requisitions and would use new data entry technology such as magnetic card swipes and bar codes. The system was specified in-house and written by a consultant to run on a central computer. The MIS department manages this system.

The system is now up and running, but some major procedural changes are being considered to increase repair information, particularly details on task performance and the use of codes to designate repair activities. The receiving area is also in the process of being computerized.

Data collection and use. Work on a bus is initiated by a job order ticket on which is written the problem observed, based on either an operator's report or a mechanic's observation. The ticket receives a bar-coded sticker, and is assigned to a mechanic for work. The mechanic opens work on the job by reading the bar code on the ticket and swiping his personal magnetic card at a work station, then pushing a button to indicate that he is starting the job. Similar actions are done to indicate when he is leaving a job or has finished it. To order parts, the mechanic fills out a barcoded parts request, using the number of the vehicle under repair. The parts clerk ties the part number to the requisition by bar-code scanning the requisition and the parts bin, but the tie to the vehicle is done later at manual data entry. Note that the parts are formally tied to the vehicle, not the job number.

Work done is written on the job card and manually entered into the job record by data entry personnel. Searches of a vehicle's repair history can then be limited by looking for keywords in the written text. The modifications under consideration would use a six-position job code to identify repair actions, which would be scanned by the mechanic as a bar code at the completion of a task.

The mechanics use repair histories about 2 to 3 times per shift, but access currently requires clerks to call them up. For roadcall jobs, the recent histories are printed out automatically and given to the mechanics before they head to the vehicles.

The original design of the maintenance system was to facilitate access to information already in use by maintenance management. One of the major pieces of information used by management is parts usage in repair jobs. Prior to this, it was done manually using paper records (with a 3-day delay) but is now done with computer and only has a 24-hour delay (for the final data entry). Other reports include a history report for closed jobs and a number of employee-based reports showing such things as attendance and breakdown of work activity.

Innovations. Because the current system is new and some functions are still being added, VIA is still exploring other methods of using the available data. Switching from paper data to the computer has greatly improved the efficiency of their standard procedures.

Future plans. Plans to use repair codes and to break down tasks into subparts (diagnosis, repair, check) are under way, and are being implemented shop by shop to test how well the system works. The increasing capability to do ad hoc reports (without burdening the MIS department) substantially improves the use and quality of data throughout the maintenance system.

Toronto Transit Commission (TTC)

Basic statistics. The TTC is a large multimodal transit agency serving the metropolitan Toronto area (244 sq mi). It operates nearly 1,600 buses (including a 25-bus natural-gas fleet), approximately 250 light rail vehicles, and a heavy rail subway with 622 vehicles. The buses are maintained out of eight operating garages, backed up by one heavy maintenance and rebuild garage. Maintenance employs approximately 800 people. The average age of TTC's bus fleet is relatively old (10.4 years) due to their following government standards for bus age and to a hiatus in acquisition, which has now been relaxed.

Maintenance information system. The TTC's Vehicle Maintenance System (VMS) is used for its bus and streetcar fleet. (The subway has its own system, which reflects both the difference in complexity between the vehicles and the organization of maintenance work.) It is a radically modified version of the system developed and used by Metro-Dade. Development of the system began in 1989 in response to a perceived need for a maintenance management system for supervisors and mechanics, as opposed to a reporting system for upper management. VMS was specified and its development overseen by a core group of maintenance supervisors from TTC, backed up by technical people from the management services group (data processing). This team was the interim administration of VMS, and was responsible for its development, fielding, and initial support. Fielding is now complete; as of this writing the future management structure of VMS has not yet been decided.

Data collection and use. Data entry is done by the mechanics themselves and is checked by foremen. The primary interest is in capturing the problem, system/subsystem code, and what was done, since these form the basis of the most-used reports. Information regarding parts used in a repair is not much used by maintenance management; overall parts usage is captured by a separate material information system, which is used for ordering and issuing parts. In the opinion of the VMS managers, the computer entry is less time-consuming for the mechanics than the older system of filling out paper job cards, and data quality has steadily improved as the mechanics have switched to using VMS information during repair. The only drawback is that data can be lost during very heavy workload periods, such as during extremely cold weather.

Fuel information is kept locally by operating garage, but is not tied to individual buses or not captured by VMS. VMS is also used for timekeeping purposes, feeding hours reported directly into payroll. Several components are serial-number tracked on buses (engines, transmissions, compressors, and sometimes starters) but little use has been made of the data.

One feature of VMS is that, due the open nature of the information, most performance measures for each garage can be read by all managers across the system.

VMS is oriented to the garage maintenance manager, and its aim is to provide 20 to 30 standardized reports for which the manager specifies parameters (such as dates and vehicles included). These are the most important reports for the garage manager:

1. Status Summary Report, which indicates the number of buses available for service, along with the requirements for rush-hour and normal service and any special needs, such as charters. It is updated in real time as work is finished.
2. Roadcall/change off list, which lists all vehicles with a roadcall, their problem, and status.
3. MTO inspection list, which lists the due date of the next 6-month inspection for each vehicle.
4. Repeater list, which lists the number of defects by subsystem for all vehicles which have been in the shop above a minimum number of times in a given time period (like 2 weeks).
5. Work pending list, which lists all deferred maintenance by vehicle. This is used to plan work so that the out-of-service time will include the deferred maintenance for any vehicle brought in for repairs.
6. Summary of closed work orders (period covered specified by the manager) which allows a review of work recently done, defects noted, and length of time the vehicle was in the shop.

VMS also supports a central group of technical assistants, licensed mechanics who work for the superintendent of garages and use VMS to view problems and trends across garages. The reports that they use are aggregate ones, such as the Status Summary Report, and ad hoc reports based on special queries of the VMS data.

Innovations. TTC's innovations are in the implementation of a multi-garage information system in which data flows back and forth easily, and in mechanic entry of repair information. Everything that gets recorded about a repair is done by the person who either did it or supervised it. This means that start-up requires training for all mechanics and a buy-in period during which mechanics discover that VMS usefulness depends directly on their data entry.

Future plans. One aim is to enhance data entry by introducing such things as bar-code readers and touch screens. This will allow better data collection on serial-number-tracked components and on parts usage per repair order. Another aim is to automatically capture warranty claims information to make full use of the contracted for support.

At the time of the visit, TTC was undergoing reorganization, in which the garages were separated into individual operating units, with maintenance and operations responsible to a single garage manager. The role of a central maintenance analysis group had not been fully settled.

Ryder Commercial Leasing and Services

Basic statistics. Ryder Commercial Leasing and Services (RCLS) is the entity in Ryder Systems Inc., which specializes in vehicle leasing. RCLS has 900 branches, most of which have their own repair facilities and each of which is a separate profit center. The total fleet is 145,000 vehicles, with approximately 25% to 30% turnover per year. They have a technician (mechanic) workforce of approximately 8,300. Branches have 400 to 500 vehicles and 20 technicians.

Maintenance information system. RCLS has developed a comprehensive proprietary maintenance information system called FastTrack. In the early 1990s, most of the branch maintenance information processing was manual and paper-based (forms were physically transferred to the division where selected data elements were entered into a computer for transfer to headquarters and further analysis). RCLS had been experimenting to find a way to automate different parts of the maintenance information collection and use. In late 1991, a decision was made to decrease the amount of time maintenance management was spending on paperwork in favor of more interaction with customers and supervising technicians. Accordingly, RCLS started development of FastTrack in 1992.

FastTrack consists of five parts: service island automation, automated diagnostics, vehicle on-board computer, shop management system, and technical information. The automated diagnostics and computerized technical information do not communicate with the other parts; they simply provide tools and information for the mechanics as they work. Various parts of FastTrack have been fielded in different phases, but the fielding of the shop management part was being completed in summer 1995.

Data collection and use. Data collection from the service island automation and the vehicle's on-board computer is completely automated; the only human intervention is the attachment of a probe to the vehicle computer outlet on the outside of the vehicle. Vehicle identity and fuel usage are automatically captured for billing and the on-board computer provides some diagnostic information.

In the shop management system, the mechanics provide parts information and work time, and the full nine-digit ATA code for the part of the vehicle worked on, as well as text comments. These are entered locally into the shop management system by data entry clerks, not technicians. The system also maintains configuration information on each vehicle as repairs are made; for a tractor with an electronically controlled engine, 15 parts are tracked by serial number and 200 parts are tracked by manufacturer and date of installation.

Since the shop management module is fairly new, much of the use locally is the generation of fairly standard reports related to jobs closed and labor information. However, one of the features of the shop management system has had a great impact on the maintenance operation; this feature is a breakdown of individual mechanic qualifications and experience within a branch (internal Ryder training and external certification), which it uses daily for automatic job assignment.

FastTrack also sends much of the information from shop management and the service island to upper levels of the company (district through corporate). The newness of the system means that upper management is only beginning to appreciate the benefits gained from these data.

Innovations. Some of the most innovative aspects of FastTrack are diagnostics and technical documentation and the use of on-board computers for vehicle status. The shop management system schedules the mechanics into jobs, based on the mechanics' training, the time needed for the job, and the job's deadline. It can further redo a schedule if a particular job hits an unexpected obstacle. This was done specifically to relieve the branch maintenance manager of this timeconsuming task.

The configuration information is tracked in much greater detail here than at any other organization visited. The gains are twofold; by keeping careful track of warranty information, RCLS can collect payments due, and warranty claim generation is entirely automatic, freeing up the mechanic.

Future plans. Since fielding of various parts of FastTrack is either still under way or has just been completed, RCLS is still exploring the uses of such a rich collection of data. While the shop management module offers a number of cutting-edge capabilities at branch level, bigger opportunities are probably in the use of data at the national level to compare branches and note where good ideas and problems are occurring, and to provide information about nationwide performance of equipment from different manufacturers and in different configurations. This requires a corporate-level analytic staff with maintenance expertise.

ENDNOTES

1. *Transportation Research Circular 289: Proceedings of the 1984 Bus Maintenance Productivity Workshop,* Transportation Research Board, National Research Council, Washington, DC, 1985.

2. For example, one commercial provider of e-mail services requires a $35/year fee, but otherwise no minimum monthly charges; it also offers an optional Windows-based e-mail management software package at $99 to increase the ease of handling, filing, and retrieving e-mail messages.

3. This would be equivalent to the common Internet procedure for issuing "requests for discussion" and "call for votes" for proposed new bulletin boards.

4. UPS, in contrast, has had its maintenance management information system in place for years, although with upgrades in capability.

5. The FastTrack system is described in Appendix B.

6. John E. Dolce, *Analytical Fleet Maintenance Management,* Warrendale, PA: Society of Automotive Engineers, Inc., 1994, p. 176.

7. (Giuliani, 1987). For example, the interval between oil changes for a sample of agencies ranged from 6,000 to 12,000 mi; miles between lubrications ranged between 3,000 and 12,000 mi; safety inspections occurred anywhere between 900 and 9,000 mi.

8. A similar suggestion was made in the *Transportation Research Circular 289,* Page 8 (see endnote 1).

9. Waivers are given in certain cases, and some agencies have contingency or reserve fleets, not available for peak service, which do not count in the official spares. Further, when an agency is in the process of accepting a large shipment of new buses, the spares ratio may exceed 20 percent for several months.