Leveraging Information for Better Transit Maintenance

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CONTENTS

Acknowledgement ........................................................................................................ iii
Disclaimer ....................................................................................................................... iii
Figures ........................................................................................................................... vii
Tables ............................................................................................................................ ix
Acknowledgements ....................................................................................................... xi
Abstract ......................................................................................................................... xiii
Summary ......................................................................................................................... xv
1. Introduction and Research Approach ....................................................................... 1
   Project Overview ......................................................................................................... 1
   Research Approach .................................................................................................... 2
   Outcomes of Phase I Work ......................................................................................... 5
   Organization of Report .............................................................................................. 8
2. Spreading Ideas through Electronic Communication .............................................. 9
   Findings ...................................................................................................................... 9
   Applying a Strategy for Institutionalizing Electronic Communication in Transit Maintenance .................................................................................................................. 31
   Conclusions and Steps for Implementation .............................................................. 41
3. Using Information to Support Maintenance Decision Making ............................. 43
   Introduction .............................................................................................................. 43
   Interpretation, Appraisal, and Applications .............................................................. 46
   Conclusions and Future Steps .................................................................................. 73
4. Testing Innovations through Experimental Design ................................................. 77
   Findings ..................................................................................................................... 77
   Interpretation and Applications ............................................................................... 80
   Conclusions and Suggested Research ...................................................................... 88
   Suggested Further Reading ...................................................................................... 89
5. Leveraging Information For Better Transit Maintenance ....................................... 91

Appendices
A. Phase I Research .................................................................................................... A-1
B. Phase II Case Studies .............................................................................................. B-1
C. Maintenance Data Typology .................................................................................. C-1
D. References .............................................................................................................. D-1
FIGURES

Fig. 1—A Descriptive Model of the Bus Maintenance Function ........................................ 3
Fig 2—Growth in Electronic Communication by Domain, 1991-1995 .......................... 15
Fig. 3—Department of Transportation Home Page and Links to FTA ..................... 25
Fig. 4—PM Schedule and Work Due, Milwaukee County Transit System .......... 47
Fig. 5a—Pending Work at TTC, February 1993 .................................................. 51
Fig. 5b—Pending Work at TTC, July 1993 ......................................................... 51
Fig 6—Vehicle Repeater Report, TTC ................................................................. 54
Fig. 7a—Raw Defects by Subfleet ........................................................................... 56
Fig. 7b—Highest Defect Rates for Subfleets, by Percentage ................................. 56
Fig. 8—Roadcalls/Changeouts Trend, TTC ......................................................... 57
Fig. 9—Source of RC/COs at TTC by Subsystem ............................................... 58
Fig. 10—Cross-Garage Comparison of NTF (No Trouble Found) Rates, TTC ...... 59
Fig. 11—Garage Differences in NTF Rates by Subsystem, TTC ......................... 60
Fig. 12—Graphical Presentation of Mechanic Callback Rates ............................... 61
Fig. 13—Multi-Year Monthly Trend for Roadcall Rates, Harris County TA ....... 62
Fig. 14—Short-Term and Long-Term Roadcall Rate Trends, Los Angeles MTA . 63
Fig. 15a—Effect of "Purrfection Inspection" on Road Failures ............................ 65
Fig. 15b—Effect of "Purrfection Inspection" on Vehicle Defects ......................... 65
Fig. 16—Data Overload: Factors Affecting Roadcall Rates .................................. 66
Fig. 17—Monthly Performance Report Format, Reno RTC .................................. 69
Fig. 18—Changes in Maintenance Cost Per Mile for Individual Test/Control Pairs .......................................................... 84
Fig. 19—Difference in Maintenance Costs Per Mile (Test - Control) for Individual Test/Control Pairs ................................................................. 85
Fig. C-1—Structure of Maintenance Data .............................................................. C-2
TABLES

Table 1  Attendance at Bus Operations and Technology Conference, May 1995 12
Table 2  Electronic Communication Capability and Interest among Transit Agencies ................................................................. 19
Table 3  TTC MTO Due Date List, Lansdowne Garage ......................................................... 49
Table 4  Breakdown of Costs by System ............................................................................. 86
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ABSTRACT

This report documents a study of innovative practices for transit bus maintenance, generated from analysis of current practices in leading transit agencies and transportation-related private firms. A set of ten "best practices" were documented in the first phase of the project; the second phase executed more intensive study of three of those practices, all related to the theme of better exploitation of information resources: electronic communication for transit maintenance, using maintenance information to support maintenance decision making, and using designed experiments in testing maintenance innovations. This study concluded that transit industry networking via electronic communication should be pursued through "top-down" and "bottom-up" strategies, with an organization like the American Public Transit Association playing a major role. It also found a need to disseminate new and more powerful ways to combine and present maintenance data to aid the diagnosis of the maintenance process. Finally, it concluded that designed experiments, especially at larger agencies, can be a powerful means for validating new procedures and for creating the basis for standardized procedures across the industry, but that coordination of designed experiments, possibly through Federal agencies, may be required in some cases.
SUMMARY

USING INFORMATION AS A TOOL IN MAINTENANCE MANAGEMENT

This report focuses on several means for exploiting the emerging capabilities of information in maintenance management. As part of the research project's charge to look for "innovative practices" in transit maintenance, it targeted information usage as one of the most rapidly growing and changing parts of the maintenance function. This revolution is being driven by three factors:

- increasing spread and power of computer technology;
- expanding capabilities for quickly processing data into report formats;
- growing networking of computers 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:

- maximizing the spread of ideas through electronic communication;
- improving the use of data to manage and diagnose the maintenance operation;
- validating the benefit of innovations through controlled testing.

The three are linked. Good ideas are of most use when their value is firmly grounded in rigorous testing, preferably through designed experiments. 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 in the "electronic town hall" of the maintenance community is a needed final test for any new idea to become a new standard in the industry.

ELECTRONIC COMMUNICATION

Electronic forms of communication, based on the increasing networking of computers worldwide, is likely to become a pervasive and dominant form of
sharing information in the coming years. For members of the transit community, joining this world is more a question of "when" and not "if." However, as this report argues, the strategy followed for developing electronic communication can help or hinder its development. The report presents the case for a structured implementation strategy based on creating "seed groups" exchanging email to handle ongoing business among dispersed members of the transit community, with the aim of familiarizing members with the value and power of electronic communication, and enhancing its spread across the entire industry.

We argue for a "top-down" element of the strategy, recognizing that ensuring that the quality of the information exchanged needs some level of guidance and oversight. We have argued that APTA is best positioned to play such a role.

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

- Volunteering of 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;
- Designation of APTA personnel, hardware and software necessary to support committee and subcommittee use of electronic links;
- Development of a larger and longer-term APTA plan to support electronic communications in the transit industry, including email address directories, alias management, home page coordination and annotation, and preparation of tutorial packages for new users;
- Dissemination of the APTA plans to the membership at large to facilitate independent efforts to develop electronic links, coordinated as need be with APTA efforts;
- Solicitation of vendor and governmental participation in electronic links, especially through home pages, for access through an APTA gateway.

Ongoing research, either by consultants or by APTA personnel, can play a valuable role as the implementation proceeds in analyzing emerging usage trends, judging developing problems and weaknesses in the growing network, and suggesting corrective actions.
EXPLOITATION OF MAINTENANCE INFORMATION

This report explores some emerging issues in the use of information in maintenance management. It found that the value of information is dependent on the situation and the person using it; how it is put together and presented is similarly situation-dependent.

In this research we found that the capabilities and much of the content of most maintenance management information systems, in public and private organizations, bear many similarities. Computerization is the rule. The large 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 contacted can generate the more standard performance measures, such as miles between roadcalls and cost per mile.

We also noted a lack of standardization, especially in the area of codes. There is no equivalent in transit of the American Trucking Association's Vehicle Maintenance Reporting Standards (VMRS). Such a system, if modified to fit the characteristics of transit vehicles, could potentially be of great use to transit maintenance managers. We believe, however, that consideration of any type of industry standards for maintenance data must be preceded by consideration of how such data would be used.

This report attempts to open the discussion of how best to use information to support maintenance management decision making. We believe that most agencies are already well-positioned to make good use of existing data resources while neither settling on an industry standard nor pursuing expansion of data collection capabilities. The power of information exploitation, as we argue in this chapter, flows as much, and possibly far more, from ways of combining and presenting data as from the volume of data collected themselves.

To demonstrate this, we present a series of examples based on current uses of data among agencies studied (occasionally modified by us) that present particularly innovative 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.

We put forward some general principles for using information to support decision making:

- Combining and comparing different data elements is often a powerful way of revealing underlying trends;
• Simple time trends may suggest whether performance is good or bad, but they can be misleading if relied upon by themselves;

• Any measurement of performance should be "indentured" in that it should lead to further refinement of the analysis to determine underlying causes of performance;

• Graphical presentation can be the most effective and convincing means for depicting performance and should be used as often as possible, if done clearly and efficiently.

For improving the use of information for diagnostic purposes, the following recommendations may prove helpful:

• creating and presenting tutorials on information usage and presentation, to be delivered at APTA conferences and made available through electronic or hardcopy means;

• dissemination and discussion of current effective information usage practices in transit agencies, either at conferences or using emerging electronic town halls;

• encouraging maintenance managers to use available local talent to provide analytical support for diagnosing maintenance problems.

This project also investigated differences between public transit agencies and private transportation firms in information usage. We found few differences in the "diagnostic" capabilities discussed above; private firms appear no more innovative or advanced than the better agencies studied (this may be in part due to the more demanding information gathering and reporting environment faced by public transit agencies). Several firms studied, however, are using data to create "information-based" maintenance operations that are far 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.
DESIGNED EXPERIMENTS

Maintenance organizations in transit agencies are engaged in a variety of innovations in their maintenance policies and practices, for reasons ranging from new economic pressures to pure pride in improvement. The use of designed experiments for such tests is virtually nonexistent in agencies of every size. This is unfortunate, because designed experiments would allow agencies to get more precise and credible answers from their tests by ensuring that enough vehicles were used, and valid comparisons were made, allowing a quantitative measure of whether the innovations were in fact truly beneficial. Further, random selection of test vehicles would help assure that the results were generalizable to the entire fleet. Such experimentation will require some resources not currently employed, particularly in the design of the experiments, but there should be substantial savings in rigorously and definitively testing innovations and implementing only those which show clear and quantifiable benefits.

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 at individual agencies or as multi-agency experiments (as are done with medical multi-center trials). Some interesting innovations to test might be preventive maintenance or oil change intervals: as noted, they currently vary widely from agency to agency. Such a test would attract wide interest, because PMs are such a conspicuous part of maintenance activity. One outcome of such an experiment, particularly if carried out at multiple agencies, might be a comprehensive guide to the effects of different climates and operating conditions on the appropriate length of the PM interval.
1. INTRODUCTION AND RESEARCH APPROACH

PROJECT OVERVIEW

Problem Statement
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 (Gaebler and Osborne, 1992); many governmental entities are looking at private firms to see if the cutting edge practices emerging as a new business revolution are applicable to transit (Hammer and Champy, 1993).

Objective
The objectives of this project were to survey innovative practices relevant to transit maintenance being used either in cutting edge 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 for potentially valuable innovations was specified at the onset of the project; its initial charter was quite broad. Thus, work was executed in two quite separate phases: a first phase to do a general survey of candidate new practices; and a second phase to study in more detail the most promising candidates identified in the first phase of research. As shown below, the candidate innovations were grouped into the three input areas of capital, labor, and information. In consultation with the project review panel, it was agreed that new practices exploiting information and information technology showed the greatest promise for helping maintenance managers reduce costs while maintaining service. The major objective of the second phase of research thus became to determine how emerging trends in information usage and dissemination could be exported to the population of transit maintenance managers.
RESEARCH APPROACH

Analytical Framework

An open systems approach to the problem of improving transit bus maintenance is used. This approach recognizes that to understand how complex systems function—whether biological (like the human body) or organizations (like a bus maintenance division)—it is essential to identify and analyze the component parts, but not to treat them in isolation; rather, open systems theory concentrates on the interdependence of the different parts and the way in which they are affected by shifts in the external environment.

Any system has a goal, or outcome, it seeks to achieve. For bus maintenance that goal is to apply resources (labor, capital, information) in a cost-effective manner to help meet the service objectives of the agency: on-time delivery of clean, comfortable, and reliable buses.

As Figure 1 shows, system performance is affected by its environment. Climate, service profile, ridership levels, regulatory environment, lobbying by interested parties, etc.—all will affect the maintenance organization's ability to deliver its promised outcome in terms of service performance.

Within this environment, a bus maintenance organization will produce outcomes through a series of processes relating the three major inputs of capital, labor, and information. Agencies strive to seek efficiencies in the outputs of individual processes (e.g., improving inventory management to reduce spare parts requirements). Bundles of outputs aggregate into overall system outcomes.
Fig. 1—A Descriptive Model of the Bus Maintenance Function

The quality of an agency’s maintenance will be driven by how capital, labor, and information are used, individually and in combination with each other.

What are or should be agency strategies for using capital (vehicles, parts inventory, facilities, equipment, etc.), labor (mechanics, other maintainers, support personnel), and information (computerization, performance goals, technical and other kinds of knowledge)? How should agencies make rational tradeoffs among the inputs? What strategies should they follow for increasing efficiencies across the inputs without sacrificing service quality? And what are the sources for the these strategies?
Research Tasks

To investigate these questions, the following research tasks were executed.

Task 1. Literature Review. This task included a comprehensive review of the literature related to maintenance strategies and practices, with the focus on strategies and practices potentially transferable to the transit industry. Products included a working paper with a critique and annotated bibliography of the relevant literature on maintenance strategies and practices. The results of this task are summarized in Appendix A.

Task 2. Site Visits of Innovative Organizations. In this task, project team members conducted field visits to leading transit agencies and private transportation firms to investigate cases where innovative strategies and practices have been successfully implemented and where potential for transferability to the transit industry as a whole exists. Innovative transit agencies were identified via expert interviews in combination with statistical analysis of agency performance in the Section 15 database. Cutting edge private firms were identified by expert interview and literature sources.

Task 3. A Descriptive and Analytical Framework of Transit Maintenance Operations. This task called for creation of a framework for the systematic evaluation of alternative maintenance strategies and practices.

Task 4. Establish Scenarios. Evaluation of innovative strategies needs to take account of the range of differences among transit agencies (e.g., climate, geographic conditions, agency size, and so forth) that may influence the effectiveness of maintenance strategies and practices.

Task 5. Work Plan Development for Evaluation of Strategies. Alternative methods were developed for evaluating the strategies that offer the greatest potential payoff for the transit industry, including a research approach, assumptions, data requirements, sample sizes, and scope of analyses.

Task 6. Interim Report. The mid-point documentation of the project presented best emerging practices and strategies identified through site visits and literature review and suggested potential priorities for Phase II work to be decided upon by the project review panel.

Task 7. Data Gathering and Site Visits. Data were gathered to support the evaluations decided by the review panel from the list of candidates. This
included additional site visits, telephone surveys, further literature review, and expert interviews.

Task 8. Evaluation of Alternative Strategies. The data gathered in Task 7 were evaluated to determine feasibility and applicability of the recommended strategies and practices.

Task 9. Develop Recommendations. Based on the findings of Task 8, specific recommendations, with necessary guidelines and supporting materials, were developed to facilitate implementation of those recommendations.

Task 10. Final Report. This document is intended to disseminate results of the project to the transit community at large.

OUTCOMES OF PHASE I WORK

A series of hypotheses about innovative strategies was generated from the literature review and the site visits (see Appendix A for an overview of each of these) and were presented as potential candidates for Phase II work. The following presents those hypotheses, divided by major input area.

Capital Issues

Spares Ratios

A low spares ratio may not increase maintenance costs.

Our initial research leads us to hypothesize 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 would allow exploration of alternatives to on-hand inventory for meeting parts needs.

Inventory stock purchase accounts for a substantial part of maintenance costs; there are also personnel costs for inventory management and purchasing. In addition, running out of a needed part has a cost in both maintenance productivity and in spare vehicles to cover those which are awaiting parts.
Labor Issues

Specialization 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’s 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 on-vehicle repair to more specialized functions, such as component rebuild.

In-house versus contract-out

Contracting-out of certain classes of work is practiced by commercial transportation firms, based on careful tradeoffs of costs. Some of these maintenance tasks which are performed on transit buses may be able to be accomplished more efficiently by contracting out for them, rather than 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 which we have observed differ in one striking fashion from the commercial organizations: in general 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**

*There is a basic set of process information whose coordination 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 which we identified as high-performing were distinguished by close (often informal) relations with upper management; the importance of maintenance to the agencies mission was transmitted by the highest levels, and rigorous performance measures were established and used to monitor performance.

**Focus of Phase II**

At the Interim Panel Meeting, and in a follow-up vote of the entire panel membership, the project team was directed to focus on one particular area of input innovation, better exploitation of information. Three of the hypotheses, with their associated work plans, were selected for more intensive study:

- Information sharing
- Exploiting maintenance information for managing operations
- Designed experiments

The results of these work plans are reported in this Final Report.
ORGANIZATION OF REPORT

Each of the next three chapters focuses on one of the particular areas of exploiting information and follow the same format: findings, appraisal and application, and conclusions and recommendations. Chapter 2 presents the results of work on information sharing, and suggests strategies for electronic networking of transit agency maintenance managers. Chapter 3 takes up the issue of better exploitation of maintenance information resident in maintenance management information systems; it presents both an overview of the kinds of data collected, the costs and potential benefits of doing so, and explores some of the more innovative uses of that information in public and private transportation organizations. Chapter 4 investigates the potential benefit of using designed experiments in transit maintenance, providing an overview of the concept, illustrating its relevance to transit, and suggesting some possible applications. Chapter 5 integrates the results of the three work plans and suggests directions for developing a larger strategy for exploiting information in transit maintenance.
2. SPREADING IDEAS THROUGH ELECTRONIC COMMUNICATION

FINDINGS

Introduction and Overview

One of the critical means for improving the performance of any operation is through access to valuable information. Transit maintenance is no different. The primary source of knowledge on most effective maintenance practices is found less in research studies or even maintenance manuals than it is in the collective experience of practitioners: the body of maintenance managers, supervisors, foremen and mechanics who ply their trade on a daily basis.

Yet, as this chapter demonstrates, 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 wealth of ideas and innovations being discovered on a daily basis remains for the most part limited to a few individuals.

The idea proposed in this section is to leverage emerging information technology to increase the reach of maintenance personnel networks as well as the speed of information dissemination. As described below, we believe the most promising means for doing so is via electronic forms of communication. This chapter has three goals: to demonstrate the need for new forms of communication in the transit maintenance community; to describe electronic communication and to show possible benefits and difficulties; and to propose a strategy for spreading its use in the transit maintenance world.

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 twelve most important issues raised. The top priority marked by this group of maintenance experts was an improved information network; the second priority (of eleven issues ranked) was to establish a maintenance council, one of whose early goals was to itself establish an effective information database and exchange
network. Participants at that meeting had reason to wish for more effective information sharing with their colleagues. As a group, they believed that "current methods used to collect, summarize, and disseminate relevant bus maintenance information [were] inadequate" and that "significant improvements to information exchange can be made easily by applying present technologies in computer hardware and telecommunication" and that such improvements could be made without great expense or lengthy implementation.\(^1\)

The situation has not much improved since then. Several attempts, such as BusNET and an email bulletin board set up by Houston Metro failed because many of the properties had neither the resources or management support to participate in helping to develop the tool; similar results occurred when APTA attempted to include a regular column on tech briefs in its weekly industry newsletter.\(^2\)

When asked their main source of information and advice, most maintenance managers we 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 Bus Operations and Technology Conferences. Still, granted the highly valuable nature of these interactions, the shortcomings of both are apparent. Most phone networks appear to be very small, perhaps no more than five to ten other managers. While association meetings expose attendees to a far wider range of their compatriots, the expense and difficulty of traveling reduces access to these forums for the larger population of maintenance personnel. The dependence on meetings for sharing information especially disadvantages small agencies, with their limited resources, and individuals below the level of maintenance manager. In addition, the relative infrequency of such meetings makes them less effective for quickly disseminating new ideas and information.

In a resource-constrained environment, travel will become increasingly less an option for the transit maintenance community. Evidence from the Section 15 data collection bears on this point. Until 1991, Section 15 collected travel expense information from approximately 130 Level A reporting agencies. Those data

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\(^2\) Information on Houston Metro and the APTA newsletter is from an anonymous TCRP E-1 panel member.
show a wide variation in the resources agency provided for travel to meetings. Total expenditures for travel (yearly average, for the 1989-1991 period) ranged from a low of $331 to a high of $1,301,545; the range for travel dollars on a per employee basis was $14 to $533.\(^3\) While overall spending on travel stayed roughly the same for the three year period of 1989-1991 (going from $9.4 million in 1989 to $9.6 million in 1991, with no adjustment for inflation), there were signs of increasing divergence among agencies. The median spending by agencies declined by almost ten percent in the three years ($21,000 in 1991, compared to $22,900 in 1989) while that of the largest agencies actually increased significantly (e.g., the 75th percentile spending increased from $52,900 in 1989 to $65,500 in 1991).\(^4\)

More recent evidence bears out the disadvantage of smaller agencies especially. A breakdown of the attendance at a recent APTA Bus Operations and Technology Conference (in Reno, NV, May 7-11, 1995) confirms the advantage of the larger agencies. Table 1 groups agencies by size and shows the number of agencies with representatives at the conference and the average number of individuals representing the agency.

\(^3\) Travel expenses are for the agency as a whole and the per employee ratio is based on total employment of the agency.

\(^4\) This masks wide variation in spending among otherwise comparable agencies. For example, in the 1989-1991 period, Kansas City Area Transportation Authority spent $248 per employee for travel; Broward County Transportation District, with roughly the same number of employees, was only able to budget $33 on a per capita basis.
Table 1
Attendance at Bus Operations and Technology Conference, May 1995

<table>
<thead>
<tr>
<th>Agency size</th>
<th># of agencies</th>
<th>% attending BOTC</th>
<th>#attendees/agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1000 vehicles</td>
<td>9</td>
<td>100</td>
<td>4.7</td>
</tr>
<tr>
<td>500-999</td>
<td>16</td>
<td>81</td>
<td>4.2</td>
</tr>
<tr>
<td>250-499</td>
<td>17</td>
<td>59</td>
<td>4.1</td>
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<tr>
<td>100-249</td>
<td>52</td>
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<td>2.5</td>
</tr>
<tr>
<td>50-99</td>
<td>58</td>
<td>36</td>
<td>2.3 (*)</td>
</tr>
<tr>
<td>1-49</td>
<td>190</td>
<td>7</td>
<td>2.1</td>
</tr>
</tbody>
</table>

(*) - Excludes host agency Reno RTC; 2.7 with Reno RTC included

Source: 1995 APTA BOTC Registration List

Transit’s situation compares somewhat unfavorably with what we found in the private sector. Our impression, in talking with private firm maintenance managers, was that they highly valued and sought out exchanges with their counterparts from other firms, even to the extent of trading tips (such as on best parts suppliers) that would seem to help their competitor; their density and frequency of communications appeared, at least qualitatively, to be greater than that found in transit. More substantively, private firm maintenance managers benefit from the sheer scale of many of these operations. The more prominent firms—UPS, FedEx, Ryder, and so forth—are national, indeed international, in scope, and can leverage the knowledge of employees from all over the world. FedEx maintains a company-wide email system fulfilling many of the functions we 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; indeed, it allows any such employee 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 dispersed industry structured like public transit. By "electronic communication" we refer to the transmission of information via linked computers. As described below, these exchanges can run the full gamut from casual comments exchanged between two individuals to postings of substantial documents for a world-wide audience. This networking of computers, typically (if inaccurately) referred to as the
"Internet," the Information Superhighway, or "cyberspace," is a rapidly emerging phenomenon that few can have escaped noticing. We refer to the phenomenon by the term "electronic communication" to emphasize less the role of computers than the idea of communication among members of a community, with large implications for the social interactions of those members. As we argue below, the technology and the computer knowledge required are not that large (certainly for some of the basic and, indeed, the most valuable uses of electronic communication) but the social barriers and cultural practices may be the more difficult obstacle to overcome.

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

Maintenance personnel--principally but not exclusively maintenance managers--are a natural such community. Many of the issues of maintenance management are common to all members:

- what should I know 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 I start expecting corrosion problems in my particular climate?

In virtually every case, there is someone involved in transit--whether another maintenance manager, a vendor representative, or so forth--who 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 sensitivities to the expression of possibly critical information in a public forum. We will touch on some of the legal issues below, but it is worth noting that in a competitive enterprise, such as the sale of parts and equipment, all parties can benefit from the free exchange of information. The proceedings of the 1984 Bus Maintenance Productivity Workshop, a close example of what a newsgroup exchange might look like, demonstrated this. To take but one illustration, a discussion of fuel injectors, one maintenance manager
noted that 7A55 injectors in RTS buses were experience very short life with heavy exhaust smoke; other managers voiced similar problems and noted that they had switched to other injectors. A vendor representative, who was present at the meeting, indicated that the problem was caused by an enlargement of the spray tip holes due to contaminants in the fuel. \(^5\) It is quite possible that the even higher visibility of electronic exchanges—with the whole transit world able to listen in—may keep these discussions as civil and information-filled.

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

**Importance of the Implementation Strategy**

**Explosive Growth of Electronic Communication.** There is good reason to believe that adopting forms of electronic communication and adapting to its pervasiveness is not a matter of "if" but "when." In an extremely short period of time, electronic communication-like capabilities have grown from a novelty item for computer aficionados, to a widespread phenomenon, to an increasingly irreplaceable tool for people in many different professions. Figure 2 gives a sense of that vast growth in electronic communication capabilities in just a few years, represented by the number of host computers tied into the Internet. By a common rule of thumb, each host computer linked into this system represents about ten individuals who use the host computer to send email, browse, and move documents back and forth; this suggests that the population using electronic communication has grown from just three million in 1990 to upwards of fifty million at latest count—and the numbers have been doubling yearly for the past six years.

Another critical feature of its growth is who is using these new channels. In its early years, the Internet's principle users were scientists, academicians (usually in the hard sciences) or in government (principally the military). Increasingly, private individuals and commercial firms have tended to dominate

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the growth of the network. Figure 2 gives evidence of this trend; it shows the number of host computers by "domain." In the past few years, as the figure shows, commercial organizations are becoming the most frequently-added locations for electronic communication connections.

![chart showing growth in electronic communication by domain, 1991-1995](http://www.nw.com/)

**Fig 2—Growth in Electronic Communication by Domain, 1991-1995**

More and more, experts in the field believe that electronic communication will become a standard means of communication in the future. The use of email is likely to spread and further supplant existing alternatives, such as Post-Office delivered mail, faxes, and voice mail; households are likely to use electronic communication capabilities to handle routine household functions.6 Connection capabilities are becoming both cheaper and more widespread; the latest operating system for PCs, Windows 95 marketed by Microsoft, has prepackaged connecting software.

**The Need for an Implementation Strategy.** If electronic communication is the wave of the future and if, as is substantially true, most of its development is

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6 The mainstream media are rife with discussions of the future of electronic communication. For some representative examples, see the special "cyberspace" issues of *Time* ("Welcome to Cyberspace," Spring 1995) and *Newsweek* ("Technomania: The Future Isn't What You Think," February 27, 1995); see also the survey article in the *Economist* ("The Internet," July 1, 1995); the *Economist* has provided an electronic version of the same article, substantially expanded with hypertext links, at [http://www.economist.com/intro.htm](http://www.economist.com/intro.htm).
"bottom-up" and uncontrolled, what need is there to propose a strategy for implementing it in transit?

We offer four main reasons for proposing such a strategy:

- many of the most useful forms of electronic communication (mailgroups, bulletin boards, home pages) will be of greatest professional use to the community if they are constructed and (to some degree) managed by an overarching organization;

- supervised growth is likely to further disadvantage the least advantaged members of the community, as the largest agencies make the greatest investment in these capabilities;

- rather than increasing ties among the transit maintenance community, unstructured growth of electronic communication is more likely to create any number of small, invisible, and fragmented groups, making the lack of cohesion even worse;

- early communication needs to be managed or monitored to make the "tone" most agreeable to the community at large; if the communications channels are "hijacked" by a small and too-vocal group early on, that could drive away many otherwise interested individuals.

In the next part of this section, we give a brief overview of the history of electronic communication and some of its present and future capabilities. We discuss its current use in the area of transportation. We finish the chapter with a proposed implementation strategy for the transit maintenance community.

Overview of Electronic Communication, Its Capabilities, and Applications to Transit

As we noted above, all of the various terms for electronic communication refer to different aspects of one basic phenomenon: the intercommunication of people via computer networks. This section is a very brief introduction to several of the currently most prevalent forms of such electronic communication, along with some of the uses that are being made of these modes in areas of transit. As the news stories have made clear, this is a very rapidly changing area, and so this section is neither exhaustive nor detailed.

Networks. Computers need to be connected together in networks, at least at intervals, to communicate. These pervasive networks form the backbone of
the electronic communication revolution; at this writing all of the industrialized countries and many developing ones have access to some form of computer communication. But the networks have a bewildering variety of names, access methods, charges, and other characteristics. Perhaps the most well-known of the networks is the Internet, but many (perhaps most) users access the Internet via other networks such as a local network at their office or school.

Rather than try to describe this aspect of the rapidly changing, complex world of electronic communication, we will bypass it completely. For the purposes of electronic communication, the key question is not which network a user is connected to, but whether the user can (ultimately) exchange messages with a desired correspondent. If they can, the connection mechanism is fairly transparent; only if the parties cannot exchange messages do they have to delve into the details of their connections. For our purposes here, we'll assume that most users can find a link between themselves (a good assumption and one which becomes easier to accept as connections multiply).^7

**Electronic mail (email).** Email is the oldest, simplest and (currently) most wide-spread method for people to communicate via computer. A person uses a computer program to construct a message consisting of an address and a body, and then turns the message over to another program to deliver. Originally email could only transport simple text, but now it can consist (with proper care) of complete word-processing documents, graphics, audio, or even executable computer programs. The obvious parallel with regular mail gives it its name.

The advantage of email is that unlike regular mail it is very fast (regular mail is "snailmail" to email users) with delivery taking place in seconds or minutes for users working on computers that are continually connected to the Internet. Its advantage over the telephone is that (like fax and voicemail) the recipient need not be present to receive the message, but can read it at leisure and give a considered response. Its advantage over fax and voicemail is that an email message can be sent to a large number of addressees just as easily as to a single recipient simply by including more names in the address list. Most email systems allow users to refer to lists of recipients by a single name (an "alias") to facilitate such multiple mailings.

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^7 Most restrictions on communication do not arise from problems with external links, but from internal organizational restrictions on who can use the links to external networks.
To use email effectively, organizations need to have a fairly large nucleus of people who use it regularly and consistently. It has proven especially useful where users need to communicate text promptly between users who are physically separated or who work somewhat different schedules. Such convenient communication works as well around the world as within a city or building.

Several of the transit agencies we visited were using email internally for managers and other white-collar workers: schedules, memos, and meeting announcements were routinely routed electronically. This was a particular advantage in agencies with multiple garages, where paper communication was previously done by daily courier; email allowed several cycles of query and answer within a business day. However, most of these agencies with internal email had very limited external access, except for MIS personnel. In particular, we did not meet any maintenance manager who used email to communicate with his peers at other agencies or with APTA. On the other hand, state DOTs were starting to embrace email as an effective means of linking their geographically dispersed offices, and, once they established these links, were actively communicating with other state and local DOTs.

Table 2 offers some insight into the current state of connectivity among transit agencies with data derived from the 1995 APTA membership survey. The table shows that internal networking of agency computers has become nearly standard in the industry. It shows as well that a significant portion of agencies have external connectivity, whether through the large commercial providers or strictly for email. There is little doubt that this kind of connectivity has increased greatly in just a few years, and is likely to maintain or exceed this pace in the near future.\textsuperscript{8} The table also shows that there is substantial interest among at least part of the transit community in the kinds of information that might be made available through electronic forms.

\textsuperscript{8} A 1992 survey of computer capabilities in 38 small transit agencies in North Carolina showed eleven (28 percent) were networked for sending data to and from a home office using Carbon Copy+ software, and two more used Procomm, another communications software (Nalevanko, 1993). Compare this to 60 percent of small transit agencies currently with networked PCs and 23 percent with external connectivity in some form.
Table 2
Electronic Communication Capability and Interest among Transit Agencies

<table>
<thead>
<tr>
<th></th>
<th>All transit agencies</th>
<th>Agencies with 50 or fewer vehicles</th>
<th>Agencies with more than 50 vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of respondents</td>
<td>164</td>
<td>70</td>
<td>94</td>
</tr>
<tr>
<td><strong>Access to</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Networked PCs</td>
<td>69</td>
<td>60</td>
<td>74</td>
</tr>
<tr>
<td>Internet, CompuServe, Prodigy, other network</td>
<td>29</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>External email</td>
<td>12</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td><strong>Interest in: Ecomm access to:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legislative updates</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information on APTA meetings</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APTA membership directory</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APTA publications</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: 1995 APTA Membership Survey

Given the limited communication between the maintenance function in transit agencies, simple email has great potential as a convenient and effective means of communication for these organizations.

**Mailgroups (Listservs).** A mail group is a list of email users who have a particular common interest. There is a single email address for the group; mail to that address is copied by a program known as a listserv (hence the alternative name) and sent to all users on the list, much as with an alias. Users can send questions to the entire list and carry on discussions which are visible to the group on topics which are germane (usually) to the list’s common interest. This has all of the advantages of email (and requires nothing more than email connectivity between each user and the central address) with the additional advantage of connecting the user to a group with the same concerns.

Mailgroups come in two forms: unmoderated and moderated. Unmoderated lists accept any user onto the list and transmit any messages sent. Its operation is for all practical purposes completely automatic; the vast majority of mailgroups were initially unmoderated. However, some mailgroups felt abused by some users who sent large amounts of mail, or wrote messages in a
manner considered uncivil by other users. This led to moderated mailgroups in which a designated person sifts the messages, eliminating those which are not on topic or which do not meet some agreed-upon standard of relevance or politeness.

Moderation of lists has had a mixed reception. On the one hand, the moderated groups (in the authors' opinion) are far more pleasant to read. On the other hand, disagreements occur, and censorship powers can be misused. Further, censorship has led to some legal questions. However, given the purposes to be served in the transit community, such a group should at least limit membership to individuals from transit organizations, particularly when the program is being initiated.

As an example of the use of mailgroups in general transportation, the "DOT" mailgroup is devoted to government (primarily state and local) departments of transportation, where engineers and planners share information on various aspects of highway and transit administration. The membership includes academics, consultants, and other transportation professionals and is international: one recent request for information on estimating government subsidies to automobiles came from a researcher at the Indian Institute of Technology in New Delhi.

**Bulletin Boards.** Bulletin boards are a method of electronic communication which have been replaced for the most part by newsgroups and net browsers (see below). There are still many in use, however, since the equipment needed to access them is quite modest: a simple terminal. Bulletin boards are collections of messages and files kept on a central computer to which users gain access by logging in via a remote terminal, either by a modem or through a computer network. The bulletin board computer presents the user with a restricted set of commands (usually through a simple menu): options include reading or downloading certain files kept on the computer, or reading or posting electronic messages on a list kept on the central computer (hence the name). As with mailgroups, the message list allows users to ask questions and get answers from other users, and to discuss topics among themselves, looking at messages, asking further questions and commenting on previous responses.

Bulletin boards in transit have had at best checkered success. One attempt to create an industry bulletin board called "BUSNET" in the mid-1980s failed for lack of interest and support. More recently, FTA has supported two electronic
bulletin boards and information resource centers. The Transit Safety and Security Bulletin Board, operated out of the Volpe National Transportation Systems Center, provides a central communication point for information on transit safety, including FTA Regulations, Notice of Proposed Rulemaking and final rules; Transportation Safety Institute training; safety and security-related publications; and other related areas. FTA's Rural Transit Assistance Program (RTAP) supports the contractor-maintained TAP-IN bulletin board providing access to information in the RTAP national Resource Center, and allowing participants to send and receive email and to take part in on-line conferences. The US Department of Energy's National Renewable Energy Laboratory (NREL) maintains an electronic connection to its Alternative Fuels Data Center (AFDC) providing information on alternative fuels issues, including performance data on alternative-fueled transit buses. While each of these bulletin boards has attracted interest from a subset of the transit industry, awareness and use of them has not spread into the population at large.

Newsgroups. Newsgroups are a further evolution of mailgroups. A user with access to a computer that supports newsgroups sends a message (constructed with an editor and newsgroup software) with an address identifying which newsgroup it is destined for. The network distributes the message to other computers that carry that newsgroup and to other networks for their distribution. Newsgroup messages are stored under the name of the newsgroup; users on the computer can elect to read that newsgroup using special software and then have access to the messages that are stored there.

One advantage of newsgroups is the saving of space: a message is only stored once on a computer or set of computers, not sent individually to each user. A second advantage is that a user can select a newsgroup to read without having to subscribe by sending a message to a central computer as with a mailgroup.

As with mailgroups, newsgroups can be moderated or unmoderated. For moderated newsgroups, the messages are sent to a central location for clearance before posting. The disadvantage of the unmoderated groups is that they are open to anyone, and on a controversial topic can be flooded by people who have

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9 A user ID and password for the AFDC can be obtained by calling 1-800-423-IDOE. NREL now provides access on the World Wide Web via http://www.afdc.nrel.gov. See below about the World Wide Web.
strong opinions and send a lot of messages. Such newsgroups do not currently appear to be of much use to business organizations.

There are literally thousands of newsgroups, some international, some local, on almost any conceivable topic. Many are academic (e.g. physics, statistics, biology, etc.) or computer-related (offering a forum for users of particular software or hardware), but there are hosts of other topics. Most computers do not access all newsgroups due to constraints of space or interest. In particular, businesses typically carry only those newsgroups germane to their business, although that can include newsgroups where their customers post messages.

There are a number of USENET groups on the Internet devoted to transportation and transit-related issues, with perhaps the most relevant being devoted to urban planning (alt.planning.urban) and urban transit (misc.transport.urban-transit). While some of the discussions are quite informative, the overall quality of discussion is uneven.

**On-line conferences.** On-line conferences take newsgroups one step further and provide real-time communication between users over their computers, via programs that allow users to type in messages and read responses as they are typed. For business use, these have a lot of the disadvantages of telephone calls in requiring the other user to be physically available at the other end of the connection to communicate. On the other hand, when a meeting is required, the online conferences are much cheaper, both relatively and absolutely, than bringing people physically together. And the quality of the communications amenities is in flux, as commercial firms require features such as common whiteboards, audio, video and fax.

**Browsers and the World Wide Web.** Within the past three years another mode of electronic communication has sprung up which is a substantial enhancement of bulletin boards: the use of browser programs such as Mosaic and Netscape on the World Wide Web (WWW). There are several reasons for the emergence of this mode. As with bulletin boards, some organizations and individuals wanted to make information available on a fairly permanent basis for perusal by users. At the same time, personal computers had matured to the point where virtually all had access to both mouse-based interfaces and graphics displays capable of displaying complicated graphics, including color pictures. Browsers exploited these capabilities. A user prepares a document which can be
read by a browser; the document includes information on formatting, pictures, color, etc. The document is then made available over the Internet and users with browsers can access the document and read it. Perhaps the most important feature of browser documents is that they can contain pointers to other documents elsewhere on the network; users can jump between documents with a simple mouse click without worrying about typing in complex addresses. This "network" of browser documents is the "World Wide Web."

This area of electronic communication has seen the most explosive commercial growth in the last year, as many different organizations have put up their own core document ("home page") on the WWW. King County Metro (Seattle, WA) is one of the early leaders in exploiting new ways of using electronic communication. The new Riderlink system, initiated in December 1994, is a World Wide Web site on the Internet providing information to Seattle residents about a broad range of transportation options, including bus schedules and routes, ridematch applications, and information on forming vanpools (Campbell 1995; Tolliver, 1995). King County Metro has also put contract documents for vehicle procurements and capital projects on-line, making them accessible to contractors from assembly sites (Tolliver, 1994). More recently, the American Public Transit Association has established its own home page (accessed via Mosaic or Netscape with the address "http://www.apta.com") as has the Transportation Research Board (address "http://www.nas.edu/trb/trb.html"). The list is expanding rapidly: as of this writing, the APTA home page lists 49 other transit-related home page sites the browser can access with a simple mouse click.

To illustrate how a home page works via a browser, we selected the recently established home page of the U.S. Department of Transportation. Figure 3 demonstrates both the kind of information available at this site (at the time of writing) and how a Web site works. Each of the "buttons" can be clicked on with a computer mouse to send the browser to another location, with other information. The figure shows the chain to locate information about the Federal

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10 King County Metro, perhaps befitting the agency that supports Microsoft, has also greatly expanded its use of electronically-based information within the agency itself. Email is a standard tool in agency operations; more recently, King County has brought on-line its labor contract, and in the future Metro's Maintenance Information Retrieval System will include schematics and specifications on-line for vehicle maintenance personnel. (Tolliver, 1994).
Transit Administration. Once the user has found the DOT home page, he can click (in this example) on the button "Browse the DOT Administrations" (Figure 3a). That brings up a list of the operating administrations of DOT (Figure 3b); clicking on FTA brings up Fig. 3c, the home page for FTA. Clicking on "FTA Information" leads to Fig. 3d, which points to currently available files about FTA.
Fig. 3—Department of Transportation Home Page and Links to FTA
The Social Effects of Electronic Communication

With all the explosive growth of the Internet, there has been little serious study of what underlies its growth. Who is able to take advantage of it and what kind of individual is deterred from using electronic communication? What conditions are necessary to bring about a community of people with shared interests and knowledge who use this form of communication to talk to each other?

One exception to this lack of study is RAND's experimental design for testing how "electronic communities" can be created and for measuring the impact of electronic communication on social networks. (Bikson, 1991; Eveland 1989). In a year-long field experiment, RAND researchers oversaw the electronic networking of a group of geographically dispersed members of a work-based community, that of current and retired workers for the Los Angeles Department of Water and Power (DWP). To test the effect of using electronic communication (in this case, email) on how such colleagues share information and carry out assigned tasks, the researchers designed an experiment (see Chapter 4 on designed experiments) in which they randomly assigned retired and soon-to-retire DWP employees to two teams, with one team using traditional forms of communicating (phone, fax, etc.) while the second team was able to use email, in addition to phone and other means. Both teams were assigned the same task: work collaboratively to design a document about the pleasures and difficulties of retired life, drawing on the experience of retired DWP workers and touching on concerns of those soon to be facing retirement. The RAND researchers kept track of a variety of social interaction measures with the aim of determining how much electronic communication was used over the course of the year-long project by users new to the idea and assessing the impact of such new forms of communication.

The results of the experiment were striking. After a relatively fast period of familiarization (less than three months), the group with email access interacted with each other in ways far different than the control group. The density of their relations were far greater—they communicated with each other more and each talked with a far greater part of the group than was the case in the non-email team. Their leadership structure was much more flexible, and as the groups took on a number of tasks different individuals in the email group took the lead for specific items much more so than in the other group. For the email-supported
group, distance was no barrier: those the farthest away participated just as much as those located near each other, whereas for the non-email group, distance from the main group virtually eliminated participation for many individuals. The email group took on themselves much more ambitious tasks than the control group, deciding to supplement its work with a survey of a broader range of retirees, analyzing the data, sharing the results among the members of the task force and incorporating their revisions into the final text. Finally, members of the email group expressed much greater satisfaction with the product of the effort and of their role in that effort.

What the RAND study showed was less the role of complicated technology than the importance of computer connections as an enabler for new ways for colleagues to work together and share information. The participants on the email group, having the same goal as the control group, exploited the technology to construct new ways of working together. They created a more fluid management structure, one that exploited the abilities of each participant more fully; they were able to accomplish more than anticipated because they early on realized the strengths of the new system for moving information back and forth in a reliable, rapid manner. Lastly, they used the new technology to increase the quality of their social ties. At the end of the experiment, the email group continued their relationship and began to bring others into their network.

Cost Issues in Facilitating Electronic Communication

Assuming an initial investment in basic hardware (a personal computer and a telephone line), the costs of electronic communication are low and dropping rapidly. Current major providers of email and on-line access, such as CompuServe, America Online, and Prodigy, charge a base rate of $9.95 per month, including five hours of connect time (with each additional hour costing $2.95) and permitting one hundred messages of approximately one hundred lines each; these messages, of course, can go to any number of addresses (Anderson, 1995) There are no destination charges; email sent around the world costs no more than that sent next door.

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11 In the future it may not even be necessary to have a personal computer to access email. With minor hardware and software additions, email may be processed through televisions, fax machines or even the telephone. See Robert Anderson et al., Universal Access to E-Mail: Feasibility and Societal Implications, RAND, MR-650-MF, 1995.
To establish electronic communication, the new user would have to invest (beyond the computer and telephone line) in a modem and interface software. A high-speed modem (14.4K or 28.8K) and common software (such as Versaterm) would tend to cost no more than $150. Indeed, most new computers for sale come with internal modems and interface software already packaged in them; standard operating systems, such as Windows 95, also come with interface software included.

Electronic communication is highly likely to be cheaper than the communication channels it replaces, principally voice communication and faxes. There should, in fact, be a net savings from switching to e-mail and other forms of electronic linking, and relying less on more expensive forms of communication, such as long-distance telephone calls.\(^\text{12}\)

That price differential is likely to increase in the near future. Both the costs of basic e-mail terminal capabilities and the lines they go over are dropping rapidly. The history of leased lines in recent years shows a sharp downward trend in prices; according to one source, private line prices fell by 80 percent just between 1989 and 1994 (Anderson, 1995). With the explosion of subscribers, that trend is likely to gather speed.

**Issue Areas in Electronic Communication Development**

Electronic communication does not solve all problems. In many regards, the potential of electronic communication is just that—unrealized potential—and it will be a long time before it has completely matured.

**Difficulties in Navigating.** A major problem with electronic communication derives from its major strength: it is the product of millions of uncoordinated users, and as a result, much of it is unedited, anarchic, and at times downright maddening. There is still no simple way of finding out an individual's email address, along the lines of telephone directory assistance; the best means remains to ask the person or have them send you email. Browsing among file servers and home pages can be particularly discouraging because of the lack of structure in cyberspace; with little to guide the uninitiated jumping

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\(^{12}\) The primary reason for the cost advantage of electronic communication over more analogue forms of communication, such as voice, is because electronic communication uses "packet switching" in which a single message is broken into digital bits and fed through common lines more efficiently than voice communication where, typically, one conversation monopolizes the line.
via hypertext from computer to computer, the new user can quickly feel lost in a vast and useless maze.\footnote{As put by Clifford Stoll in the \textit{Newsweek} special edition on the cyberspace ("The Internet? Bah!", p. 41), "Lacking editors, reviewers or critics, the Internet has become a wasteland of unfiltered data . . . Logged onto the World Wide Web, I hunt for the date of the Battle of Trafalgar. Hundreds of files show up . . . one's a biography written by an eighth grader, the second is a computer game that doesn't work, and the third is an image of a London monument. None answers my question, and my search is periodically interrupted by messages like, 'Too many connections, try again later.'"} Like email addresses, finding what's useful in the vast reaches of cyberspace is still most typically accomplished by word of mouth.

\textbf{Uncertain Legal Environment.} Another concern about the future spread and use of electronic communication is the increasingly tangled legal question, focusing particularly on transmission of indecent material and liability for libel. This is an especially volatile area, where the law is quickly evolving. Of recent interest are the moves by the Congress to regulate the flow of questionable material through the Internet with the Communications Decency Act, an amendment to the 1934 Communications Act; passed overwhelmingly by the Senate, this had not become law at the time of writing. If passed, it would make service providers liable for any lewd or indecent material passed through their system (Browning, 1995). Of perhaps greater concern is potential legal liability for defamatory or libelous material posted electronically. This could include unsupported defaming of a vendor's equipment or libelous statements about individuals. With the dizzying evolution in electronics communication, it is not surprising that the law has not yet caught up; it is difficult or impossible to say with confidence at this time what precautions providers of this service will have to take to guard against any legal liability. Several recent cases suggest possible directions, however. One case, \textit{Cubby, Inc. v. CompuServe, Inc.}, considered whether a network service provider would be liable for defamatory statements made on a bulletin board to which it provides access. The court in this case found that CompuServe was not responsible for any libelous statements because it had neither the knowledge nor reason to know of the any defamatory statements. Like many service providers, CompuServe virtually instantaneously uploads and disseminates all products it provides, giving it no more control over content than a newsstand or a library (Appelman, 1995).

A more recent case, \textit{Stratton Oakmont v. Prodigy Services}, builds on the earlier case. In this instance, a commercial online service provider was in fact
found liable for defamatory statements posted by a subscriber on one of its bulletin boards and thus made available to all service subscribers. The court directly contrasted CompuServe and Prodigy by the level of editorial control. The case opinion noted that, in contrast to CompuServe, "Prodigy held itself out to the public and its members as controlling the content of its computer bulletin boards [and that] Prodigy implemented this control through its automatic software screening program" as well as a set of guidelines that bulletin board managers are required to adhere to. Since the intent was to create a "family environment" by deleting material on the basis of offensiveness and "bad taste," the court concluded that Prodigy was responsible, and liable for, any libelous or defamatory material transmitted to its subscribers.¹⁴

With the law in such flux, there are no hard and fast rules that if followed will guard against any liability. Clearly, attempts to monitor and control the content of posted material can create the possibility of liability; as one expert in the field has commented "the maxim that 'a little knowledge is a dangerous thing' may very well apply in this case." That is, this expert notes, a network provider is likely to be safest if no monitoring or if full monitoring and removal of offending messages is instituted (Appelman, 1995). With the law changing so rapidly, consultation with competent lawyers at the time service is contemplated is likely to be the safest course to avoid any potential legal complications.¹⁵


¹⁵ The "DOT" mailgroup discussed previously has recently issued to all subscribers a waiver and release of liability statement, after consulting with the attorney for North Dakota State University, where the mailgroup is maintained. This is the text of that statement:

"Operation of the Department of Transportation Discussion Group Listserv is a voluntary project of the Upper Great Plains Transportation Institute, the North Dakota Department of Transportation, and North Dakota State University. Subscribers to the Listserv, by participating in the in the Discussion Group, agree to release the above named sponsors and their employees and agents from any and all claims, demands, actions or liability for material placed on or distributed on the Listserv now or in the future, and expressly waive all rights under North Dakota Century Code Section 9-13-02 which provides as follows: 'A general release does not extend to claims which the creditor does not know or suspect to exist in his favor at the time of executing the release, which if known by him must have materially affected his settlement with the debtor.' This release does not waive any claim, demand, action or liability against any individual who sends anything via the Listserv, but only the retransmission of the same by the sponsors and their employees and agents as stated above.

"By continuing membership in the DOT Discussion Group beyond the receipt of this message, you implicitly agree to the terms of the foregoing Waiver and Release. If you do not agree with the terms of the Waiver and Release, you must immediately signoff of the DOT Discussion Group. . ."
APPLYING A STRATEGY FOR INSTITUTIONALIZING ELECTRONIC COMMUNICATION IN TRANSIT MAINTENANCE

Building and Defining the Community.

The electronic communication world is an emerging one of thousands, perhaps millions, of "cyberspace" communities, people spread around the world linked only via computer connections. Many who might profit from joining them are excluded simply because they didn't know where to find them. Attempts to build these communities are often thwarted early on by the "chicken and the egg" problem. Simply put, individuals will only make continued use of an electronic communication environment if early on they discover something of value in it; usually, the value comes from what other individuals post to the network. But at the very beginning, before any momentum has been created, there is likely to be less of value being transmitted; thus, early users may quickly dismiss this tool.

This is especially the problem with a far-flung community like transit (or transit maintenance). A purely "bottom-up" strategy by which individuals build their own connections to others in the industry will either fail for lack of a critical mass or will build only small groups to the exclusion of many other potentially interested participants.

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 creating home pages providing regulatory information and direction to other information sites. However, such strategies tend mostly 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, with the goal of as complete inclusiveness as possible; typically, Internet growth has followed the "bottom-up" path. We believe an alternative strategy is possible, both a "bottom up" and a "top down" one, with the goal of building the basis for an inclusive and networked community of transit personnel communicating frequently via electronic means. For the reasons given, we do not believe this is likely to happen by itself; it needs guidance and encouragement; even more, it requires a plan. We next discuss
such a strategy with the aim of applying the benefits of electronic communication to the transit maintenance world.

**General Outline of the Strategy**

The strategy proposed here follows from the lessons of RAND's electronic communication experiment in networking retired DWP employees. It is based on combining both "bottom-up" and "top-down" approaches to propagating electronic communication capability and use. This means:

- Electronic communication usage will spread, and its particular uses will be defined, by what the community of users decide as a product of their interactions;
- However, 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, the American Public Transit Association (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 the role of "nuclei" or "seeds" to help create the critical mass to make electronic communication self-sustaining.

Circulation of individuals in and out of APTA committees will increase exposure to electronic communication and help make it a standard communications tool. As electronic communication takes off on its own, APTA can play additional roles to facilitate and encourage communication, to guide users through the chaotic world of information sources, and possibly to help maintain the tone and level of quality of the information exchanged.

Finally, the principle point of entry into electronic communication for new users should be via email and email-like capabilities (such as aliases and mailgroups). These formats are the easiest to understand and use and avoid the frustrating nature of browsers and file servers; in addition, they are the best tool for passing information that relates to tasks needing executing.
"Bottom Up": Creating a Critical Mass of Electronic Communication Users

The "chicken and the egg" problem is a serious one in creating an electronic communication community. Users must have a reason to log on and check their email; if too often, nothing is there, they will stop doing so. Soon enough, this will ensure that nothing will be there. As the RAND DWP experiment suggested, 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. For DWP retirees it was to execute a project among geographically dispersed participants where the product was of use to them and their colleagues.

APTA Subcommittees as an Electronic Communication "Seed Group." A similar strategy is applicable to the transit maintenance community. APTA subcommittees have many characteristics that make them a potentially valuable starting point for spreading electronic communication:

- their members share common goals and common tasks (e.g., developing agendas for APTA conferences, creating guidelines for new practices for the transit community)
- the membership is geographically dispersed, limited (between conferences) to phone or fax communications
- the membership brings in the various parts of the transit community, including agency personnel, consultants, and vendor representatives
- committees have leaders who have an obligation and an incentive to increase exchanges among the members, and can be counted on to spur the use of communications channels.

APTA subcommittees also have the advantage that they cover a wide swath of the population 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 seven representing consultants, universities, government, and service providers.

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16 There are five subcommittees: Body, Suspension, and Brakes; Driveline; Maintenance Facilities; Maintenance Management; and International Bus Maintenance Roadeo.
Application of Electronic Communication to Subcommittee Tasks.
Preparing agendas for upcoming APTA meetings is a common task for APTA committees and subcommittees. This commonly requires vetting of papers, communication with authors, and deciding on final candidates. Most of this effort takes place between committee meetings by phone, fax or other means. Electronic communication can play a central role by expediting the discussion and decision processes. Abstracts, or entire texts, of 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 is comprised of 25 representatives of transit agencies and vendor organizations and are very dispersed geographically. The Committee’s goal is, in the first phase, 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 soliciting industry members’ feedback through questionnaires and, of course, holding frequent meetings themselves.

Such a concentrated and goal-oriented effort among such a large and dispersed group would most likely overwhelm telephone and fax communication capabilities; this type of work, as the DWP experience above suggests, is well-suited to be handled by email.

Mechanics of the Implementation. The idea of email 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 intra-agency messages via email; substantial numbers of agencies have external email capability and subscribe to major commercial on-line providers of electronic communications. As we argued above, email probably should serve as the first entry point for electronic communication and can help familiarize the new user with the idea of electronic communication in a less technologically-intimidating fashion before the user advances onto other capabilities (such as browsing or file transfers).
The costs and management demands for implementing an email networking of APTA committees should be fairly low. At a minimum, each member would need to establish an external email connection. If the agency or organization does not already provide one, inexpensive accounts can be maintained with a commercial provider.\footnote{17}

\textit{Alias Maintenance.} Once all members of a networked group, such as an APTA subcommittee, have email addresses, participants can exchange messages with any number of addressees, from one to the entire group. For large mailings, using email "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 be created to 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 email addresses underlying the alias, and make changes (additions and subtractions to the list) as the membership changed. The alias would reside on the host computer of the alias maintainer.

For example, if 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." By email 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 25 or so names and addresses associated with the "psc" alias and retransmit the message to all members of the list, with the entire process taking usually minutes or seconds.

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 (such as a 486 or more capable computer) with

\footnote{17 It would be useful if the external account could feed email directly into the existing agency email system, if one exists. The advantage would be that the user would not have to log in to more than one system to check email. The organization system administrator would have to be involved in making this function, of course. Many administrators are justifiably concerned about the danger of computer viruses from transporting foreign files into an agency system; however, since we are proposing the exchange just of email messages, and no executable files, this should not be a problem.}
the requisite communication software, an external connectivity account (such as an Internet connection or a commercial account), and one or more modems and phone lines. Alias maintenance would require a fairly small slice 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 email 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 (like Versaterm or ProComm) are relatively inexpensive, typically under $100. Commercial accounts prices are not onerous either. A popular commercial provider of online services (extending well beyond just email) currently charges a baseline price of $9.95 per month including (in addition to on-line magazines, access to many bulletin boards and so forth) a limit of 100 email messages per month up to 100 lines each; additional messages would add to the cost. Another commercial service, which is a provider of pure email 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. With a normal line of text being around 50 bytes, most short messages (30 to 40 lines) would cost around $0.70. A long message, such as a ten page document, would cost in the range of $2.00 - $2.50.

Such costs could directly substitute for current long distance charges, for phone of fax. A one page email would cost no more than a single four minute long distance phone call; it would be considerably cheaper than the same phone message (and many messages left with secretaries) to a large group of people. To send a ten page document to one person might cost several dollars by fax, multiplied by the list of addressees; via email it would be charged only once.

Thus, while there are likely to be some startup costs, the overall expenses of using email connections are likely to be much less than with phone or fax, in addition to the ease and speed of communicating in this fashion.

Natural Growth of Electronic Communication Networks. Using email, and having hands-on experience with how it facilitates communication, is likely

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18 For example, one commercial provider of email services requires a $35/year fee, but otherwise no minimum monthly charges; it also offers an optional Windows-based email management software package at $99 to increase the ease of handling, filing, and retrieving email messages.
to lead to increase in its uses. As email use has gathered momentum inside the agencies, with employees finding it increasingly necessary to their daily operations, so too inter-organizational use will build its own energy. This will be facilitated as members move into and out of the committees. Many may wish to stay linked into committee message traffic even after they are no longer official members. Others no doubt will wish to build their own email networks and their own aliases to link together circles of colleagues. APTA might also provide alias management capability for these more independent networks. As has happened in the vast number of mailing groups, word of an interesting or useful group spreads, and more and more individuals email in asking to join. Most will remain silent readers of the posted traffic ("lurkers," in the sometimes odd argot of the Internet) while others will add energy to ongoing discussions. For groups with much to discuss, the problem is not too few members but too many; the overload of discussion and digression into other areas can become problems; typically the solution is to create new topical groups, proceeding in parallel with the original one.

Once this stage has been reached, the electronic networking of the community will have reached takeoff, and email exchanges will have become a standard means of communication in the industry, no doubt more valuable than telephonic ties are now. With the diffusion of knowledge of maintenance practices will come an increased spread of information for using this new tool as well, as the more enthusiastic users spread the word about using browsing capability or file transfers. As that happens, the full range of electronic communications capability will tend to 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, as new users discover its value, there is a clear need for a "top down" component for influencing its development. Some of the early demands for top-down management have already been touched on; they include the need for a clearinghouse for information to get the new user started; maintenance of committee aliases; and a "switchboard" computer to move email to the right destination. As the network matures and grows beyond committee functions,
the need for some form of top-down management will evolve and, in fact, grow. This subsection discusses some of the main functions of the "top-down manager."

**APTA as a Top-Down Manager.** APTA, as the representative voice of the transit community, and the organization that spans its major constituents, is the natural candidate to facilitate electronic communication among its members and with the larger world beyond. It is a role that clearly could not be played by a governmental agency nor by any specific private concern. Many of APTA's current 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 an extension of the kinds of things APTA already does.¹⁹

**Major functions of top-down management.** There are a variety of services such a manager should provide; the following list is suggestive, though the needs will change as the technology of electronic communication changes.

*Facilitate initial nuclei.* As has been discussed, APTA should encourage making electronic communication a (or 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.

*Maintain directory services.* As the number of users increase and spread into the general population, one emerging difficulty will simply be finding out how to send email to any specific person. Directory services are still primitive on the Internet, and early attempts to create the equivalent of long-distance telephone directory assistance have been disappointing; typically, the best way to get an email address is to ask the person you're sending it to.

APTA can play a valuable role by maintaining a directory of email addresses for members of the transit community and putting them in an easily accessible format. Such a directory could be a relatively sophisticated searching mechanism (allowing the searcher, say, to inquire the name and email address of the maintenance manager of a particular agency) or it could be as simple as an alphabetized list, with email addresses and titles, of all members of the directory.²⁰

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¹⁹ And APTA may find that as electronic communication spreads, its costs, such as in its large scale mailings, may decrease as more are done electronically.

²⁰ FTA currently maintains such a directory for staff members on its home page (see Figure 3).
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 email directory.

Establishing and managing bulletin boards. While many of the electronic conversations will be "private" (read only by subscribers to the alias or the mailing group), there is great value in having more public discussions that all can read or contribute to. This is one of the functions that electronic bulletin boards and newsgroups, discussed earlier, provides. It would be of particular value for APTA to establish and maintain some number of bulletin boards on a variety of topics; these could act as a continuous "town hall" for a large number of topics 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 charged with 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, as discussed, is that they are accessible to all and can be read at the individual’s convenience, without the postings overwhelming his electronic mailbox.

APTA, in managing these bulletin boards, could sponsor their startup, soliciting ideas for topics and voting on whether they should be initiated.\footnote{This would be equivalent to the common Internet procedure for issuing "requests for discussion" and "call for votes" for proposed new bulletin boards.}

Being a clearinghouse for browser resources. One of the most frustrating things for new users is the chaotic, 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 user to what he or she would really want to see. Such capabilities may be coming, but they are still some way off. 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 gateway and a reference librarian to the resources that the community puts on the Internet. APTA might consider taking the following actions:
• Maintain the APTA home page on the World Wide Web that, in addition to providing information about APTA itself, serves as an organized gateway to transit-related information resources elsewhere in the Web;\(^{22}\)

• Encourage 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 potential information resources via "one stop shopping" through the APTA gateway; in this regard, the APTA home page could be organized to make finding the desired home page easy (such as locating all the connections to vendors in one screen);

• Provide annotations to these links to provide some guidance to what the user will find there; this could greatly reduce the frustration of users forced to aimlessly search for what might be on a home page without knowing exactly what they'll find; such annotations would have to be updated fairly often to stay current.

*Being a technical advisor of the last resort.* Finally, APTA should strongly consider offering technical help to its members as they adopt electronic communications. While using email is becoming easier all the time, as will no doubt be true of browsers as the demand increases, the new user may still find himself easily thwarted by startup problems. APTA might consider offering some of the following resources:

• Hard or soft copy information packages to help new users get started;

• Making a technical advisor available through an 800 number to answer questions;

• Disseminating information on available packages and their costs;

• Acting as a last resort to subsidize operating costs for cash-strapped members.

\(^{22}\) An APTA home page has already been established, as noted above, and provides access to some of the kinds of transit information recommended here. It is accessible through the address <http://www.apta.com>.
CONCLUSIONS AND STEPS FOR IMPLEMENTATION

Electronic forms of communication, based on the increasing networking of computers worldwide, is likely to become a pervasive and dominant form of sharing information in the coming years. For members of the transit community, joining this world is more a question of "when" and not "if." However, as this chapter has argued, the strategy followed for developing electronic communication can help or hinder its development. This section has argued for a structured implementation strategy based on creating "seed groups" exchanging email to handle ongoing business among dispersed members of the transit community, with the aim of familiarizing members to the value and power of electronic communication, and enhancing its spread across the entire industry.

The chapter has also argued for a "top-down" element of the strategy, recognizing that ensuring that the quality of the information exchanged needs some level of guidance and oversight. We have argued that APTA is best positioned to play such a role.

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

- Volunteering of 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;
- Designation of APTA personnel, hardware and software necessary to support committee and subcommittee use of electronic links;
- Development of a larger and longer-term APTA plan to support electronic communications in the transit industry, including email address directories, alias management, home page coordination and annotation, and preparation of tutorial packages for new users;
- Dissemination of the APTA plans to the membership at large to facilitate independent efforts to develop electronic links, coordinated as need be with APTA efforts;
- Solicitation of vendor and governmental participation in electronic links, especially through home pages, for access through an APTA gateway.

Ongoing research, either by consultants or by APTA personnel, can play a valuable role as the implementation proceeds in analyzing emerging usage.
trends, judging developing problems and weaknesses in the growing network, and suggesting corrective actions.

As a final word, we emphasize the importance of the transit community being proactive. The transit industry needs to be leaders versus followers in making electronic communications the standard. Not only will the resulting product become widespread earlier, but it is more likely to be shaped to the particular demands of transit personnel, and organized to suit their needs for expression better.
3. USING INFORMATION TO SUPPORT MAINTENANCE DECISION MAKING

INTRODUCTION

Information and Data in Maintenance

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

Data are the individual numbers, codes, text, etc. 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 both the phase I and phase II 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 that this core data could be collected and retained easily for most transit organizations (most have adequate computer capability, although not necessarily directly available to their maintenance organizations). There have been particular advances made in data capture devices: bar code readers, magnetic card swipes, ruggedized input devices (keyboards and touch screens), and computers on vehicles and individual components. Much commercial attention has focused on the use of such devices to ensure the quality of collected data, particularly by eliminating errors which occur when paper forms are used for collection. As noted in Appendix C, 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 less agreed upon.

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 and to suggest and evaluate possible actions or alternatives. Both data collection and

\[1\]See Appendix C for a typology of maintenance data.
information production are critically dependent on the capabilities of computer technology (which is one reason that they are often confused).

Although there is a core of maintenance data elements, the combinations of those data, and the information potentially available are virtually infinite. Information production is therefore both an art and a science, and needs to be tailored to circumstances and 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 as solutions for real problems.

An emerging strength of more capable management information systems is ease of use of "post processors," by which data may be manipulated fairly easily for any purpose the user needs. Some systems allow data to be downloaded for use by other computer applications, such as spreadsheets. The spread of these capabilities, versus more expansion of data collection capabilities or advances in data coding, are likely to most powerfully increase maintenance managers' ability to track, troubleshoot, and control their operations.

**Tentative Principles of Information Exploitation**

While there is no way to categorize the uses of information in managing maintenance operations, some general principles can be put forth regarding how that information is used. Among these are:

- Combining and comparing different data elements is an often powerful way of revealing underlying trends;
- Simple time trends may suggest whether performance is good or bad, but they can be misleading if relied upon by themselves;

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2 Eliyahu Goldratt, a noted analyst of business processes and information usage writes, “Intuitively we understand information to be that portion of the data which impacts our actions or if missing or not available will impact our actions. For different people or even for the same person at different times, the same string of characters might be data or information. . . The distinction between data and information does not lie in the content of a given string of characters [but] more in its relationship to a required decision. If we don't know in advance what type of decision we are going to make, if we don't know in advance what exactly we will need, then every piece of data might at some time be considered information. Is it any wonder it is so difficult to distinguish a data bank from an information system?” (Goldratt, 1990).
• Any measurement of performance should be "indentured" in that it should lead to digging below the numbers to determine further causes of performance;
• Graphical presentation can be the most effective and convincing means for depicting performance and should be used as often as possible, if done clearly and efficiently.

As the following will make frequent use of graphical illustrations of information use, it is useful to lay out some of the principles of graphical presentation enumerated by the leading expert in the field, Edward Tufte. Graphical excellence, according to Tufte (1983),

• is the well-designed presentation of interesting data—a matter of substance, of statistics, and of design;
• consists of complex ideas communicated with clarity, precision, and efficiency;
• is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space; and
• requires telling the truth about the data.

Structure of chapter

This section has four parts. The first is an anthology of innovative uses of maintenance data from the transit agencies visited or interviewed in Phase II of the project. Based on our visits and material acquired, we selected a set of reports, graphs, and other products that combined data to produce information that materially helped maintenance managers run their operations and detect, diagnose and solve problems. These information displays are innovative, in that they were found only at a single agency, but could clearly be of use to all agencies. In some cases where the data were useful and the ideas innovative but the presentation weak, we reconfigured the presentation to sharpen the message.

The second section is an overview of the approaches to maintenance information collection and use by the best private fleet management firms we visited. In all of these organizations data collection is seen as integral to the maintenance process, in controlling it and in helping to help cut costs while improving performance. Information derived from their data is used pervasively to structure and guide their maintenance processes.
The final section summarizes findings about this "sampler" of good practices, revisits the general principles, and offers recommendations for transit agency use.

INTERPRETATION, APPRAISAL, AND APPLICATIONS

With good uses of information virtually uncountable, this chapter attempts to demonstrate some of the ways information usage can be better applied to managing maintenance by presenting a "sampler" of innovative ideas and techniques. The examples include information-based scheduling; exploiting subsystem and failure codes; better exploration of time trends; and new performance measures and performance measure tracking. Following these, the chapter discusses in broader terms new advances in information usage found in private transportation-focused firms.

Scheduling Inspections and Repair

Completing all scheduled repairs, maintaining a smooth flow with limited backlogs, and insure that repair work does not pile up are all day-to-day responsibilities of the maintenance manager and his staff. Except perhaps in the smallest agencies, managers can profit from information tools to increase scheduling efficiency.

Required Work Due. A simple display from Milwaukee County Transit System shows at a glance several useful pieces of information for managing scheduled inspections. Figure 4 depicts an example of the Milwaukee display. It shows, by bus, the mileage variance for due inspections (with the most overdue listed first) and shows the servicing requirements for each bus, with an 'X' noting a required engine oil change or oil filter replacement or so forth.
## WEEKLY INSPECTION REPORT FOR REVENUE VEHICLES

### 5,000 MINOR INSPECTION

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21 RECORDS READ 19 RECORDS PROCESSED

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Fig. 4—PM Schedule and Work Due, Milwaukee County Transit System
**Smoothing Planned Inspection Workload.** Managing the flow of scheduled inspections can be greatly enhanced through graphical presentations. Toronto Transportation Commission (TTC) produces a standard report projecting upcoming calendar-based inspections to give garage managers a six-month preview of the demand for inspections. An example of the report for one garage is shown in Table 3. Such a simple graphical presentation accomplishes several goals at once: it identifies the vehicles needing inspection at a particular point in time; and it shows visually the size of the workload pending. The latter point is especially important for managers seeking to smooth out the workload, for example, to avoid problems created by summer vacations. In the example given in the table, an overload might be anticipated for August and, to a lesser extent, in July; the garage manager might attempt to move as many of the inspections as possible into May or June.³

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³ One of our panel members commented that a similar inspection workload device had been introduced and widely utilized at San Francisco MUNI.
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**TOTAL:** 6

**GARAGE FLEET TOTAL:** 158
The MTO inspection required of TTC buses is calendar-based and so simple to lay out on a monthly basis, but the same technique could be applied to mileage-based inspections. If vehicle mileage over time can be tracked, projecting future mileage should permit at least an estimate of when the vehicle will be up for inspection, thus permitting graphical presentation of future inspections like that in the figure.\textsuperscript{4}

Managing Repair Backlogs. Much of the power of computerized information systems lies in rendering visible what otherwise might be hidden and creating the basis for comparison. An example is backlogged work by garage. TTC's new management information system, the VMS, began operation in February 1993; among its reports was one showing pending work orders by garage, heretofore something that was not tracked or compared across the agency's eight vehicular garages. The very first report showed substantial differences across garages in this measure and served to motivate garage supervisors to bring their levels of deferred work in line with the rest of the agency. An early result of using this management tool was that within a few months total pending work had declined and differences had leveled out among the garages, as Figure 5 demonstrates.

\textsuperscript{4}One reviewer noted that operating environment should also be considered when scheduling regular preventive maintenance.
Fig. 5a—Pending Work at TTC, February 1993

Fig. 5b—Pending Work at TTC, July 1993
Using Subsystem Codes

The increasing spread of subsystem codes was discussed earlier, along with issues of their possible standardization. In our view, that takes a backseat to how subsystem codes (and other codes discussed below) can or might be used. Including such codes in computerized work order files is a potentially powerful tool for organizing information about maintenance performance and tracking particular problems. Several illustrations are presented here.

Tracking Repair Histories by Subsystem. One of the most powerful uses of computerized maintenance information is expanding the maintenance workforce’s ability to diagnose current vehicle problems by tracking down previous work and recurring problems on that vehicle. While files of paper work orders also capture history of work on vehicles, the search capability of computerized systems have added new power. A typical vehicle may accumulate tens or hundreds of work orders in a single year; a mechanic is likely to be concerned only with the previous history of a specific type of fault. Computer searches on fault code or subsystem code, or possibly a keyword-based search through textual description will allow the searcher to zero in on all the previous work done in just that area.

Evidence from our site visits suggests this capability is becoming more available to the shopfloor personnel executing repairs. One A-level Mechanic at Orlando LYNX described how computerized search mechanisms enhance diagnosis and repair. In the Orlando operation, the supervisor or lead man will track down cases of suspected repeater problems and will call up subsystem-related work orders for up to the previous two years. The mechanic then takes the lead in searching through these sorted work orders to discover any particular patterns that suggest a problem. In one example given to us, an air conditioner compressor was replaced twice in the space of a few months. Looking at the vehicle itself, the mechanic suspected that the expansion valve had not been replaced; he checked back through the parts-used files for the period, confirmed that no such replacement had been done, and put on a new valve. The compressor problem disappeared. By being able to zero in on a subsystem (air conditioner) and a particular fault (compressor problems) and the parts used (to determine if a specific part had been replaced), the computerized history proved, in the mechanic’s words, "a real boon . . . in eliminating a lot of trial and error" by
eliminating the time required to mechanically troubleshoot the system from scratch.

The innovative agencies visited are acting to increase access to this information on the shop floor. At LYNX, all but one of the Class A mechanics are using the system, though the only available terminal is in the maintenance supervisor's office. At San Antonio VIA, plans are progressing to install easy-to-use repair history terminals throughout the shop floor. Meant to be used mainly for accessing repair histories, the terminals will be driven by simple arrow-key commands, moving the mechanic along menus for vehicle, system code, parts used or repair done, and so forth. A mechanic will be able to follow an extended repair history for a vehicle just by moving an arrow via a few key strokes.

Detecting Repeater Vehicle Problems. Since the great majority of problems are not indicative of a repeating fault, a great deal of time can be wasted tracking down each repeated fault to see if it is part of an underlying recurrent problem. At some locations, we were told that foremen and mechanics "have a sense" if a vehicle is coming in with a repeating problem, or that they remember particular problems with vehicles. No doubt, many can do this to some extent; however, with hundreds, or thousands, of repairs on a fleet of vehicle being executed, many persistent problems may escape notice.

One agency, Toronto Transit Commission, has designed a particular effective reporting tool for signaling emerging repeat problems in its vehicles. This report, illustrated in Figure 6, demonstrates at a glance which vehicles may be having particular problems and the location of those problems. The figure gives a snapshot of repeat problems for a two week period for one part of a the fleet at a single TTC garage. For each vehicle (listed by vehicle number), it shows the number of incidents (road calls and change-outs by subsystem code (air conditioning, air system, electrical, transmission, etc.) The figure shows for the 23 vehicles listed, the great majority had no significant repeat problems in the two weeks. The eye is immediately drawn to two exceptions. Vehicle 6183, with four electrical problems in just two weeks, clearly needs closer examination, as does 8393, with three driveline problems in that period.
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Fig. 6—Vehicle Repeater Report, TTC
The benefit of such a programmable report is that in a matter of moments the supervisor can track patterns over any desired period of time. By choosing different parameters, he can look two, three, four or however many weeks back and see if apparent problems (like the electrical problems of vehicle 6183) form a real trend, persisting over time, or are an accidental blip in the last two weeks. With a bit more sophisticated programming of the report, large numbers (such as the four electrical problems) can be made to appear larger or in a different color on the computer screen, immediately attracting the user's attention.

The TTC tool is especially effective in its simple yet powerful graphical depiction of potential vehicle problems. The same technique could be applied to level of troubleshooting, but will only be a useful tool if it follows the same strategy of directing the user's eye immediately to the problem.

One agency visited produces a somewhat similar product showing aggregate failures by subsystem for subfleets at the agency; see Figure 7a. While providing some valuable information, the presentation is not as useful as it might be for the busy maintenance manager or garage supervisor: it simply is too time-consuming to find out where the real problems are. We have transformed the data in Figure 7a to tell a different story. In Figure 7b, the defects per subsystem are presented in percentages, both for the entire fleet and for each subfleet. The standard of comparison arises from this: one looks for specific subsystem problems in a subfleet, cases where the percentage of subsystem defects is far higher than in the fleet as a whole. Since in the large majority of cases, the rate of defects in a subfleet is the same or less than that in the whole fleet, the information tells us nothing useful, and can be excluded. We retain only the cases where the subsystem may be a particular problem for a set of vehicles (with defect rates roughly twice or worse than in the entire fleet). In Figure 7b, potential subsystem problems in parts of the bus fleet are much more apparent.5

5 Note that this does not compare problems across subfleets, for which a different form of presentation would be more useful. This type of display is best suited for detecting subsystem problems within a particular subfleets. Overall, the subfleets may be quite reliable.
Fig. 7a—Raw Defects by Subfleet

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Fig. 7b. Highest Defect Rates for Subfleets, by Percentage

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56
Combining Subsystem Codes with Time Trends. Using data in combinations can be a powerful tool for unlocking secrets of the maintenance process that might otherwise remain unknown. Figure 8, again drawn from a reporting tool used at TTC, helps demonstrate this. It shows the trends in roadcalls/change outs\textsuperscript{6} (RC/COs) over one year (it also shows something called "NTF," which will be discussed below). The figure shows a rather dramatic spike centering around January. By itself, this is merely a historical record suggesting no explanation.\textsuperscript{7} Examining the trend in combination with other factors, such as subsystem codes, helps the maintenance manager track the problem more closely to its roots. Figure 9 gives an illustration of this. It shows the contribution of various subsystems to RC/CO occurrences; it depicts a more typical month (November) with the most problematic month (January). The source of the spike immediately becomes apparent: it is virtually all located in heating/ventilation problems, with other contributions from the air and door systems.

Bus Fleet - Maintenance Roadcalls
for 93/10/01 to 94/09/30

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\includegraphics[width=\textwidth]{Fig8.png}
\end{center}

\textbf{Fig. 8—Roadcalls/Changeouts Trend, TTC}

\textsuperscript{6} At TTC, a roadcall designates a service interruption; a change out signifies that the vehicle had to be replaced during the route run.

\textsuperscript{7} However, as shown later, comparison to previous years might carry explanatory power, if the same trend persists year to year. That in itself, however, would not suggest a solution.
Fig. 9—Source of RC/COs at TTC by Subsystem

Failure Codes

As discussed in Appendix C, failure codes can be a problematic source of data. Often a burden on the mechanic performing repair, failure codes often tell little more than that the system was "broken" or "leaking." Mechanics we interviewed were much more interested in subsystem codes combined with narrative text of the problem and the repair, and repair parts used.

Some failure codes may be far more informative, however. One such is the "no trouble found" code used at some agencies. In Figure 8 above, roadcalls/change outs are shown along with the number of such occurrences in which no fault could be diagnosed. This is potentially a serious problem: about a fifth of all road problems were NTF, suggesting either unnecessary disruption to passenger service, or future disruptions from undiagnosed problems.

Reducing NTFs to the minimum would seem an important concern for any maintenance manager. Information systems can help isolate the problem. It might be one of skills (differing by mechanic) or standard operating procedures (differing perhaps by repair garage) or by equipment type (differing by make or
model of the equipment or by subsystem). (There might also be a need for an operator training program.) Each of these possibilities might bear examination.

Figure 10 demonstrates one comparison made at TTC, that among the agency's eight vehicle repair garages. It shows wide variation among the agency garages, with NTF rates ranging from seven percent to almost 35 percent, a fivefold swing. A next step might be to take that cross-garage comparison down to the subsystem level. Using TTC data, we generated Figure 11, which compares NTF rates by some major subsystems between the most problematic garage for NTF occurrences (designated as garage 5C2) to the average NTF rate for all other garages. The figure suggests where the garage may be having diagnostic problems: in engine and brakes. While the garage's highest level of NTFs is in heating/ventilation, the difference between it and the other garages is in these two other subsystems.

Bus Fleet - Maintenance Roadcalls
by Garage
for 93/10/01 to 94/09/30

Garage

% No Trouble Found
% NTF

Fig. 10—Cross-Garage Comparison of NTF (No Trouble Found) Rates, TTC
Mechanic Callback Rates. Information systems can be used to discover problems in mechanic performance. If used to browbeat or punish mechanics, such performance tracking can inspire distrust or (since mechanics are typically the source of the data) result in incorrect or missing data. Used positively, such information can be used to uncover correctable problems that can lead to improved performance (and career prospects) for the mechanic.

Callbacks are one such potentially serious problem. Figure 12, adapted from data from one agency, suggests ways of presenting callback data that immediately isolate potential mechanic diagnosis and repair problems. It shows for a group of mechanics at one garage the percent of their repairs resulting in callbacks over one month, ordered by descending mechanic callback rates. The figure immediately shows, as no table or other form of graphic would, that a small group of mechanics may have some skill deficiency: while the large majority of mechanics exhibit low callback rates, four are clearly marked by large numbers of callbacks.
Changes over Time

Monthly and Yearly Trends. Perhaps the most prevalent form of data comparison in transit agencies is the time trend, typically showing monthly rates of some measure for the previous year but often looking back one or a few months. While looking at changes of performance over time can be quite useful, if not used properly they can be misleading. For example, few would be surprised if roadcalls (especially for engines and air conditioners) rose in the South in the summer; the user implicitly does a cross-year comparison and knows, from previous experience, that there are seasonal trends in roadcalls. Sometimes making that comparison explicit can be of great use. Figure 13, depicting monthly rates of roadcall performance at Metropolitan Transit Authority of Harris County (including Houston, TX) demonstrates this. It shows several things at once in a single graph: monthly trends in roadcall mileage; comparison across up to three years in roadcall performance; and the contribution of mechanical problems to the overall roadcall rate.
Fig. 13—Multi-Year Monthly Trend for Roadcall Rates, Harris County TA

The combination of recent trends by month with larger trends over several years can be particularly powerful, as the previous figure shows. The yearly performance report for Los Angeles Metropolitan Transportation Authority (MTA) demonstrates this in a different format. Figure 14, excerpted from an MTA report, combines recent monthly performance in roadcall mileage with a longer view over a five year period. This presentational method shows considerable monthly variation around a mean; when looked at from the longer, more aggregate perspective of yearly increments, longer swings—both positive and negative—become apparent.
FLEET RELIABILITY:
BUS & EQUIPMENT MAINTENANCE DEPARTMENT
HAS CONTINUED TO IMPROVE MECHANICAL RELIABILITY

FLEET RELIABILITY
MILES BETWEEN ROADCALLS

FLEET RELIABILITY
HISTORICAL - MILES BETWEEN ROADCALLS
Capturing Before and After Effects. Changes from month to month or year to year are not always the time trend of interest. If maintenance procedures are changed, it can be quite valuable to capture the effect of that change by measuring performance before and after the new procedure is instituted (this is especially critical when executing the designed experiments discussed in Chapter 4). Orlando LYNX made such a major change in 1994 when it began its "Purrfection Inspection" program. Vehicles entering the program undergo at their initiation intensive maintenance to eliminate all accumulated defects and backlogged maintenance. In each succeeding preventive maintenance visit, the vehicle is again to be returned to its "purrfect" condition, with no defects or backlogged maintenance allowed to accumulate. LYNX began the program on a pilot basis with some of the oldest and most defect-ridden buses, with the expectation that early aggressive action combined with rapid elimination of future problems would result in lower labor demands and decreased defects and roadcalls. Figure 15 tells the LYNX story about roadcalls and defects. It shows, in both tabular and graphical form, the before and after performance of some of the first buses entered into this new program; the numbers reflect the number of roadcalls and defects in the five PM intervals preceding the new treatment and the five PM intervals following its introduction. The first part of the figure, capturing roadcall performance, suggests that the program had decreased service interruptions in these vehicles. However, as the accompanying table shows, roadcalls are infrequent enough (with some buses having only two in the ten inspection interval period) to blur whatever effect the program may be having. The second part of the figure, showing before and after performance in defects, is much more dramatic. Here, the evidence suggests a dramatic effect from the new program, with a 56 percent overall decrease in defect rates, and virtually every bus showing significant declines. By presenting a wide array of information, both tabular and graphical and across different measures, the maintenance managers at this agency were able to create a stronger case for this new procedure and lay the basis for expanding it to the entire fleet.8

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8 A complete test of the new program, which we do not present here, would also have to take into account changes before and after in manpower input, and compare that to a control group, that is, a similar group of vehicles which were not being put through the program. This latter point is discussed in Chapter 4.
Fig. 15a—Effect of "Purrfection Inspection" on Road Failures

Fig. 15b—Effect of "Purrfection Inspection" on Vehicle Defects

65
Avoiding Data Overload. As demonstrated above, computerized databanks can be a powerful tool. It can be tempting to go too far in slicing data to find trends and causes of behavior. Figure 16, obtained from one of the agencies studied, is an example of this. In combining all road calls, mechanical road calls, temperature swings, humidity, and weekends and holidays onto one display, it risks conveying little or no information at all.

ROAD CALLS FOR THE MONTH OF JANUARY, 1995
BY DAY

JANUARY

HIGH TEMP.  MECH. ROAD CALLS
ALL OTHER ROAD CALLS  LOW TEMP.
HUMIDITY

R RAINFALL OF MORE THAN 1/2 INCH
SATURDAYS AND SUNDAYS UNDERLINED IN RED
HOLIDAYS BOXED IN RED

Fig. 16—Data Overload: Factors Affecting Roadcall Rates
**Performance Tracking**

*New Performance Measures.* Computerized databanks and new forms of data collection can help create new and more effective performance measures in maintenance. There is a rough consensus on what the performance measures are fundamental, such as cost per mile and miles between service interruption [Maze, 1987]. While such measures can reflect the overall health of the maintenance operation, others can serve as diagnostic tools to find sources of problems and suggest corrections.

Orlando LYNX and Metro-Dade focus on workload mix between scheduled and unscheduled maintenance; both aim to minimize effort going into unscheduled maintenance and have created both goals and a measure for tracking how they are proceeding to the goal. San Antonio VIA, to take another example, is concerned about repair delays arising from slow delivery of parts from the stockroom to the mechanic at the vehicle or the part under repair. New data collection methods, involving time-stamping swipe cards, allow tracking of time from the parts request until it is delivered at the window (and perhaps later to the location of repair); VIA initially set a goal of 15 minutes for 1994-95; projecting that the actual time is about 12 minutes, the maintenance department moved the goal for the next year to just ten minutes.

More sophisticated inventory management systems, tied to the overall maintenance management information system, allow better tracking of inventory performance and its impact on maintenance effectiveness. VIA, faced with a highly space-constrained parts room, focuses on rapid inventory turnaround and keeping accurate tabs on its inventory; two of its most important performance measures are thus inventory turn rates and inventory cycle count adjustments. Los Angeles MTA adds to inventory turn measures a focus on inventory accuracy (parts on-hand divided by parts ordered) and also closely tracks buses held from service due to lack of available parts.

This small sample of examples suggests no more than that agencies differ in what measures they put particular emphasis on; little standardization of performance measures is likely nor indeed necessarily desirable. Maintenance managers would likely benefit from cross-agency comparisons of what kinds of measures are used and what value different managers get out of them. This would seem an excellent subject for discussion via electronic communication.
Finally, one strength of computerized data systems is archiving of data. Should the maintenance manager wish to establish a new performance measure, quite often the data he needs to establish a baseline will already exist in the files.

Packaging Performance Measures—Small Agencies. Despite the power of computerized information systems and the increasing capability of reportwriters, manpower demands for analysis and report preparation may be significant. Many agencies, particularly small ones, may have little time and manpower to spare to do sophisticated performance tracking and analysis. In their case, simpler and direct tracking of performance may suffice. Reno Regional Transportation Commission has developed a succinct monthly report that, its maintenance manager believes, meets the regular information demands for an agency of its size (approximately 60 buses). Figure 17 shows the two-page monthly report used by Reno RTC; included are the major performance indicators (roadcall mileage, parts cost, inventory held, maintenance overtime, and inspections executed) and a wide variety of general statistics. For ease of generating and tracking information, comparisons are limited to the previous month (or at most three months).
MONTHLY STATISTICAL REPORT

MONTH OF ________________

1. Mechanical Road Calls
   Objective ____________
   Prior Month ____________
   % Over/Under ____________

2. Parts Cost Per Mile
   Month ____________
   Month ____________
   Objective ____________

3. Man Hours Per 1,000 Miles
   ____________
   Prior Month ____________

4. Inventory Per Coach
   ____________
   Prior Month ____________

5. Maintenance Overtime of
   ____________hrs.
   Total Paid Hours
   Objective ____________
   Prior Month ____________

6. Inspection Interval
   ____________
   Prior Month ____________

7. Inspections Planned/Performed
   ____________
   Prior Month ____________

8. Total Maintenance Cost Per Mile*
   ____________
   Prior Month ____________

9. Revenue Vehicle Miles (Fleet)
   ____________
   Prior Month ____________

10. Tire Mileage Average
    New ____________
    Recap ____________
    Prior Month ____________

* Cost factors are Labor, Parts (Computer Only), Fuel, Tires, Etc.

Fig. 17—Monthly Performance Report Format, Reno RTC

69
Statistical Report Continued: Month of

<table>
<thead>
<tr>
<th>Total Maintenance Hours Available</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Maintenance Hours Completed</td>
<td></td>
</tr>
<tr>
<td>Total Maintenance Paid Hours</td>
<td></td>
</tr>
<tr>
<td>Total Maintenance Overtime (Hours)</td>
<td></td>
</tr>
<tr>
<td>Total Maintenance Hours Lost</td>
<td></td>
</tr>
</tbody>
</table>

**HOURS LOST:**  
- Vacation   
- Sick   
- F.H.   
- Tires   
- Personal   
- STD   
- Holiday   
- Bev.   
- Other  

**MISC. MECHANIC MAN HOURS:**  
- Lot Boy   
- Service Island   
- Tires   
- Road Call   
- Clean-up   
- WCL  

**TOTAL MECHANIC R.O. HOURS**   
+ 5%   

| Total Completed Maintenance Man Hours/1,000 mi. |   |
| Mechanic Man Hours and Road Call Hours/1,000 mi. |   |
| Mechanic Road Call Hours/1,000 mi. |   |

**PREVENTATIVE MAINTENANCE INSPECTIONS:**  
- A.   
- B.   
- C.   
- D.   

**TOTAL FOR MONTH**   

Fig. 17—Monthly Performance Report Format, Reno RTC (cont'd)
Maintenance Information Usage in Commercial Firms

In phase I and II of the project we visited facilities and offices of six commercial firms who operate transportation fleets (somewhat broadly defined): FedEx, Arkansas Best Freight (ABF), Laidlaw, American President Lines (APL), Ryder Leasing, and United Parcel Service (UPS). Detailed descriptions of each organization can be found in the appendices dealing with the site visits/case studies for each phase. In this section we outline some of the innovations in the collection and use of maintenance information being pursued by these firms, and compare and contrast the innovations with those in mass transit. First we characterize the overall approach\(^9\) to maintenance data taken by these organizations, and then we discuss how two of these firms are taking a new direction in using information to develop their maintenance operations.

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

The commercial organizations all saw their maintenance data as an asset, valuable for the aid it could give them in making their maintenance operations more cost-effective. This was reflected in the belief that data collection was part of the job of mechanics and foremen, and not a secondary task that could be neglected for “real work”. However with the exception of UPS, this realization had occurred fairly recently, and all of the firms were in the process of upgrading both their collection of maintenance data and the provision of information for maintenance management to mechanics, foremen and maintenance managers.\(^10\) These organizations were therefore not much different from public transit agencies in terms of maintenance management up to the beginning of the 1990s

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\(^9\)All of the organizations we visited were very willing to discuss their present collection and use of maintenance information and their future plans in general terms. However, they were reluctant to give us specific, detailed examples of information use because they considered many of these to be of a proprietary nature.

\(^10\)UPS, in contrast, has had its maintenance management information system in place for years, although with upgrades in capability.
(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 very rapidly in developing and installing new, state-of-the-art maintenance information systems (for example, Ryder went from a paper system at its maintenance centers to FastTrack\textsuperscript{11} in three 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 establish centralized staffs to do analysis of their data that looked across centers. This function was long-standing in UPS, while the other firms were considering such groups in the expectation of adding value to their collections 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 they planned to use their maintenance data to help improve their maintenance practices, all saw the biggest payoff as the guidance the data would give to procurement decisions. In the view of the commercial firms, 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 \textit{and} major components.

Although the commercial firms have largely similar views on the above issues, we observed that there was a difference in the firms we visited in how they were using maintenance information. One set of firms took a \textit{diagnostic} approach to the use of maintenance information. Their information is focused on vehicles: keeping track of repairs, PM and safety inspection schedules, and 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 assigning work and assessing mechanic performance by individual judgment. 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

\textsuperscript{11} The FastTrack system is described in Appendix B.
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, that is, 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 form work. For these firms, the maintenance information system is critical for day-to-day operation.

Information-organized maintenance aims to use information to minimize work which is not direct repair work, whether mechanic or supervisor, in particular administrative paper work (although the computer makes its own demands). To get accurate information to do this, both firms have used computers to reduce the data collection burden, even at a high initial cost in hardware and software development. Both Ryder and UPS have also invested effort in bringing together all needed resources to the mechanic when a repair is started so that a job can be completed without a 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 scheduling maintenance and moving administrative tasks to the information system, while insuring that all resources needed for a given 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.

CONCLUSIONS AND FUTURE STEPS

Conclusions

This chapter has explored some emerging issues in the use of information in maintenance management. If no hard or fast rules are presented, that is because no hard or fast rules exist: the value of information is dependent on the situation and the person using it; how it is put together and presented is similarly situation-dependent.
In this research we found that the capabilities and much of the content of most maintenance management information systems, in public and private organizations, bear many similarities. Computerization is the rule. The large 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 the more standard performance measures, such as miles between roadcalls and cost per mile.

We also noted a lack of standardization, especially in the area of codes. There is no equivalent in transit of the American Trucking Association's Vehicle Maintenance Reporting Standards (VMRS). The ATA codes describe the vehicle, problems, action taken, by whom, where, and at what cost.\textsuperscript{12} Such a system, if modified to fit the characteristics of transit vehicles, could potentially be of great use to transit maintenance managers. We believe, however, that consideration of any type of industry standards for maintenance data must be preceded by consideration of how such data would be used.

Our research revealed that many agencies collect subsystem, failure, and repair coded information, and that these coding systems are undergoing substantial modification to make them easier to remember or look up. 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 very 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 used by TTC, was frequently included in performance measurement, but few if any other codes were so employed.

This chapter has attempted to open the discussion of how best to use information to support maintenance management decision making. We believe that most agencies are already well-positioned to make good use of existing data resources with neither settling on an industry standard nor pursuing expansion of data collection capabilities. The power of information exploitation, as we argued in this chapter flows as much, and possibly far more, from ways of combining and presenting data as from the volume of data collected themselves.

To demonstrate this, we presented a series of examples based on current uses of data among agencies studied (occasionally modified by us) that illustrate particularly innovative 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.

We put forward some general principles for using information to support decision making:

- Combining and comparing different data elements is often a powerful way of revealing underlying trends;
- Simple time trends may suggest whether performance is good or bad, but they can be misleading if relied upon by themselves;
- Any measurement of performance should be "indentured" in that it should lead to further refinement of the analysis to determine underlying causes of performance;
- Graphical presentation can be the most effective and convincing means for depicting performance and should be used as often as possible, if done clearly and efficiently.

We demonstrated these principles with examples drawn from current agency use, such as:

- graphical tools for managing scheduled repair;
- report generation on backlogged repair and comparison across facilities;
- parameter-driven problem repeater graphics;
- time trend analysis of subsystem codes;
- multi-level tracking of diagnosis problems, revealed by the "No Trouble Found" fault code;
- graphical tracking of problems in mechanic performance;
- effective presentation of monthly and yearly time trends;
- new types of performance measures and packaging of measures.

In our comparison of public transit agencies and private transportation-related firms, we found few differences in these data uses for "diagnostic" purposes. Several firms studied are using data to create "information-based" maintenance operations that are far 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.

Such detailed and closely-controlled workflow of the maintenance process generates benefits for these firms but clearly increases their dependence on computer-based management systems and the personnel needed to run them, generate schedules, and coordinate the execution of all these activities. The systems also require realistic and feasible shop standards to work efficiently. Adopting such systems would be a substantial undertaking for transit agencies, but one worth considering if budget pressures continue.

**Future Steps**

For improving the use of information for diagnostic purposes, the following recommendations may prove helpful:

- creating and presenting tutorials on information usage and presentation, to be delivered at APTA conferences and made available through electronic or hardcopy means;

- dissemination and discussion of current effective information usage practices in transit agencies, either at conferences or using emerging electronic town halls;\(^{13}\)

- encouraging maintenance managers to use available local talent to provide analytical support for diagnosing maintenance problems.\(^{14}\)

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\(^{13}\) An example is Michael Wehr, "Milwaukee County Transit System Maintenance Department Performance Indicators" (no date), from which material for this chapter was drawn.

\(^{14}\) For example, at San Antonio VIA statistical students from the local college were asked by the maintenance manager to investigate a problem with premature brake failures. The students were able to track the problem to delayed aftereffects of especially heavy rainfall; the maintenance manager instituted new inspection procedures to avoid future problems of this type. In many cases, these partnerships can be highly advantageous for both sides. The benefit to the manager is clear; the students receive real-world training in the kinds of statistical problems that their teachers often encourage them to look for.
4. TESTING INNOVATIONS THROUGH EXPERIMENTAL DESIGN

FINDINGS

Purpose of chapter

Is an innovation in maintenance practice worthwhile? Will its potential benefits outweigh its costs? We observed that in most of the agencies we visited the usual procedure for evaluating changes to maintenance practices is based on informal tests. In contrast, in several other areas such as manufacturing, agriculture and medicine, such evaluations are planned and executed by using designed experiments to insure that the results are valid and credible. In this chapter we describe in general terms the use of such experiments in the context of fleet maintenance and how adoption of these techniques can benefit the industry by helping to speed evaluation and dissemination of innovative practices. The chapter is not meant to be a how-to guide, but does provide ideas about how experiments can be useful to transit maintenance and suggestions and references for more in depth information.

Evaluation of new maintenance practices

It has become a truism in the transit industry that there is increasing pressure for agencies to improve their performance in all areas, including maintenance. Agencies are expected to use fewer resources and to produce more output from gains in productivity, particularly from changes in processes to improve efficiency. A key tool in improvement is trying out new methods to see if they improve performance.

Before implementing a new method across the organization for all vehicles, new methods are often tested in a pilot program. The reason for using a pilot program, such as applying a new maintenance technique to part of fleet, is that it is often uncertain how much of an improvement the new method will produce. The new technique might even have unanticipated harmful effects, in which case 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.

In the course of our visits we were struck first of all by how many innovations had been adopted by different agencies. These included brake retarders, the use of oil analysis, new tools for repairing and cleaning a bus, alternative fuels, etc. However, the second striking point was that these innovations had not diffused uniformly through the industry. In the cases of both brake retarders and oil analysis we found agencies that insisted that these were valuable innovations that saved substantial resources, while in other agencies the same techniques were characterized as not worth their cost. Similarly, it has often been pointed out\(^1\) that preventive maintenance schedules differ widely between agencies, even for agencies that have similar equipment and similar environments.

Faced with this difference, we asked how changes were evaluated. In virtually all cases, the answer was the same: 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 over the entire fleet. However, there was little recorded about how the vehicles were selected or how the performance was evaluated. Basically, 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 by chance 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 that was considering the new technique could not be addressed without running separate tests at the new agency. However, there has been a great deal of work in science and

\(^1\) (Giuliani, 1987). For example, the interval between oil changes for a sample of agencies ranged from 6,000 to 12,000 miles; miles between lubrications ranged between 3000 and 12000 miles; safety inspections occurred anywhere between 900 and 9000 miles.
industry on carefully designing and carrying out just such tests, work which is not being used by the maintenance organizations in the transit industry. The adoption of these techniques for designed experiments provides an important opportunity for transit maintenance to do a better job of accurately evaluating proposed changes in maintenance procedures.\(^2\)

**Designed Experiments**

Beginning in the first years of this century, a large body of techniques for designing and executing experiments has been developed by statisticians and researchers in science and industry. For our discussion here we will refer to these procedures as *designed experiments* (other terms used are controlled experiments or scientific experiments). A designed experiment is a carefully structured test which uses statistical methods to accurately estimate the changes produced by the test. Such tests are particularly useful in situations where there are substantial amounts of inherent variability, i.e. the response to the test is mixed with variations in response due to other factors. Designed experiments allow the two types of effects on response to be separated and measured so that the effect of interest can be accurately assessed.

Modern interest in designed experiments dates to the beginning of the twentieth century with 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, age, etc. from the actual effect of changes in maintenance procedures.

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\(^2\)A similar suggestion was made in the Proceedings of the 1984 Bus Maintenance Productivity Workshop, (Transportation Research Board, 1985, p. 8).
Designed experiments in maintenance

In general, maintenance has lagged behind production in many parts of industry in the use of designed experiments. The reasons are not entirely clear, but may include more 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 (which changes with each repair) than in a manufacturing process. The result is that (with some exceptions) new methods are evaluated by small informal tests. However, such informal tests have a number of problems which can obscure or distort the effects of significant improvements.

INTERPRETATION AND APPLICATIONS

Basic concepts of experimentation

There are three basic concepts of experimentation which intertwine in the design of experiments. We will describe each of these separately first, and then show how they fit together in a simplified situation in which a test of a new maintenance innovation is performed.

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 even 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, 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 is very likely to detect any meaningful effect from the maintenance innovations.

The second concept is that of representativeness, the extent to which the vehicles tested are like the other vehicles in the fleet. This is important because eventually the innovation under test 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, etc.) 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 that of 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 fairly fundamental point, but one which is ignored in many testing situations.

Experimental design is a set of methods, primarily statistical, which takes account of the effect of all three concepts to set up a test which has enough test vehicles, is generalizable and has good controls so that an accurate estimate can be made of the effect of a new maintenance innovation. In particular, designed experiments can show how to select controls in a clever way so that variability and the number of vehicles required is reduced, saving time and money on the test while still giving accurate answers. These methods have received extensive development by statisticians so that they can address a wide range of practical situations. (See the suggested reading at the end of the section for some introductory texts on designed experiments.)

Problems with informal testing

The problems with informal testing are implied by the above points:

- The number of buses to test is usually determined informally, without a quantitative assessment of both the variability in effect to be expected or about the size of improvement that needs to be detected.
- The control group is rarely formally defined. The improvement in the test fleet is informally assessed, presumably against the fleet as a whole, which may not be appropriate because the fleet may differ substantially from the test buses.
- The 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 or not an improvement is seen in the test buses 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.

Example: Extending PM Intervals

In order to make these ideas more concrete, we present here an example of how designed experiments might be applied in transit. We will deal primarily with the issues of representativeness and controls, although the analysis of the experiment will illustrate how statistical summaries can give sharp answers even when there is substantial variability. Transit managers will readily see where we have made simplifying assumptions (although we will comment on some of these assumptions as we go). Although the details in an actual agency would be more complex, it is important to note that statistical techniques are available for much more complicated experiments than the one described here.

Consider a situation in which a maintenance manager is facing an expansion of his fleet. In order to continue his current PM schedule, he would need to increase the number of maintenance personnel. However, lengthening PM intervals would allow fleet expansion without an increase in personnel. He is aware of the wide diversity of PM intervals among agencies with similar equipment and operating conditions as noted above, which suggests that extending PM intervals might not increase maintenance costs (both scheduled and unscheduled). However, it would clearly be prudent to test the effect of increasing the PM intervals before implementing the change fleetwide.

For this example, we will focus on the change in maintenance costs per mile (parts and labor) between buses on the extended PM regime and those on the current one. The manager would also be keenly interested in the difference in roadcalls as well; however, there are some technicalities in looking at the effect of a test on fairly rare events that we want to avoid in this discussion. With just a little more sophisticated treatment roadcalls could be included in the analysis, and this would not substantially affect the discussion below on selecting the test fleet and controls.
We’ll consider an agency that has several hundred buses, so that the manager can dedicate 50 buses to the new PM regime. Because he is interested in the performance of the entire fleet, he insures that the test fleet is representative by selecting them randomly (perhaps by writing the bus numbers on slips of paper and drawing fifty).

The next problem is to select controls for the experiment, buses against which to compare the results from the test buses. These buses will be kept on the old PM regime. The manager knows that there are many factors which affect maintenance costs, and so to make the comparison as fair as possible he selects 50 control buses which are matched to the experimental buses. The characteristics used for matching would include characteristics such as the make of bus, type of route, age, and perhaps garage if the agency has multiple garages. The point is to make each test bus-control bus pair as directly comparable individually as possible.

This lays out the basic structure of the experiment. If the experiment were being performed at an actual operating transit agency, there would be a number of other practical details to be considered. However, for this example, we’ll skip these and present a brief overview of the analysis of the experiment, focusing on the effect of an extended PM schedule on total maintenance costs per mile. The numbers here are purely notional.

In Figure 18 we show the raw data from our hypothetical experiment. The bus pairs are numbered from 1 to 50; the triangle shows the maintenance cost per mile (computed over the time the experiment was run) for the control buses, while the square gives the maintenance cost per mile for the test buses. A vertical line connects the costs for each pair to aid comparison. There is quite a bit of variability: sometimes the test bus is more expensive to run than the control, sometimes the control is more expensive. While this figure displays the

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3 As we noted above, the choice of the number of vehicles for a test can be determined statistically from the variability of the output measure (maintenance cost in this case), presumably from previous experience. We’re going to gloss over this step in this example and assume that the manager has determined that 50 buses is an adequate number to reveal effects of interest.

4 For example, setting the length of the test (a year would allow a complete cycle of weather conditions), insuring that both the control and test buses keep closely to their assigned PM schedule, and making sure that PM mechanics do not inadvertently give special treatment to either the test or control buses. These are the details which make execution of an experiment difficult in the “real world”: see the references at the end of the section.
data's variability well, it makes it very difficult to see whether there is a consistent difference between the two fleets.

![Graph showing maintenance cost per mile for individual test/control pairs](image)

**Fig. 18—Changes in Maintenance Cost Per Mile for Individual Test/Control Pairs**

In Figure 19 we show the *difference* in maintenance costs between test and control vehicles in dollars per mile. As before the pairs are numbered from 1 to 50, but now there is only one point for each pair, indicating the difference between the test and control bus maintenance costs (differences greater than zero indicate that the test bus cost more to operate than the control bus). There is quite a bit of variability in the differences, ranging from about -$0.15/mile to $0.15/mile. The *average* difference is $0.003/mile (plotted on the graph as the solid horizontal line), i.e. the test fleet costs just a bit *more* to maintain than the control fleet.
Fig. 19—Difference in Maintenance Costs Per Mile (Test - Control) for Individual Test/Control Pairs

However, we've already noted the substantial variability of the cost difference between vehicle pairs. Is the cost of operating the test fleet really higher than operating the control fleet (i.e., is the difference really less than zero), or would a repetition of the experiment give us an decrease in cost. Here is where the statistical aspects of experimental design come into play. Statistics allows the calculation of a confidence interval\(^5\) for the estimated cost increase of $0.003/mile, based on both the variability of the differences and the number of bus pairs in the experiment. The variability is sizable, but since there are 50 pairs of vehicles in the experiment the resulting confidence interval is quite small: in this case the confidence interval is from -$0.01/mile to $0.02/mile (the interval is represented in the figure by the two dotted lines parallel to the solid line representing the average). But, this confidence interval does include zero,

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\(^5\) This is a 95% confidence interval, which means that if we did this experiment 100 time, 95 of those times the real average difference would lie in the confidence interval. In particular, since 0 lies in the interval we cannot say that extending the PM intervals caused the maintenance cost to go up or down.
implying that there is no firm evidence of a cost difference between the fleets.
The positive difference that we do see is due to random variation; a second experiment might well give a slightly negative cost. An objection that might be raised is that although zero is included in the confidence interval, the average we found is in fact positive. Could we get a smaller confidence interval (and hence a better estimate), and perhaps rule out zero? Yes, by using more vehicles in the test; given the size of effect the manager wants to detect, designed experiments can estimate the number of vehicles needed. This illustrates why depending on only a few test vehicles can cause an experimenter to be uncertain about whether an effect really exists.

Extending the PM interval did not significantly reduce overall maintenance costs. (As noted before, the manager would also certainly look at the increase/decrease in roadcalls.) However, since the agency fortunately has a maintenance information system that can subdivide maintenance costs by system, the analysis of the data can be carried one step further to break down the maintenance cost per mile, for example, into contributions from engine, air conditioning, and brake maintenance. In Table 4 we present the notional breakdown of the maintenance cost into these three categories, including the vital confidence interval so that we can interpret the average difference for each system as we did for the total maintenance cost.

<table>
<thead>
<tr>
<th>System</th>
<th>Test Cost $/mile</th>
<th>Control Cost $/mile</th>
<th>Difference $/mile</th>
<th>Confidence Interval $/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>0.12</td>
<td>0.16</td>
<td>-0.04</td>
<td>(-0.05,-0.03)</td>
</tr>
<tr>
<td>Air</td>
<td>0.15</td>
<td>0.19</td>
<td>-0.04</td>
<td>(-0.05,-0.03)</td>
</tr>
<tr>
<td>Conditioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brakes</td>
<td>0.18</td>
<td>0.10</td>
<td>0.08</td>
<td>(0.07,0.09)</td>
</tr>
</tbody>
</table>
In Table 4 we see that the means for both engine and air conditioning maintenance are both less than zero and the confidence intervals do not include zero, implying that for these two categories the increased PM intervals reduced cost. The costs of brake maintenance rose sharply, by about eight cents per mile which offset the decreased costs in the other two categories. And note that the confidence interval for brake maintenance also does not include zero, implying that this cost increase must be taken seriously. Using this information the maintenance manager might well decide to lengthen the PM interval for the entire fleet, but include an inexpensive periodic brake check to help keep brake maintenance in line, thereby getting much of the benefit of extended PM intervals and avoiding the major source of cost increase.

This example is simplified, as we said at the beginning. However, it does illustrate how a designed experiment can help to estimate the effect of a change in maintenance policy in quantitative terms (in this case, to help estimate the change in costs incurred by the change) and can assure the manager that, in spite of the variability of the individual data points, the conclusion is reliable enough for him to take action. More sophisticated statistical techniques can allow experiments to be more flexible. For example, for many agencies experimenting on 50 buses may pose an unacceptable risk, particularly with a new practice whose effects are unknown. In those cases, pilot tests with small numbers of vehicles can be used to see if there are large harmful effects (large effects can be detected with smaller sample sizes). If the new practice passes the pilot test, a larger, full-scale experiment can follow to more precisely estimate benefits.

Relevance for transit maintenance

The example gives some of the flavor of how experimental design would be applied to testing innovative maintenance practices, and some idea of the benefits. 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.

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6 For those with some familiarity with statistics, the may recall that when we are comparing several confidence intervals, the intervals must be widened to account for the multiple comparison. This has been done in this case.
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 therefore be likely to find experimental design most useful: they have both the size to be able to conduct a test on an adequate number of vehicles, and they have the resources to get help with experimental design.

It might be also be possible to conduct an experiment at a collection of small agencies in cooperation with each other. Such an undertaking would need to have a central coordinating and planning authority to design the experiment and make sure that the plan was being adhered to. 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. Further, there is currently great interest in statistics in the field of meta-analysis (Hedges and Olkin, 1985) which uses statistical techniques to quantitatively synthesize results 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 large, centrally-controlled, expensive experiment. The use of such techniques in transit could allow even small-scale experiments at many different properties to yield strong, 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 new economic pressures to pure pride in improvement. The use of designed experiments for such tests is virtually nonexistent in agencies of every size. This is unfortunate, because designed experiments would allow agencies to get more precise and credible answers from their tests by ensuring that enough vehicles were used, and valid comparisons were made, allowing a quantitative measure of whether the innovations were in fact truly beneficial. Further, random selection of test vehicles would help assure that the results were generalizable to the entire fleet. Such experimentation will require some resources not currently

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7 However, Japanese manufacturing firms train factory operators in elementary statistical design with the expectation that they will use it in evaluating local changes in manufacturing processes. See, e.g. (Mitra, 1993), pp. 6, 12.
employed, particularly in the design of the experiments, but there should be substantial savings in rigorously and definitively testing innovations and implementing only those which show clear and quantifiable benefits.

Use of designed experiments might also reverse the current 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 at individual agencies or as multi-agency experiments (as are done with medical multi-center trials). The latter possibility is particularly attractive because it would allow the inclusion of small transit agencies. Small agencies typically do not have enough vehicles to do a controlled experiment that has an adequate sample to detect interesting results. However, many small agencies could participate in a multi-site experiment and pool their results. The design and administration of such trials is more complicated than the example given here, and would require coordination by entities like APTA or FTA.

Some interesting innovations to test might be preventive maintenance or oil change intervals: as noted, they currently vary widely from agency to agency. Such a test would attract wide interest, because PMs are such a conspicuous part of maintenance activity. One outcome of such an experiment, particularly if carried out at multiple agencies, might be a comprehensive guide to the effects of different climates and operating conditions on the appropriate length of the PM interval.

SUGGESTED FURTHER READING
There are a large number of articles, books and courses devoted to the design, execution and analysis of experiments in industry. The sources used in the preparation of this chapter were


There are many other books and articles on the topic, ranging from primers for production workers to highly theoretical treatises of limited use to real world practitioners. The above are pragmatic in their focus.

The American Society for Quality Control, 611 East Wisconsin Ave., P.O. Box 3005, Milwaukee, WI, 53201, has an extensive list of publications on statistics, experimentation, quality control and reengineering, and teaches short courses all over the country on these topics as part of its certification program.

Finally, as a gentle introduction to the statistical topics mentioned here, one of the best books is

5. 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, we believe that the third aspect is the most important: transit maintenance people have plenty of ideas to share, both in maintenance practice and in the use of maintenance information, but their chances to do so are limited by geographic dispersion and the fiscal realities of travel budgets. Given the previous history of failed attempts to build electronic communication in transit, we think that the strategy we have proposed in which APTA committees pioneer electronic communication is workable and makes use of APTA’s role as the voice of the transit industry.

Electronic communication can also form the foundation of efforts to better utilize maintenance information. As we noted in Chapter 3, 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. At a minimum electronic communication between people with analytic responsibilities in different transit organizations (particularly small ones) would broaden the ideas available to them in trying to better utilize their resources and diagnose problems.

The increasing sophistication of computer-based maintenance information systems will give maintenance managers even more knowledge to share. The ability to archive data even on small computers (hard disk memories of a gigabyte and greater are commonplace and soon to be replaced by more capability), the increasing ease in using data management tools, such as spreadsheet programs, and the growing flexibility of report writers will grant maintenance managers more freedom to explore levels of performance and the reasons for that performance. This dynamically growing capability argues for experimentation and exploration on the part of the community of maintenance managers. Rather than seeking too early standardization across the industry, whether of data elements or of report formats, maintenance managers in agencies
large and small should be encouraged to develop data systems and report styles that fit their own needs, while continually comparing and contrasting them with what their counterparts are doing. The examples offered in Chapter 3 give evidence that much creativity is already flowering in the industry.

The proposal to use designed experiments in evaluating maintenance innovations stands somewhat 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 we visited (particularly FedEx) were beginning to run some simple experiments. As with electronic communication, there is an important role for a coordinating agency such as APTA or possibly FTA to play in encouraging the use of designed experiments and insuring that adequate technical advice is procured. And there is a potential interaction between electronic communication and designed experiments: the information produced from experiments can be shared efficiently with electronic communications (electronic communication can help maintenance organizations share ideas on designing experiments as well).

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 more like "symbolic analysts," in the common phrase. They need to understand the importance of information and its manipulation in helping them better carry out their jobs. In responding to demands for more flexible and efficient management, they must strive to be more analyst, experimentee, and communicator than they heretofore have been. This is especially evident in the demand for broader and deeper communication, along the lines promised by electronic networking. If, as argued, this form of communication becomes pervasive and "inevitable," 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 as well 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 boondoggle. 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 probe for reasons for poor
performance, even if what it reveals is initially discomfiting.

We are told that we live in an "information age." Many fields, maintenance
included, are discovering that they are in fact "information intensive," i.e. they
can actually utilize 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
at least as important and affected perhaps even more by electronic
communication. 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. PHASE I RESEARCH

Two of the principal tasks of Phase I of this research project were to review the relevant literature regarding transit maintenance and general innovations in the performance of maintenance, and to conduct a series of site visits of public transit agencies and private firms involved in maintenance to survey organizations recognized as pursuing more innovative strategies in maintenance.

This appendix documents in some detail the results of those two tasks. In the first part, we present some of the results of the literature review, concentrating on the standard transit maintenance literature produced in the 1980s and 1990s. In the second part of the appendix, we present an overview of the site visits made and the list of candidate "best practices" generated from those visits. These were earlier summarized in Sec. 1 of this report and formed the basis for choosing the direction of work during Phase II, as described in the introductory section of this report.

LITERATURE REVIEW

While excellent work has been done on transit maintenance management strategies, we found a lack of work that attempted to integrate across the resource areas or was sensitive to tradeoffs among resources that maintenance managers can use. Specifically with regard to capital costs, we noted only fairly sparse work on vehicle capital issues (little apart from replacement strategies) and virtually nothing on spare parts inventory management. In the labor area, while there was good early research on work standards, the follow-through has not been as great as might have been expected. Weaknesses in this area include work on worker skills, training, labor contracts, and human resource management. In the information area, most of the work concentrated on scheduling tools, failure analysis, and performance measures; more would appear to be needed on how information should flow within and between organizations.

The evidence of ongoing change in the commercial world may have relevance for transit. Among potentially applicable business practices are leaner inventories and faster throughput ("just-in-time" type strategies), benchmarking
performance, focusing on "core competencies," and more aggressively using information and information technology.

The following documents the preceding points in more detail. It is adapted from a somewhat more extensive literature review performed for this project; this complete literature review is available in Marc Robbins and Lionel Galway, "Research Trends for Improving Bus Maintenance: A Literature Review," RAND, PM-197-TCRP, December 1993.

In this section, we review some of the main research results in bus maintenance in the past fifteen years. That research has experienced peaks and ebbs; most of the work we cite comes from the period of greatest sustained interest in this area, extending roughly from 1983 to 1987. The section is broken into two parts, first reviewing the substantive findings of the research and then commenting on the methodological strategies used. We finish with a few summary comments on accomplishments of the research and work left to be done.

**Bus Maintenance Literature: Substantive Areas**

**Performance measures.** Means of capturing performance measures have been an early and sustained interest in the literature on bus maintenance and, indeed, on the mass transit industry as a whole.

The work of Fielding and his colleagues see, for example, Fielding, Glaudthier and Lave, 1978; Fielding, Babitsky and Brenner, 1985; and Fielding, 1987) has been instrumental in helping create a structure for performance measures underlying Section 15 data. That structure is based on three pillars: cost efficiency, cost effectiveness, and service effectiveness. Cost efficiency describes how well input factors such as labor, equipment, facilities, and fuel are used to produce outputs, such as vehicle hours or revenue vehicle miles; effectiveness measures the consumption of transit output as well as the impact of transit on societal goals, such as reducing traffic congestion. Service effectiveness can be captured by such measures as utilization of service; cost effectiveness might be measured by operating revenue per dollar of operating cost.

As Maze and Cook (1987) expressed it, performance measurement needs to be a reflection of performance objective. If those measures do not fit the needs of the organization, they will be routinely ignored or, possibly worse, manipulated to serve external demands. Maze and Cook (1987) and List and Lowen (1987)
surveyed managers to determine what measures would best help them achieve performance objectives. While the former found top managers favoring simple indicators of two performance attributes (vehicle reliability and vehicle maintainability), the broad variance in responses prevented the emergence of any consensus among maintenance managers on what information is most important. Similarly, List and Lowen found a preference among maintenance managers for measures of vehicle reliability, such as miles between roadcalls, and other measures that might pinpoint causes of reliability problems (e.g., drivetrain performance), as well as other measures monitoring costs, labor and vehicle condition.

The use of performance measures spread slowly through the industry. Attanucci, Jaeger and Becker (1979) found that in the pre-Section 15 period, properties used measures primarily for reacting to negative changes in the environment and few used measures in a systematic way. A somewhat later study (ITE Committee 1982) found a wide variety of measures used but with little uniformity across agencies. Maze (1987) later expanded his work to provide some basic principles and methods for maintenance managers in collecting data, analyzing them, and establishing maintenance performance measurement systems fitted to the needs of the agency.

Performance measures have frequently been the focusing of external auditing agencies. These audits have frequently had at best mixed results (e.g., on the San Francisco Bay Area Performance Audit Program, see Watkins, 1986). Fielding (1992) summarized and evaluated the most prominent attempts at using performance measures to evaluate agencies. He found little success in using these measures as incentives for managers and workers. Attempted programs, such as in Pennsylvania, Michigan, St. Louis, the Delaware Valley, Los Angeles County, as well as in Federal audits, failed fully or partially for a variety of reasons: using too many measures; failing to provide independent oversight; creating time lags between performance and measurement; not taking into allowance natural differences between agencies, and so forth. Perhaps the most successful auditing program has been that run by the State of California which, by contrast, uses a small set of indicators evaluated by independent auditors in a publicly-released document.
**Manpower.** With most maintenance resources expended on manpower, more efficient usage of maintenance labor has been a prime focus of the academic literature.

Prior to 1976, according to one study (Haenish, 1976), there was no work on standard times for performing maintenance functions. His research on work standards at the Chicago Transit Authority was a first step in the direction of establishing standard times and procedures for the basic functions in bus maintenance. The aim of this (and succeeding work) was not merely to establish time limits but to analyze the process of work to increase productivity by, for example, cutting waste in the process, increasing parts availability, and aiding the scheduling of manpower. In this study, productivity improvements of 30 to 50 percent and beyond were achieved.

A few years later Inaba (1984) surveyed bus agencies on their use of work standards. He found about 40 percent used standards, mostly for detecting problem areas, management by exception and measuring employee performance. Several researchers attempted to develop models to help managers develop and implement work standards. Drake and Carter (1984) produced a model which quantified the impact of local characteristics (e.g., vehicle miles, peak fleet, climate, fleet mix, accident frequency) against time required for maintenance work to allow managers to customize work standards against the needs of their particular agency. Purdy (1990) used a case study analysis of one transit agency to show how an agency's maintenance management information system can yield the information needed to develop work standards for that locality. Mundle et al. (1984) also performed an analysis demonstrating how hours available matches with estimated job loads.

**Scheduling tools.** Much of the workload in bus maintenance facilities is amenable to standard operations research analytical tools, such as scheduling functions. There were numerous attempts in the 1980s to develop such scheduling models to help managers exploit limited resources.

Dutta and his colleagues have been major contributors in this area, with several different variations on repair scheduling techniques (1986, 1987, 1989); in his work, he and colleagues have experimented with different scheduling strategies, such as SPT (shortest processing time), first come/first served, last come/first served, limiting waiting times, and so forth. A continuing problem, he found, has been lack of suitable data for real-world testing of these models.
Martin-Vega (1981) was able to overcome this problem when he was invited in to help solve the scheduling problem at an agency. In this real-world experiment, he was able to apply SPT scheduling to solve the problem (buses stacking up for airconditioner repair, with the queue masked by lack of data visibility and a high spares ratio), resulting in faster workflow and greater vehicle availability.

Scheduling of repair, such as preventive maintenance, is often sensitive to the specific needs of the agency. List, Satish and Lowen (1986) developed a multifactor failure algorithm for scheduling repair that in part aids managers to better take into account the nature of the service they provide. Their methodology incorporated various measures of service provided (miles driven, stops, hours) that reflect different types of bus routes and tied them into demanded levels of maintenance.

What scheduled maintenance intervals should be is still largely an unresolved question. The best analysis of this question to date is probably Giuliani (1987), who surveyed a wide range of agencies on their scheduled maintenance practices. While there was general agreement that such scheduled maintenance is a vital part of keeping buses running efficiently, maintenance managers differed widely in the standards they used, without it being necessarily clear that these differences were rationally based in the specific needs of their agency.

An important reason for scheduled maintenance is to prevent unscheduled component failures in service; however, it is difficult to set those scheduled intervals without knowing what the reliability (that is, failure rates) of those components look like. Two studies did extensive analysis of this problem. Kosinski, Foerster and Miller (1982) did detailed analysis of failure data in one agency to develop failure curves for components, toward the aim of establishing the most cost-effective times for removal and replacement of components during scheduled maintenance. Maze and Dutta (1984) did a similar analysis of transmission failures to determine differences in reliability among types of components. Both studies achieved some success in laying out failure parameters, but were limited in their application by the messy data available in the real world.

**Computerization issues.** Computerization in transit maintenance has followed the two streams of acquiring management information systems (MIS) and developing automated bus diagnostic systems.
Collura and McOwen (1984) did an early survey of MIS at small agencies and developed cost and resource estimates for acquiring such systems. In the next year, Gitten et al. (1985) did a larger-scale survey of computer use in the industry, finding computer use to be scattered and not well accepted at that time. He developed a set of possible uses of MIS for transit bus maintenance and offered a strategy for acquisition and implementation of such systems.

There have been several attempts to analyze the benefits of implementing automated diagnostics systems for buses, whether on-board, external probe, or some combination of the two. Wood (1985) gives a rationale for their possible benefits, emphasizing their ability to catch incipient failures before they cause service interruptions. Casey (1983) documents a field experiment with the Automated Bus Diagnostic System (ABDS) for the New York Transit Authority. Though the test's usability was limited by lack of data and some design flaws, Casey found that roadcalls were indeed reduced through use of the ABDS, though repair hours generally increased. Chew (1985) described a similar experiment in Great Britain, using the Fault Diagnostic and Condition Monitoring (FDCM) system, which, like the ABDS, was intended to detect probable failures early, thus reducing unscheduled maintenance and the extra cost and service disruptions associated with it. The early test of this system, according to Chew, showed that significant savings could be made by adopting such a system and integrating it into standard maintenance processes.

Facilities. Several researchers have focused on the issue of maintenance facilities, including optimal layout, sizing, and location to maximize maintenance manpower efficiency and minimize deadhead time.

Maze, Khasnabis and Kutsal (1982) did a straightforward simulation of a mixed-integer problem to compute optimal sizes and sites of garages; later (Maze and Kutsal, 1982; Maze, Khasnabis and Kutsal, 1983) the method was applied to a specific agency (Detroit), using the optimization model to test the assertion that 250 buses is the "optimal" size for a maintenance facility. They found that there is in fact no "optimal" size and that each garage planning problem should be considered unique.

Andrle and McCollum (1985) analyzed data from thirty maintenance facilities built in the previous fifteen years to create some guidelines for initial feasibility phases of facility planning. Using vehicle miles as an indicator of maintenance needs, he performed regression analysis to determine the most
commonly used amount of space for individual maintenance and maintenance-related functions (e.g., maintenance bay space per 100,000 miles, size of tire shop, brake reline shop, parking area, etc.)

A more recent study (ATE Management, 1993) analyzed the current needs of agencies for maintenance facility upgrades or replacement, using surveys and case study site visits. While 76 percent of the agencies graded their current facilities as adequate or better, those surveyed anticipated further capital needs of $2.1 billion over the next five years. Among the findings of the case study analysis was that, as with maintenance intervals, there is a general lack of consensus in many areas (such as indoor versus outdoor parking, underground storage of fuel, alternate fuels maintenance requirements, best facility size, etc.) and in general, experience is not adequately shared in the industry.

**General management strategies and practices.** Another set of studies might be put in the category of general management strategies and practices. Foerster and his colleagues (1984) did case study analyses of eight agencies to determine which general practices might best explain good performance. Among their findings were that pre- and post-run inspections by drivers were important (as was involving drivers in general in caring about the maintenance of the buses they drive); that homogenous fleets were an aid in reducing maintainability problems; that managers should pursue goal-directed "management by objective" strategies; and that good relations between management and labor were an important component for efficient and cost-effective maintenance.

In a related work Foerster and some of these same colleagues (1983) argued for the need for strategic planning tools to improve maintenance performance and control costs. Primary among these methods (and discussed to some degree previously) were work methods analysis and job time and cost analysis, as well as failure history analysis and workload and budget forecasting procedures.

Zimmerman (1986) did a study similar to the Foerster set of case studies, focusing on effective maintenance strategies in New York State bus agencies. He found, among other results, that spares ratio strategies were driven principally by size of the agency; like Foerster, that driver involvement was a critical strategy; likewise that better agencies had rigorous policies regarding preventive maintenance; that record keeping is important (especially for catching incipient failures) but that performance measures are problematic; and that rational and
efficient parts procurement and inventory control are needed to control the number of down buses awaiting parts.

Maze (1987) developed a set of principles and techniques to guide maintenance management. Among his principal findings were, again, the importance of generating needed data and developing effective performance measures; pursuing life-cycle cost methodology during vehicle acquisition (on which, see also Hide (1990) and Maze and Cook (1986); on methodologies for vehicle replacement strategies, see Carter, Drake and Sims (1990); and increased information exchange among maintenance managers; Maze (1986) in particular called for a database of maintenance experience across transit agencies to facilitate life-cycle costing, especially for smaller agencies that cannot maintain the vehicle history records like a large agency. Similarly, participants at the 1982 Bus Maintenance Improvement Workshop (Abkowitz, 1983) agreed that more information dissemination was critical to improving bus reliability. In addition, they argued, there is a need for increased field testing and evaluation of promising reliability control strategies and more support of training and in-house technical ability.

Finally, there have been several attempts to develop tools to aid managers in estimating cost relationships for maintenance activities. An early attempt was by Purdy and Wiegmann (1987), based on site visits to 23 California transit agencies. The result of this work was a series of graphical displays by which maintenance managers could estimate their costs based on the size and type of their fleet, as well as some other characteristics. A more ambitious cost model was developed by KPMG Peat Marwick (1992) based on a set of ten principles, including recognition of past trends but anticipation of future operations; incorporating all functional responsibilities; focusing primarily on cost drivers; applying peer transit property experience; and structuring for sensitivity analyses.

**Bus Maintenance Literature: Methodological Issues**

**Types of studies.** In looking over the bus maintenance literature, it is useful to classify the works not by subject but by the type of study that was done. This approach focuses on the types of research strategies that have been used in transit bus maintenance research and also allows us to identify some gaps: potentially useful studies which have not been done. In our survey of the
literature we have noted that the studies may be roughly divided into the following categories:

(1) Analyses of Section 15 data. These studies look at a large number of agencies, sometimes augmenting the Section 15 data with other data sources, such as climate, terrain, or local economic conditions. The focus here is on broad, cross-sectional views of the transit industries, with comparisons between agencies that are similar in operating conditions. (e.g., Arlinghaus and Nystuen, 1986a, 1986b, 1987)

(2) Case studies. These are thorough, in-depth looks at one or a series of individual bus agencies. Here the focus is on the individual agency, its particular problems and its own individual solutions. (e.g., Foerster et al., 1984).

(3) Quantitative analysis. These studies utilize some techniques of statistical data analysis or operations research, such as survival analysis or queuing theory, with data collected from maintenance records of operating agencies. The purpose is to demonstrate that the data collected by the agency is in fact sufficient to support the suggested analysis. In most instances the technique is not implemented at the test agency, nor is empirical testing done to establish the costs and benefits of applying the techniques (although in most cases the advantages of the techniques are highly plausible, given their uses in other areas). (For example, Kosinski et al., 1982; Maze and Dutta, 1984).

(4) Modeling. A closely related class of studies build simulation models of maintenance activities at various levels of detail, and use the models to show the advantages of different maintenance policies, e.g. scheduling maintenance in the order of shortest job. See, e.g. (Dutta, 1986, Dutta, 1987, Dutta, 1989).

(5) Workshops. The final general class of reports is that of workshop meetings, where maintenance managers meet to discuss maintenance issues. These meetings can address high-level policy (dealing with boards of directors) or the “nuts and bolts” of maintenance practice (problems with air conditioner positioning, the merits of brake retarders, etc.). (Transportation Research Board, 1983, Abkowitz, 1983; APTA, 1986.)

Gaps in the literature. This breakdown reveals a surprising gap in the literature: little published record exists of field experiments, where a new policy or analysis technique was actually implemented at a bus agency and the results observed. Two examples of these rare reports are (Martin-Vega, 1981) which relates the application of the SPT rule to bus repairs to eliminate a long repair
queue, which had grown to crisis proportions and (Casey, 1983) which describes the demonstration of an automated diagnostic system in New York City.

This gap is all the more surprising in that the various workshops and trade magazines often mention, when profiling an agency or manager, a list of new things that are being tried at the agency. However, these seem not to be published formally for a larger audience and no report is made of detailed findings and procedures.

There are two plausible results from this practice. First, diffusion of new ideas and practices may well be discouraged, since hard data is not presented in detail for consideration. For example, the merits of brake retarders were being discussed in the mid 1980s; today their use is still mixed and agencies cite uncertainty as to the benefits as one reason for deciding not to use them.

Second, problems with experimental practice are not brought out, discussed, and resolved. Again, the 1982 (Transportation Research Board, 1983) maintenance workshop noted that few if any agencies have the ability to design and carry out good experimental trials of new policies and practices. This is not surprising: carrying out a good experiment in the real-life setting of an operating bus agency is not a trivial task. However, without sharing accounts of successful and unsuccessful experiments, little use can be made of one agency’s hard-won knowledge. Further, the design of efficient experiments in a real-world environment, with the proper use of controls to unambiguously establish results, is not a simple matter; the industry would benefit from shared experience in this area as well.

This gap is one which could be addressed by encouraging collaboration between agencies and the academic community in designing and executing actual experiments to rigorously compare different practices. Such encouragement could lead to significant inter-agency communication because experimentation could be more easily supported by consortia of transit agencies.

Observations. This overview has given evidence of substantial good work in the field of bus maintenance. Such areas as work standards, facility size and location, repair scheduling, failure rates, and even specific reliability problems (as discussed in maintenance workshops) have received sustained and professional attention.

Nonetheless, there are some elements of analysis that would appear to be missing. The first is any attempt to develop an integrated view that relates all
inputs and outputs of the bus maintenance function to detect systemic inefficiencies and potential areas for improvement. What drives overall maintenance costs? What determines the need for high spares ratios, or allows agencies to maintain smaller ones? What is the best tradeoff between fleet age and maintenance costs, and what is the best tradeoff between fleet age and spares ratios? What are the major causes of bus downtime? Is inventory being used efficiently? How important is fleet diversity in minimizing maintenance costs? How important are the make and model of vehicles in performing maintenance cost efficiently? These are but a few of the questions that, at this stage, we are not adequately prepared to answer; more to the point, we are very far from being able to specify a complete model that would combine all of these elements, and others, to identify areas for increased efficiencies in bus maintenance.

A second, and related, major area is that of data, an issue of long-standing concern in the field. While the main body of the data, captured in the Section 15 data system, is of unusual quality, it is severely limited in answering some of the more pressing questions in this area. Its value lies mostly in allowing cross-agency and over-time comparisons; what it cannot help us do, however, is answer the question of why these differences appear.

The absence of shared information among agencies or between agencies and researchers is quite striking (with certain obvious exceptions). It is somewhat surprising that this occurs in an industry with little or no competition among its members; in many areas, the level of shared data is higher among competing truck firms or airline companies that we have seen among public transit agencies.

The last area of weakness is one discussed in the last subsection: the absence of documented attempts to do field tests of new concepts and follow them through in a real-world environment (though, again, there are striking exceptions, such as Martin-Vega's work on SPT scheduling and the New York City test of the Automated Bus Diagnostic System). In such a stable industry as public transit buses, there may be a role for external actors, such as the Federal Transit Administration, to encourage and sponsor potentially valuable field experiments of new ideas.
Emerging "New Management Paradigm" in the Commercial World

An important source of innovative ideas for improving transit bus maintenance may be found from the business world. In the competitive world of market-based firms, new concepts for increasing efficiency or meeting customer needs are quickly developed, tested, and diffused through the industry or discarded. The emergence of an increasingly global economy has enhanced that trend, as firms in the United States must now compete not only with other American companies but also with increasingly competent challengers from every corner of the globe. As is well known, in many industries America's fiercest competitors have been Japanese firms. Especially in automobiles and consumer electronics, Japanese firms have made major inroads into the American economy. It is generally recognized that their success owes much to new concepts of how manufacturing should be conducted and how the customer should be attended to. These new ideas are powerful and coherent enough to come under one rubric, and are commonly called the "New Management Paradigm." In this section, we examine some recent literature on this New Management Paradigm, or NMP; after giving an overview of the concept and how it relates to manufacturing, we finish by examining some recent trends relating to the overhaul and remanufacturing industries and to airline maintenance.

Emergence of a "New Management Paradigm"\(^1\). Whatever theory or name is applied to the new paradigm—TQM, JIT, and so on—there is a common theory among businesses today. The elements of that theory stress that customer desires are paramount and change quickly; that combined with increased competition has led to an unstable environment where firms must be especially supple if they wish to survive; that that suppleness does not allow for waste or inefficiency; that inefficiency and waste are removed by paring down the organization to the essentials and reengineering its processes to be smoothly-operating and goal-oriented; that this emphasis on "leanness" increases the importance of quality control at every step of the process and continuous improvement to constantly root out waste of material and time; and that to accomplish all this, vertically-integrated organizations must give way to more

\(^1\) Parts of the following are adapted from Levine and Luck, 1994.
decentralized systems where workers at all levels have more power to improve their processes.

Two themes are central in this new approach to manufacturing: simplification and the elimination of waste. Simplification refers to eliminating encumbered processes where no value-added is gained; it looks toward replacing the focus on function with one on process, on moving from a complex multi-department process flow to cellular manufacturing, or, in general, to the "reengineering" of activities from a blank slate to clean out no longer useful or obsolete parts of the organization. Waste means any use of time, material, inventory, manpower, or other assets which can be eliminated without detracting from the quality of the manufactured goods.

Manufacturing concerns use a set of techniques, or strategies, for pursuing these two goals, including:

- **Quality improvement techniques** (e.g., statistical process control) to prevent defects and ensure all components meet nominal requirements, thus reducing the need for buffer stocks (Juran, 1988);
- **Making work processes highly visible** reduces variation due to information availability and so immediately highlights problems in workflow when they occur;
- **Ensuring the accuracy of information used by workers and schedulers** (e.g., Bills of Materials, inventory counts, etc.) helps prevent wasted time used to rectify mistakes;
- **Developing standardized work procedures and having all workers use them**, where those standards (often detailed down to the second) are determined in large part by the workers themselves;
- **Balance capacity across subprocesses**, or, as one theorist of the NMP put it, be able to "exploit the constraints" (bottlenecks) that afflict all manufacturing processes (Goldratt, 1986);
- **Standardize components and assembly sequences across models**;
- **Reduce delivery time variability**, both for deliveries within the plant and from suppliers, and while speed is usually important it is less important than reducing variability, that is, the unpredictability of when parts will be available (Shapiro, 1992);
• *Orderliness and cleanliness* help insure that grime and dirt are not allowed to reduce quality or degrade equipment performance, or that time is not wasted searching for tools or parts kept in disorder (Nakajima, 1988).

To begin the process of improvement, an increasing number of companies are using benchmarking (Camp, 1987). In benchmarking a firm wishing to improve one process studies the same, or related, process in another firm even (or especially) if the firm is not in the same manufacturing sector. A classic example of this was the effort of Xerox to improve its picking, packing, and shipping process by studying the superior performance of the mail-order firm L.L. Bean.

Another emerging trend on the part of manufacturing firms is their identification of "core competencies," or specifying those products they will make, or processes they will emphasize, to the exclusion of other distracting candidates. In a step back from the "synergy" movement of the 1960s and 1970s, a firm will shed itself of too large a line of products and concentrate on producing those critical items in which it can be dominant. Thus a firm might not produce all kinds of household appliances, but might focus on the core competence of motors or compressors for refrigerators, washing machines and the like. (Prahalad, 1990)

Related to the idea of core competencies, rather like a corollary, is the increasingly popular practice of "outsourcing," the contracting out of processes and functions that traditionally have been kept within the structure and under the control of the firm. Thus, more and more firms are shedding those parts of their organization that handle warehousing, inventory control, purchasing, distribution, and so forth (Oliver, 1991; Richards, 1993).

Within the organization, various new technologies and techniques are increasing the effectiveness of management control. More companies are moving to advanced accounting tools to help them better understand the implications of new management strategies. Traditional accounting practices, which typically focus on direct labor and allocate other sources of input as "overhead" can lead to flatly wrong assessments of true marginal costs, especially as direct labor becomes a smaller fraction of overall costs. New accounting systems tend to be "activity-based," that is, virtually all costs are broken down and then traced to individual products and support activities (Cooper and Kaplan, 1988).
Fundamental to most cases of improved business performance is a rational incorporation of information technology (IT) (Strassman, 1990). Having been stung by very large investments in computers in the 1980s with very small payoff, many companies are focusing on more rational strategies toward integrating computers and management information systems with process changes in business operation. Organizations that adopt the new management paradigm make very specific demands of IT. As they evolve, they look for interoperable, vendor-independent systems that can accept and transmit data from a variety of users. These organizations seek to integrate all their business processes into their IT system seamlessly. Organizations are shifting their attention from systems to information, from technology to the uses to which the technology can be put (Hopper, 1990).

The last of the major innovations underlying the New Management Paradigm involves organizational design of human resources use. NMP firms typically see themselves as "empowering" their employees by devolving more and more decision-making to lower levels. Assembly workers on a JIT production line have the power to stop the assembly line if they detect defective items, just as they have increasing opportunity, and responsibility, to suggest changes in the layout and execution of their tasks (Ostroff, 1992; Stalk, 1990). In order to make increased responsibility at lower levels work, firms are coming to understand that workers must be more broadly and systematically trained than in the past, including structured training in all tasks their team performs, as well as in statistics, process improvement techniques, group skills and communication. Second, traditional evaluation and incentive programs that evaluate only individual performance are usually modified in a team environment (Kanter, 1987). Potential criteria include aspects of team performance, overall firm performance, and individual employee skill development. Third, job security provisions, such as pledges not to lay off workers because of worker-generated process improvements, are a keystone of worker/management relations. Finally, managers and indirect staff must see their role as assisting workers in doing their jobs, not controlling activities in detail.

Greatest impact in manufacturing and some services. As the NMP was born in manufacturing firms (its progenitor being called, with reason, the Toyota Production System), its greatest impact to date has been greatest in
manufacturing. Womack (1990) is the best single source for the origins, development, and impact of the NMP in the automotive manufacturing sector. For a related area in manufacturing, motorcycles, see Reid (1990). NMP principles are becoming more prevalent in the electronics and consumer electronics industry; on the case of Xerox, see Kearns (1992).

The effect of this new set of business practices has begun to spread far from the manufacturing floor, to service industries like insurance (Teal, 1991), fast food and communications (Hammer, 1993), and the service parts of manufacturing concerns, such as the account payables section of Ford (Hammer, 1990). The impact of new ways of doing business is also being felt in retail trades (principally seen in larger retail chains such as Wal-Mart, K-Mart, Mervyn's etc.) and in related providers of distribution services (see Koselska, 1992).

**Elements of NMP incorporated into remanufacturing sector.**

Remanufacturing, the process of turning reparable carcasses (or "cores") into rebuilt serviceable items, acts as a halfway house between the world of manufacturing and that of pure maintenance. On the one hand, remanufacturing firms attempt to create workflow processes similar to that of manufacturing; on the other hand (as in maintenance, but unlike manufacturing) the input of work (number of cores arriving at any one time) and the work required for each core (which depends on full inspection of that core) are highly variable. Remanufacturing firms are nonetheless adopting and adapting many of the new principles that manufacturing firms have applied.

There have been some attempts to incorporate these ideas into theories of maintenance (Nakajima, 1988; and Maggard, 1992). There has also been interest by firms in trying to apply JIT concepts to remanufacturing processes. Firms such as Friction, Inc., a remanufacturer of brake calipers and brake shoes, and Detroit Diesel Remanufacturing-West, a remanufacturer of diesel engine components, have seen their attempt to adopt JIT-like characteristics meet with some success (Keane, 1991; Rath, 1991).

Firms which see continued value in a more centralized approach to planning and execution are turning to modern planning concepts like Manufacturing Resources Planning II (MRP II), in which future production is laid out by strategic decision at the top and resources are brought together in a precise schedule to avoid work stoppages and other inefficiencies. Although tools like MRP II would seem inappropriate for the world of repair and
remanufacturing, some modified versions of it have been used with increasing success, now being in place in organizations as varied as Midland Workshop of the West Australian Government Railway, the New Jersey works of Morrison-Knudson, Pratt and Whitney, Detroit Diesel Remanufacturing--West, Springfield Remanufacturing Corporation, American Airlines, and Copeland Manufacturing (Demmy and Powell, 1991).

Some of the more innovative concepts used in manufacturing are being applied to remanufacturing, such as cellular layout of the production floor (Fargher, 1992) and statistical process control (Bothe, 1992). DoD depots are among the largest entities involved in remanufacturing in the nation and in certain regards have been leading the way in innovation. Cherry Point naval air depot, in an example just cited, has been exploring cellular layout (Fargher, 1992). Pensacola naval air depot took a larger "reengineering" view in revamping a very inefficient operation (e.g., remanufacturing leadtimes of almost 100 days). A Design Review Board comprised of mid-level managers representing the functional areas of the plant was chartered to determine an overall design for new ways to plan, schedule and execute work. Among the targeted actions were the seemingly obvious, such as increasing cleanliness and orderliness and improving visibility, to the more difficult, such as implementing kanban-style restocking systems and cellular process; other changes involved displaying performance measurement systems and a production control system. The end result was a system with substantially lower work-in-progress, 95 percent accurate real-time material tracking, and a smooth workflows with fewer "hot jobs" (Langford, 1992)

Attempts are being made to overhaul an increasingly archaic Department of Defense depot system in general. One strategy, based on work done by the Logistics Management Institute (Glass, 1988) takes as its focus a two stage approach of first simplifying repair and fabrication processes and only later introducing automated production and inventory controls or process automation. Among the means of "simplifying" are creation of work cells to eliminate wasted and confusing movement of items under repair around the shop floor; simplifying of production and inventory control is first approached not through elaborate management information systems but by eliminating as much inventory as possible and by scheduling production to meet known demand.
Improvements in Vehicle Maintenance. Remanufacturing or scheduled component repair work at depots still share many characteristics with pure manufacturing, and so are able to adopt many of new proven techniques (such as cellular layout or reduced work in progress). Perhaps a more difficult area to reform, and one of great relevance to bus maintenance, is vehicle repair itself. Nonetheless, substantial strides are being made in this area, especially in the highly competitive world of truck and air transportation. For example, a commercial linehaul firm like Freightliner maintains no more than three percent of its trucks as spares at any one time, versus an average closer to 25 percent in public bus agencies; airlines, with highly expensive vehicles maintain virtually no spares at all. With substantial revenue loss following from extended downtime, competitive firms work to reduce that time to a minimum. Northwest Airlines performs a complete overhaul of 747s in two weeks at its Minneapolis repair facility; American Presidential Lines performs scheduled overhauls on container ships once every five years and executes the work in approximately one week.

Perhaps no industry is more sensitive to the needs of high-quality maintenance while at the same time trying to limit its costs than the commercial airline industry. One of the most competitive industries in the world, airlines expend between 11 and 20% of their resources on maintenance ("$20 Billion . . ." 1990; Ott, 1993). Increasing competition has forced companies to seek every available means of containing costs. A primary means for doing so has been to extend the lifespan of the fleet. As a result, between 1975 and 1991 average aircraft age has increased from seven to twelve years; in 1975, the average retirement age was ten years, increasing to 24 by 1991 (Vechere, 1991). An aging fleet increases maintenance costs (about 1 percent per 1000 flying hours, or roughly 3-4 percent per year of aircraft life (Vechere, 1991). Despite that aging fleet, maintenance costs remained steady or even dropped as a percentage of total operating expenses between 1977 and 1986 (Rek, 1988; "$20 Billion . . ." 1990).

Among the strategies for controlling maintenance costs in the airline industry have been contract maintenance and outsourcing, implementing management information systems, and reengineering of the maintenance process.
**Contract maintenance and outsourcing.** More and more airlines are seeking to offload much of the maintenance they do and focus on more core maintenance activities while at the same time often treating their maintenance division as a profit center (though more so in Europe than in the United States, where American air carriers, while contracting out, are doing less third party maintenance themselves). The combination of both outsourcing and, when feasible, of contracting maintenance into their own facilities allows airlines to reduce overhead and increase flexibility, while increasing pressure to improve efficiency in their own shops. Without it, major carriers often suffer from overbilling from within, as maintenance divisions, in the view of one observer, "invoice extra man-hours to its captive in-house customer in order to conceal inefficiencies on other jobs." ("$20 Billion . . .," 1990). By turning maintenance divisions into profit centers, airlines force those units to squeeze out waste. British Airways Engineering, a component of British Airways, performs about 20 percent of its work for other airlines, but even the 80 percent it continues to do for its parent company is not considered captive. Previously, according to BA's director of engineering, the maintenance division might or might not deliver needed support to the airline and would give excuses why it was the airline's fault if something wasn't done right. "Under this new arrangement, it's never the airline's fault," he said, "because a business never blames its customer."

Along with the philosophic change to customer-orientation, organizations like British Airways Engineering have pursued a continuing effort to drive down costs and improve productivity in key areas: keeping aircraft on the ground as little as possible; reducing inventory to the lowest possible, and increasing work pushed through the fixed facilities. As an example, inventory levels were reduced 25 percent by employing manufacturing production "just in time" type systems both within its materials requirements planning in workshops and with suppliers. (Shifrin, 1993)

More and more work is being done by outside contractors through outsourcing. Outsourcing of maintenance increased from under 14 percent of airframe work in 1980 to a high of 28 percent in 1989, before dropping somewhat in the following years (Ott, 1993); the trend is expected to pick up again in the short term. Outsourcing is especially important for emerging North American airlines, which typically do only 20-30 percent of their maintenance in-house, versus 80-90 percent for established carriers. (Hughes, 1993) In this, airlines are
acting no differently than other businesses in America; as one expert observer put it, "This trend (of outsourcing) is beginning to sweep American business, thus enabling companies to sharply cut back on their fixed overhead and capital needs, and simultaneously enabling them to become more flexible and efficient by concentrating on their primary business" (Ott, 1993).

**Management information systems.** All providers of aircraft maintenance, whether in-house or external providers, are seeking ways of becoming more responsive and cost-efficient. A critical and growing element of that strategy is implementing new sophisticated management information systems.

Early efforts at computerization in the airline maintenance field focused on inventory control. For example, Aviall, America's largest independent engine overhaul contractor, was in the mid-1980s maintaining a computerized inventory monitoring system allowing any part to be located in real time, anywhere within the system, and dispatched to a customer; the system also allowed reservation of parts to fit customers' scheduled maintenance needs and to be shipped automatically at designated times (Sweetman, 1988). In 1986, the Air Transport Association began administering an automated information system, SPEC 2000, to enable suppliers and purchasers to share information about new parts for sale. ("ATA's Specification . . " 1986) From six suppliers and customers in 1987, the system had grown to include 99 parts suppliers and 52 airlines, with 1,470,618 records on parts. More recently, the ATA has updated and brought online its service for sharing information on excess materials. Called the Airline Inventory Redistribution System (AIRS), it provides, with payment of a fee, an online computerized network for airlines and other holders of inventory to advertise holdings of excess parts they would like to sell. Potential customers (also upon payment of fees) can access the system in real time and quickly determine available sellers of these excess parts. At present, the system links over 200 participants and maintains a database with 3.5 million line items. (Air Transport Association, no date).

Airlines have made strides in developing and implementing information systems to manage all aspects of the maintenance function. Merlin, a system developed and marketed by USAir, is such one package, seeking to improve communication between maintenance, inventory, and scheduling. It is composed of five separate systems: a Maintenance Activity Communications History (for aircraft history); a Component Control System (for usage and history
of parts); a Modification Control System (for aircraft modification planning and control); a Material Services Control System (for material planning, purchasing and receiving); and a Shop Planning System (for shop parts tracking and shop planning). The systems are integrated for handoff of information. USAir has successfully marketed the system to various other air carriers, including Federal Express, which used the system to replace several hundred individual programs. ("USAir Offers..." 1986)

Earlier this year, United Airlines switched to an integrated, highly automated operations maintenance monitoring system. The System Aircraft Maintenance Control's (SAMC) purpose is to coordinate unscheduled maintenance activities and help pilots and mechanics diagnose equipment problems. The goal is to better manage workload, prioritize departurecritical repairs, and quickly spot and identify chronic aircraft problems. (Proctor, May 17, 1993)

United Airlines has also been increasing computerization to upgrade productivity. Only recently has much of the paper-based information system been replaced by automation. The $60-million engineering and maintenance system (EMSYS) will integrate all existing maintenance-related computer systems and create a common relational database ("United Overhauls..." 1993)

In a maintenance-related version of activity-based costing, Boeing has developed a method of measuring aircraft dependability that more accurately reflects costs. The computerized methodology, called Dependability Cost, assigns costs for each repair, including direct and indirect factors, such as schedule interruption expenses, spares and spares holding costs, repair time, training, shop material and associated expenses. The model is based on Boeing US fleet statistics but can be modified to add airline-unique charges. (Proctor, Dec. 6, 1993)

Perhaps the most ambitious management information system is the Maintenance & Rebuild Control System, (M&RC) developed by Delta Airlines and Andersen Consulting. The M&RC is an integrated planning, scheduling, tracking, and record keeping application system designed specifically for the maintenance and rebuild environment. The key to the system is "closed-loop maintenance," based on the principle that the primary maintenance activities of planning, execution and management are integrated functions that receive input from and deliver feedback to other functions within the maintenance cycle. The
main functions of M&RC are to project maintenance activities and develop
schedules; plan resource requirements and determine inventory levels; track
parts and report maintenance status throughout the repair process; manage and
update records for accuracy; and maintain configuration control for the fleet and
for major assemblies. (Delta and Andersen Consulting, no date).

Reengineering of the maintenance process. The development of M&RC
was pursued with the intention of revamping the maintenance process at Delta
Airlines. A major part of that change is the move to cellular repair. Historically,
parts in need of repair are moved from shop to shop for cleaning, machining,
plasma spray and other processes in a traditional functional approach to repair.
To increase efficiencies of repair, Delta now clusters repair to expedite the flow
through of parts. The transition to cellular repair was expected to reduce
inventory demands, as much as $5 million for compressor blades and $12 million

United Airlines has sought to streamline and rationalize its arrangement for
maintenance. Recently it restructured its San Francisco and Oakland heavy
maintenance bases away from a service (or functional) orientation and toward an
aircraft (or product) focus. Whereas previously overhauls and major checks for
all aircraft were performed at these two locations, the United plan calls for
Oakland to specialize in Boeing 747 work, San Francisco to concentrate on 767
and 777 maintenance and overhauls, and 737 and 757 work to be accomplished in
Indianapolis. Only critical work would be accomplished at these United
facilities; marginal operations would be subcontracted out. Other key elements
include computerizing the operation (using the EMSYS system discussed above)
and increasing worker responsibilities through decentralization and increased
decision-making responsibility at lower levels ("United Overhauls .." 1991).

Final Observations.

This brief overview of two separate, but linked, literatures suggests several
conclusions. One, as discussed above, is that a substantial and coherent body of
literature directed specifically at the problems of bus maintenance has emerged.
There may be some remaining problems and that literature may have some gaps,
as we suggested, but as a mature literature it is unlikely that any quantum leaps
can be made by pursuing the same paths that others have trod.
Another conclusion is that many of the issues confronting managers of transit bus maintenance are faced by maintenance personnel in many different fields and industries. The commercial transportation industry's experience is similar to that of the bus world in many significant ways.

This suggests that the next step for seeking solutions for possible inefficiencies in bus maintenance is to look outside this industry and to learn from the experience of related industries. The goal of researchers might be described as promoting "cross pollination" of good ideas among these various fields.
IDENTIFICATION OF EFFECTIVE PRACTICES FROM SITE VISITS

Another major part of Phase I research was to conduct a series of site visits at agencies and firms identified as "best performers" to determine if there were general lessons in effective performance that might be applicable to the transit industry as a whole. In the remainder of this appendix, we list the agencies and firms studied and summarize the major lessons learned during 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 first three agencies visited were chosen to act as pilots for later visits, but also as sources of potential innovations.

Public Transit Agencies

Santa Monica Municipal Bus Lines, Santa Monica, CA (June 1, 1993).
Host: Assistant Director of Transportation. Santa Monica (The Big Blue Bus) has a fleet of 139 buses, with a peak demand of 106. The fleet consists primarily of GMC New Look buses, with a few Flexibles. It has a single operating garage, which carries out all maintenance and is co-located with the agency’s offices. Santa Monica is a very stable system, and heavily traveled.

Long Beach Transit, Long Beach, CA (November 22, 1993). Host: General Manager. Long Beach has a total fleet of 220 buses, with a peak demand of 170. The fleet consists almost entirely of GMC/TMC RTS buses. The agency has a single operating garage where all maintenance is done, collocated with the agency’s offices. Long Beach is currently expanding, and plans to continue adding routes and buses over the next decade.

San Diego Transit, San Diego, CA (November 23, 1993). San Diego has a fleet of 340 buses, with a peak of 255. The fleet is a mixture of models from different manufacturers, including Gillig, New Flyer, and GMC (New Look). The agency has two garages, one located at the agency headquarters. San Diego Transit is one of a set of public transit companies in the San Diego area which includes a substantial light rail operation.
Metropolitan Transit Commission, Minneapolis, MN (December 8-9, 1993). Host: Director of Maintenance. MTC has a fleet of 960 buses, with a peak demand of 848. The fleet is diverse, with about 15 different models and manufacturers. MTC employs about 240 mechanics. The fleet operates from five operating bases, supported by a central overhaul base which does component rebuilds, overhauls, and brake jobs. Inventory is kept at a central storeroom at the overhaul base with individual storerooms at each operating base. MTC is beginning a new program of marketing to regular and potential riders.

Greater Richmond Transit Corporation, Richmond, VA (December 14, 1993). Host: Director of Maintenance. GRTC has a total fleet of 186, of which 155 are needed to meet peak demand. The fleet consists largely of buses manufactured by Flxible, AMG, and GMC. The maintenance activity employs 37 mechanics, divided between running repair and a component rebuild shop, where the most senior mechanics work. The agency has a single facility for repair and storage, co-located with its offices. GRTC is managed by ATE. It has recently reduced service and is embarking on a program of realigning service and marketing itself to riders.

VIA Metropolitan Transit, San Antonio, TX (February 4, 1994). Host: Director of Maintenance. VIA has a fleet of 530 buses, with a peak demand of 425. Virtually the entire fleet is GMC/TMC RTS buses. VIA employs 70 mechanics, all working at a single repair and storage facility. VIA operates a paratransit service from the same facility. It is currently computerizing its detailed manual recordkeeping system to keep track of labor and parts usage.

San Francisco Muni, San Francisco, CA (June 10, 1994). Host: Head of Maintenance, Diesel Division. SF Muni has a fleet of 474 active and 50 reserve Diesel buses, with a peak demand of 386. Most of the fleet is Flyers, with some Orions and MAN buses. However, SF Muni has a complex transit system, which includes light rail, trolleys (electric buses) and the 26 San Francisco cable cars. In spite of the compactness of the city, SF Muni has three facilities for the Diesel fleet alone (two for 40 foot buses, and one for articulated buses), although most heavy maintenance is done in one place. Like most San Francisco city agencies SF Muni is under severe financial pressure, leading to reductions in workforce and shifts.
Commercial Transport Firms

Laidlaw Transit, Long Beach, CA (January 6, 1994). Host: Director of Maintenance, Southcoast District. This Laidlaw facility is the repair base and garage for 245 school buses which serve the Long Beach area. About 20 maintenance employees work here. The fleet is diverse, including buses of various sizes and from several different manufacturers, as well as buses equipped for physically handicapped students. The facility keeps complete paper records (especially safety-oriented items). Computerization is currently limited to a few special applications which keep track of specific areas (e.g. preventive maintenance inspection schedule). On-hand inventory is very small, but is supported by a regional Laidlaw warehouse and agreements with local parts vendors.

Arkansas Best Freight (ABF), Pico Rivera, CA (February 10, 1994). Host: Regional Maintenance Superintendent. The Pico Rivera facility is both a transshipment hub and repair facility. The repair covers 80 tractors, 240 trailers and a number of intracity delivery vans. There are nine mechanics. The focus is on inspection and replacement, since road calls can be very expensive. On-hand inventory is small, but backed up by agreements with local vendors.

United Parcel Service, Cerritos Hub, Cerritos, CA (March 1, 1994). Host: District Automotive Manager. Indianapolis office (January 28, 1994). Host: District Automotive Manager. Maintenance at a UPS hub focuses primarily on intracity package delivery vans, but a substantial part of the workload is the maintenance of the tractors which haul trailers between hubs. A hub is composed of one or more centers, each center comprising the delivery vans assigned to a single local area. Thirty to fifty vans and one mechanic are assigned to each center (although the mechanics at the hub can and do cross-level repair work across centers if necessary). The fleet is from diverse manufacturers, but built to UPS specifications, and largely homogeneous within centers. Repair work focuses on preventative maintenance inspections and replacement. On-hand inventory is small: parts are typically ordered for specific maintenance tasks which are prescheduled. Inventory is supported by a regional UPS parts warehouse.

American President Lines, Freight Terminal, San Pedro, CA (March 3, 1994). Host: Equipment Maintenance Manager, Pacific Southwest Region. This terminal stores containers and loads and unloads container ships. The
maintenance facility has responsibility for 325 pieces of powered equipment, including 56 yard tractors, and pickup trucks and forklifts. Thirteen mechanics work on site. Work is very cyclic, with five days of intense activity when container ships are being loaded, alternating with two days of lesser activity when major repairs and maintenance are done. Vehicles do not leave the terminal yard during operation. Inventory is fairly small, and not open to mechanics, but is supported by local parts vendors.

Federal Express Indianapolis Hub, Indianapolis, IN (April 12, 1994). Host: Manager of Vehicle Maintenance. This is a secondary hub, which handles about 26 flights per night. The vehicle maintenance operation (separate from aircraft) is responsible for 2000 pieces of equipment, including some of the ground support equipment. There are currently 19 mechanics, to grow to 28. On-hand inventory is fast-moving items only; part of inventory is maintained by local vendors. As with all FedEx facilities, they use the VAGIS information system for maintenance management, although it may need some future modifications to support the mix of equipment at a hub.

Federal Express Corporate Headquarters, Memphis, TN (April 13, 1994). Host: Director of Fleet Maintenance. We were presented with a general overview of vehicle maintenance at FedEx. Mechanics at distribution centers are given wide freedom, but corporate headquarters tries to set consistent national policies. This includes directing and monitoring of experiments with new maintenance practices, and will soon extend to parts ordering. We were also briefed on the development and current uses of VAGIS (FedEx's centralized maintenance information system) and on the specification process for FedEx vehicles.

Other Transit-related Organizations

Bay Area Rapid Transit District (BART) Technical Support Services, Oakland, CA (June 9, 1994). Host: Manager, Technical Support Services. This organization is responsible for BART's Maintenance and Reliability Information System (MARIS). During this visit we were given an overview of MARIS, its origins, and some of the other automation initiatives being pursued by BART. MARIS began as a system for simply relaying problems to maintenance personnel, but it now maintains incident reports and complete repair histories for each car and piece of track equipment which can be accessed from terminals located at each repair station. Mechanics consider it essential. Planned
improvements include ties to the inventory system, online maintenance manuals, and a client/server architecture.

**Gillig Corporation**, Hayward, CA (May 23, 1994). Host: Vice-president, engineering, quality control, and customer service. Gillig has been in motor vehicle manufacturing since before World War II, but has been a major player in transit since the early 1980s. Discussions included techniques of bus building, the engineering steps behind the design and improvement of new bus models, and a view of transit agency maintenance from a manufacturer's point of view.

**Synthesis of Site Visit Lessons**

In analyzing our site visits, we noted two different ways to divide our cases. The first is between commercial, for-profit organizations and public agencies. This difference is important because 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. towards capital investments) could not be used in the public sector, but that such transfer needs to be tempered with knowledge of the special circumstances of public agencies.

The second divide is between levels of performance. As noted previously, our site visits in this phase of the project were targeted toward agencies which scored well in our data analysis. However, even in this group there were clear differences in performance, which seemed closely related to their maintenance practices.

The result is that we were able to observe a range of performance levels and maintenance practices. These observations, detailed below, formed the basis for the research questions which we 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.² However,

²Waivers 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
commercial agencies and more efficient public agencies maintained ratios well below this figure. For the commercial agencies, the primary motivation were 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) did not have this visibility of cost. However, the more efficient public agencies had cut their ratios because of other expenses (e.g. rental of parking space) associated with a large spare fleet. The result is that commercial firms and the more efficient public agencies operated with spares ratios of 8-14 percent, implying that the current uniform 20 percent rate for public transit agencies needs further research.

**Inventory management.** A second area of differences was in inventory management. This area requires great care when comparing commercial organizations and public transit agencies because (1) the commercial organizations we 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 turned their inventory substantially more often (four or more turns compared to 1-2 for transit systems), and kept meticulous track of what was used to avoid repairs being halted for lack of parts. Interestingly, the methods used by the better organizations varied widely by complexity of the inventory, ranging from computerized parts lists linked to a national warehouse to a simple scheme where mechanics who found a low stock condition dropped a card on the stockman’s desk. In contrast, the lower-performing organizations had little visibility of their inventory performance (significantly perhaps for many of the public agencies, inventory was not managed by maintenance).

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

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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.
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 we visited were considering this seriously. One reason was because most of them have significant in-house rebuild capacity, but another seemed to be that the U.S. bus manufacturing industry is considered fragile and not able 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**

**Specialization versus Generalists/In-house versus Contract-out.** Two related issues which we discovered 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 tend to foster specialization of mechanics and to do most of their rebuild in-house, even that of components with 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 well 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 sites we visited professed not to use them. Instead, most relied on informal tests, where process changes were tried on a small scale and the results assessed 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 assure adequate design and to avoid duplication of effort.

**Information Sharing.** One of the questions we 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. Somewhat 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 for companies which are in direct competition in the same business; 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 many 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. Again, many of the efficient agencies now keep substantial paper records, and use them to set work standards, but have found that more 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 then necessary to decide what data are useful and feasible to record. How can such information be used to aid in planning and executing maintenance on a vehicle fleet? Current practice varies widely, and some of the more computerized organizations are not the most efficient.

**Upper Management Involvement.** Yet another issue for maintenance management is the degree to which maintenance is a concern of upper management, i.e. the extent to which maintenance is seen to be a core capability
of a transport organization. Once again, commercial firms and the most efficient public agencies have a fairly flat management structure, with the director of maintenance reporting directly to the general manager. Other public agencies have one or even two levels of management between the maintenance manager and the top executive.

One of our case study questions was to ask the general manager what information he looked for from maintenance to see if it was doing its job. 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 our study on maintenance data and information, we budgeted resources to carry out five case studies/site visits. In line with the overall goal of the project to find innovative maintenance practices, we focused our selection on finding agencies which were good at using maintenance information in the management of their maintenance processes. In particular, we were not primarily interested in the complexity of an agency’s computer system or the mere collection of voluminous data. Although it would have also been interesting to visit agencies which had problems in the area of maintenance information, we concentrated on success stories because we felt that good ideas are of more value in the context of our project than an inventory of potential obstacles.

Because we were interested in a somewhat intangible characteristic, namely whether an agency was good at using maintenance information, we felt that looking only at quantitative aspects of an agency’s information systems would not be useful. Instead, we began our search with a series of phone interviews with the members of the Maintenance Management subcommittee of APTA’s Bus Equipment and Maintenance committee. We were able to contact seventeen of the members and asked them to nominate properties that were good both at collecting maintenance data and in using the data to manage their maintenance function. In addition we also asked for recommendations of commercial fleet operators who made good use of maintenance information. To supplement the nominations from the Maintenance Management subcommittee, we also interviewed other contacts in the industry which we had made in the process of doing phase I.

Almost all of our interviewees gave us at least two to five agencies that they thought were outstanding in using maintenance information. There were some overlaps, but we ended up with a list of some thirty agencies. We then used our Section 15 database to provide basic information on each agency: primarily size and passenger load. We used this information to select 12 agencies which included a range of sizes and locations and also carried fairly heavy passenger loads in their size category.
We then prepared a short questionnaire that covered most of the details of maintenance data collection and use so that we could get an overview in a brief phone interview. We called the maintenance manager of each of our candidate agencies and asked him to answer the questions on our form. We also asked if the agency would be amenable to having us visit them as one of our case studies. Our final selection was based on the recommendations, the Section 15 data, and our phone interviews. The selections were:

- Reno Citifare (small, western)
- Orlando LYNX (medium, southern)
- San Antonio VIA (medium, southwestern)
- Toronto TTC (large, northeastern)
- Ryder Truck Leasing (commercial fleet operator)

We give a brief profile of each of the selected agencies 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 square miles) 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 he does, 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 to get 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 comprise the analytic staff, together with the maintenance manager himself. In addition to using FleetMate, Citifare also makes some use of other graphical programs to do graphical displays for their data, although this has not yet been used regularly 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 our visit it was not utilized. However, interest in electronic communication is growing since some parts of the RTC (e.g. planning) are not collocated with Citifare.

**Future plans.** Citifare is looking forward to Multisystems' promised improvements to FleetMate, particularly in the support modules such as purchasing. There were a number of features they would like to see in reporting formats, and they noted the possibility of using 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 limits restrict attendance at meetings.

**Orlando LYNX**

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

**Maintenance information system.** LYNX currently uses FleetMate, and has been doing so 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 about 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/fluxids 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.
On a routine basis, management 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 that cover longer periods summarizes roadcalls, inspections made, miles driven, etc. These reports are used routinely for monitoring maintenance performance, but they are frequently supplemented by special analyses to look at 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 trying to determine the details (e.g. components replaced) of a previous repair job on the vehicle they are working on.

Inventory is also managed exclusively by FleetMate, but there are some gaps in its capabilities here 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 workorders 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, primarily in tabular form, although graphics is 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 to provide their service.

Unlike many other properties, LYNX tracks several different components by serial number, even when moved between vehicles, with the specific aim of removing 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 who handles special analyses as one of his tasks. 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 new part-time programmer to help them utilize a new report writer, which will access the FleetMate database

B-5
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 (about 1200 square miles). It has 529 transit buses and 156 paratransit vehicles (VIAtans), all of which are maintained out of a single garage. The maintenance workforce (mechanics and support staff) number about 250. The transit fleet is entirely RTS buses, in order to gain the benefits of long experience with a homogeneous fleet.

Maintenance information system. Until the early 1990s, the maintenance function at VIA relied primarily on paper records for maintenance management, including maintenance histories of vehicles, timekeeping, etc. (One problem was anticipated response delays from sharing mainframe resources with administrative departments.) By 1994 some data were automated, and VIA was preparing to bring up 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 inhouse and written by a consultant to run on a single central computer. Administration of the system is done by the MIS department.

The system is now up and running, but some major procedural changes are now being considered to get more repair information, particularly more detail on task performance and using codes to designate repair activities. Other areas are also in the process of being computerized (e.g. receiving).

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 has a barcoded sticker applied, 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, and 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. To order parts, the mechanic fills out a bar coded parts request, but currently enters 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 at manual data entry later. Note that the parts are formally tied to the vehicle, not the job number.
Work done is currently 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 2-3 times per shift, but access currently requires asking a clerk to call it up, unless the job is a roadcall, in which case the recent history is printed out automatically and given to the mechanic before he heads to the vehicle.

The original design of the maintenance system was to enhance and make more convenient 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. This had been done manually before using paper records (with a three-day delay) and can now be done with the computer with only 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 attendance, breakdown of work activity, etc.

**Innovations.** Because the current system is new (and some functions are still being added), VIA is still exploring methods of using the data that is now available. Since VIA had a strong program of using its paper data, the immediate effect has been the substantial improvement in the timeliness of information, thereby making standard procedures more effective.

**Future plans.** The plans to use repair codes and to break down tasks into subparts (diagnosis, repair, check) are under way, but 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) is seen to be a major step forward in using the new and more timely data from the maintenance system.

**Toronto Transit Commission (TTC)**

**Basic statistics.** The TTC is a large, multimodal transit agency serving the metropolitan Toronto area (244 sq. miles). It operates nearly 1600 buses (including a 25-bus natural gas fleet), about 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 about 800 people. TTC’s bus fleet is relatively old [10.4 years] due both to government policy of keeping buses beyond the U.S. standard of 12 years 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 was begun in the late 1980s because of a perceived need for a maintenance management system to be used by 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 across TTC, backed up by technical people from the management services group (data processing). This team was the “interim administration” of VMS, and were responsible for its development, fielding, and initial support. Development began in 1989 and fielding is now complete; as of this writing the future management structure for VMS has not yet been decided.

**Data collection and use.** Data entry is done by the mechanics themselves, with checking by foremen. (Originally the plan was to have data entry people at each garage to enter data from paper forms, but this was abandoned for a variety of reasons.) 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 (see below). There is not as much attention to listing the parts used in a repair: this information is not much used by maintenance management, and 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 begun to use VMS information during repair. The only drawback is that data can be lost during very heavy workload periods, such as extremely cold weather.

Fuel information is kept locally by operating garage, but not tied to individual buses and is not captured by VMS. VMS is also used for timekeeping purposes, in that the hours reported are the figures fed directly into payroll. Several components are serial number tracked on buses (engines, transmissions,
and compressors are the primary components, but VMS has records of starters for some vehicles) but this is not yet a top priority and little use has been made of the data.

One feature of VMS is that little of the information is private, so that most performance measures for each garage can be seen by all managers across the system.

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

(1) The Status Summary Report, which indicates the number of buses currently available for service, along with the requirements for rush and normal service and any special needs such as charters. It is updated in real time as work is finished.

(2) The road call/change off list, which lists all vehicles with a roadcall, their problem, and status.

(3) The MTO inspection list, which lists the due date of the next six-month inspection for each vehicle.

(4) The repeater list, which lists the number of defects by subsystem for all vehicles which have been in the shop for more than a minimum number of times over some period (typically two weeks).

(5) The work pending list, which lists all deferred maintenance by vehicle. This is used to plan work when a vehicle is brought into the garage so that the out-of-service time can be put to good use.

(6) Summary of closed work orders (period covered specified by the manager), which allows a review of recently done work, what the defects were and how long 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 utilize VMS to look at 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 main innovations are the implementation of a multi-garage information system in which data flows back and forth easily, and mechanic entry of repair information. Virtually everything that gets recorded
about a repair is done by the person who either did it or supervised it. This meant that startup required training for all mechanics and a buy-in period where mechanics discovered that what VMS could do for them depended directly on their data entry.

**Future plans.** One primary aim is to enhance data entry, using new technologies such 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 ensure that TTC gets the support it has contracted for.

At the time of our visit, TTC was undergoing a reorganization, in which the garages were becoming separate 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. that specializes in vehicle leasing (other companies manage public transit agencies, provide student transportation, and provide comprehensive logistics services to other commercial firms). 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 about a 25-30% turnover per year. They have a technician (mechanic) workforce of about 8300. Branches typically have 400-500 vehicles and 20 technicians.

**Maintenance information system.** RCLS has developed a comprehensive, proprietary maintenance information system called FastTrack. At the beginning of the 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 with various ideas and pilot projects for automating different parts of the maintenance information collection and use. In late 1991 a decision was made that maintenance management was spending too much time on paperwork and not enough on interacting 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 (at present) 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 is being completed in the summer of 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 also 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 such as jobs closed and labor information. However, one of the features of the shop management system has had a very great impact on the maintenance operation: the shop management system maintains information about the qualifications and experience of the mechanics in a branch (internal Ryder training and external certification) which it uses for daily automatic job assignment.

FastTrack also sends much of the information from shop management and the service island to upper levels of the company (district to corporate). Here too the newness of the system means that these levels are only beginning to explore what additional insight this will give them.

**Innovations.** Some of the most innovative aspects of FastTrack are in diagnostics and technical documentation and the use of on-board computers for vehicle status. However, here we highlight a couple of points about the shop management system.
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 a time-consuming task (although he can modify the schedule if necessary).

The configuration information is tracked to a much greater detail than at any other organization we visited. One incentive for this is warranties: by keeping careful track of warranty information RCLS can collect warranty payments that are due. Further, the incentive for the mechanic is that the warranty claim generation is entirely automatic, since all information needed resides in the computer system.

Future plans. Since fielding of various parts of FastTrack is either still under way or have just been completed, RCLS is still exploring the potential uses of such a rich collection of data. While the shop management module has a number of cutting-edge capabilities that are of great utility at the branch level, the big opportunities are probably in using the data at the national level to compare branches and point out where good ideas and problems are occurring, and to help guide purchases of equipment with information about the nationwide performance of equipment from different manufacturers and in different configurations. This implicitly requires an analytic staff versed in maintenance at the corporate level.
APPENDIX C. MAINTENANCE DATA TYPOLOGY

MAINTENANCE DATA COLLECTION

Most discussions about maintenance information and data focus primarily on what data elements to collect. Since all transit agencies have a common set of maintenance decisions to be made, the (currently) relevant data elements are generally fairly easy to define, and so in general there is a common core of data that agencies collect.

However, since data collection in any field is a blend of experience, tradition, available technology and utility (not necessarily in that order) there are some differences between agencies: for example, a new technology may decrease the cost of collecting a previously uncollected data element, with the result that some agencies begin collecting and using this data. And so data collected is driven to change over time as vehicles, tools and work organizations themselves change. These factors operate differently on different agencies. Some of the agencies we visited in our case studies are collecting new data for these reasons and are in the process of evaluating the value of that data.

In this section we focus mainly on the core maintenance data, giving first a very high-level outline of maintenance data flow, followed by a more detailed typology of maintenance data that is generally collected today. We end by describing some potential new forms of data and collection methods that will be available to the transit industry in the near future.

BASIC FLOW OF MAINTENANCE DATA

It is convenient for discussion to divide the various potential maintenance data that can be collected into four categories: cost data, resource data, diagnostic data, and repair data (each of these will be described in more detail below). The general relation between these four categories are as shown in the accompanying diagram (note that all of the data feeds decisions made on repair management and actual repair).
Fig. C-1—Structure of Maintenance Data

Resource and cost data are developed by an agency from assessing its human and material capital. Diagnostic data is collected when a vehicle is brought up for repair. These three categories of data help the maintenance organization determine what repairs are actually made to a vehicle at any given repair opportunity. After the repair is completed and the vehicle released, information about the repair is collected, and some of it is retained for use as diagnostic information when the vehicle is brought in for repair in the future.

The term repair management in the diagram actually covers two somewhat overlapping types of decisions: day-to-day management, which includes deciding which repairs should be done on which vehicle, when and by who, and strategic management, which looks at longer term issues such as the maintainability and reliability of individual vehicles and subfleets, training of mechanics, facilities capacity, etc. In most public transit agencies, resource and cost information are not tightly linked to day-to-day management. In contrast, several of the commercial firms are making efforts to use this information in day-to-day decisions as well.
TYPOLOGY OF MAINTENANCE DATA

Cost data

Cost data is information on the cost of acquiring and applying various resources to repair. The most important costs are labor rates, fuel costs, and parts costs. Virtually all maintenance organizations track these closely for purposes of long-term or strategic planning, but few attempt to use these costs to plan daily repair except by informal methods.

There are a number of other costs which are usually tracked for financial reasons, such as inventory holding costs or facility and equipment depreciation, but these currently seem to have little impact on maintenance management. The introduction of so-called “new business practices” such as just-in-time inventory may try to include some specialized costs such as the expense of ordering priority shipments as opposed to letting a vehicle sit in repair or carrying inventory. These costs are only now being brought to the attention of transit organizations.

Resource data

Broadly speaking, this is information on the current capacity of a maintenance organization to do any given set of repairs. This includes parts on hand, tools, mechanics’ skills, and space constraints. In general, these are informally used in making day-to-day decisions, although the availability of any of these in a given organization depends largely on tradition. For example, parts on hand are usually visible to a maintenance organization only if the parts organization is part of maintenance.

Diagnostic data

This category contains data which is used both to monitor the performance of vehicles and also to provide information about problems to maintenance. By far the most common information collected on a regular basis is mileage and fluid consumption, which is used as a “first indicator” of mechanical problems. If there is a problem, all organizations record the symptoms observed. Many agencies keep track of who found the problem, at least to the extent of differentiating faults discovered by an operator or by maintenance personnel themselves.
Most agencies are also now maintaining a repair history accessible to mechanics for diagnostic use, consisting of selected data from the repair information (described below) produced when a repair is made. Agencies differ primarily in the coding of the information they retain, which affects how readily the history may be accessed for different uses.

A few agencies are collecting lifetime information on various components, primarily items such as engines, transmissions, starters, compressors, etc. Although this has long been standard practice in the aviation maintenance industry, the utility of this information to transit (particularly to buses) is being debated. One problem is that this type of data requires disciplined recording of component serial numbers as components are switched from vehicle to vehicle, which has not been common practice in the industry, leading to data quality problems, at least initially, in agencies that have attempted to collect and maintain this data.

Repair data

Repair is a complex activity, reflected in the potential complexity of the data that can be collected about its performance. For example, repair has different, overlapping phases whose boundaries are fuzzy, e.g. fixing one problem can also be diagnosis of the next one. Data collection about repair, particularly for storage in a computerized data system, requires abstracting the repair process into a well-defined framework which, while it facilitates retrieval and analysis of repair data, inevitably introduces some potential inaccuracy and loss of information into repair histories.\(^1\) Where agencies primarily differ in repair data collection is in the level of detail and approach to abstraction in coding their repair activities.

Job data. In most agencies repair information is organized by jobs (synonyms are “work orders” or “repair orders”), defined as events where a vehicle is taken out of service to have maintenance (both scheduled and unscheduled) done. Basic job data includes the date, vehicle identification, problems to be addressed, maintenance needs discovered while doing the job

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\(^1\) Note that including more detail does not necessarily imply less abstraction. An attempt to break down the repair process into small tasks on which information can be individually collected requires unambiguously dividing the repair work into those tasks. Can, for example, diagnosis and repair be separated?
that are deferred until a future job, and time in/out of maintenance. Selected
details of the actual repair work, i.e. the individual repairs done on the vehicle
are also recorded, usually as specific tasks. The organization of task data is
treated in the next few paragraphs.

Task data. Tasks are somewhat more difficult to define than jobs. A task is
envisioned as a related set of repair actions on a vehicle system/subsystem, but
the actual grain of a task varies somewhat across the transit industry. In general,
the aim is to characterize a piece of work of one to several hours in duration, but
to a certain extent the definition is driven by technology: if finer details of the
repair process can be captured in terms of labor time, parts usage, etc. there will
be some tendency to define tasks to be smaller chunks of work.

The basic minimum for a task description is the date, system/subsystem
worked on, usually in coded form, and a short text description of the repair
accomplished. The system/subsystem code allows retrieval of repairs by the
system which was fixed; this facilitates history use and is in itself a useful
diagnostic tool. The text description, if entered into a computer system to be
retrieved with the system/subsystem code, is valued by mechanics working on
subsequent jobs because of the detail it provides on what was actually replaced,
changed, tested, etc. Paper copies of text from the work order are often filed, but
are apparently seldom used because of the inconvenience (location far from the
shop, difficulty of limiting retrieval by system/subsystem, etc.).

A second set of task data which is used for both daily and strategic
management is the mechanic(s) who did the work, the time spent, and the parts
used. This data is either collected by all agencies we visited or they have plans to
collect it in the very near future as they bring new maintenance data systems on
line. The mechanic who did a piece of work is already usually kept in paper
form. Time spent on a job allows creation of average times for specific repairs
(plus some idea of their variability), which is needed to help match resources to
needs. Parts used can be valuable both for evaluating mechanics and for helping
to identify what work was done.

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2The work of L. DiBello and her colleagues at CUNY on NYCTA’s MIDAS system has
developed some very interesting insights into the advantages and disadvantages of text vs.
codes, and has done some experimentation with allowing system/subsystem codes to be defined
in an evolutionary way by mechanics as they work. This raises the interesting possibility of
having different levels of detail for different makes of vehicle and for different operating
environments (DiBello, personal communication).
Text is the most flexible medium for describing what happened during a repair, but generally needs to be entered into a computer for access, where its form is probably least useful for analysis. It is therefore often supplemented or even superseded by computer-oriented codes for information such as failures (what was wrong) and repair (what was done). The codes obviate the entry of handwritten text (which may be handwritten and/or unreadable) with a keyboard, and they allow recall of task records by these categories. One disadvantage with any such codes is that they abstract the task done: if both replacement and adjustment are done on a subsystem, what should be the code for the repair, unless multiple repair codes are allowed for each task?

Agencies which have decided to code failure and repair as well as system/subsystem codes have implemented them in roughly two distinct ways, which leads to some interesting questions as to how this data is used. The two approaches are:

1. Use separate codes for system/subsystem, failure and repair. This has the advantage of separating all of the codes for clarity in both entry and retrieval, but it also means that someone, a mechanic or data entry person has to look up three different codes. This means that the list of codes, for failure and repair in particular, need to be reasonably short and, since they apply to all systems, somewhat generic. This limits the detail they can provide which leads to the question of how much they can really tell the mechanic or analyst. The alternative is a detailed list of which only a few codes are ever used.

2. Use combined codes for system/subsystem and repair and omit the failure observed. This choice has the advantage of making the repair context-sensitive, since the repairs differ with system/subsystem, but again at the expense of lengthening the list.

The criterion for determining which alternative is more desirable is what use the data can be put to. There seems to be no doubt that being able to access the system and subsystem both separately and together is very useful both for day-to-day management of repair and for strategic planning (see the examples in Section 2 of the report). Repair codes allow the analysis of time requirements and parts usage to finer levels (suggesting that unless those pieces of information

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3 Technology may intervene here with increasing use of computers and context-sensitive menus for failure/repair based on system/subsystem.

4 Data entry can be aided with technology (e.g. barcode readers).
are collected the repair codes are not particularly useful). The only question then is whether repair codes need to be accessed separately for analysis; is there value in tabulating how many cleanings, replacements, removals\textsuperscript{5} etc. occurred independent of the system/subsystem. This is not clear from our case studies, nor does there appear to be any research on the subject.

Failure codes have the same problem as repair codes with their applicability to different systems/subsystems, and many agencies simply do not use them. With one clear exception, most failure codes are not interesting unless paired with a system/subsystem, and in those cases text often serves quite as well for day-to-day repair management. The exception is a code for “no trouble found”; this can be quite valuable as an indicator of problems in diagnosis over many different subsystems.

There are a number of pieces of task information which are not widely collected. When they were collected in agencies we visited or talked with, we found that the data did not yet have widespread use. The most prominent data element is the recording of a component’s serial number for diagnostic tracking. It is currently used primarily for warranty claims, although some agencies have moved towards doing lifetime analysis on tracked components to support removing a component before failure. Other such data elements include the time to get parts (request to issue) and start/stop times for a task. In these cases, technology has only recently allowed this to be captured at all conveniently and so analytic techniques and uses are not well-developed.

NEW TYPES OF DATA AND THEIR APPLICATIONS

The collection of several new data items is now feasible due to the availability of much more capable computer systems and the use of automatic input devices such as magnetic card swipes and bar code readers. For example, even desktop computers now have the capacity to store the configuration histories of many vehicles, down well beyond the few major components such as engines and transmissions that are tracked today. The use of this information is another matter: data quality problems and a lack of experience with this data both lead to lack of substantial use. This lack of experience raises the question as

\textsuperscript{5} To take examples from one of our case studies’ list of separate failure codes.
to the utility of collecting this kind of data. While the technology surely exists, it is a serious research question as to how the data can be effectively used.

One further source of diagnostic data needs to be mentioned. Current vehicle technology uses computers extensively for control of engines, transmissions and other vehicle systems. Those computers also have the capability to collect and store extensive diagnostic information about the components they control. In addition, vehicle computers can record and store global information such as vehicle location, speed, time, etc. Current vehicle maintenance systems and analysis methods have no capability yet to deal with this data, either in storing it for future use or in using it to direct repair. This wave of data collection capabilities will dwarf the data flood the industry has seen in the past few years.
APPENDIX D. REFERENCES


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D-1


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