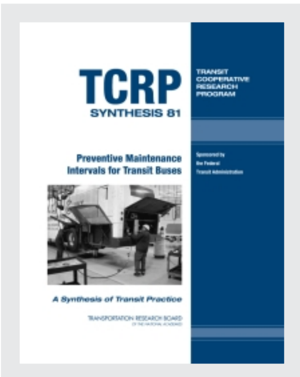

Preventive Maintenance Intervals for Transit Buses

DETAILS

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP SYNTHESIS 81

Preventive Maintenance Intervals for Transit Buses

A Synthesis of Transit Practice

CONSULTANT

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SUBSCRIBER CATEGORIES

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TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.

2010

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academy of Sciences, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by TRB. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

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The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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THE NATIONAL ACADEMIES

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Cover figure: Courtesy of LYNX, Orlando, Florida.

FOREWORD

Transit administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the transit industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire transit community, the Transit Cooperative Research Program Oversight and Project Selection (TOPS) Committee authorized the Transportation Research Board to undertake a continuing study. This study, TCRP Project J-7, "Synthesis of Information Related to Transit Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute a TCRP report series, *Synthesis of Transit Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Donna Vlasak
Senior Program Officer
Transportation
Research Board

This synthesis studied preventive maintenance measures taken by a sampling of transit agencies to ensure buses are on time, protect taxpayer investments, and promote passenger satisfaction and public safety. The synthesis is offered as a primer for use by maintenance managers and other interested transit agency staff, as well as state and metropolitan transportation and planning agency staff, university educators, and students, to help lessen the number of inconvenienced passengers and the potential for safety-related incidents. Case studies reported on an automated onboard bus monitoring system, a technician certification program, and a review of challenges faced by a transit agency dealing with a diverse fleet mix. The study revealed how preventive maintenance intervals and activities were established at different agencies, understanding that each has a different fleet makeup, operating environment, and maintenance philosophy.

This synthesis is based on the results of a survey questionnaire received from transit agencies in the United States and Canada, a literature review, and telephone survey interviews conducted with three transit agencies as case studies.

John J. Schiavone, J. Schiavone Consulting, Guilford, Connecticut, collected and synthesized the information and wrote the paper, under the guidance of a panel of experts in the subject area. The members of the Topic Panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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PREVENTIVE MAINTENANCE INTERVALS FOR TRANSIT BUSES

SUMMARY

The objective of every maintenance department is to anticipate repairs and initiate activities that prevent mechanical failures. Transit agencies perform various preventive maintenance (PM) activities at specified intervals to achieve this objective. Some intervals evolve from manufacturers' specifications and agency experiences; others are simply handed down over time with no real understanding of where they came from. This study examines preventive measures taken by a sampling of transit agencies to ensure buses are on time, protect taxpayer investments, and promote passenger satisfaction and public safety. Effective PM also ensures that buses reach useful service life as defined by the FTA.

The approach to this study consisted of a survey questionnaire, literature review, and telephone interviews conducted with three agencies as case studies. The survey questionnaire, posted on the Bus Fleet Maintenance listserve, produced 38 agency volunteers from the United States and Canada. Collectively these agencies represent a fleet of 12,062 transit buses, traveling more than 503 million miles annually. A review of the survey responses confirmed that agencies of various fleet sizes are equally represented. The sample is not random; therefore, although it is diverse in terms of size and geography, there is no guarantee that it is representative.

Survey responses revealed a mixture of both common and varied approaches to PM. The range is understandable given the variety of bus fleets, assorted onboard bus equipment, and different operating and environmental conditions. Survey responses are summarized here to provide an overview of how agencies carry out bus PM programs to help reduce the nearly half million in-service mechanical breakdowns that occur in the United States annually.

- Of survey responders, 92% conduct preventive maintenance inspections (PMIs) on buses between every 2,000 and 6,000 miles, with 71% doing them exactly at 6,000-mile intervals. No agency reported using anything but mileage for this critical PM activity.
- Sixty-one percent reset PM intervals based on the actual mileage of the previous interval; 39% base them at fixed-point intervals regardless of the previous interval.
- Forty-two percent use a window of 10% to determine if PMs are done according to schedule.
- Seventy-four percent establish PM intervals to maintain original equipment manufacturer (OEM) warranty coverage; 82% of them continue to follow OEM suggested intervals after warranties expire.
- When it comes to using OEM specifications to establish PM intervals, 87% use them for engine oil and filter changes, 71% for transmission fluid and filter changes, 60% for tire pressure and depth, 50% for brake adjustments and wheel lug nut torque, and 45% for brake lining thickness.
- All responding agencies use some form of checklist to guide PM activities; 59% use checklists unique to specific buses and equipment; and 41% use generic ones.
- Eighty-four percent provide some form of pass/fail criteria for carrying out PM inspections and repairs.
- Seventy-nine percent have written instructions for technicians to follow when conducting PMIs.

- When carrying out PMIs, 60% use skilled technicians, 16% entry-level personnel, and 24% use other skill levels (typically a combination of both skilled and unskilled).
- Sixty-one percent use the same technician to conduct all aspects of each PM activity; 39% split responsibilities.
- All 38 survey responders reported using some type of software program to schedule and guide PM activities; however, they use 22 different programs.
- Software programs that determine optimal part and component replacements based on life-cycle cost calculations are used on an extremely limited basis.
- Seventy-four percent have calculated the time needed to conduct PM activities.
- Only 63% have calculated costs associated with PM.
- The median time needed to conduct the most common PM activities is 3.0 h for an "A" bus inspection; 5.0 h for a "B" bus inspection; 8.0 h for a "C" bus inspection; 3.0 h for a heating, ventilation, and air conditioning PMI; and 2.0 h to conduct a wheelchair lift and ramp PMI.
- The median cost (parts and labor) for conducting the most common PM activities is $162 for an "A" bus inspection; $208 for a "B" bus inspection; $448 for a "C" bus inspection; $566 for a heating, ventilation, and air conditioning PMI; and $140 to conduct a wheelchair lift and ramp PMI.
- One-half of survey responders calculate the number of spare vehicles needed to support PM activities, with 55% needing a 20% spare bus ratio.
- Fifty-one percent issue a parts kit containing all parts needed for each PM activity.
- Seventy-nine percent have quality assurance (QA) measures in place to follow up on PM activities; 41% of them conduct random or spot inspections.
- When defects are noted during PMIs, 46% repair them immediately unless parts are not available, 8% make repairs provided they can be done in an established time period, 11% schedule repairs afterwards, and the remaining 35% cite other repair policies.

When asked what information, tools, or additional resources would help them establish better PM intervals and programs, agencies responded with several requests:

- Sharing of PM information between agencies;
- Consolidating all bus PM information into one convenient manual;
- More reasonable PM schedules and specifications from OEMs;
- Additional staff and resources to analyze data, failure trends, times, etc;
- Dedicated QA staff to analyze failures and update PM procedures; and
- Additional software capabilities.

The literature review produced several definitions for PM that are best summarized as a series of planned actions where labor and vehicle downtime are anticipated, and where the overriding intent of these actions is to ensure customer satisfaction by providing safe and on-time bus service. The literature review also revealed various U.S. DOT requirements pertaining to bus inspections. Included are driver inspections, periodic inspections conducted by maintenance personnel, criteria for determining equipment safety, and recordkeeping requirements.

There were several bus-specific publications reviewed on PM that, although dated, present useful information on predicting replacement intervals for parts and major components, and for calculating life-cycle costs. Modern software programs, however, make parts and component replacements easier to predict. Despite these advances, survey responses indicated limited use of these programs. An exception is Dallas Rapid Area Transit, which uses Weibull mathematics to help it decide whether to replace certain parts as a preventive measure in advance of failure.

Case studies examined an automated onboard bus monitoring system in use at the Washington Metropolitan Area Transit Authority that automatically downloads fault data as buses enter the service line. Buses actually provide verbal commands by means of onboard speakers to service personnel when malfunctions need immediate attention. Another case study examined a technician certification program established by Whatcom Transit in Washington State to make certain all technicians perform bus inspections in a like manner according to agency-established requirements. The certification program pairs experienced technicians with new hires to ensure they can correctly perform PM inspections. A review was also made of challenges faced by the Central New York Regional Transportation Authority in dealing with its diverse fleet. This agency finds it effective to have each department within its maintenance organization (brakes, electrical, etc.) perform specialized PM inspections and repairs according to detailed, vehicle-specific checklists.

Material from this synthesis found that predicting maintenance needs with accuracy is no easy task. Success or failure falls squarely on the ability of the maintenance department to develop and execute an effective PM program. Regrettably, there is no one program suitable for all agencies to follow owing to the wide variety in equipment, operating environment, and available resources. Despite the differences, five steps were identified through this study that could assist agencies in implementing a more effective PM program:

1. Monitor and Benchmark both Scheduled and Unscheduled Maintenance—A monitoring system that distinguishes between scheduled maintenance activities versus those made as reactive measures to address unexpected failures establishes a benchmark for PM performance.
2. Establish Foundation PM Intervals and Related Activities—An effective PM program is one that first satisfies regulatory requirements and manufacturers' specifications. Integrating more thorough driver and service line inspections into the overall PM program makes it more comprehensive and effective at reducing in-service mechanical breakdowns.
3. Consider Local Operating Conditions and Experiences—Once foundation PM intervals and related activities have been established they can be modified by analyzing the causes of unscheduled maintenance and accounting for local conditions and experiences.
4. Implement a QA Program—Successful PM programs depend on the quality of work done by those operators, technicians, and service line personnel who carry them out. A QA oversight function verifies that PM inspections and repairs have been done thoroughly and correctly.
5. Data Analysis and Program Refinement—PM constantly evolves. Improvement is a continuous cycle of monitoring unscheduled maintenance events, analyzing the information generated from the data to determine root causes, and fine tuning the PM program by altering intervals, adding new maintenance procedures, or both to reduce the number of unscheduled events.

Findings from this synthesis suggest four areas of future study:

1. Standard procurement language that directs OEMs to group PM schedules and activities for all bus-related equipment into one convenient location.
2. An industry-sponsored peer review program that assesses fleet conditions in terms of the number of per-bus defects and safety violations, examines records to determine adherence to PM policy, and assists agencies in establishing more effective PM programs.
3. Determine staffing level requirements for maintenance personnel including the number of technicians needed to carry out PM activities based on fleet size, fleet makeup, level of advanced technology, operating conditions and environment, and other factors.
4. Examine how maintenance data could be analyzed to assist maintenance managers in establishing more cost-effective PM intervals and related repair activities.

CHAPTER ONE

INTRODUCTION

PROJECT BACKGROUND AND OBJECTIVES

Preventive maintenance (PM) measures are performed at relatively fixed intervals throughout the transit bus industry. In some cases the intervals and related PM activities are based on legal requirements, the agency's operating environment and experiences, and specifications provided by equipment manufacturers. There is also anecdotal evidence suggesting that in some instances, the interval was simply borrowed from a peer organization with little or no other basis than "if it worked there, it should work here."

This survey of current practice determines just how PM intervals and activities are established at different agencies, understanding that each has different fleet makeup, operating environment, and maintenance philosophy. Information obtained through this study is used to establish:

- How transit agencies identify PM intervals and activities;
- Common PM intervals used in transit, notable variations, and the rationale for both;
- Experience level of the staff performing different PM activities;
- Repair policies for defects identified during PM inspections;
- Quality assurance (QA) measures placed on PM activities;
- Particular components or systems that may benefit from a special PM interval;
- The role of daily service line functions in PM;
- How PM intervals relate to spare ratio and useful life;
- How PM programs relate to road call experience and bus availability;
- Allocation of parts and labor costs for PM;
- Software programs that facilitate the PM process; and
- Tools for predicting parts failures.

This study is intended as a primer on transit bus PM for use by maintenance managers and other interested agency personnel, officials of state and metropolitan transportation and planning agencies, and university educators and students. In particular, bus maintenance personnel will be able to compare their PM program with others, learn from peers, and implement new procedures as proactive measures to help anticipate and prevent mechanical breakdowns instead of merely reacting to them. In 2007, there were more than 425,000 transit bus mechanical failures that resulted in revenue service interruptions in the United States (*1*). Although breakdowns can never be fully eliminated, measures taken by transit agencies to improve their PM program as a result of information obtained from others will help lessen the number of inconvenienced passengers and the potential for safety-related incidents.

TECHNICAL APPROACH

The approach to this synthesis included a literature review, a survey of transit agencies, and telephone interviews with three agencies selected as case studies. A Transportation Research Information Services (TRIS) search using several different keywords was conducted to aid the literature review.

The survey questionnaire was designed to elicit PM statistics directly from those responsible for transit bus maintenance. Once the survey questionnaire was finalized with input from the oversight panel it was posted on the Bus Fleet Maintenance listserve managed by the University of South Florida, Center for Urban Transportation Research. Of the 38 U.S. and Canadian agencies that volunteered to participate, all completed the survey for a 100% response rate. Table 1 shows the distribution of responding agencies by fleet size.

Agencies that responded to the survey operate a combined fleet of just over 12,000 buses traveling more than 503 million miles annually. The propulsion makeup of the average bus fleet is 78% diesel, 14% compressed natural gas (CNG), 4% electric-hybrid, 2% gasoline, and 2% electric trolley. The Fleet Profile of all participating agencies is attached as Appendix A, sorted by fleet size, fleet makeup in terms of bus propulsion type, and fleet mileage. A copy of the survey questionnaire with summarized responses is attached as Appendix B. The sample is not random; therefore, although it is diverse in terms of size and geography, there is no guarantee that it is representative.

REPORT ORGANIZATION

Following this introductory chapter, chapter two summarizes the findings of the literature review and presents the PM classifications used in this study, which also serves to review the subject of PM. Chapter three, the first of two chapters to present survey findings, examines the state of the practice with a focus on PM intervals, including how agencies establish and

TABLE 1
TRANSIT AGENCY BY SIZE

No. of Buses in Fleet	No. of Agencies Responding	% of Agencies Responding
1–50	7	18
51–100	6	16
101–200	6	16
201–300	5	13
301–500	6	16
500+	8	21
Total	38	100

schedule those intervals, common PM intervals used, and procedures for determining when parts need to be replaced. Chapter three also examines factors that most influence the setting of PM intervals such as manufacturer specifications and the agency's own experiences based on data collection and analysis, environmental and operating conditions, and fleet make-up.

Chapter four looks at specific PM inspection, repair, and overhaul activities that take place at scheduled intervals. This chapter also examines checklists and other tools used to guide PM activities, manpower and bus spare ratio considerations, QA measures, PM cost calculations, and how agencies go about repairing defects identified during PM inspections.

Chapter five consists of three case studies that examine defined aspects of PM. Included are:

- A technician certification program developed by the Whatcom Transportation Authority in Washington State to improve the quality of PM.
- An automated onboard system in use by the Washington Metropolitan Area Transit Authority (WMATA) that automatically downloads vehicle health data as the bus enters the service line by means of wireless communication, and actually provides verbal instructions to maintenance personnel regarding vehicle faults that need immediate attention.
- The PM approach used by the Central New York Regional Transportation Authority (Centro) to deal with its wide variety of bus types and various PM classifications it has created to address fleet diversity.

The report ends with conclusions, lessons learned, and suggested areas of future study (chapter six).

CHAPTER TWO

LITERATURE REVIEW AND PREVENTIVE MAINTENANCE CLASSIFICATIONS

INTRODUCTION

This first portion of this chapter summarizes findings from a literature review of PM programs. The second provides a general overview of PM classifications, which also serves to review the overall subject.

LITERATURE REVIEW

Findings from the literature review are grouped under various PM definitions found, inspection regulations established by the U.S.DOT, PM portions of a comprehensive study written specifically for buses, and five essential steps to PM as adopted from the trucking industry.

Preventive Maintenance Definitions

Although PM definitions are expressed differently, the literature search revealed that the intent is very similar. Weibull, a noted resource for predicting component reliability, defines PM as a schedule of planned maintenance aimed at the prevention of breakdowns and failures (*2*). The definition continues by stating:

> The primary goal of PM is to prevent the failure of equipment before it actually occurs. It is designed to preserve and enhance equipment reliability by replacing worn components before they actually fail . . . Recent technological advances in tools for inspection and diagnosis have enabled even more accurate and effective equipment maintenance. The ideal PM program would prevent all equipment failure before it occurs.

The Department of Defense defines PM as:

> The care and servicing by personnel for the purpose of maintaining equipment in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects (*3*).

A study entitled *Bus Fleet Management Techniques Guide,* reviewed in greater detail here, provides a similar definition:

> Preventive maintenance is carried out at predetermined inspection intervals, typically based on accumulated mileage, or other prescribed criteria, such as when a monitored condition exceeds a tolerance level. This type of maintenance is intended to reduce the likelihood of the in-service failure of components by anticipating their failures . . . As preventive maintenance is increased, the amount of emergency repairs should decline, thereby increasing the efficiency of the maintenance operation and resulting in better control of costs (*4*).

John Dolce in his book *Fleet Management* expresses a similar definition with a focus on PM inspections:

> Preventive maintenance inspection . . . is a systematic servicing and inspection of motor vehicles and equipment on a predetermined interval based on time, mileage, engine hours, or gallons of fuel used. The interval varies with the type of equipment and the use to which it is assigned (*5*).

As the various definitions imply, equipment and manpower considerations are critical. However, the most important tenet of PM is to ensure customer satisfaction by presenting buses that are safe to passengers, preserve taxpayer investment, and are capable of delivering on-time service without mechanical interruptions. Effective PM also allows buses to reach their useful service life as defined by the FTA.

Department of Transportation Regulations

The literature search also revealed a series of U.S.DOT regulations. Local and state governments typically have similar requirements; agencies are urged to seek out and become familiar with all legal aspects of vehicle inspection and repair.

Code of Federal Regulations Title 49

The U.S.DOT has several publications that pertain to vehicle inspections. Primary department of transportation (DOT) requirements reside in the U.S. Code of Federal Regulations (CFR), Title 49, which applies specifically to transportation. Of special interest is CFR 49 Chapter Three, which contains regulations established by the FMCSA, a division within the U.S.DOT (*6*). The government agency is charged with reducing crashes, injuries, and fatalities involving large trucks and buses. In addition to enforcing commercial driver's license (CDL) requirements and the transportation of hazardous materials, FMCSA issues and enforces a host of regulations affecting vehicle safety, including periodic inspections. While FMCSA regulations apply to commercial trucks and buses, many transit agencies use them as a guideline for their own maintenance operations.

CFR 49 Part 396

FMCSA's Vehicle-Related Regulations, CFR 49 Part 396, specifically addresses inspection, repair, and maintenance. Table 2 lists various subparts of Section 396. Guidance on some regulations is provided by the FMCSA, indicated by "Yes" in the last column of Table 2. Summary guidance information is provided here; complete information is found at http://www.fmcsa.dot.gov.

Appendix C summarizes interesting sections of CFR 49 Part 396 in greater detail. Of particular interest is Section 396.5, Inspection, Repair and Maintenance, which requires push-out windows, emergency doors, and emergency door marking lights to be inspected every 90 days at minimum, and maintain records showing compliance. Technicians must be qualified to carry out vehicle and brake inspections (Parts 396.19 and 396.25). Minimum criteria needed for passing vehicle inspections are also listed (Appendix G of Part 396). Again, transit agencies may want to review these commercial vehicle requirements and adapt them for their own use.

CFR 49 Part 393

Another essential DOT requirement is CFR 49 Part 393, Parts and Accessories Necessary for Safe Operation. Although most are directed at manufacturers to ensure compliance with Federal Motor Vehicle Safety Standards (FMVSS), the end user is responsible for ensuring that parts remain in place, are operational, and continue to comply with requirements when replaced.

CFR 49 Part 37

Under 49 CFR Part 37, Americans with Disabilities Act (ADA), "Transportation Services for Individuals with Disabilities," transit agencies are required to have a system of regular and frequent maintenance checks for wheelchair lifts, ramps, and other required equipment on non-rail vehicles that is sufficient to ensure that the lifts are operative. Although ADA does not prescribe how wheelchair lifts and other required accessibility equipment are to be maintained, Section 37.163 states that "the point of a preventive maintenance program is to . . . catch broken lifts as soon as possible, so that they can be repaired promptly" (*7*).

Responsibility for assuring accessibility equipment reliability becomes a collaborative effort between bus operators and maintenance personnel. Although there is no specific requirement for daily cycling of lifts or ramps, many agencies require operators to perform this practice before beginning service (see Operator Inspections on page 11). Operators are, however, formally required to immediately report lift failures, while maintenance personnel must promptly make repairs. Agencies are in violation of ADA if they fail to check lifts regularly and frequently, or they exhibit a pattern of lift breakdowns in service. Additional information regarding ADA maintenance requirements can be found at http://www.fta.dot.gov/civilrights/ada/civil_rights.

Satisfying Inspector Requirements Through Automotive Service Excellence Certification

One way to ensure that technicians meet applicable regulatory requirements is through the Automotive Service Excellence (ASE) Transit Bus Maintenance Certification Program. The ASE program, previously available only for automobile and truck technicians, has been expanded to include buses. The program, which is completely voluntary, was made possible by TRB through TCRP.

TABLE 2
FMCSA VEHICLE-RELATED REGULATIONS, PART 396

Part	Regulation	Guidance
396.1	Scope	
396.3	Inspection, repair, and maintenance	Yes
396.5	Lubrication	
396.7	Unsafe operations forbidden	
396.9	Inspection of motor vehicles in operation	Yes
396.11	Driver vehicle inspection report(s)	Yes
396.13	Driver inspection	Yes
396.15	Drive-away and tow-away operations and inspections	
396.17	Periodic inspection	Yes
396.19	Inspector qualifications	Yes
396.21	Periodic inspection recordkeeping requirements	Yes
396.23	Equivalent to periodic inspection	Yes
396.25	Qualifications of brake inspectors	Yes
Appendix G	Minimum Periodic Inspection Standards	Yes

Note: Applies to commercial trucks and buses.

ASE certification provides an objective measurement of mechanical and electrical competency in ten specific bus areas. Several tests, including those for bus brakes and electrical/electronics, have already been developed. One pertaining to preventive maintenance inspections (PMIs), referred to as Test H8, is also now available. Additional information and study guides can be obtained from ASE at http://www.ase.com. Information on the ASE program is available from TRB at http://www.trb.org.

Bus Fleet Management Techniques Guide

Although written in 1985, *Bus Fleet Management Techniques Guide,* Maze et al. (*4*) offers useful insight and information regarding PM as it applies to transit buses. The *Guide* addresses three basic areas:

1. Statistical analysis of component and part failure mileages for maintenance planning,
2. Life-cycle economic analysis for component and bus replacement and decision making, and
3. Nontechnical methodologies for maintenance management information systems.

Optimum Component PM

Of interest to this study is information regarding the optimum level of PM for each part or component, which according to the *Guide* depends on five factors:

1. Component Failure Patterns, classified as "age-dependent," such as brake shoes, and "age-independent" such as fuses. Preventive replacement is only appropriate for components that exhibit age-dependent patterns.
2. Repair Costs. If it costs just as much to repair an item before it fails as it does after it fails, then the item should be replaced after it fails, except where failure of the part in question can cause collateral damage or result in service interruption.
3. Vehicle Spare Ratio. The flexibility to schedule preventive component replacements is a function of the number of spare buses available.
4. Ability to Monitor Component Condition. PM can be performed when a condition check indicates that the component is wearing out. Brake shoe inspections are a common example.
5. Safety implications. In cases where safety is involved (i.e., brakes), safety rather than cost minimization should dictate preventive and corrective maintenance levels.

Predicting Component Failure

The *Guide* devotes several chapters to Weibull Distribution Failure Analysis, which uses a scientific approach to determine intervals for replacing parts and components. As noted in chapter three of this study, the Weibull analysis allows managers to predict component life by monitoring life data from a representative sample of vehicles. Since publication of the *Guide,* computer programs have been developed that more easily make the needed calculations. One such application used by Dallas Area Rapid Transit (DART) is described in chapter three of this study.

Four Approaches to Component Maintenance

The *Guide* describes that part or component maintenance can be accomplished in four ways:

1. Condition-Based Maintenance, where monitoring and inspections are used to determine replacement intervals. Brake shoe wear and oil consumption are two examples.
2. Fixed-Mileage Maintenance, where maintenance actions are carried out at regular mileage intervals such as engine oil and filter changes.
3. Operate-Until-Failure Maintenance, where all maintenance actions are corrective in nature. This is done as a default in cases where parts are not being monitored or when it is more cost-effective to replace a part after failure because there are no safety or service interruption implications.
4. Design-Out-Maintenance, where the maintenance problem is removed through redesign. An example given is where the location of the air conditioning system in advanced design buses of the early 1980s was moved into a separate compartment above the engine.

Life-Cycle Costing

The *Guide* also discusses the applications of life-cycle costing (LCC), where PM is identified as a significant cost driver. Although most of the discussion applies to the overall vehicle procurement, similar LCC principals presented in the *Guide* can be applied to individual bus parts and components.

Additional information regarding LCC is presented in a TRB paper by Hide et al. (*8*). Detailed and accurate monitoring of vehicle operating costs on a component basis is essential to determining lifetime performance of individual vehicle types. Research conducted by the authors identified 12 months as the most satisfactory period over which to aggregate vehicle operating costs. A comprehensive LCC system provides management with the ability to monitor current cost trends, predict future costs, and assess the implications of different policy decisions. According to the study, benefits of an LCC system have been demonstrated to be the equivalent of renewing 1.5% of the vehicle fleet annually at no additional cost, while at the same time improving vehicle availability.

Five Steps to Effective Preventive Maintenance

In the article "Five Steps to Improving a Government Fleet Preventive Maintenance Program," Robert Johnson, with the National Truck Equipment Association, offers a sensible approach to optimizing PM programs (*9*). Elements of that approach have been modified based on the literature review and survey responses to make them more comprehensive and applicable to bus transit.

1. Monitor and Benchmark both Scheduled and Unscheduled Maintenance—The effectiveness of a PM action or program cannot be evaluated unless scheduled and unscheduled maintenance events are accurately tracked by bus type (year, make, model, etc.) and major bus components (engine, transmission, axles, etc.). Monitoring provides a benchmark to gauge whether modifications made to the PM program are indeed producing fewer service interruptions. Adding detail about each repair will greatly assist with failure analysis.
2. Establish Foundation PM Intervals and Related Activities—Essential elements of PM include daily operator and service line inspections and periodic PMIs. Bus operator inspection requirements are specified in DOT regulations. However, agencies can also provide basic technical training to bus operators and work with them in a team setting to make their inspections integral to the overall PM program. Likewise, daily service line inspections can be enhanced with additional activities and by making greater use of electronic onboard monitoring and reporting systems.

   When it comes to scheduling PM, the most efficient scenario according to Johnson is one where activities are grouped and the number of intervals or "touches" is minimized. The process begins by fully understanding PM requirements established by original equipment manufacturers (OEMs), as well as safety inspection requirements established by federal and local authorities.
3. Consider Local Operating Conditions and Experiences—Once foundation intervals and activities have been established to satisfy OEM and regulatory requirements, Johnson recommends adding other preventive steps. Included are those that address local operating conditions and take into account experiences gained through the agency's monitoring program and fault analysis.

   Modifications to foundation intervals must conform to regulatory requirements. Actions taken outside OEM specifications may violate warranty coverage and are best done in consultation with them.
4. Implement a Quality Assurance Program—A PM program is only as good as the operators, service line personnel, and technicians carrying out the work. To ensure PM activities are done correctly, a QA program is vital. In cases where technicians performing inspections are also required to make any needed repairs, there may be a tendency to overlook certain defects to avoid the work involved. In other cases personnel may lack experience and the ability to properly identify defects. Given the importance of PM and related safety implications, all tasks—inspection and subsequent repairs—must be done correctly. This could be verified by random spot checks performed by dedicated QA personnel or by maintenance supervisors and lead technicians. Any deficient work identified should then be used as an opportunity to retrain staff.
5. Data Analysis and Program Refinement—Examine incidents that take place between planned maintenance events, look for trends and causes of failures, and take corrective action by adjusting scheduled PM activities and intervals accordingly. Needed actions resulting from analyses should be included on PM checklists and work orders for technicians to follow. These instructions require constant updating and should be unique to each bus and equipment type.

   Regardless of how well conceived and executed, a PM program is constantly evolving based on new data and changing technology, conditions and service demands, and fleet retrofits and acquisitions. Some PM actions are put in place to address new propulsion technologies. Others are seasonal, temporary, or directed at specific fleets such as aging buses that typically need more attention. A PM program must evolve over time to be effective. Monitoring systems that distinguish between scheduled and unscheduled maintenance will help determine if changes made to the PM program are yielding desired results.

PREVENTIVE MAINTENANCE CLASSIFICATIONS

PM can be classified in various ways. For this study, it is broken down into three fundamental elements:

1. Inspections;
2. Repairs, campaigns, and replacements; and
3. Overhauls/refurbish.

Basic information provided here is also intended as a general overview of PM. Chapters three and four detail measures taken by survey responders in carrying out specific PM activities.

Inspections

Inspections are the most common form of PM and typically consist of three separate and distinct functions:

1. Service line inspections,
2. Operator inspections, and
3. PMIs.

Service Line Inspections

Service line inspections are generally done daily as buses get refueled and cleaned. The purpose is to check vital fluid levels, examine tires for excessive wear and adequate air pressure, visually check for body and other damage, and to obtain as much information as possible about the well being of major bus systems. How service line inspections are conducted depends on the level of automation.

With a manual approach, inspections are done with little or no electronic assistance. Although vital and necessary, the method is limited because personnel performing these duties (referred to as cleaners or hostlers) generally lack technical experience. Manual inspection procedures usually consist of "bumping" the tires with a rod or stick, listening for a particular sound that indicates low tire pressure; manually checking engine oil, transmission fluid, and coolant levels; visually checking the engine compartment for leaks, listening for unusual sounds and other abnormalities; and walking around the bus to note inoperative lights and body damage. Hostlers also enter fuel and fluid consumption data and note any inspection irregularities before taking buses through the washer and back to parking locations. Driving to and from the service line also serves as a road test of sorts.

Manual service line functions are gradually being replaced by more sophisticated electronic systems such as the one used by WMATA highlighted in chapter five. The system continually monitors and records onboard functions and transmits abnormalities in real time and automatically downloads data as the bus enters the service line depending on how critical the malfunction is. Advances in electronics, now part of virtually every bus control system, make it much easier to collect onboard data because of the ability to electronically monitor, store, and report abnormalities when prompted (*10*).

Integrated onboard data collection with automatic downloading is an ideal service line tool in that it relieves hostlers of making many routine daily inspections and provides information well beyond the abilities of even the most experienced technicians.

Operator Inspections

Bus operators also provide an excellent daily inspection opportunity, especially when assigned to the same bus where they can become more sensitive to abnormal conditions. Operators, depending on agency size, may be legally required to perform pre-trip inspections as part of their CDL requirement (*11*). CDL requirements direct operators to inspect:

- Engine compartment (engine off)
- Engine start and instrument function
- Brake systems, including air brakes (if applicable)
- Passenger entry and wheelchair lifts and ramps
- Emergency exits and related warning devices
- Passenger seating
- Doors and mirrors
- Vehicle is level with no audible air leaks
- Fuel tank(s) and fill cap
- Exterior compartment doors
- Battery box.

It would benefit agencies to become thoroughly familiar with CDL pre-trip inspection requirements for their particular operation and integrate the inspections into their overall PM program. Additional information is available at the CDL Digest, http://www.cdldigest.com.

As mentioned earlier in this chapter, the ADA requires agencies to have a system for regular and frequent checks, sufficient to determine if wheelchair lifts are actually operative. Because ADA requires operators to inform the agency when a lift breaks down in service, many agencies also require bus operators to cycle lifts daily as part of the pre-trip inspection routine to ensure that lifts are indeed operational.

An operator inspection card is typically used to document pre-trip inspection findings along with any other abnormalities that may develop in service. The card is completed and returned daily to the maintenance department for review. Some agencies go a step further by having maintenance personnel greet operators returning from service to review noted defects, whereas others provide operators with feedback regarding maintenance actions taken as a result of reported problems.

PMIs

PMIs are an essential PM element. Buses are brought in at established intervals for various inspections and service work. The intent is to identify and correct problems on a systematic basis before they become more serious. Early detection allows agencies to plan and prioritize repair schedules, order needed parts, and accordingly plan staff allocation. The alternative is addressing failures when they occur in revenue service, resulting in service delays and passenger inconveniences. In more extreme cases, undetected and neglected equipment defects can lead to injury.

In addition to federal, state and local requirements, an essential factor in establishing PMI intervals is the need to change oil and provide other chassis lubrication as specified by the equipment manufacturers. The oil change interval also provides an excellent opportunity to inspect other critical areas and take corrective action based on identified defects. Some agencies separate inspections as a stand-alone function using specially trained technicians who focus only on inspections without being required to perform repairs.

A critical aspect of conducting PMIs is to determine when identified defects get repaired. Understanding that it may not be possible from a time and parts availability standpoint to immediately correct all noted defects, some type of priority system is warranted. Some agencies assemble a list of those defects that must be corrected before a bus is allowed back into service. Safety-critical defects based on federal and local regulations are typically on this list, along with other defects that affect component life. All other noted defects are either rescheduled or left to the next PMI.

Repairs, Campaigns, and Parts Replacements

Repairs

After defects are identified as part of the inspection process they require repair. Allowing defects to exist over time defies the purpose of PM. When technicians and drivers continually notice the same defects on buses they have a tendency to accept them as the norm.

Implementation of a defect classification system that clearly identifies safety and other critical defects is one way to prioritize when defects get repaired. Regardless of the approach used, defects identified during a PMI should be repaired either before the bus resumes revenue service or at the next scheduled PMI. Allowing defects to accumulate causes the fleet to deteriorate over time.

QA measures such as those described in chapter four can help ensure that defects are properly identified and repaired. Another approach is to hire an outside inspection firm to conduct a fleet audit on a periodic basis, where defects are itemized on a percentage of buses to obtain an objective assessment of fleet condition. An alternative is to have the industry create a peer review of maintenance experts to conduct periodic reviews.

Campaigns

Campaigns or retrofits are scheduled repairs that take place on an entire series of equipment or buses made in response to a common problem. As an example, a new bushing found effective at preventing doors from coming out of adjustment is installed on all buses using that bushing type. The wholesale replacement, which can be scheduled as part of a regularly scheduled PMI or separately, is taken as a preventive measure to improve safety and reliability, and reduce road calls and other unscheduled events.

Replacements

Another PM repair activity involves replacing parts and components before they fail. In a perfect world the life cycle of key parts and components would be calculated from a database of agency information and replacements made at the optimal interval. In reality, the ability to estimate equipment life is a difficult task (*12*). Many variables make it hard to predict with accuracy when a vehicle component or part will fail. Variables include corrosion, manufacturing inconsistencies, material fatigue, and whether loading on the component is static, cyclic, or dynamic. These factors combined with the inability to establish an effective database of historical operating conditions such as operating pressure, temperature, and vibration further complicate life-cycle estimates.

Despite these variables, mathematical models have been developed to predict equipment life. The models are routinely used in aerospace and military applications, where consequences of failure are more severe and resources more plentiful. Chapter three provides more detail and examples of various tools available to make such predictions.

Overhauls/Refurbish

Certain equipment is completely refurbished or overhauled on a periodic basis as a preventive measure. This typically occurs on larger, more expensive items such as entire bus overhauls, typically done at mid-life, and large components such as engines, transmissions, and axles. Other such components include fareboxes, radios, starters, alternators, and brake system components. As with the replacement of individual parts, overhauls are ideally done at the end of the life cycle to prevent more serious and costly problems.

Overhauls also provide an opportunity to upgrade components to later technology. For example, when engines reach the end of their life cycle they can be upgraded with redesigned parts to extend service life and reduce exhaust emissions. The same applies to other components where longer-lasting brushes are installed in electric motors when refurbished, and where electronic equipment is fitted with improved circuit boards to improve reliability.

CHAPTER THREE

SURVEY RESULTS: PREVENTIVE MAINTENANCE INTERVALS

INTRODUCTION

This chapter examines PM intervals, scheduling methods, procedures for determining when parts or components require replacement, and factors that most influence the setting of PM intervals such as manufacturers' specifications and local operating environment. Information provided in the chapter is based on material obtained from survey responses.

PREVENTIVE MAINTENANCE FREQUENCY

PM intervals are separated into three classifications: inspections, repairs, and overhauls. The Fleet Profile of agencies responding to the survey, from which data on PM intervals were obtained, is shown in Appendix A. It includes agency name, location, fleet makeup in terms of bus propulsion type (e.g., diesel and CNG), bus quantities, and combined fleet mileages.

Inspections

Daily Service Line Inspections

Eighty-eight percent of those agencies responding to the survey conduct daily service line inspections. The high number is expected given that the time needed to refuel buses provides an excellent opportunity to check essential fluid levels and make other vital inspections. One agency conducts these inspections bi-weekly, whereas another does so every time the bus is in the workshop, or every 20 days.

PMIs

PMIs are typically based on the minimum interval established by the OEM to change engine oil and provide other lubrication services. The most common suggested oil change interval is 6,000 miles. Some newer engines with more advanced emissions controls, especially those with exhaust gas recirculation (EGR), require more frequent oil change intervals at 3,000 miles.

Of those responding to the survey, 92% conduct PMIs at intervals that fall within 2,000 (one agency) to 6,000 miles, with 71% falling right at the 6,000 mile mark. The remaining 8% conduct PMIs at intervals of 6,500 to 7,500 miles.

The primary reason for using miles to schedule bus PMIs appears to be that agencies find it more convenient to use miles rather than hours of service and other time-based interval options recommended by the OEMs. One exception is Seattle Metro, which a few years ago changed its PMI interval for the electric trolley bus fleet from its standard 3K/6K/12K/24K mile interval to a 28/56/168/336 day schedule. The agency switched its PM interval policy because the trolleys, although not logging many miles, experience large passenger loadings owing in part to the free ride zone where they operate. The base PM interval for the trolley fleet originally was 3,000 miles, which was not an accurate indicator of how these vehicles were being used. Because Metro wanted the trolleys to receive similar PM attention as its traditional diesel fleet, and the diesel fleet accumulates approximately 3,000 miles per month, the agency established a 28-day PM interval for its trolley fleet. The move also leveled out the inspection load in that it could now perform PM inspections on 25% of its trolley fleet each week, thereby cycling the entire trolley fleet through PM inspections every month.

Metro is currently evaluating whether the 28-day PM cycle should be extended to 56 days by testing the interval on a sampling of 20 trolley buses. The agency closely monitors service interruptions and unscheduled maintenance, both of which have decreased since instituting the 28-day PM inspection cycle. Metro will decide on extending the PM intervals to 56 days based on how well the test fleet performs compared with the baseline buses.

Ride On in Montgomery County, Maryland, which currently uses mileage-based PMI intervals, is investigating basing those intervals on fuel consumption, but at this time had not yet concluded its study. Additional information regarding its approach is included later in this chapter. Despite a message posted on the Bus Maintenance listserve asking for other examples of agencies using something other than mileage to establish PMI intervals, none were provided.

When asked if agencies use different intervals for other buses in their fleets, 57% noted using distinct PMI intervals, whereas the remaining 43% use the same PMI interval for all buses. The primary reason given for conducting more frequent inspections (i.e., those in the 3,000 to 4,000 mile range) pertain to hybrid buses (one response), smaller paratransit vehicles (10 responses), and buses with EGR (three responses). One agency extended its bus PMI intervals from

5,000 to 6,500 miles as a forced cost-saving measure, knowing that doing so would increase road calls. In this case, the agency disregarded an essential PM tenet to ensure reliable bus service for the sake of improving customer satisfaction.

Once a standard PMI interval is established (i.e., every 6,000 miles), PM activities requiring less frequent intervals are typically worked into the base inspection. Although the industry lacks standardized nomenclature, the term "A" inspection is generally used to denote the base inspection where engine oil is also changed and the chassis lubricated. Additional activities can then be added at multiples of the base "A" inspection, such as "B" inspections done at 48,000 miles to also service the transmission, or a "C" inspection at 60,000 miles to perform other tasks. Intervals vary depending on equipment needs and local operating requirements.

Grouping additional PM activities into regularly scheduled events is certainly more efficient. However, in some cases agencies cannot keep buses out of service for extended periods of time to perform all needed tasks and bring them in separately. In other cases, OEM specified intervals do not always coincide with existing intervals. Bus systems requiring additional inspections, whether at regularly scheduled intervals or separately, include:

- The heating, ventilation, and air conditioning (HVAC) system;
- Wheelchair lifts and ramps;
- Cooling system;
- CNG tanks;
- Fare collection;
- Articulation joint;
- Electrical equipment, including radios and the automatic vehicle location (AVL) system;
- Hydraulic system; and
- Brakes and air drier equipment.

The intervals at which additional bus systems are inspected and serviced drew varied survey responses, strengthening the view that no one PM inspection program is suitable for all. Except for HVAC and wheelchair lift and ramp inspections, survey responses to specialized PM inspections were too diverse to classify. Tables 3 and 4 summarize survey responses regarding additional inspections added to address HVAC and wheelchair lifts and ramps.

Preventive Maintenance Repairs

When asked to list repair activities done as preventive measures based on time, mileage, or other condition (other than failure), survey responses were also varied and difficult to classify. However, the specialized repair activities and related intervals summarized in Table 5 from the survey responses provide several examples for comparative purposes or for agencies to adopt into an existing PM program.

TABLE 3
HVAC INSPECTION INTERVALS

Interval	Survey Response
6,000 Miles	13 (33%)
Annually	6 (20%)
Seasonally/Bi-Annually	4 (13%)
5,000 Miles	1
7,500 Miles	1
12,000 Miles	1
30,000 Miles	1
44,640 Miles (72,000 km)	1
Bi-Weekly	1
60 Days	1
180 Days	1

Preventive Maintenance Overhauls/Refurbish

Overhaul and refurbish activities done as a preventive measure based on time, mileage, or other condition, not because of failure, received responses in six categories. Four responders rebuild engines in full-size buses (35 ft and larger) at 300,000 miles; two perform rebuilds at approximately 450,000 miles. One agency replaces Detroit Diesel Corporation (DDC) S50 engines at 350,000 miles, Cummins model ISC engines at 375,000 to 400,000 miles, and Cummins model ISB engines at approximately 250,000 miles.

Regarding transmissions, one agency rebuilds them at five years, another at 300,000 miles. One agency rebuilds wheelchair lifts at 10 years. When it comes to refurbishing full-size buses, one agency does it at 6 years and another at 7 years. One agency does complete body and paint between 7 and 10 years, whereas another repaints buses every 3 years.

TABLE 4
WHEELCHAIR LIFT AND RAMP INSPECTION INTERVALS

Interval	Survey Response
6,000 Miles	18 (47%)
7,500 Miles	2
Annually	2
4,000 Miles	1
5,000 Miles	1
7,000 Miles	1
12,000 Miles	1
24,000 Miles	1
30,000 Miles	1
Bi-Weekly	1
60 Days	1
90 Days	1
Bi-Annually	1

TABLE 5
PM INTERVALS FOR SPECIFIC REPAIRS

Repair	Application	No. Response/Interval
Service Air System	All w/air brakes	1—24,000 miles
		1—48,000 miles
		1—60,000 miles
		1—Annually
		1—Bi-annually
		1—Every 1–2 years
Change Air Valves	All w/air brakes	1—60,000 miles
Replace Rear Brake Chambers	All w/air brakes	1—150,000 miles
Replace Brake Application Valve	All w/air brakes	1—150,000 miles
Replace Belts/Tensioners	- Cummins engines - All buses in fleet	1—100,000 miles 1—48,000 miles
Replace Spark Plugs	CNG buses	1—15,000 miles
Valve Adjustment	All buses in fleet	1—36,000 miles
Engine Tune-Up	30 ft and larger buses	1—50,000 miles
		1—350,000 miles
Replace Engine Harmonic Balancer	40 ft buses	1—125,000 miles
Check Diesel Particulate Filter (DPF) Backpressure	All w/DPF	1—6,000 miles
Replace DPF	All w/DPF	1—24,000 miles
Replace Crankcase Breather Filter	All w/filter	1—24,000 miles
Service Turbocharger	All w/turbocharger	1—50,000 miles
Repair/Replace Radiators	35 ft buses	Every 8 years
Replace Cooling System Thermostats	35 ft–45 ft buses	60,000 miles
Replace AC Fan Motors	40 ft buses	1 – Every 4 years
Adjust/Replace Front Wheel Bearings	Not specified	1—24–26,000 miles
Service Driver Seat	All buses in fleet	1—Every 6 years
Replace Fire Suppression Squib	All w/squib	1—Every 3 years
Adjust Doors	All buses in fleet	1—18,000 miles
Repair Farebox	All w/fareboxes	1—6,000 miles
		1—48,000 miles
Replace Shock Absorbers	30 ft–60 ft buses	1—60,000 miles
Replace Ultra-Capacitor Fan Motors	Hybrid buses	1—48,000 miles

METHODS FOR ESTABLISHING PREVENTIVE MAINTENANCE INTERVALS

Scheduling Techniques

All agencies responding to the survey use some form of computer-based program to ensure PM intervals are conducted on time; three supplement this process with an Excel spreadsheet, one supplements the process with manual recordkeeping. The variety of programs used is overwhelming; 38 responders reported using 22 different programs. A slight majority (56%) indicated that they are pleased with their PM software program, whereas 24% are not; 20% did not answer. Of all responding agencies, 82% claim the programs are flexible enough to make changes, 8% say they are not; 10% indicated the question is not applicable because intervals are set by manufacturers' specifications and changes are not needed. In addition to using a computer-based program to establish PM intervals, 87% also use it to guide and track the actual PM activities, whereas 3% do not; 10% said the question was not applicable.

Although scheduling programs may differ, the concept is to provide an indication of when buses are due for the next PM activity. Table 6 shows a program report example that identifies buses closest to requiring a 6,000 mile PM inspection listed in descending order. The full table would include all buses in the fleet and could be tailored to account for buses that require different intervals.

Table 6 or a similar report would be reviewed daily to schedule PMs. Indeed, intervals would be done at the exact interval. Actually, PMs are done slightly before or after the scheduled interval, which has a cumulative effect over time.

Agencies were asked if PM intervals are based on fixed points (i.e., every 6,000 miles, every 30 days, etc.) or are they reset based on the last actual interval. Of those responding, 61% reset intervals based on previous intervals regardless if it was early or late, whereas 39% conduct PMs at fixed-point intervals. For those who reset intervals based on the previous one, subsequent inspections could be thrown off even if the schedule shows it to be "on time." For example, if scheduled 6,000 mile "A" inspections were done at an average of 6,500 miles, the 24,000 mile "B" inspection would actually be done at 26,000 miles. Because each "A" inspection was done within an acceptable window of 10% of the scheduled interval, the "B" inspection would also be considered "on time," even though it was actually performed 2,000 miles beyond the required interval. Setting PMs at specific intervals mitigates the cumulative effect.

Ensuring On-Time Preventive Maintenance Performance

Agencies also use a variety of means to ensure PMs are done on time. Of responding agencies, 42% use an acceptable window of 10%, 5% do not use an interval window,

TABLE 6
REPORT SHOWING NEXT PM INTERVAL DUE IN DESCENDING ORDER

Bus Number	Life Miles	Last PM Mileage	Miles Since Last PM	Miles to Next Scheduled PM
333	239,900	233,924	5,976	24
326	272,406	266,449	5,957	43
343	245,127	239,236	5,891	109

and 53% use other methods. Of those using other methods to determine if PM intervals are done on time, 65% use some type of a mileage-based system that falls outside the 10% window. Those using an on-time acceptability window greater than 10% risk the cumulative effect of having subsequent inspections done beyond the suggested interval even though on paper they appear to be punctual.

Computer-Based Systems to Guide Preventive Maintenance

As indicated earlier, agencies reported using a wide variety of computer-based programs to schedule their PMs. When asked if these programs are also used to guide and track actual PM activities (i.e., follow-up repairs, parts, costs, etc.), 87% say they do. More capable programs are part of a larger Management Information System (MIS) that tracks and helps manage many maintenance-related activities, including repairs, costs, parts inventory and purchasing, fuel and lubricant dispensing, vehicle history files, vehicle availability, timekeeping, payroll, account payable, facilities maintenance, and others. These systems also have the capability of distinguishing between scheduled and unscheduled PM activities.

Several agencies indicated that their programs generate a unique checklist based on bus type to guide technicians through the inspection process. The work order, common in virtually every automotive maintenance operation, continues to be the basis for issuing PM work to technicians, providing historical information regarding past work, and for technicians to note defects and parts usage.

The Whatcom Transportation Authority, Bellingham, Washington, uses a vendor-developed MIS program. It generates a work order that identifies the maintenance tasks to be performed on a given bus, provides historical data for that bus, tracks parts and labor based on information provided by technicians, and manages warehouse inventories. Included with the work order is a listing of parts needed to perform each PM activity along with a specialized checklist based on the specific bus type. Work orders are all bar-coded and parts inventories automatically readjusted. The system also separates those activities done as scheduled events as opposed to those done on an unscheduled basis, which is essential for tracking PM performance.

Innovative Approaches to Establishing Preventive Maintenance Intervals

The survey sought to identify any unique or innovative approaches used to establish PM intervals. Fluid analysis was mentioned by several responders. Here agencies take samples of vital fluids such as engine oil, transmission fluid, and coolant at the end of the drain interval and send those samples to a laboratory to identify deteriorating conditions and determine if fluid intervals need to be extended or made more frequent. Fluid analysis results showing traces of wear metals and other contaminants also provide early indications that components are beginning to fail, thereby allowing agencies to schedule repairs and overhauls before more serious and costly problems develop.

Normal fluid analysis reports may be an indication that oil drain intervals could be extended. Before doing so however agencies need to consult their oil analysis lab to become familiar with the ramifications of doing so and gain authorization from the component manufacturer to ensure warranty coverage. Use of synthetic and other lubricants may be allowed by OEMs under certain conditions to extend oil change intervals. When extending fluid change intervals, one must also consider the results of conducting less frequent inspections.

Chapel Hill Transit, North Carolina, maintains close communications with bus, engine, transmission, and other OEMs to obtain information regarding activities that might be added to the PM program based on their insight and experiences. Agencies such as Rockford Mass Transit, Illinois, speak with others in bus maintenance to learn from their experiences. The San Diego Metropolitan Transit System analyzes statistical data on breakdowns and adds items to its PM program. The Santa Clara Valley Transportation Authority (VTA) uses a committee of maintenance personnel headed by the agency's engineering department to establish PM intervals, but is careful not to exceed OEM specifications.

Coast Mountain Bus, Burnaby, British Columbia, Canada, has recently established a QA program for PMIs and uses feedback to fine tune its PM program. Two procedures are used. One is an Inspection Change Request form, attached as Appendix D, which can be completed and submitted by anyone in the maintenance department to suggest changes to the PM program. The agency's QA team investigates each request to determine whether the PM program needs to be altered. The investigation explores and considers any impacts the change would have on individual groups within the department (e.g., Material Control, Parts, and Work Planning). Any change made to the PM program ultimately must be approved by the Fleet Technical Support Manager.

Another form of feedback used by Coast Mountain to improve its PM program is monthly bus audits conducted by the QA team. The audits are done at least once a month on a recently inspected bus. These audits are reviewed by management to ensure that all defects were identified and proper steps taken to repair them. The audits are also used to determine if new maintenance practices might be investigated.

Montgomery County, Maryland (Ride On) monitors mileage, engine hours, and fuel consumption to establish a mileage-based interval appropriate for each PMI. The agency is also monitoring a test vehicle to determine if PM intervals are better established using fuel consumption. It is its theory that fuel consumption is a stronger indicator of the severity of operating conditions than mileage alone. The agency's initial test began with a 2007 International bus model 3200IM with a VT365 engine. Unlike Detroit Diesel or Cummins engines operated by Ride On, International according to Ride On does include an option for changing the engine oil and filter according to fuel consumption. For this particular engine, the specification is 1,000 gallons of fuel, 10,000 miles, six months, or 350 h. When making its calculations using an average miles per gallon of 5.85, 1,000 gallons of fuel consumption averaged 5,850 miles. Because it already uses miles to trigger PM intervals the agency rounded it to 6,000 miles to keep it consistent with their existing interval.

Going forward, Ride On will continue its investigations and believes that using fuel consumption for setting PM intervals is more appropriate for Bus-to-Block operations where buses are assigned to the same route every day and average fuel consumption is more consistent. Table 7 illustrates how buses on different Ride On routes accumulate mileage at different rates. Buses used in Interstate commuter service accumulate nearly four times the mileage in less than half the time as buses operating on a city route.

One agency does some work ahead of scheduled PMIs at 6K and 12K intervals to avoid the 24K and 48K inspections from consuming too much time, thereby fitting work in to suit schedule demands.

Miami–Dade Transit, Florida, uses its MIS system to track the history of each major bus sub-component, analyze the data, and includes specific inspection, replacement, or adjustment activities to take place at certain intervals based on the analysis. Trend analysis conducted from the data determines the distance in miles between needed actions, and PM intervals are established accordingly. Miami–Dade has two types of PM, a 3,000 mile PM referred to as an "O" inspection and a 6,000 mile "A" inspection. The "O" inspection is basically an oil and lubrication service with additional safety inspection items. The 6,000 mile "A" inspection is where the agency adds tasks based on manufacturers' specifications, regulatory requirements, and collected data. Miami's PM scheduling software, as with most others, maintains life-to-date mileages on each bus. If their trend analysis dictates that a part should be replaced at a certain time, the PM scheduler is programmed to flag the action. As an example, their trend analysis reveals that the reliability of brake slack adjusters drops off significantly after 60,000 miles. When buses reach a 60,000 mile interval, the task "Remove and Replace Slack Adjuster" appears as a PM action item.

Predicting Parts Replacements

In addition to establishing PM intervals, programs are also available to accurately predict part and component replacements just before they fail. Most are based on the Weibull analysis, named for Swedish engineer Ernst Weibull (*2*). It allows managers to make predictions about the life of all products in the fleet by "fitting" a statistical distribution to life data from a representative sample of vehicles. The data set can then be used to estimate important life characteristics of a product such as reliability or probability of failure at a specific time, mean life for the product, and failure rate.

Applying these models, however, requires resources to collect accurate data and apply mathematical formulas or run software programs. Even with required resources, determining the life cycle of a particular part is difficult. One survey respondent admitted to understanding the benefits of predictive models, but unfortunately does not have the time or money to use them.

DART, on the other hand, has found what it considers a relatively easy method to calculate part replacement intervals. The software program is available through Oliver Interactive, Inc, and is called Relcode (*13*). Using Weibull mathematics,

TABLE 7
COMPARISON OF ROUTE MILES

Route Number	Service	Miles	Hours	Average Daily mph
61	City	533	64	9
100	Interstate commuter	1,974	31	32.5

the program determines probabilities of component failure and helps the user decide whether to replace parts as a preventive measure (i.e., in advance of failure) or only on failure.

Relcode requires two basic user inputs. One is data from agency records, including the life history of each part being analyzed such as how long each bearing, belt, or shaft lasted before it was replaced. The other user input consists of estimating (1) the cost of carrying out a preventive replacement of the component being analyzed, and (2) the cost of replacing the component in the event of an in-service failure. Reports are provided in the form of graphs and tables. One example, shown as Figure 1 plots the probability of survival over time for a drive belt.

DART uses Relcode software for a variety of tasks such as documenting fleet defects, identifying premature failures, estimating budgets and stocking levels for common replacement parts, and to determine optimal PM parts replacement cycles. Concerning parts replacements, DART examines the mileage or time when failures occur, takes the average of all failures identified, and uses the program to determine if it is more cost-effective to replace parts at certain intervals or replace only on failure.

The software has allowed DART to identify a variety of failure patterns such as:

- Premature failures,
- Failures resulting from design defects or issues related to installation,
- Failures that occur when the item is not suitable for its intended application,
- Random pattern failures,
- Failures affected by external factors,
- Wear out failure patterns (when item reaches end of its service life)
  - Gradual increase in failures
  - Sudden sharp increase in failures.

Required inputs consist of the number of parts in service, the date parts were placed in service, cost of the part, cost to replace the part, and date when each part fails. Reports generated by the program are used as a decision-making tool to determine when to replace the part in question. Figure 2 shows that it is more cost-effective to replace a particular brake valve after it fails. Depending on the part, the agency examines the data and weighs whether a failure could result in a road call or other service interruption. Because the part shown in the Figure 2 example affects braking, the agency would replace it at an optimal interval.

Not all parts are analyzed for PM replacement purposes, and DART is quick to note that Relcode is not the only tool

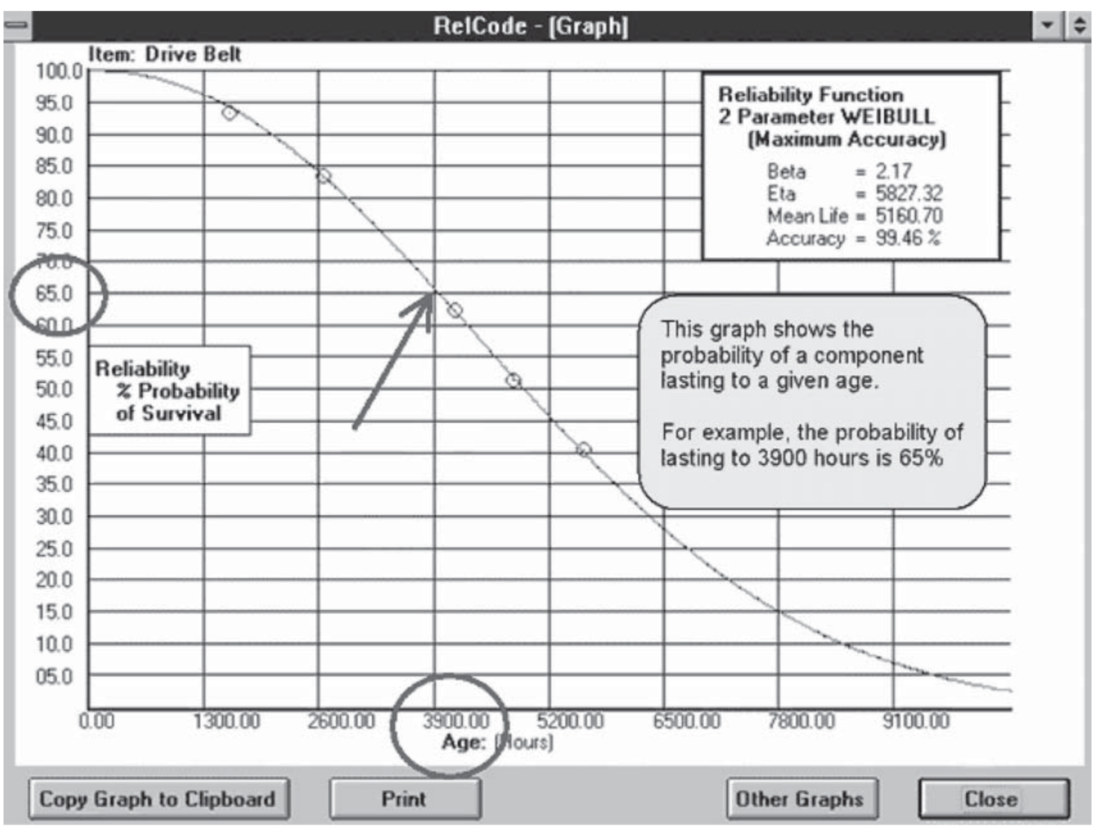

FIGURE 1 Probability of component lasting to a given age.

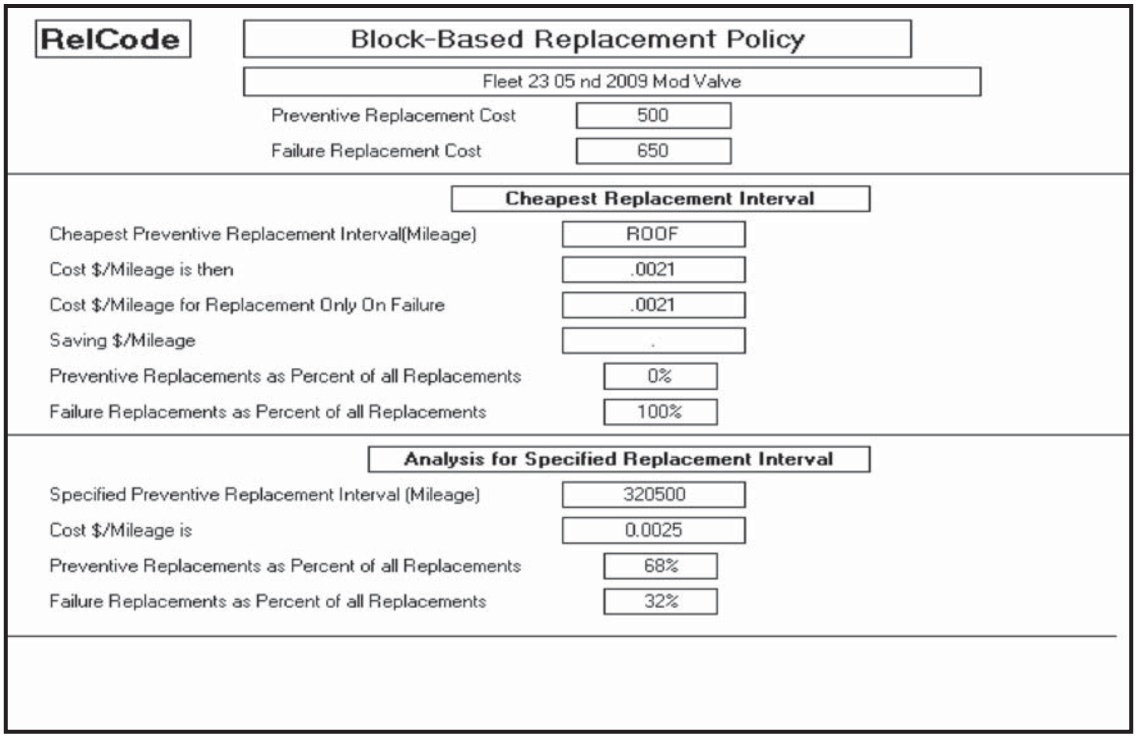

FIGURE 2 Relcode report showing the least expensive replacement interval.

used to determine part replacement intervals. In addition to brake valves, it has also been used by DART to study hydraulic fan controllers, automatic voice announcement system controllers, brushless motors, and to project optimal engine overhaul intervals.

Another software model that calculates part replacements is available from the ReliaSoft Corporation, which also uses Weibull mathematics (*14*). Figure 3 plots the cost per unit time versus time to determine the minimal cost of replacement.

As shown in Figure 3, corrective replacement costs increase as the replacement interval increases. According to the model, the less often a PM action is performed the higher the corrective costs. The longer a component is allowed to operate its failure rate increases to a point where it is more likely to fail, thus requiring more corrective actions. This figure is a theoretical example and is not based on any specific bus part or component.

The opposite is true for the preventive replacement costs. The longer you wait to perform PM, the lower the costs; if you do PM too often, costs are greater. When both cost curves are compared there is an optimum point that minimizes replacement costs. To arrive at this one must strike a balance between the risks (costs) associated with a failure while maximizing time between PM actions.

The mathematical model formulated by Reliasoft to determine PM replacements is attached as Appendix E. Another method for calculating mean time between failures is described in a paper by Mondro prepared for IEEE (*15*). Unlike complex calculations that can be awkward, Mondro presents a much simpler method for calculating mean time between failures without appreciable sacrifice in accuracy. Despite the claim, the model does require what appears to be a detailed calculation. Agencies may find computer-based software tools such as the one used by DART easier to use.

Additional information on the application of Weibull mathematics to predict parts replacements is found in *Bus Fleet Management Techniques Guide* (*4*) described in the Literature Review section of chapter two.

FACTORS THAT AFFECT PREVENTIVE MAINTENANCE SCHEDULING

Manufacturers' Specifications

OEMs have established specified intervals for determining when PM activities take place. Table 8 shows survey responses for the most common OEM specifications responsible for shaping agency PM intervals. Again, the diversity is great. Reasons for the diversity include dissimilar equipment, different operating and environmental conditions, and that OEMs typically offer a choice of specific intervals depending

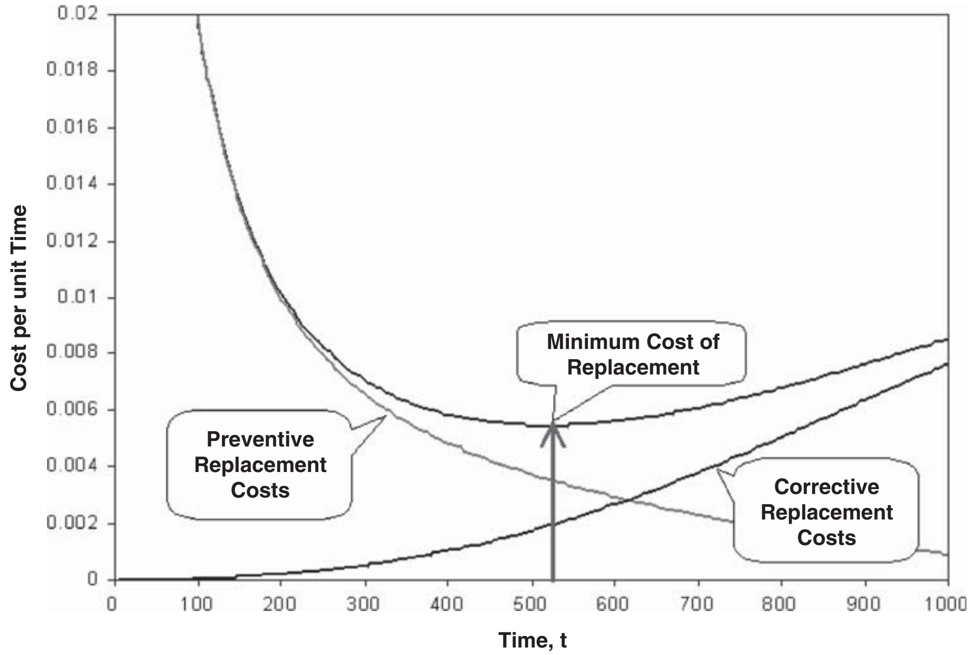

FIGURE 3 Cost curve for preventive and corrective replacement; cost per unit time versus time.

on how their equipment is used. In the case of extended transmission fluid changes shown in Table 8, the longer intervals (70K to 100K miles) are typically a function of using synthetic fluids. Although more costly to purchase, some transmission OEMs specify it. Rockford Mass Transit conducted a return on investment study and found that extended transmission fluid drain intervals and labor savings justified the extra purchase cost.

Other single-entry responses not shown in Table 8 included differential flushing, engine tune up and adjustments, and inspections of steering, CNG, fire suppression, farebox, and camera equipment.

Although adhering to OEM specifications is critical, finding a single schedule that represents all bus components can be difficult. A suggestion made by several survey responders is to require bus OEMs to consolidate all PM specifications into one document location as part of APTA's Standard Bus Procurement Guidelines. Another is to consolidate all replacement parts information into a single document and make it available in electronic format.

Influence of OEM Warranty Coverage

When asked if OEM warranties influence the setting of PM intervals, 74% of survey respondents claimed it does. Not abiding by OEM specifications for PM can be grounds for dismissing warranty claims if the OEM can prove the problem was caused by neglected maintenance. One agency noted that OEMs often look for evidence of improper service or maintenance as a way of voiding warranties and related costs, implying that agencies strictly follow OEM specifications to ensure reimbursement of warranty claims. Although the responses show most agencies meet or exceed OEM requirements to maintain warranty coverage, some are willing to extend intervals and risk losing warranty coverage. A sensible approach expressed by some survey responders is to clear any PM deviations with the OEM in advance of violating the specified intervals.

Survey responders were also asked if they change PM intervals after the OEM warranties expire. Of those responding, 82% continue to follow OEM intervals; 18% change them after warranties expire. Of those that change intervals, some actually increase intervals (i.e., perform them less often) after warranty coverage expires, whereas some make the intervals more frequent. VTA (San Jose), after careful evaluation of several factors including equipment failure rates, found that more frequent maintenance intervals were required after the warranty expires and buses age. One agency increases PM intervals of batteries because of extra loads placed on them by onboard electrical and electronic systems. Others use oil and fluid analysis to extend intervals, whereas another agency extends change intervals for spark plugs and coalescing filters used in CNG engines.

Data Driven Factors

Changes made to PM intervals as a result of specific operating and environmental conditions are provided in the next four sections. Based on the wide range of preventive measures

TABLE 8
PM ACTIVITIES INFLUENCED BY MANUFACTURERS' SPECIFICATIONS

PM Activity	No. of Responses	Intervals Established as a Result of OEM Specifications
Change engine oil/filter	19	6–6.5K
	8	No interval given
	4	3–4K
	1	5K
	1	15K
Change transmission fluid/filter	7	48–60K
	7	70–100K
	6	No interval given
	4	4–12K
	3	24–36K
Check brake throw	8	5–6.5K
	4	No interval given
	2	1.5–2K
	1	3K
	1	Weekly
	1	Every 2 weeks
	1	40–60K
	1	Per state requirement
Check brake thickness	6	6–6.5K
	5	No interval given
	2	1.5–2K
	1	3K
	1	Weekly
	1	Per state requirement
	1	Every 2 weeks
Check wheel nut torque	7	6–6.5K
	6	No interval given (1PM)
	3	3–4K
	1	Weekly
	1	24K
	1	At alignment or tire change
Check tire pressure/depth	8	6–7.5K
	7	No interval given
	3	Daily
	2	2–3K
	1	Weekly
	1	Per state requirement
	1	Every 2 weeks
HVAC	1	Bi-yearly
	1	15K (24,000 km)
Wheelchair lift/ramp	2	6K
	1	30K
Articulation Joint	3	6K
Fuel Filter	2	12–15K
Change hydraulic fluid	1	6K
	1	30K

taken, managers will need to determine which are appropriate for their particular application.

Table 9 summarizes specific PM activities put in place because of data and information generated from road call reports, driver pre/post trip reports, service line inspections, and other sources.

Environmental Influences

When asked what specific PM activities have been put in place because of unique environmental conditions such as extreme heat, cold, humidity, winter salt use, and other environmental factors, agency responses also varied. PM activities, corresponding interval and location by geographic location (state) are shown in Table 10.

Operating Conditions

Table 11 summarizes specific PM activities in place because of unique operating conditions such as duty cycle, terrain, road conditions, and other such factors.

Fleet Makeup

Table 12 summarizes specific PM activities taken because of agency fleet make-up including diesel buses equipped with

TABLE 9
PM ACTIVITIES INFLUENCED BY DATA AND INFORMATION

PM Activity Based on Data/Information	Interval
Electrical connections/wiring	As needed
HVAC	Spring and Fall, seasonal, bi-weekly
Check batteries/charging	6K (3); 12K; 24K
Check air system	12K; 18K; air dryer 24K
Check belts, tensioners	5K; 6K
Bumper mounting bolts	Visual 6K, re-torque and paint at 24K
Check hoses and cables	Various
Brake inspection	6K (3); every time bus comes over a pit
Camera system inspection	6K; 24K
Diesel particulate filter check	6K; 12K; 24–30K replacement
Farebox PMI	6K; 24K
Automatic vehicle location PMI	12K
Engine-related activities	6K
Oil change more frequently owing to high soot	3K
Fuel management system	6K
Check potential chaffing of various lines to previous fires	Various intervals
Rear door inspection	6.5K
Tire pressure	10 days minimum
Multiplex system batteries	Bi-annual
Engine thermostats	60K
Tow air check valve	100K
Safety inspection	Every time bus is in the shop or every 20 days
Lift/ramp inspection	6K; bi-weekly
Centrifugal oil filter cleaning	24–48K

diesel particulate filters (DPF) and other emissions control technologies, CNG buses, paratransit buses, etc. As noted in Table 12, three agencies report inspecting CNG tanks every three years or 36,000 miles. This is a requirement of FMVSS 304, which also includes a provision that CNG tanks be labeled with this interval (*16*).

Needed Tools and Resources

Survey responses regarding what information, tools, or additional resources would help agencies do a better job to establish PM intervals include:

- More staff and resources to analyze data, failure trends, times, etc.; good supervision; and well-trained personnel (eight responses).
- More precise presentation of PM information from manufacturers, such as comprehensive PM tables located in one central document (three responses).
- Sharing of agency PM information on emissions, engines, and transmissions.
- Examples of other transit PM schedules.
- Specified life expectancy of equipment.
- More reasonable PM schedules and specifications from the OEMs. Most are reasonable; however, sometimes one can detect a few unreasonable intervals that are probably designed to "cover" the OEM or component manufacturer.
- A dedicated QA program to analyze failures and suggest updates to preventive maintenance procedures.
- Software to track actual idle time to achieve a more precise accountability of both engine and transmission life cycles.

TABLE 10
PM ACTIVITIES INFLUENCED BY UNIQUE ENVIRONMENTAL CONDITIONS

PM Activity Based on Unique Environmental Conditions	Interval	State (no. of responses)
HVAC PMI	Spring and Fall	PA
	Spring	CA
	6 months	NY, TX, NC, WA (2)
	Annual	MD, IL
	Annual, in addition to 6K	TX
	6K	FL (2)
HVAC filter change	3K	FL
	Every PM	NM
Auxiliary heater inspection	6.5K	WI
	6K	IL, WA
Wheelchair lift/ramp PMI	Daily by drivers	PA
	60 days	FL
Air dryer service	Seasonal	WA
Air dryer overhaul	Bi-annual	GA
Drain air tanks	Bi weekly in Oct.–April	DC
Oil and filter change	3K	FL
Glow plug system service	Annual	MD
Radiator cleaning	6K	WI, CA, MD, FL
	6 months	NY
	30 days	FL
Seasonal inspection	Spring	CA
	Fall	CA, UT
Diesel particulate filter service	3K	MI
Underside and radiator cleaning, and inspecting and maintaining electrical systems owing to salt environment	As needed	UT

TABLE 11
PM ACTIVITIES INFLUENCED BY UNIQUE OPERATING CONDITIONS

PM Activity Based on Unique Operating Conditions	Interval
HVAC filters	Bi-weekly
Heating system inspection	Annually
Suspension	6 months
Brake inspection	Every 2 weeks
Replace brake application valves	150K
Replace rear brake chambers	150K
Air dryer inspection/service	Annual (Oct.–Nov.)
Replace slack adjusters	100K
Radiator cleaning	1–2 times per year as required, owing to plugging. Usually as a result of operating near construction sites or high dust areas
Radiator/charge air cooler cleaning	3K (approx.)
Tire sidewall check	Daily (service line check)
Engine oil and filter change at less than	3K
OEM rrecommendation	7.5K
Change engine air filter	6K
Under-carriage inspection	6K

TABLE 12
PM ACTIVITIES INFLUENCED BY FLEET MAKE-UP

PM Activity Based on Fleet Make-Up	Interval (no. of responses)
CNG	
- replacement spark plugs	24K (1), 36K (1), varies (1)
- drain oil from fuel filters	Every PMI (1)
- inspect tanks	3 years (2), 36K (1)
- clean vent lines	Annually (1)
- drain CNG filters	Weekly (1)
- check/service methane detection system	12K (1)
07 Diesel	
- crankcase ventilation/filter	24K (1)
- diesel particulate filter service	6K (2), not yet established (1)
- exhaust gas recirculation service	3K (1)
Use of brake tester	PMI, accident or driver complaint (1)
Fire suppression system	12K (1)
Paratransit PMI	4.5K (1), various (1)

CHAPTER FOUR

SURVEY RESULTS: CONDUCTING PREVENTIVE MAINTENANCE-RELATED ACTIVITIES

INTRODUCTION

This chapter reviews procedures used by agencies to carry out PM tasks such as use of inspection checklists and other tools that guide technicians through the PM process, labor allocation in performing PM tasks, and PM costs in terms of parts and labor. Also examined are various QA measures taken by agencies along with the various approaches taken to repair defects noted during PMIs. Information provided in this chapter is based on material obtained from survey responses.

CHECKLISTS AND OTHER GUIDANCE TOOLS

Checklists

Checklists provide a useful tool to help guide technicians through each PM activity. The checklist documents that activities did take place on a certain bus at a given interval, which is helpful in satisfying inspection recordkeeping requirements (49 CFR Section 396.21) established by the U.S.DOT. Unique checklists are pertinent to specific buses and related equipment. The opposite is a generic, less-effective checklist used for all bus types in the fleet regardless of equipment make or type.

All responding agencies use some form of checklist to guide PM activities. Common checklists are those for bus inspections, HVAC inspections, and wheelchair lift and ramp inspections. Table 13 shows the percentages of responding agencies using a unique checklist to conduct common PMIs.

Agencies reported using checklists for 20 individual PM categories, including the three listed in Table 13. Of those, 59% use checklists unique to specific equipment. Other PM areas where checklists are used include:

- Charge air cooling PMI
- Brake system PMI
- Cooling system PMI
- Farebox PMI
- Radio system PMI
- CNG tank PMI
- Articulation joint PMI
- Fire suppression system PMI
- Transmission PMI
- Electrical system PMI
- Driver seat PM repair
- Articulation joint PM repair
- Farebox PM repair
- Fire suppression system PM repair
- Radio PM repair
- Engine PM overhaul
- Transmission PM overhaul.

Centro, Syracuse, New York, has a fleet of just under 300 buses and uses 21 specialized PM classifications that cover different bus types, HVAC, wheelchair lifts, electrical system, fire suppression, and others. Additional information on Centro's PM program is included as a case study in chapter five.

A good example of a unique bus PMI is provided by Capital Metro Transportation Authority, Austin, Texas, developed for Optima buses. The checklist begins with general instructions, continues with an explanation of terminology, defines conditions under which immediate repairs can be made, and provides work instructions. A section of that PMI is included as Appendix F.

In addition to the checklist, Capital Metro includes what it calls "repetitive functions" sheets that itemize service, repair, and replacements that need to take place or be "repeated" at specific intervals for each bus type. For example, the agency replaces headlights at certain intervals regardless of their condition. For buses with a faulty idler pulley the repetitive sheet calls for a new design replacement.

PM checklists and repetitive sheets are updated as new information becomes available. Capital Metro's MIS system prints checklists and repetitive sheets just before each PMI to ensure technicians are provided with the most current information.

Pass/Fail Criteria

Inspection checklists also include specific pass/fail criteria to denote acceptable standards for equipment condition and performance. Of survey responders, 84% include some pass/fail criteria for carrying out PMIs and repairs. Pass/fail criteria for brakes are mentioned by nearly all survey responders who include criteria on their checklists. Figure 4 shows pass/fail criteria established for measuring brake stroke taken from

TABLE 13
POPULAR PMIs WHERE CHECKLISTS ARE USED

PM Activity	Those Using Generic Checklist	Those Using Unique Checklist
Bus PMI	39%	61%
HVAC PMI	38%	62%
Lift/ramp PMI	37%	63%

Capital Metro's PMI checklist for Optima buses. The checklist includes space for technicians to list measurements for each wheel location, and provides additional information for carrying out the procedure. The chapter five case study for the Whatcom Transportation Authority in Bellingham, Washington, highlights the agency's emphasis on requiring technicians to conduct tests and take measurements as part of PMIs.

Other areas where PMI criteria are provided include:

- Battery voltage
- Tire tread depth
- DPF backpressure
- Brake interlock regulator setting
- Suspension kingpin play
- Door open/close speed
- Air compressor cut-in pressure
- Brake S-cam bushing wear, lining thickness, and drum temperature variances
- Wheel lug nut torque
- Exhaust smoke opacity
- Air system pressure build-up time
- Engine oil pressure, fan speed, and idle speed
- Alternator amperage and voltage outputs
- Transmission and retarder performance
- Bus ride height.

Specific inspection criteria provide technicians with reference for what is acceptable and ensures that inspections are done in a consistent manner and in compliance with regulatory requirements. Agencies typically establish pass/fail and other criteria through a combination of OEM specifications and U.S.DOT requirements. Criteria listed on agency checklists must be consistent with these requirements; those who violate them are subject to the penalty provisions of CFR 49 Part 396.17, Periodic Inspections (*17*). Depending on the infraction, the DOT can issue a warning, levy a fine, or even close the maintenance operation. Inspection criteria that breach OEM requirements can result in rejection of warranty claims.

Written Job Instructions

PM tasks are more effectively carried out when technicians are provided with precise instructions that reflect the agency's work expectations. A majority agree, as 79% of those responding to the survey develop written instructions for PM-related activities. One resource for developing written procedures is *TCRP Report 109: A Guidebook for Developing and Sharing Transit Bus Maintenance Practices* (*18*). The *Guidebook* includes several examples of PMI instructions and checklists complete with inspection criteria.

One approach to developing written PMI instructions is where materials used by the agency's training department are consistent with, if not identical to, reference materials avail-

Inspect and measure brake pushrod stroke.	Pass Fail
Brake Stroke Measurements Axle / Stroke Front axle 1.75" max Drive axle 2.0" max Record Brake Stroke Measurements: LF ______ RF ______ LR ______ RR ______ *Slack adjuster to push rod angle approximately 90^o with brakes applied* *Ensure full range of brake movement without binding*	☐ ☐

FIGURE 4 Brake stroke measurement criteria.

able to technicians in the workshop. An exceptional example of PMI instructions is produced by the Central Florida Regional Transportation Authority (LYNX) in Orlando. The opening paragraph to their *Preventive Maintenance Procedure Manual,* which contains detailed step-by-step instructions for each PMI task, makes several significant points:

> The preventive maintenance procedures and checklists contained in this document were assembled and defined with the assistance of Lynx's Technicians, Training Assistants, Supervisors and other staff employees. The process of updating this document and our Preventive Maintenance Program is ongoing. Procurement of new equipment and/or technology, failure of systems and/or components as well as other factors can effect changes in our Preventive Maintenance Program.

The statement clearly indicates the importance of developing instructions as a joint labor–management effort, where both sides accept the procedures as appropriate. LYNX also recognizes the importance of continually updating the inspection process based on changing technology and new information. Instructions are divided into various sections, each with color photos, clear instructions on when to bring abnormalities to the attention of a supervisor, specific pass/fail criteria, and references for each major PMI activity where technicians can find more detailed information when needed. A portion of those instructions is included as Appendix G.

Everett Transit in Washington uses an approach where its MIS, based on bus number, prints out the appropriate PM checklist complete with work instructions and pass/fail criteria. By having checklists in an electronic format the agency can update them as needed, providing technicians with a current checklist each time a PM activity is conducted for a particular bus.

The Whatcom Transportation Authority in Bellingham, Washington, also provides technicians with PM checklists and detailed instructions for each vehicle type. Doing so helps the agency adhere to DOT requirements, as summarized in the Literature Review section of chapter two and detailed in Appendix C.

LABOR AND SPARE RATIO CONSIDERATIONS

Skilled Versus Entry-Level

Survey responses indicated a split regarding skill levels required to conduct PM inspections, with 60% using skilled technicians, 16% using entry-level, and 24% using other skill levels, primarily a combination of both. Reasons given for each approach are compelling. Those who favor skilled workers stated that technology is dynamic and changing as buses evolve, and increased skill sets are needed even for basic PM tasks. They also contend that skilled technicians better satisfy contractual obligations with OEMs and legal DOT requirements, and are more qualified to assess equipment condition and identify defects.

Conversely, some who favor using entry-level technicians maintain they have no "bad habits" and can be trained from the start on how to do a PMI correctly. Others use lower skill level workers when possible as a training process to help them learn vehicles. Some agencies only hire skilled technicians, making the issue mute.

Some who use a combination of worker skills limit unskilled workers to basic tasks such as service line inspections and the cleaning of filters and radiators. Others use entry-level workers to perform inspections and then follow up with a skilled technician for verification and repair. Some pair up skilled and entry level technicians for training purposes. One agency trains all workers to conduct PMIs to achieve "a singularity of effort," to get away from the mindset where technicians are responsible for particular jobs.

Splitting Work Responsibilities

Survey responders are also divided on whether to use the same technician to conduct all aspects of PM or split responsibilities between routine tasks and more demanding ones; 61% have the same technician conduct all PM activities; 39% split responsibilities. Those who maintain one skill level in their workshop have no choice. Some who split responsibilities use a technician with limited abilities for routine PM tasks while using specialists to work on brakes, air conditioning, engine tune-ups, tires, and other more critical areas. Some use specialized electronic shop personnel to perform all farebox, radio, and AVL-related PM. Because of DOT inspection requirements for brakes and air conditioning, some agencies specifically use specialists dedicated in these PM areas.

Some agencies assign one technician to PM activities for better work accountability. When several technicians are involved it can become unclear as to who completed the task. Having a single technician responsible for the entire PMI also avoids one technician interfering with another's work, and avoids confusion as to who completed—or did not complete—specific aspects of the PM. Others use a single technician until the shift ends when another takes over. Some agencies assign one technician to shorter-duration PMIs and double up when PMs are more comprehensive. Other agencies favor a team approach, where each technician is assigned certain bus areas.

Agencies such as the Chicago Transit Authority assign inspection-only activities to one group of technicians and the repair of identified defects to another. The advantage is that dedicated and specially trained technicians only focus on identifying defects with no responsibility for repairing them. The disadvantage is that buses need to be rescheduled for lubrication servicing and repair of noted defects.

Work Rules and Standards

When asked if work rules influence the type of skilled technician allowed to conduct PM activities, 39% of survey responders reported having such rules, whereas the majority (61%) do not. Other work rules are union-related where certain job classifications require certain skills. At some level agencies require basic rules because of DOT training and experience requirements, especially those pertaining to brakes and air conditioning refrigerant.

The Whatcom Transportation Authority (WTA) uses only journey level technicians with in-house certification to inspect and repair vehicles. Doing so helps ensure that regulatory requirements are met. The certification program came about because the manager realized that checklists were lacking; each technician determined if a component or system was in safe operating condition. That determination, according to the manager, "was all over the map." The in-house-developed certification program, described further as a case study in chapter five, establishes inspection and repair standards and removes any ambiguity when performing inspections.

Time Calculations

Seventy-four percent of responding agencies calculate time needed to conduct PM activities, 26% do not. One responder gave up calculating time because technicians are called away so often that timeframes are not very accurate, and instead goes by "ball park numbers" that the agency believes "are close." Giving up, however, is not appropriate. Auto dealerships and private trucking companies routinely account for the time needed to conduct maintenance activities. The United Parcel Service, for example, calculates the time of every fleet activity down to the minute, and evaluates maintenance costs as a percentage of the cost to ship an average package (*19*).

Calculating PM time is essential for establishing budgets and staffing levels. PM that becomes more effective at reducing breakdowns, however, will not necessarily reduce overall labor requirements because of increased preventive measures added to scheduled activities. Time spent on PMs as reported by survey responders also varied with "A" PM inspections ranging from 1 to 5 h. The median of 3 h, however, represents a more realistic time for this inspection. Table 14 shows the average and median number of hours reported by 28 agencies to conduct "A," "B," and "C" PM inspections. As indicated in this table, the mean hours to complete a "B" inspection adds 2 h of additional activities to the "A" inspection for a total of 5 h, whereas the "C" inspection averaged another 5 h of activities for a total of 8 mean hours.

Bus Spare Ratio

Half of agencies responding to the survey calculate the number of spare vehicles needed to support their PM program. Of those, 55% report needing 20% spare vehicles, consistent with the FTA maximum allowance. It is assumed that many in this category have simply cited the FTA requirement without making formal calculations. The 20% ratio required for PM does not provide for additional spare buses needed for unscheduled maintenance, accident damage, and other non-PM related maintenance activities. The remaining responses most likely reflect the actual number of spare buses needed to support PM activities. Excluding those reporting the FTA maximum of 20%, 44% require a spare ratio of 5% to 6%, 33% require 10% to 12% spares, and 22% need 15% spares.

PREVENTIVE MAINTENANCE COSTS

When asked if PM costs are calculated in terms of combined parts and labor, 63% do, whereas 37% do not. Although most understand the importance of identifying PM costs, the high number (more than 1 in 3) that does not track this important indicator is alarming. Table 15 shows combined parts and labor costs calculated by agencies to conduct most common PMIs. Again, the large disparity in cost reflects the wide variety of fleet equipment, PM activities, and nomenclature used by agencies to define various PM events.

Pre-Packaged Preventive Maintenance Parts Kits

One way to improve the efficiency of PM inspections is to pre-package kits with all needed parts and supplies. Filters, gaskets, hardware, and replacement parts required for routine servicing can be pre-packaged into convenient kits and handed to technicians with the work order when PMIs are assigned. Doing so not only ensures technicians will install needed parts, but avoids the unproductive time associated with technicians waiting at the parts counter while parts are collected.

TABLE 14
LABOR HOURS NEEDED TO CONDUCT PMIs

PM	Low (hours)	High (hours)	Average (hours)	Median (hours)
Bus PMI A	1	5	3.1	3.0
Bus PMI B	1.5	10	4.8	5.0
Bus PMI C	2	14	7.3	8.0
HVAC PMI	1	8	3.6	3.0
Lift/Ramp PMI	0.75	8	2.5	2.0

TABLE 15
PARTS AND LABOR COSTS NEEDED TO CONDUCT PMIs

PM	Low ($)	High ($)	Average ($)	Median ($)
Bus PMI A	31	364	184	162
Bus PMI B	54	790	291	208
Bus PMI C	91	965	459	448
HVAC PMI	225	1,078	623	566
Lift/Ramp PMI	108	860	369	140

Of survey responders, 51% reported that their work order generates a parts kit containing all parts needed for each particular PM activity; 49% do not. Agencies that pre-package parts kits noted that they have one prepared for each PM type. Some agencies stated that they would implement such a procedure after reading the survey question. Other agencies identify parts needed for each PM but do not consolidate them into kits.

QUALITY ASSURANCE PROCEDURES

In a perfect world workers would do their jobs properly and oversight would not be needed. Given the safety implications of conducting PMIs, however, QA becomes an essential element of the PM function. A majority of survey responders (79%) have QA measures in place for PM activities. Of those that do, 41% conduct random or spot inspections. Capital Metro in Austin, Texas, inspects 5% to 10% of all PMIs, whereas San Diego Metropolitan Transit System conducts QA spot inspections quarterly. The QA program used by Beaver County Transit in Pennsylvania is driven by drivers' daily reports and road calls.

Montgomery County, Maryland, rarely conducts QA spot checks on individual buses, but uses another procedure to oversee its PM program. Dispatch logs are reviewed weekly to identify service interruptions caused by mechanical failures. Previous work orders are reviewed to note if other factors could have led to the failure, and to determine if a PM task could be put in place to prevent reoccurrences.

REPAIR OF NOTED DEFECTS

Each PM inspection typically results in a list of identified defects. Exactly when those defects are repaired is determined by agency policy. Regardless of policy, agencies typically address critical and safety-related defects immediately and then deal with less critical defects as time and resources allow. Milwaukee County Transit "red tags" critical defects that must be repaired before buses can be released for service. The maintenance software program at WTA will not allow safety-related defects to be deferred—they must be repaired.

Agencies that allow buses back into service with safety-related defects do so at great risk. Defects not considered safety-critical or time-sensitive could certainly be rescheduled for a later time. However, as mentioned earlier, continually postponing the repair of defects over time will cause buses to become unappealing to riders and get to the point where a deteriorated fleet condition becomes accepted.

Of responding agencies, 46% reported that all defects are immediately repaired unless parts are not available, 8% repair all defects that can be done within a set time period (e.g., 1 h, up to 2 h, or 3 h), and 11% schedule identified defects for repair at a later time. Remaining agencies cite other repair policies. Of agencies that schedule repairs for a later date, 62% track follow-up completion by keeping work orders open, 12% use software programs or spreadsheets, and 12% use a manual system. One agency reported not tracking completion of noted defects at all.

CHAPTER FIVE

CASE STUDIES

INTRODUCTION

Three case studies were selected from the survey results to provide more in-depth examples of PM programs. Personnel directly involved with these programs agreed to be interviewed by telephone. In some cases, more than one person at an agency participated in the interviews.

Case studies were selected because of PM features of interest and use to other agencies. WTA in Washington State was selected to review its technician certification program that requires all technicians to perform PM activities in a like manner according to agency-established requirements. WMATA was chosen because of its innovative onboard monitoring system that automatically downloads fault data as buses enter the service line. A case study was also made of the PM challenges faced by Centro, which operates nearly 300 buses with 23 different classifications using 21 different PM schedules.

WHATCOM TRANSPORTATION AUTHORITY

Introduction

WTA was selected as an example of a smaller agency (fewer than 100 buses) that has taken proactive measures to improve its PM program. The agency has instituted a Technician Certification Program for conducting PM inspections. In addition to visually examining buses, WTA requires technicians to take measurements and conduct tests of certain components and systems to more accurately represent equipment condition. The Technician Certification Program was initiated to ensure that all technicians approach safety-critical inspections with the same level of understanding and abilities. The agency is also investigating whether to involve its information technology (IT) department in the PM of intelligent transportation system (ITS) equipment.

Agency Overview

WTA is the public transit provider for Whatcom County, Washington, operating both full-size and paratransit buses. WTA's service area encompasses approximately 840 square miles, logging about 4.9 million boardings and 2 million miles annually. Fixed-route transportation services are provided by 56 full-size buses, and paratransit services include 40 accessible 15-passenger buses.

WTA's fixed-route maintenance was performed by the city of Bellingham Public Works Department; smaller buses and support vehicles were maintained by two WTA technicians, with most work being out-sourced. In 2002, WTA moved into a new facility and broke its contractual ties with the city regarding vehicle maintenance. The first change was to bring maintenance work back in-house. The second was to bring the PM program back under the agency's control. After seven years of continual improvement, WTA's current PM program bears little resemblance to the city's original operation.

Preventive Maintenance Program Review

WTA uses a 4,000 mile PM interval for its paratransit buses and a 6,000 mile interval for full-size buses. The agency's PM program is constantly evolving, using OEM specifications as a base supplemented by actual agency experiences and input from technicians. The MIS generates a unique inspection sheet for each bus, based on bus make, model, and age; mileage interval; previous work history; items deferred from the last PM inspection; and other inspection items requiring special follow-up attention based on a previous repair or inspection. Any defects that get repaired are itemized separately from routine inspection tasks, allowing parts and labor costs to be tracked under separate categories.

WTA has a specific policy regarding repair of defects noted during the PMI. If the defect is safety-critical or prevents the PM from being completed the defect gets repaired immediately. Otherwise, QA personnel on the shop floor prioritize which defects get repaired. Deferred repairs automatically appear on the next PM sheet generated by the MIS. Work orders remain open until the defect is repaired. The maintenance manager reviews all open work orders daily. The agency's policy, however, is get as much done as possible while the bus is in the shop.

Technician Certification Program

After gaining control of its maintenance operation WTA realized it needed a formal Transit Technician Certification Program where all technicians would carry out safety-sensitive maintenance tasks in a manner prescribed by the agency. The ten safety-sensitive systems and components identified by WTA are:

1. Service and Parking Brake
2. Air System
3. Steering System
4. Suspension and Undercarriage
5. Tires, Wheels, and Wheel End Components
6. Exterior Lights, Mirrors, Signals, Wipers, and Warning Devices
7. Fuel and Exhaust Systems
8. Interlock Systems
9. Interior Lights, Gauges, Warning Devices, Controls, and Safety Equipment
10. Wheelchair Lifts.

According to WTA, the ten areas represent the bulk of systems and components that if not properly inspected and maintained have the largest propensity for causing vehicle accidents and/or passenger injuries.

A training and certification program was especially needed for PM inspections because technicians were hired with diverse fleet experience. Lacking direction from the agency, each technician performed inspections differently. Standards were needed to establish how PMs were conducted, defects were identified, and follow-up repairs were made.

An important step in establishing job consistency was to develop a task list of 75 inspection items. Next was to establish procedures that clearly identified what technicians looked at during a PMI and conditions under which items are serviceable and when they need to be replaced. Inspection criteria were determined using OEM manuals and service bulletins, DOT regulations, Technology and Maintenance Council (TMC) suggested practices established by the ATA, and other available reference materials. In areas where there was no clear published standard, a standard was established based on agency experiences.

Under WTA's Certification Program technicians must demonstrate the ability to carry out safety-critical PM inspections and repairs. WTA hires technicians as skilled journeymen and requires them to work side by side with experienced agency technicians to learn how to perform specific tasks to established WTA procedures. Each technician is given a series of tasks and must successfully carry them out under the supervision of a lead technician who serves as a Task Administrator. Passing the Certification Program is entirely hands-on, with no written test. If a task is not successfully completed, additional training is provided until the task is mastered. Tasks in all ten safety-critical areas must be successfully completed before a technician receives certification, and every technician is expected to be certified. A spreadsheet is used to track each technician's progress.

The Technician Certification Program takes up to two months to complete. Training is provided in each of the ten safety-sensitive task areas, conducted by lead technicians and supervisors using service manuals and training videos. Limited off-site instruction is also provided, with technicians experienced in certain areas providing targeted training. Because many of the new hires are former truck technicians, training is primarily intended to help in the understanding of unique bus aspects and in becoming familiar with WTA shop procedures. A key outcome of the program is that technicians conduct PM inspections in a consistent manner where they are required to measure and test many safety-critical systems and components instead of simply checking them off.

Technicians receive a certificate upon successful completion of the program, along with a shoulder patch that is sewn on to their uniform. The patch is shown in Figure 5.

Improved Maintenance Performance

WTA's Technician Certification Program produced some initial challenges as both labor and management had to adapt to new leadership, working conditions, and work procedures. Once resolved, the agency experienced significant improvements in the form of a reduced number of road calls and service interruptions. To track road calls the agency moved to a Vehicle Maintenance Reporting Standards (VMRS) system. VMRS was developed as a standardized coding convention for tracking equipment assets and maintenance repairs by the TMC of the ATA. Although transit is required by the FTA to report service interruptions according to definitions identified as part of the National Transit Database, many agencies such as WTA also use VMRS coding to more accurately classify road calls.

FIGURE 5 WTA technician certification program patch.

Since instituting its Certification Program WTA has eliminated or reduced road calls in several key areas.

- Eliminated "hot wheel" road calls and malfunctions related to wheel bearing torque and adjustment procedures. A new WTA procedure specifically calls for technicians to follow the TMC Recommended Practice for bearing adjustment, which requires them to use a dial indicator and follow precise instructions. Before that a front wheel had come off a bus because the wheel bearing overheated and failed from improper adjustment.
- Reduced brake-related road calls and malfunctions. The Certification Program trains technicians to use measuring tools such as "go/no-go" gauges, spider gauges, dial indicators, and other brake component measuring tools to document brake wear. Brake components are now replaced because a technician measured and found tolerances outside specification limits. Previously, technicians would change out every single brake component, good or bad, just because it was done that way in the past.
- Reduced air system-related malfunctions. A procedure to inspect and test air compressors, especially with 2007 engines where the air compressor inlet is located just below the EGR outlet, reduced the number of road calls resulting from insufficient air pressure. The agency found soot and engine exhaust residue in the air system and was able to take action by notifying the bus OEM that vehicle air system components were being contaminated and damaged by engine exhaust residue coming from the air compressor. Although this issue was actually an engine manufacturer's problem, WTA impressed upon the OEM that this problem may have safety implications if not corrected. WTA insisted that the engine OEM identify the exhaust contamination source, causing the OEM to respond with a campaign to re-route the air compressor inlet further upstream from the EGR to prevent exhaust gases from entering the air compressor inlet.
- Eliminated tire, wheel, and wheel-end-related road calls. New procedures direct technicians to pay closer attention to tire wear indicators. WTA purchased a portable alignment system and now schedules buses for alignments when technicians note abnormal tire wear patterns.
- Reduced exhaust system-related road calls. Technicians are trained to identify abnormal DPF system conditions and resolve potential problems before they result in a road call.
- Eliminated wheelchair lift and ramp-related road calls. Four technicians were sent to factory training classes and returned to train other WTA technicians. Trained technicians then developed PM tasks and training for the wheelchair lift portion of the Certification Program. PM inspections now include extensive lift and ramp checks.

Preventive Measurement Program Refinements

WTA constantly reviews unscheduled maintenance events and enhances its PM program in a proactive manner to help reduce future occurrences. All maintenance employees are encouraged to provide input into PM checklist tasks, how PMIs are conducted, and the intervals at which PM activities take place. Following are some of the refinements made to improve the PM program as a result of the collaborative participation:

- Added an in-depth door inspection procedure in response to safety concerns.
- Added brake system inspections to test air system alarms and valves.
- Added procedure to inspect turbochargers on higher-mileage buses to prevent turbocharger failures and resulting damage to exhaust after-treatment devices.
- Added procedure to torque oil drain plug to prevent over-tightening and resulting oil pan damage.
- Added in-depth brake inspections. Brake drums are removed and foundation brakes inspected and S-cam wear checked to ensure all brake components are in serviceable condition. Particular attention is paid to environmental factors that contribute to brake wear and malfunctions such as water, sand, and salt intrusion.
- Enhanced wheelchair lift and ramp inspections and servicing based on specialized training provided by the OEM. Many of the road calls in the past were the result of incomplete inspections and servicing.
- Added air compressor tests to detect oil and soot contamination, and to check settings.
- Added sampling of hydraulic oil to reduce hydraulic pump failures on older buses.
- A "Bowmonk BrakeChek" tester is used during the road test portion of every PM regardless of vehicle size or application to verify braking system performance. All results are documented. Testing has identified poor brake performance that otherwise would not have been identified by only conducting a visual inspection.
- Purchased new wheel lug nut torque tools and added procedures to eliminate broken wheel studs caused by over-tightening lug nuts. Pneumatic torque wrenches stall once lug nuts reach correct torque settings. The agency has not experienced a broken wheel stud or loose lug nut since purchasing the new tools.

The addition of new procedures and tools is designed to get technicians to take more measurements during PM. The new procedures require technicians to initial (rather than simply √) every PMI check on the checklist to foster a sense of "ownership" for each PMI checklist item. Fortunately, the agency has not had any serious accidents or fatalities; however, if one does occur the agency can produce documentation showing that vehicles were inspected to a consistent standard, measurements were taken, tests conducted, and results documented to prove the bus was in safe operating condition following inspection.

Quality Assurance

To make certain PM inspections are done to agency standards lead technicians also work as QA inspectors. They check three or four items at random during each PMI. If measurements taken during the random QA inspection do not match, the technician is asked to re-measure. The QA inspector gets to know the capabilities of technicians and provides instruction when needed. A QA stamp is used when inspections are done correctly.

Intelligent Transportation System Equipment

WTA, as with many other agencies, is experiencing unprecedented growth in the number of ITS devices intended to provide increased passenger information, safety, and security. Examples of onboard ITS equipment includes AVL, automatic next-stop annunciators, video surveillance cameras, traffic signal preemption, and others. Although this equipment has done much to improve transit's image and integrate it with other transportation modes, it rarely affects the physical operation of the bus such as the engine or braking system does.

Given the complexities of ITS, WTA's maintenance department finds it difficult to keep pace with the training required to properly diagnose, maintain, and repair this equipment along with the various communication protocols that integrate them. The extra work load also creates a dilemma as to which failed equipment gets repaired first—ITS or foundation bus equipment? The proliferation of ITS equipment also adds to the PM workload.

Because WTA's IT department has a good understanding of ITS equipment, the agency is considering a program that involves them in the PM process.

Getting the IT department involved allows them to more fully understand maintenance requirements for ITS equipment. Input is expected to help WTA prioritize its overall maintenance needs with those of the IT department.

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

Introduction

WMATA was selected for this case study because of its innovative approach to downloading data at the service line by means of wireless communication as buses return from revenue service, and the use of onboard speakers to give verbal commands to personnel regarding faults that need immediate attention. The system also provides an itemized report of all vehicle faults, allowing the maintenance department to prioritize repairs. Early identification of faults on a daily basis through expanded onboard monitoring allows the agency to respond more quickly with PM action, which typically would not take place until the next scheduled PM interval or after a sudden breakdown occurred.

Agency Overview

The bus operation at WMATA, known as Metrobus, provides service to the nation's capital 24 hours a day, 7 days a week, with 1,500 buses logging about 134 million trips annually. WMATA serves a population of 3.4 million within a 1,500-square-mile jurisdiction. The agency operates approximately 460 CNG buses and 50 hybrid buses, with 200 more in the process of being delivered.

Background

In 1995, WMATA began searching for a method of communicating bus stop, route, and transfer information to meet ADA requirements. After testing, the agency selected an Automatic Voice Annunciation System manufactured by Clever Devices, and installed the system on 264 new buses in 1997. Discussions between the two organizations led to expanding the Voice Annunciator to include bus performance and operation monitoring.

The first automatic vehicle monitoring (AVM) system was installed on two buses in 1998, and has grown steadily since then as did the number of onboard conditions being monitored. Today, 703 of WMATA's buses are equipped with AVM, and five of its 10 depots are equipped to download service information from those buses. Transfer of all data at the service line is done wirelessly.

Automatic Vehicle Monitoring System Description

Buses continually monitor, measure, and report the status of critical onboard bus systems and components. Robust onboard data collection is made possible through the SAE J1939 communications protocol used by drivetrain components (e.g., engine, transmission, and brakes) to send and receive control commands. For example, if wheel sensors detect that drive wheels are losing traction (i.e., spinning on a slippery surface) a command can be sent to the engine to reduce its speed regardless of driver action. The same J1939 communications network also has the ability to monitor and record various operating conditions or parameters within the system.

When certain parameters outside acceptable ranges are detected, the fault is broadcast over the J1939 communications network and stored in memory. Drivers receive a warning light or buzzer if faults are more serious. If a catastrophic failure is about to occur, instructions sent over the J1939 network will automatically reduce the engine's power or cause it to shut down altogether. Sometimes parameters are exceeded but not severe enough to warn the driver or take drastic action. In these cases, technicians use scheduled PM events to plug diagnostic readers into the communications network to access data that can point to a developing problem. However, instead of accessing the data at PM intervals every 6,000 miles, WMATA with its AVM system now has the benefit of obtaining critical data on a daily basis.

Vehicle monitoring systems such as the one used by WMATA are designed to "listen in" on communications that take place over multiple onboard systems by means of the J1939 network and can be programmed to report abnormal conditions in various ways. One is to broadcast certain faults in real time over the bus radio system to headquarters. Another is to broadcast faults by means of short-range wireless communications as the bus enters the service lane, the method selected by WMATA. As a bus enters the range of a service line antenna, shown in Figure 6, data are transmitted from the bus to the maintenance department.

The AVM system first performs a health check of itself, making sure the monitoring and reporting system is functioning. The system then goes through various checks including engine; transmission; heating, ventilation, and air conditioning; door system functionality; and brake pushrod travel, an indication of brake wear. If not within acceptable parameters, the Voice Annuciator portion of the system will make a "maintenance action necessary" announcement to the hostler (cleaner) when he or she gets back in to park the bus.

Critical faults are flagged, and the control center and maintenance department are both notified to hold a bus from service. Less critical abnormalities appear on a daily exception report delivered to the maintenance manager, which lists every fault code generated by the AVM onboard diagnostic system. Data produced by the system goes to a database where a software product developed by the AVM manufacturer produces a series of reports and e-mail notifications.

FIGURE 6 Antenna receives wireless data from WMATA buses.

A sample Exception Summary Report is shown as Appendix H. It lists fault codes generated for each bus, the day and time each fault occurred, and provides a description of the fault. In the example provided, Bus No. 2616, a 2005 Orion IV 40-foot with John Deere CNG engine, generated seven different faults on a given day including engine coolant temperature above 212 degrees, fuel valve fault signal, a nonfunctioning brake actuator at axle #1 left side, natural gas tank pressure input voltage low, and others. None were serious enough to warn the driver, but based on the data provided, WMATA is in a better position to schedule repairs and prevent the escalation of defects into more serious ones.

According to WMATA the approximate cost for the AVM system is around $20,000 for each onboard bus monitoring system; cost for wayside equipment was not available. Maintenance of both wayside and onboard AVM equipment is provided by the vendor under a service contract with WMATA.

Custom Applications

For electronically controlled components such as engines, transmissions, and anti-lock braking systems, the task of collecting fault data is somewhat straightforward. However, door systems typically lack electronic control ability. Custom solutions were applied to determine door opening and closing times. Monitoring those signals allows WMATA to determine if a door was taking too long to close or was opening too fast. If so, the AVM system generates a fault code sent to the maintenance department as the bus enters the service line.

Understanding that too much information can be overwhelming, WMATA went through a process of determining which faults might trigger a "maintenance action necessary" announcement to service line hostlers. The process involved weeding out unimportant, irrelevant, and even erroneous fault codes, and building in system filters to tighten monitoring parameters.

In another application, engine temperatures were more closely monitored to prevent overheating. Previously, certain bus engines would overheat because the design of the cooling radiator causes it to clog with debris. When this occurred the engine control system triggered a warning light to the driver, and in more severe cases automatically shut down the engine. WMATA cleaned radiators every day to prevent service failures, knowing that some radiators probably did not require it. Now the AVM system is set up to issue a warning at the service line when the coolant temperature is approximately 12 degrees lower than the engine parameter set point. Early warning of rising temperature indicates that the radiator needs to be inspected and cleaned. The early warning now allows WMATA to clean specific radiators only when needed.

Preventive Maintenance Benefit

As stated earlier, critical defects are repaired immediately, whereas those that can wait are typically scheduled for another time or at the next scheduled PM interval. Every day each bus division receives a printout of all faults found on the fleet. Data are reviewed, faults prioritized, and repairs scheduled accordingly. Senior shop personnel also review past bus histories and conduct trend analysis to determine the exact repair procedures required to correct abnormalities. A detailed work order is then given to the technician, relieving him or her from performing certain diagnostic tasks. All activities are designed to make efficient use of the early warnings provided by the onboard data collection and daily reporting system. The objective is to prevent initial problems from growing into larger ones that typically require more labor and parts to correct, can potentially cause a safety incident, and result in an in-service breakdown.

Service line hostlers could not achieve the same level of fault detection. Indeed, AVM has expedited the service line function because hostlers are relieved from making several of the customary inspections. Combined with those daily inspections that hostlers do make, the automated system greatly contributes to the PM function. Acquiring the same level of daily information would require a skilled technician to perform individual tests on each onboard component and system. The ability of AVM has also streamlined the PMI function because much of the inspection work is now done by the bus itself.

Other Benefits

Once a database was established WMATA was able to use the information to develop technical specifications. AVM provides the agency with vast amounts of real world information that can more accurately define performance requirements in a bid specification. When specifying door systems, for example, WMATA includes real world data that reflect actual door cycles to ensure the system is robust enough to handle the agency's operating environment.

WMATA also uses the data for compliance purposes. For example, drivers are required to cycle their wheelchair lifts before beginning service. Based on reports generated by AVM, division superintendents can determine if the daily procedures were indeed followed.

WMATA is also saving on warranty claims. For example, when newly delivered buses exhibited a problem with dragging brakes, data collected by AVM revealed an engineering flaw that was traced back to the axle manufacturer. The finding caused the manufacturer to reline brakes on 250 buses at its own cost. Other trend analyses done with AVM data revealed early problems associated with the fire suppression system caused by faulty engineered sensors and faulty control logic that affected transmission shift quality. Collecting and reviewing data on a daily basis serves as a predictive maintenance tool, allowing WMATA to identify problems early on instead of waiting for the next 6,000 mile PM interval or a breakdown to occur.

The manufacturer supplying buses to WMATA also uses the AVM system at its plant to pre-check the functionality of the automated voice annunciator system. The system could be used to verify the operation and build quality of other electronic onboard systems on new buses as they come off the assembly line, allowing in-plant inspectors to make more informed evaluations before accepting buses. Preventive measures taken at the plant have the potential to save the manufacturer money by addressing quality issues before buses arrive at the agency.

CENTRAL NEW YORK REGIONAL TRANSPORTATION AUTHORITY

Introduction

Centro operates 279 buses under 32 different classifications, which collectively fit into 19 different PM schedules. This case study examines how the agency manages its PM program given the diversity.

Agency Background

Centro is headquartered in Syracuse, New York, and serves the counties of Onondaga, Oneida, Cayuga, and Oswego. The agency has a staff of 675 employees; its fleet travels 7,500,000 miles annually carrying approximately 38,000 passengers daily and 14.4 million passengers annually.

Bus Classifications

Despite having 279 buses under 32 different classifications, Centro separates them into two basic categories for the purposes of conducting PM:

1. Full-size transit buses (30 ft and larger), of which the agency has a total of 229; and
2. Paratransit buses, of which it has a total of 50.

Of the 229 full-size buses, 102 are traditional diesel, 120 are powered by CNG, and 9 are hybrids. Table 16 shows the full-size bus fleet and Table 17 shows the paratransit fleet. Both tables also include the respective class designation code for each bus type. The codes are important because they are used to assign buses to specific PM inspections.

Preventive Maintenance Classifications

As mentioned previously, Centro has PM classifications for full-size buses and another for the smaller paratransit fleet. Table 18 shows the various PM schedules established for

TABLE 16
CENTRO FULL-SIZE BUS FLEET

Bus Type	Bus Class Designation Code	Quantity
2007 Gillig—Hybrid	07HB	9
2003 35 Ft Orion V—CNG	2003	5
30 Ft New Flyer D30LF—Diesel	3004	10
1999 Orion V—Diesel	3099	6
2007 Gillig 35 Ft—Diesel	3507	2
2008 Gillig 40 Ft—Diesel	3608	3
2008 Gillig 30 Ft—Diesel	3708	3
40 Ft New Flyer D40LF—Diesel	40D05	23
40 Ft New Flyer C40LF—CNG	40G05	8
40 Ft New Flyer C40LF—CNG	40H05	11
1991 40 Ft Orion V DSL—Diesel	500	1
1999 40 Ft Orion V—CNG	599	78
1995, 96, 00 MCI 102D3—Diesel	601	12
1996 Orion V—Diesel	960RI	4
1997 Nova Bus—CNG	97N5	18
1999 Orion V—Diesel	990RI	22
2009 Gillig 35 ft—Diesel	3709	4
2009 Gillig 40 ft—Diesel	3609	5
2009 MCI D4000—Diesel	901	5

its full-size bus fleet. The intervals are based on a base 6,000 mile "A" PM, where an entire vehicle inspection takes place along with an engine oil and filter change. The "B" inspection takes place every 12,000 miles, and consists of an "A" inspection with the addition of replacing the fuel filter and cleaning the centrifugal filter. Centro's "B2" inspection, which takes place every 36,000 or 72,000 miles depending on the bus, consists of repeating the "A" and "B" services with the addition of replacing the transmission fluid and filter. All mileage-based PM intervals also have a time-based alternative. For example, the "A" PM takes place every 6,000 miles or six months, whichever comes first.

The remaining inspections are time-based (i.e., every 45 days, etc.). Centro has separate PM inspections for the electrical system; the HVAC system; wheelchair lifts; fire suppression system; farebox; air drier; and a PM inspection that encompasses the driver's seat, destination signs, and the emergency windows. There are also separate time-based intervals for engine tune-ups and chassis dynamometer testing.

TABLE 17
CENTRO PARATRANSIT BUS FLEET

Bus Type	Bus Class Designation Code	Quantity
2003 Ford Van	03FOH	3
2006 Eldorado Aerotech	2006P	3
2003/04 Ford Van	203	15
2005 Ford Van	205	8
2007 Ford Van	207	4
2009 Eldorado Aeroelite	209	13
2009 Ameritrans	0209	4

PM schedules for Centro's paratransit bus fleet consists of only two inspection categories. As with the larger buses, the base "A" inspection is set at 6,000 miles and includes an engine oil and filter change. The "B" inspection, which takes place every 18,000 miles, repeats the "A" inspection and adds transmission fluid and filter replacements. Table 19 shows the two inspection classifications for Centro's paratransit buses.

Although the oil change interval for buses powered by International engines is 14,000 miles, the interval was changed to 6,000 miles because of excessive bus idling as revealed by oil analysis. The agency is firmly committed to its oil analysis program, which includes both engine oil and transmission fluid. Identifying solids and other contaminates in the oil/fluid allows Centro to take maintenance and repair action before a relatively minor problem results in catastrophic failure.

Preventive Maintenance Procedures

Each department within Centro's maintenance organization is responsible for conducting its own PM inspections. Electrical, HVAC, farebox, and other dedicated departments within maintenance have their own specialized inspection

TABLE 18
PM CLASSIFICATIONS FOR FULL-SIZE BUSES

Designation	Activity	Interval	Bus Class Designation Codes
A PM Service	PM inspection Oil/filter change	6,000 mi/6 mos.	501, 599, 600, 601, 2003, 97N5, 3004, 40DO5, 40G05, 40H05, 07HB, 96ORI 990RI, 3608, 3708, 3609, 3709, 901
B PM Service	A PM service Fuel filter Centrifugal oil filter	12,000 mi/12 mos.	501, 599, 600, 601, 2003, 97N5, 3004, 40DO5, 40G05, 40H05, 07HB, 96ORI, 990RI, 3608, 3708, 3609, 3709, 901
B2 PM Service	A PM service B PM service Transmission fluid and filter change (synthetic)	72,000 mi/96 mos.	501, 599, 601, 6010, 2003, 3004, 40DO5, 40G05, 40H05, 07HB, 96ORI, 990RI, 3608, 3708, 3609, 3709, 901
B2 PM Service	A PM service B PM service Transmission fluid and filter change (synthetic) Water filter	36,000 mi/24 mos.	97N5
C1 PM Service	A PM service B PM service Transmission fluid and filter change (synthetic)	One time only at 3,000 mi	Newly purchased vehicles only
D Inspection	Chassis dynamometer testing	Every 365 days	All
E Inspection	Complete electrical system inspection	Every 365 days	All
F Inspection	Complete fire suppression system inspection	Every 180 days	599, 97N5, 2003, 3004, 40DO5, 40G05, 40H05, 07HB, 3507, 3608, 3708, 3609, 3709, 901
F2 Inspection	Replace fire suppression squib	Every two years	599, 97N5, 2003, 3004 (older buses are equipped with a manual style actuator that is required to be replaced at a 2-year interval)
F6 Inspection	Replace fire suppression chemical agent tank	Every six years	599, 97N5, 2003, 3004, 40DO5, 40G05, 40H05, 7HB, 3507, 3608, 3708, 3709, 901 (new buses are equipped with an electronic actuator that last 12 years, but are changed at the 6-year interval)
G Inspection	Complete farebox inspection	Every 90 days	All with farebox

(*Continued on next page*)

TABLE 18
(*continued*)

Designation	Activity	Interval	Bus Class Designation Codes
H Inspection	Complete HVAC inspection	Every 180 days	All
H1 Inspection	HVAC filter replacement	Every 45 days	07HB
L Inspection	Complete wheelchair lift inspection	Every 45 days	All with lift and ramps
N Inspection	PM cartridge (with oil separator)	Every 365 days	All
N2	PM air drier	Every 2 years	All
Q Inspection	PM driver seat, PM destination signs	Every 180 days	All
T Inspection	CNG tank inspection	Every three years	All with CNG
TU Inspection	Engine tune-up	Every 365 days	All

TABLE 19
PM CLASSIFICATIONS FOR PARATRANSIT BUSES

Designation	Activity	Interval	Bus Class Designation Codes
A PM Service	PM inspection Oil/filter change Wheelchair lift inspection	6,000 mi/6 mos.	201, 203, 205, 207, 209, 0209, 03FOH, 2006P
B PM Service	A PM service Transmission fluid and filter change Fuel filter Air filter	18,000 mi	201, 203, 205, 207, 209, 0209, 03FOH, 2006P
F Inspection	Complete fire suppression system inspection	Every 180 days	209, 0209
F6 Inspection	Replace fire suppression chemical agent tank	Every six years	209, 0209
N2	PM air drier	Every two years	209, 0209

crews responsible for conducting PM activities. Within each department one work crew is dedicated to inspections, whereas another is dedicated to repairing defects found during inspections. Safety-related defects are repaired immediately, whereas other defects noted during inspections are rescheduled for a later time.

Centro uses the Jakware Fleet Management System to track PM activities. The system schedules the appropriate PM inspection based on the bus mileage and its designation code. For example, 1994 40-ft Orion V diesel buses have a designation code of 501. The MIS schedules buses with that designation code to receive PM services according to the following schedule:

- "A" PM (oil and filter change) every 6,000 miles or six months,
- "B" PM (fuel and centrifugal oil filter) every 12,000 miles or 12 months,
- "B2" PM (transmission) every 36,000 miles or 24 months 97N5 RTS Nova's only,
- "B-2" PM (transmission) every 72,000 miles or 96 months,
- "C-1" PM one-time inspection at 3,000-mile interval,
- "D" PM (chassis dynamometer) every year,
- "E" PM (electrical) every year,
- "F" PM (fire suppression) every 180 days,
- "F2" PM (squib replacement) every 2 years,
- "F6" PM Chemical agent tank replacement every 6 years,
- "G" PM (farebox) every 90 days,
- "H" PM HVAC inspection every 180 days,
- "H1" PM HVAC filter replacement hybrid buses only,
- "L" PM (wheelchair lift) every 45 days,
- "N" air drier cartridge w/oil separator every 1 year,
- "N2" air drier "F" PM (fire suppression) every 180 days,
- "Q" PM (driver seat, destination sign, emergency windows) every 180 days,
- "T" PM CNG tank inspection every 3 years, and
- "TU" PM (engine tune up) every year.

Buses with other designation codes receive PM services according to other schedules depending on the bus type and its onboard equipment.

Every work order generated for a PM inspection has its own unique checklist tailored to a specific bus type or component. In addition to "checking off" that a specific item was inspected, checklists also require technicians to record certain information such as brake adjustment measurements and measuring stopping distance measurements during brake tests. Technicians performing the inspections, as well as those repairing noted defects, are trained by Centro before being required to perform their duties. Most of the training involves working with a first-class mechanic and monitoring performance to ensure they are qualified to handle the assigned PM tasks.

The agency strives to make all repairs noted as part of the PM inspection that same day, depending on parts availability and scheduling. The MIS generates a separate work order for every defect identified during the PM inspection. Work orders remain "open" (unresolved) until a repair is made to correct the specified defect, whereby the work order is then "closed" (resolved). If multiple work orders are open on the same bus, the technician is required to indicate separately whether they will also be making those repairs. If not, they must indicate the reason for keeping the work orders open. The agency has a policy of closing out all work orders at the end of each month.

Specialized Preventive Maintenance Activities

Centro has specialized PM classifications to address specific bus equipment such as the electrical system, HVAC system, and the fire suppression system. The agency has also developed special procedures for its CNG and hybrid bus fleets. The intent of these specialized PM activities is to focus attention on certain bus areas and repair any noted defects as part of a scheduled activity to minimize unscheduled work.

Electrical Preventive Maintenance

The "E" electrical PM inspection takes place annually on all full-size buses. It was initiated three years ago to address the many electrical-related defects typically found during "A" inspections, and because of road calls and service interruptions caused by these defects. Since instituting the "E" inspections on an annual basis, service interruptions for electrical problems have been significantly reduced.

The six-page "E" inspection addresses all electrical areas of the bus, including electrically controlled aspects of the air system. It includes 28 different electrical areas such as the starting and charging systems, lights, multiplex system, interlocks, accelerator and brake pedals, public address (PA) system, kneeling system, wheelchair lift, electrically controlled brake valves, and all other electrical/electronic areas of the bus. Incorporating brake system inspections into the "E" inspection works well because so much of the braking system, including the anti-lock braking system, is electrically controlled, and because at Centro the electrical and pneumatic departments are combined.

Heating Ventilation and Air Conditioning Preventive Maintenance

The HVAC or "H" inspection takes place on each bus every six months to check the entire system. There is one inspection protocol for buses with air conditioning, and another for those without it. Inspections are classified by bus area, denoting certain tasks for equipment located on the street side of the bus, in the engine compartment, the defroster compartment, and other such areas. A separate “H1” inspection, which takes on certain buses every 45 days, replaces a series of HVAC-related air filters.

Fire Suppression Preventive Maintenance

The fire suppression or “F” inspection is based in part on OEM specifications, as well as requirements set forth by the National Fire Protection Association. There are 23 separate procedures for conducting this inspection with detailed work instructions provided that they also include a series of warnings and notes. For example, one warning reminds technicians to always install a shipping plate and an anti-recoil plate when transporting a pressurized agent cylinder. A note included in the inspection procedures reminds technicians to avoid using solvents when cleaning gauge faces to prevent damaging the plastic face. Instructions are very detailed and use a step-by-step process.

Centro’s separate “F2” PM inspection replaces the fire suppression squib every two years, whereas the “F6” inspection replaces the chemical agent tank every six years.

Hybrid Preventive Maintenance

To address the PM needs of its hybrid buses, Centro uses its existing PM schedule developed for similar diesel buses with the addition of unique PM tasks for hybrids. For example, according to the OEM, battery cooling filters unique to Centro’s hybrid buses require replacement every 15 days. However, after evaluation, the agency determined that filters were not sufficiently dirty after this interval and extended the interval to 45 days to coincide with its “H1” HVAC inspection when cabin filters are replaced. For hybrid buses, Centro’s “H1” inspection also includes a battery cooling filter replacement. Centro, however, continues to evaluate the replacement of this filter and is considering extending its replacement beyond 45 days.

At the “B2” inspection, where transmission fluid is changed every 72,000 miles on traditional buses, Centro replaces fluids and filters unique to the hybrid drive unit, which on the Allison system replaces the traditional transmission. The synthetic fluid used in the hybrid unit is identical to that of the standard transmission, and so is the fluid change interval. For Centro, as with every agency, new PM requirements that can be kept within the framework of existing PM intervals avoid the downtime associated with creating separate intervals.

Centro is closely monitoring fluid quality through its oil analysis program. As a result of the findings, the agency has reduced the interval (i.e., made it more frequent) for some transmissions and may do the same for its hybrid fleet.

Compressed Natural Gas Preventive Maintenance

Centro’s CNG buses adhere to the same PM schedule as diesel buses, but with added procedures. Because CNG buses have a spark ignition system, tune-ups for these engines consist of changing sparkplugs and CNG tanks and piping is inspected for leaks as part of the “T” inspection. Although the OEM suggests changing the crankcase breathers at 18,000-mile intervals, Centro changes them at 6,000 miles because condensation buildup clogs the filter and will freeze in the winter resulting in elevated crankcase pressure. Centro uses the same 6,000-mile interval for its diesel buses equipped with crankcase ventilation filters.

Other Agency Initiated Preventive Maintenance Activities

Based on its experiences and operating environment, Centro has also initiated other PM activities:

- Fuel filters are replaced every 12,000 miles to avoid problems such as freezing in the winter.
- Air cleaners are changed every 18,000 miles because salt used on roadways in the winter shows up in the oil analysis results as high sodium and magnesium in the crankcase. Also, when the ambient air humidity is high and there is salt on the road, it actually draws the salt in through the air cleaner.
- During the “L” (wheelchair lift) inspection the hydraulic filter is replaced every 45 days even though the OEM suggests an annual replacement.
- An “N” inspection was recently added to replace the air drier cartridge annually.
- Engines and radiators are steam cleaned within 90 days to mitigate overheating problems, especially those caused by clogged radiators.

CHAPTER SIX

CONCLUSIONS AND LESSONS LEARNED

INTRODUCTION

This chapter summarizes conclusions, presents lessons learned from this synthesis project, and offers areas for further study. Material drawn from this work highlights the importance of developing a preventive maintenance (PM) program that considers approaches and information from several sources, but ultimately is one that meets the unique requirements of each agency. The chapter is organized in three sections:

1. Conclusions
2. Lessons Learned
3. Future Study.

The future study needs offered at the end of this chapter focus on providing agencies with additional tools and resources to help enhance their PM programs.

CONCLUSIONS

This synthesis revealed that it takes a substantial amount of insight, ability, and experience to establish service intervals and carry out inspection, repair, and overhaul activities in such a way that the collective actions are effective at preventing minor mechanical issues from resulting in mechanical breakdowns that disrupt passenger service. Given that nearly a half million service interruptions occur annually in the United States owing to mechanical failures, no PM operation, regardless of how effective, will ever fully eliminate them. However, a PM approach that monitors unscheduled maintenance, determines underlying causes, and schedules activities to prevent them will improve bus reliability and customer satisfaction.

Investigations made through this study make clear that agencies with effective PM programs are those that direct as much maintenance activity as possible into scheduled events where labor, parts, and vehicle downtime are anticipated and planned. The opposite is "reactive maintenance," where emergency repairs are made in a triage setting in hopes of producing the minimum number of buses needed to meet peak service demands.

Regardless of how well a PM program is developed and executed, certain factors cannot be controlled. For example, one agency identified and replaced a leaking wheel seal in early stages of failure. The perceptive action prevented the seal from saturating the brake lining, avoiding the cost of replacement and a potential safety incident. However, the new seal was defective and failed within days, resulting in a service interruption after all. Examples such as this coupled with new propulsion technologies, FTA requirements that buses operate a minimum of 12 years, and increased ridership in the face of reduced budgets make the job of PM formidable.

Maintenance managers do not need this study to tell them how difficult PM is. Based on survey comments received they seek:

- An indication of where they stand among other agencies with regard to PM intervals and related activities.
- Sharing of information, especially examples of how other agencies approach PM.
- Additional staff and resources to analyze data and failure trends, and update PM procedures accordingly.
- Additional staffing to allow dedicated quality assurance (QA) personnel to follow up on PM inspections and ensure all defects have been properly identified and repaired.
- Additional software capabilities.
- More reasonable PM schedules and specifications from original equipment manufacturers (OEMs).
- A request for OEMs to place all vehicle PM requirements in one convenient, easy-to-access reference location.

Study findings make evident that each agency approaches PM according to its own fleet makeup, operating conditions, and available resources. Although some approaches are common across the industry, others are mixed. Various methods presented in this study allow agencies to consider them for applicability to their own operation. Collective approaches provided here can also provide a benchmark for others to gauge where they stand within the industry with regard to carrying out PM activities.

One area of commonality pertains to bus preventive maintenance inspections (PMIs), where all responding agencies use mileage-based intervals, with 6,000 miles being the norm. Only one agency is investigating the use of fuel consumption as the basis for establishing intervals, whereas another has gone to time-based intervals for its electric trolley bus fleet. There is virtually no common ground with regard to software programs used to schedule and guide PM activities and only a slight majority is pleased with those programs. Most agencies surveyed base their intervals on the actual mileage of the previous interval, regardless if it was early, late, or on time. Only one survey respondent, Dallas Area Rapid Transit, uses a software program to predict part failures based on life cycles. These predictive tools are more commonly used in aerospace and other resource-rich transportation sectors.

Most agencies base PM intervals on OEM specifications to maintain warranty coverage, and continue to follow that interval after warranties expire. All use checklists to guide PM activities, but only half develop ones unique to specific buses and equipment. Nearly all agencies surveyed include some type of pass/fail criteria for carrying out PM activities, and most provide technicians with written job instructions.

Regarding the skill level of those performing PMIs, a slight majority use experienced technicians; others use entry-level personnel or a combination of both. Most use the same technician to conduct all aspects of the PM activity as opposed to splitting responsibilities. It is assuring that the vast majority of survey responders have some type of QA measures in place to follow up on PM activities. An assessment of how effective they are at actually reducing unscheduled maintenance, however, was outside the scope of this project.

More than one in four agencies responding to the survey have not calculated the time needed to conduct PM activities, making it difficult to accurately determine staffing levels and budgets. Those making the calculations reveal that the mean time needed to conduct an "A" bus inspection is 3 h; 5 h for a "B" bus inspection; 8 h for a "C" bus inspection; 3 h for a heating, ventilation, and air conditioning PMI; and 2 h to conduct a wheelchair lift/ramp PMI.

Two of three responders have calculated costs associated with PM. Those making the calculation indicated that the median cost for both parts and labor for conducting common PM activities is $162 for "A" bus inspections; $208 for "B" bus inspections; $448 for "C" bus inspections; $566 for heating, ventilation, and air conditioning PMIs; and $140 for wheelchair lift/ramp PMIs. Only half of reporting agencies issue a parts kit with all needed parts when assigning PM work orders. Fewer than half repair defects noted during PM inspections as soon as they are identified; others reschedule as needed.

Half of survey responders need 20% spare vehicles to support PM activities, consistent with the FTA maximum allowance. The percentage is high considering that additional spare buses are needed to compensate for buses out of service as a result of accidents, awaiting parts, or in need of other maintenance activities. Remaining spare ratios reported by survey responders are between 5% and 15%, which is more representative of the actual spare fleet needed to conduct PM.

LESSONS LEARNED

Synthesis findings convey that there is no one PM approach or formula suitable for all agencies owing to the variations that exist. Each maintenance operation must make use of all available information and then establish PM intervals and related activities tailored to its unique fleet and operating characteristics. Robert Johnson, writing for the National Truck Equipment Association, puts it succinctly: "It's a combination of science with trial and error." To help agencies enhance their existing PM programs, the following lessons learned from this study are offered:

- A monitoring system that clearly distinguishes scheduled and unscheduled maintenance is essential for benchmarking PM performance and for determining if changes made to the PM program are having a positive or negative effect.
- Regulatory requirements and OEM specifications serve as the foundation for establishing PM intervals and activities. Becoming thoroughly familiar with these requirements helps ensure compliance.
- Once the foundation PM program is established adjustments are best made through analyses of unscheduled maintenance data, specific equipment needs, operating conditions, local environment, and other local factors. Programs that violate legal requirements may result in penalties, whereas straying beyond OEM specifications may violate warranty coverage. Consulting with OEMs before making any changes makes use of their knowledge and ensures continued warranty reimbursement.
- Effective PM programs are constantly evolving as new information is obtained and operating conditions and fleet equipment change. PM programs that remain stagnant are most likely inadequate.
- Monitoring the completion of PM activities at assigned intervals determines if they are being done according to schedule; a 10% early/late window is considered acceptable.
- PM checklists are helpful in guiding technicians through the inspection process.
- Unique PM checklists specific to each bus and equipment type that are continually updated tend to be more useful than generic checklists that cover a broad range of equipment and provide less detail.
- Including as much pass/fail criteria as possible on PM checklists assists technicians in determining what is acceptable for inspection items based on regulatory and agency established requirements.
- Printing up-to-date PM checklists just before the PMI ensures that technicians perform their tasks according to current information.
- Providing technicians with work instructions helps to properly complete PM inspections, repairs, and other maintenance activities. A sound example is the Central Florida Regional Transportation Authority (LYNX) included as Appendix G.

- Skilled technicians are more capable of carrying out PM because of their experience and ability to identify equipment abnormalities. Inexperienced technicians can receive valuable instruction by working alongside experienced mentors.
- Involving bus operators as an integral part of the PM program through improved communication with the maintenance department can greatly assist with early fault diagnosis and detection.
- Although in its infancy, automated onboard monitoring and data downloads done as part of the service line function provide expert means of identifying bus faults before they can escalate into failures and service interruptions.
- QA measures put in place to oversee PM inspections and other activities performed by operators, service line personnel, and technicians help ensure that bus maladies are properly identified and repaired.
- A classification system that clearly identifies critical and safety-related defects from more routine ones helps satisfy legal requirements, prioritizes the repair of noted defects, and makes certain that buses with more serious faults are corrected before resuming revenue service.
- Tracking of all other defects noted during the PM inspection process (i.e., those that are not critical or safety related) helps ensure that they are repaired before or at the next scheduled PMI to prevent the gradual accumulation of defects that eventually leads to fleet deterioration.
- Predictive models, software programs, and other analysis tools, although not used extensively in bus transit maintenance, can provide assistance in determining optimal replacement intervals for key parts and components.
- Packaging all replacement parts needed for PMs into one convenient kit maximizes efficiency by not having technicians wait while an order for multiple parts is filled.
- Calculating the time and costs associated with each PM activity accurately determines budgetary and staffing requirements.

SUGGESTED AREAS OF FUTURE STUDY

Four areas of future study are offered as a result of the findings.

1. OEM PM materials consolidated into one concise document. This could be done by developing standard procurement language in APTA's *Standard Bus Procurement Guideline* document. The request is in response to manufacturers that disperse PM requirements for intervals and related tasks throughout several documents, making them difficult to locate. The tendency to scatter PM material is understandable because bus manufacturers use many different vendors for major bus subsystems and components. Producing an integral PM document would help agencies more easily locate information needed for their PM programs. Requests were also made that spare parts and PM documentation be provided in electronic format.
2. An industry-sponsored PM peer review program. Managers have a difficult time assessing their PM programs and lack sources for feedback and guidance to improve overall maintenance performance. Distance between service interruptions or road calls is one measure, ratio of scheduled and unscheduled maintenance is another. Research could be directed toward developing a program that would involve experienced maintenance managers traveling to agencies when requested to investigate the PM program, make a peer assessment regarding agency PM performance, and provide suggestions for improvement. The review team would also involve the participation of bus and major component OEMs with direct experience regarding their products to help improve agency PM programs.

   Although the FTA does some of this through its triennial review process, a targeted review by those experienced in transit bus maintenance would be able to make specific suggestions for improving PM.
3. Staffing level requirements determined for maintenance personnel. Several survey responders also called for additional PM staffing and resources. One way to provide assistance would be to research staff requirements needed to conduct PM. The research could canvass the industry to determine staffing requirements for the entire maintenance operation including PM.

   No recent studies have investigated bus maintenance staffing requirements. Nor are there guidelines to assist agencies in determining adequate levels based on fleet size, operating conditions, fleet age, level of vehicle technology and electronics, facility locations, or other such relevant factors. Such a document would help maintenance managers secure appropriate staffing to conduct PM.
4. Maintenance data analyzed to assist maintenance managers establish more cost-effective PM intervals and related repair activities. Despite available tools, many transit agencies continue to rely on "seat of the pants" intuition to establish PM intervals and activities. A study to assist agencies collect, monitor, and analyze data will allow them to more efficiently determine PM intervals and the preventive measures that take place within those periods.

ABBREVIATIONS AND ACRONYMS

ASE	Automotive Service Excellence
ATA	American Trucking Association
AVL	Automatic vehicle location
CENTRO	Central New York Regional Transportation Authority
CFR	Code of Federal Regulations
CDL	Commercial Driver's License
CNG	Compressed natural gas
DART	Dallas Area Rapid Transit
DOT	Department of Transportation
DPF	Diesel particulate filter
EGR	Exhaust gas recirculation
FMVSS	Federal Motor Vehicle Safety Standards
HVAC	Heating, ventilation and air conditioning
IT	Information technology
ITS	Intelligent transportation systems
MIS	Management Information System; also referred to as Maintenance Information System
OEM	Original equipment manufacturer
PM	Preventive maintenance
PMI	Preventive maintenance inspection
PSI	Pounds per square inch
QA	Quality assurance
VMRS	Vehicle Maintenance Reporting Standards
VTA	Santa Clara Valley Transportation Authority
WMATA	Washington Metropolitan Area Transit Authority
WTA	Whatcom Transportation Authority

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APPENDIX A

Fleet Profile

	Agency	Fleet Makeup	Fleet Total	Combined Fleet Mileage
	1–50 Buses			
1.	Wilson Transit (Wilson, NC)	D–7	7	254,998
2.	Gastonia Transit (Gastonia, NC)	D–7 C–1	8	262,088
3.	Utah Transit Authority (Salt Lake City, UT)	H–3 G–10	13	21,115,000
4.	Sumter County Transit (Bushnell, FL)	D–5 G–23	28	666,324
5.	Waukesha Metro Transit, City of Waukesha Transit Commission (Waukesha, WI)	D–31	31	821,211
6.	Rockford Mass Transit District (Rockford, MA)	D–39	39	1,271,470
7.	University of Maryland Shuttle, UM (College Park, MD)	D–45	45	1,007,600
	51–100 Buses			
8.	Beaver County Transit Authority (Rochester, PA)	D–52	52	1,718,712
9.	Star Metro (Tallahassee, FL)	D–62 G–5	67	2,009,922
10.	Everett Transit and City of Everett (Everett, WA)	D–60 H–3 G–15	78	2,113,739
11.	Xpress Regional Commuter Service (Atlanta, GA)	D–84	84	3,200,000
12.	Whatcom Transportation Authority (Bellingham, WA)	D–56 G–40	96	3,872,000
13.	Chapel Hill Transit (Chapel Hill, NC)	D–95 H–3	98	2,900,000
	101–200 Buses			
14.	Capital Area Transportation Authority (CATA) (Lansing, MI)	D–120 H–10	130	4,200,000
15.	Palm Tran (West Palm Beach, FL)	D–139 H–3	142	7,600,000
16.	Spokane Transit Authority (Spokane, WA)	D–137 H–9	146	6,200,000
17.	ABQ Ride (Albuquerque, NM)	D–1 C–74 H–76	151	4,980,000
18.	Omnitrans (San Bernardino, CA)	D–2 C–163 H–3	168	8,769,543
19.	GRTC Transit System (Richmond, VA)	D–176	176	5,510,578
	201–300 Buses			
20.	Long Beach Transit (Long Beach, CA)	D–167 H–62	229	7,957,110

21.	San Diego Metropolitan Transit System (MTS) (San Diego, CA)	D–13 C–245 H–1	259	11,006,333
22.	Capital Metro Transportation Authority (Austin, TX)	D–263 H–3	266	11,477,000
23.	Central Florida Regional Transportation Authority DBA: LYNX (Orlando, FL)	D–280 C–10	290	16,920,000
24.	Broward County Transportation Department (Pompano Beach, FL)	D–280 H–12	292	13,615,292
	301–500 Buses			
25.	Central NY Regional Transportation Authority (Centro) (Syracuse, NY)	D–174 C–120 H–9	303	5,897,170
26.	Liberty Lines Transit (Yonkers, NY)	D–300 H–3	303	10,900,000
27.	Montgomery County Division of Fleet Management Services (Ride On) (Rockville, MD)	D–251 C–95 H–14 G–11	371	15,473,939
28.	Niagara Frontier Transit Metro Systems Inc. (Buffalo, NY)	D–346 H–43	389	12,300,000
29.	Santa Clara Valley Transportation Authority (VTA) (San Jose, CA)	D–401 G–49	450	18,013,336
30.	Milwaukee County Transit Systems (Milwaukee, WI)	D–484	484	18,569,682
	501 and Over Buses			
31.	OTS Inc. (Honolulu, HI)	D–481 H–50	531	22,333,152
32.	VIA Metropolitan Transit (San Antonio, TX)	D–415 G–104 L–19	538	21,984,000
33.	MARTA (Atlanta, GA)	D–159 C–441	600	38,125,000
34.	Maryland Transit Administration (MTA) (Baltimore, MD)	D–656 H–10	666	19,980,000
35.	Metro Transit (St. Paul, MN)	D–809 H–67	876	30,268,310
36.	Miami–Dade Transit (Miami, FL)	D–893	893	40,908,850
37.	Coast Mountain Bus (Burnaby, BC, Canada)	D–968 C–58 E–226	1,252	59,000,000
38.	Washington Metropolitan Area Transit Authority (WMATA) (Washington, DC)	D–1,000 C–461 H–50	1,511	50,163,000
	Totals	D–9,457 C–1,669 H–434 G–257 E–226 L–19	12,062	503,364,369

D = diesel, C = CNG; H = hybrid; G= gas; E = electric trolley; L = LPG.

APPENDIX B

Survey with Summarized Responses

SYNTHESIS QUESTIONNAIRE
PREVENTIVE MAINTENANCE INTERVALS FOR TRANSIT BUSES

Total number of agency responses: 38

Transit System Characteristics:

1. **How many total buses are currently operating in your fleet?**

Total Diesel	9,457
Total CNG	1,669
Total Hybrid	434
Total Gas	257
Electric	226
LPG	19
Total Survey Fleet	12,062

2. **What is the total annual miles traveled (approx.) for the combined bus fleet?**

Total 30-foot & Over Annual Fleet Mileage	464,755,387
Total Under 30-foot Annual Fleet Mileage	30,511,782
Total Annual Fleet Mileage	503,364,369

PM Classifications

3. **Which of the following maintenance activities are scheduled according to an established interval? Examples of intervals include mileage, time, hours, season, etc.**

PM Inspections
Service Line Inspection

Daily: 88% **Other:** 12%

Bus PM Inspection (PMI)

6,000 Miles: 71%
2,000–6,000 miles: 92% **6,500–7,500 miles:** 8%

Other PM Inspections

HVAC: 6,000 miles: 33%	Annually: 20%	Twice a Year: 13%
Lift/Ramp Inspection:	6,000 miles: 47%	
	Within 7,500 miles: 63%	
Driver Inspection:	Daily: 100%	Multiple Daily Inspections: 9%

Do you use different PMI intervals for other buses in your fleet?

YES: 57% **NO:** 43%

If yes, explain:
The primary reason given for conducting more frequent inspections, in the 3,000–4,000 mile range, pertain to hybrid buses (one response); and those operating smaller paratransit vehicles (10 responses) and buses with engines fitted with exhaust gas recirculation (EGR) (three responses), both of which require more frequent oil change intervals.

PM Repairs
Only list those repair activities done as a preventive measure based on time, mileage, or other condition, not because of failure.
Agency responses were varied and somewhat difficult to classify. Except for oil/fluid and related filter changes, repair activities done as preventive measures drew assorted responses. Air system servicing was reported by six agencies with differing intervals: 24,000 miles, 48,000 miles, 60,000 miles, annually, twice per year, and 1–2 years.

PM Overhauls/Refurbish

Only list those overhaul/refurbish activities done as a preventive measure based on time, mileage or other condition, not because of failure.

Agencies responded in six categories. Four responders rebuild engines in full-size buses (35 ft and larger) at 300,000 miles; two perform the rebuilds at about 450,000 miles. One agency replaces DDC S50 engines at 350,000 miles, Cummins ISC engines at 375–400,000 miles, and Cummins ISB engines at about 250,000 miles.

Establishing PM Intervals

4. **What method do you use to make sure PM intervals are conducted on schedule?**
   Computer Based Program: 100%
   Computer Based Plus Excel Spreadsheet: 8%
   Computer Based Program Plus Manual Books: 3%

5. **What interval "window" do you use to determine if PMs are done on schedule?**
   10% of mileage/hours: 42%
   Not Tracked: 5%
   Other: 53%, **Explain:** 65% of these use some type of mileage-based system

6. **If you use a computer based software program to establish PM intervals, is it flexible enough to allow you to make changes?**
   YES: 82% **NO:** 8% **NA:** 10%, Intervals are set by people, or manufacturer recommendation

6a. **Are you pleased with the software program used?**
   YES: 56% **NO:** 24% **NA:** 20%

What is the name of the program used?

Thirty-eight responding agencies report using twenty-two different computer based programs to track PM intervals.

7. **If you use a computer based software program to establish PM intervals, is it also used to guide and track the actual PM activities (repairs made, parts used, etc.)?**
   YES: 87% **NO:** 3% **NA:** 10%

8. **Are PM intervals based on fixed points (i.e., every 6,000 miles, every 30 days, etc.) or are they re-set based on the last actual interval (i.e., if the first PM was conducted at 6,300 miles then next one is scheduled for 12,300).**
   Fixed Point Interval: 39%
   Re-set Based on Previous Interval: 61%

9. **Which manufacturer (OEM) recommendations most influence the setting of PM intervals? (Check all that apply and include the interval.)**
   Responses are summarized in chapter three, Table 8.

9a. **Do OEM warranties influence the setting of PM intervals?**
   YES: 74% **NO:** 26%

If yes, explain how:

Responses are summarized under **Influence of OEM Warranty Coverage** in chapter three.

9b. **Do you change your PM intervals after an OEM warranty has expired?**
   YES: 18% **NO:** 82%

If yes, explain the activity and why it's changed:

Responses are summarized under **Influence of OEM Warranty Coverage** in chapter three.

10. **What specific PM activities have been put in place because of data/information made available to you from road call reports, driver pre/post trip reports, service line inspections and other sources? (List all that apply and include the interval. Read questions 11–13 before answering.)**
    Responses are summarized in chapter three, Table 9.

11. **What specific PM activities have been put in place because of unique environmental conditions such as extreme heat, cold, humidity, winter salt use, and other environmental factors? (List all that apply and include the interval.)**
    Responses are summarized in chapter three, Table 10.

12. What specific PM activities have been put in place because of <u>unique operating conditions</u> such as duty cycle, terrain, road conditions, and other such factors? (List all that apply and include the interval.)
Responses are summarized in chapter three, Table 11.

13. Which PM activities have been put in place because of your agency's <u>fleet make-up</u> (diesel, CNG, paratransit, etc.)? (List all that apply and include the interval.)
Responses are summarized in chapter three, Table 12.

14. List any unique or innovative approaches you use to establish PM intervals.
Responses are summarized under *Innovative Approaches to Establishing Preventive Maintenance Intervals* in chapter three.

15. What information, tools or additional resources would help you do a better job to establish PM intervals?
- Sharing of agency PM information regarding emissions, engines and transmissions.
- Examples of other transit PM schedules.
- Recommended life expectancy of equipment.
- More precise presentation of PM information from manufacturers such as comprehensive PM tables. The most difficult part of establishing a PM program is gathering up all of the requirements that the manufacturers have hidden throughout the manuals (3 responses).
- Good supervision and well trained personnel (2 responses)
- More reasonable PM schedules and recommendations from the OEMs. Most are reasonable, but sometimes you can detect a few unreasonable intervals that are probably designed to "cover" the OEM or component manufacturer.
- More staff and resources to analyze data, failure trends, times, etc. (6 responses)
- Software to track actual idle time to achieve a more precise accountability of both engine and transmission life cycles.
- A dedicated quality assurance section to analyze failures and recommend updates to preventive maintenance procedures.

Conducting PM Activities

16. Once PM intervals are established, do you use a checklist to guide your PM activities?
YES: 100% **NO:** 0%

If yes, check all PM activities below where a checklist is used. Also indicate if the checklist is generic in that it applies universally to all applications, or if the checklist is unique in that it applies to specific equipment.
Responses are summarized under *Checklists* in chapter four. Also see Table 13.

17. Do you provide technicians with written instructions to help them carry out PM inspections and activities?
YES: 79% **NO:** 21%

If yes, list those PM activities where instructions are provided:
Responses are summarized under *Written Job Instructions* in chapter four.

18. Do you provide specific pass/fail criteria for carrying out PM inspections and repairs (i.e., front brake throw 2.0″ max)?
YES: 84% **NO:** 16%

If yes, list those PM activities where pass/fail criteria are provided (or attach PM checklist showing all criteria):
Responses are summarized under *Pass/Fail Criteria* in chapter four.

19. What is the skill level of personnel carrying out PM inspections?
Skilled: 60% **Entry-Level:** 16%
Other, List: 24% (1 journey level, 1 use both, 1 must have two years experience, 1 trains with skill tech.)

Explain why you use particular skill levels for carrying out PM activities:
Responses are summarized under *Skilled vs. Entry-Level* in chapter four.

20. Do you use the same person to conduct all aspects of the PM activity or do you split responsibilities between routine tasks (i.e., change oil, check tire pressure, etc.) and more demanding tasks (adjust brakes, etc.)?
Same technician does it all: 61% **Split PM responsibilities:** 39%

Explain why you use one approach over the other:
Responses are summarized under *Splitting Work Responsibilities* in chapter four.

21. Are there any work rules at your agency that influence the type of skilled technician allowed to conduct PM activities?
YES: 39% **NO:** 61%

If yes, describe them:
Responses are summarized under *Work Rules & Standards* in chapter four.

22. Have you calculated the amount of time needed to conduct PM activities?
YES: 74% **NO:** 26%

If yes, indicate your findings in terms of hours needed to conduct each PM activity.
Responses are summarized in chapter four, Table 14.

23. Have you calculated the number of spare vehicles needed to conduct your overall PM program?
YES: 50% **NO:** 50%

If yes, indicate your findings regarding the number of spares in terms of percentage of the overall fleet needed to conduct your PM program.
Responses are summarized under *Bus Spare Ratio* in chapter four.

24. Have you calculated the cost of conducting PM activities in terms of combined parts and labor?
YES: 63% **NO:** 37%

If yes, indicate the cost in dollars (parts and labor total) to conduct specific PM activities.
Responses are summarized in chapter four, Table 15.

25. Before beginning a PMI do you issue a work order that generates a parts kit containing all parts needed for the particular PM activity?
YES: 51% **NO:** 49%

26. Do you have any quality assurance measures in place to follow-up on PM activities?
YES: 79% **NO:** 21%

If yes, describe those measures.
Responses are summarized under *Quality Assurance Procedures* in chapter four.

27. When it comes to PM inspections, indicate the policy you use to repair defects found during the inspection process.

Policy	**Response**
All defects are immediately repaired unless parts are not available.	46%
All defects that can be repaired in a given amount of time (1 hour, up to 2 hours, and 3 hours) are repaired; all others are scheduled.	8%
All defects are scheduled for repair at a later time.	11%
Other	35%

Describe other repair policies:
Responses are summarized under *Repair of Noted Defects* in chapter four.

If you schedule repairs for a later date how do you track completion?
Responses are summarized under *Repair of Noted Defects* in chapter four.

28. What specific aspects of PM intervals would you like this Synthesis Report to address?
- I would appreciate a movement to standardize information from manufacturers. It is very difficult to bring all of the pieces together if they are allowed to continue to hide or bury PMI and servicing information and intervals throughout manuals.
- Issues with certain types of vehicles/equipment
- Rationale for PM intervals
- Hybrid PM programs
- Would like to see examples of check off sheets and SOPs

- Costs and how PMI identified defects are addressed
- What are safe intervals.
- I expect basic bus PM intervals will be a moving target because so many agencies have various types of equipment and operating conditions. I think that emphasis on the more sophisticated components and systems—emissions systems, multiplex, etc., may warrant some attention in the report. Of particular interest are the 2007–2010 engine emission systems, hybrids, PM intervals on technology systems (AVL, video, and other information systems) that the fleet shop may not be prepared to PM and repair but PM and repairs are required. As buses become increasingly more technologically advanced there will no doubt be additional systems to address during the periodic PM. Who should do it?
- Time study?
- HVAC is the standard Thermo King inspection forms. Our bus PM forms are split between large bus, small bus, and service vehicles. The series of forms for each vehicle type are mostly generic with specific references to a unique component due to bus/vehicle type if applicable. Since we are pretty much 90% New Flyer and 100% Champion this becomes less of an issue and we try to maintain commonality of components within the fleet between build years if at all possible. We are in the process of updating our forms as we've added articulated buses. We are also cleaning up to remove past references to past model bus components no longer in use. We are going to go with an electronic PM inspection form as part of this update process. From that point updating the form becomes very easy when required due to the introduction of new components or bus types.
- That each fleet type and make or model can affect what items are addressed on a PM inspection. PM checklists should differ as do vehicles being inspected.
- I would also like to see that the report addresses changing and evolving technology that vehicles have, increased skill sets needed to perform PM inspections and the amount of labor time to do the PMI is also increasing with additional technologies.
- Although I don't track it I am interested in time information. Also just general intervals for all the sub systems will be useful. Also if anyone has information on going away from the standard 6,000 mile interval showing that you can save money and still have a dependable fleet would be interesting.
- Time standards for specific tasks
- Extended intervals, what has worked and what has not
- Calculating intervals using vehicle performance as a factor
- Estimated times, confirmation of correct intervals, inspection process; i.e., who inspects, who lubes, who does repairs, how shop is laid out, etc., who's not using paper; i.e., all electronic data entry at mechanic level; i.e. hand helds.
- PM Best Management Practices
- Peer Reviews of PM Programs
- I'm looking for something someone else has thought of that I have missed.
- If cost savings can be achieved though different methodologies. Also, if there is a recommended review and quality assurance process that could be used as a guideline or template for establishing intervals (if it could only be that easy . . .)
- Areas and ideas for improvement
- Stay on top of things the best you can
- Should the schedule PMI be shortened or lengthened.

Please add anything else you feel would benefit your peers with regard to PM intervals.

- PMs are scheduled on a 6,000 mile cycle. Each PM occurs every 6,000 miles. Specific system inspections are conducted as part of PMs labeled "PM (interval)" and "INSP (interval)," calculations of labor hours and total costs include the specific system inspections for the appropriate interval.
- A discussion of synthetic versus conventional oils and lubricants. Comparisons of PMIs relative to operating costs per mile, engine/trans life, bus changes. I know our program is improving based on internal performance reports. However, I'm not exactly sure where to set realistic goals. At this point, I'm pushing reductions in bus changes and improved vehicle availability while staying within budget. How we compare to other agencies however is not clear.
- Any cost savings
- The one thing that I really had to get a handle on was getting all of the technicians on the same page as far as inspection and repair criteria for safety-sensitive systems. The checklists have the same checks, but how the technician determines if a component or system is serviceable and safe was all over the map. To help resolve the inconsistencies that I was finding in how different techs inspected everything I designed an in-house certification program that included over 70 specific inspections and tasks that everyone was trained to perform the same way and to the same standard. This has worked well for our shop. It establishes inspection and repair standards and removes any ambiguity when performing inspections.
- The items listed below are intended to become part of the PM process at some time in the future:
  Legacy PM items with increased frequency due to other factors:
  Batteries—Increased electrical load
  Differential—Hybrid Bus—Increased wear due to increased torque
  Air Compressor—Replaced based on predictive analysis
  Brakes—Hybrid Bus—Additional lubrication requirements due to extended brake life.

New PM items due to the introduction of new equipment. It is intended to PM the listed items 2 ×'s per year addressing all listed items at the same inspection:

Destination Signs
Farebox
Camera Video
Automatic Voice Annunciation
Automatic Passenger Counting
The hybrid drivetrain presently installed on 43 buses is currently being integrated into the PM program.

- PMI checklists should be specific for the fleet they are created for and the checklist should be dynamic and change as needed to reflect items that are determined to be high maintenance or that have higher failure rates. Smaller agencies should work with OEMs and larger agencies.
- Intervals are being extended by OEMs because of better vehicles, parts and the oil we use. For example we recently ordered several Sprinter vans and they have a oil change interval recommended be the OEM of 10,000 miles.
- Safety first—so a good PM program with Master Technicians is a must for public safety and extending equipment life. Our families and friends are on the buses we maintain and travel the same streets as our buses so we can never be too safety minded.
- The county transit agency has adopted a PM program based on conducting two (2) inspections. The mileage intervals for these PMs are as follows: PM "A" every 6K miles and PM "O" every 3K miles.
- I feel that the sharing of information is an important part of establishing a comprehensive maintenance program. Coming from a transit maintenance organization that does not have a dedicated staff for writing preventive maintenance procedures, I try to get copies of other properties' maintenance programs and incorporate some of their practices into our preventive maintenance program.

APPENDIX C

CFR 49, Part 396, DOT Inspection Requirements

PART 396.3—INSPECTION, REPAIR AND MAINTENANCE

This subsection requires every motor carrier to systematically inspect, repair, and maintain all motor vehicles subject to its control. Of particular interest to transit is a requirement that push-out windows, emergency doors, and emergency door marking lights in buses be inspected at least every 90 days. Every agency's PM program must abide with this requirement or risk legal consequences.

Another requirement is that all records pertaining to vehicle inspections be kept for a period of one year and for six months *after* the motor vehicle leaves the motor carrier's control. Records need to include the nature and due date of the various inspections, maintenance operations to be performed at each inspection, and a record of tests conducted on push-out windows, emergency doors, and emergency door marking lights on buses.

PARTS 396.11 & 396.13—DRIVER INSPECTIONS & REPORTS

To comply with this subsection, bus operators must report in writing at the completion of each day's work the condition of vital parts and accessories including:

- Service brakes
- Parking (hand) brake
- Steering mechanism
- Lighting devices and reflectors
- Tires
- Horn
- Windshield wipers
- Rear vision mirrors
- Coupling devices
- Wheels and rims
- Emergency equipment.

The inspection report requires operators to list any defect or deficiency that would affect the safety of the vehicle or result in its mechanical breakdown. If no defect or deficiency is discovered by the driver, the report needs to indicate this. Any safety-related defect listed on the driver vehicle inspection report must be repaired before that vehicle can be placed back into service. All operator reports and corrective action must be kept for three months.

PART 396.17—PERIODIC INSPECTIONS

This subsection requires every commercial motor vehicle to be inspected. Specific parts are detailed in Part 396 Appendix G of the requirement (additional information provided below). Agencies are required to keep records of the inspections; failure to conform may result in penalties.

PART 396.19—INSPECTOR QUALIFICATIONS

Agencies are legal responsibly for ensuring that technicians performing inspections are qualified. Inspectors must understand the inspection criteria set forth in 49 CFR Part 393, Parts and Accessories Necessary for Safe Operation (see below) and Appendix G of this subsection (also see below), and must be capable of identifying defective components. Inspectors must be knowledgeable of and have mastered the methods, procedures, tools and equipment used to perform inspections, and must be capable of performing inspection through experience, training, or both.

To meet training requirements technicians must have successfully completed a State or Federal-sponsored training program, or have a combination of training and/or experience totaling at least one year. Records of technician qualifications must be retained by the agency throughout employment and for one year afterwards.

PART 396.21—PERIODIC INSPECTION RECORDKEEPING REQUIREMENTS

Under this subsection, agencies are required to complete a report that identifies the:

- Individual performing the inspection;
- Agency operating the vehicle;
- Date of the inspection;
- Vehicle inspected;
- Vehicle components inspected and describes the results of the inspection, including the identification of components not meeting the minimum standards set forth in Part 396 Appendix G below; and that
- Certifies the accuracy and completeness of the inspection as complying with all requirements of Section 396.

A copy of the inspection report needs to be retained by the agency for fourteen months from the date of the inspection report and made available if needed to Federal, State or local officials.

PART 396.25—QUALIFICATIONS OF BRAKE INSPECTORS

Because of the obvious safety implications of braking systems, those who perform inspections, maintenance, repairs or service to commercial vehicle brakes must comply with specific requirements. They must:

- Understand the brake service or inspection task to be accomplished and can perform that task;

- Be knowledgeable of and have mastered the methods, procedures, tools and equipment used to perform an assigned brake service or inspection task; and
- Be capable of performing the assigned brake service or inspection by experience, training or both.

Training and experience requirements are satisfied when technicians have successfully completed a certified apprenticeship and/or training program, or have brake-related training or experience totaling at least one year. Such training or experience may consist of participation in formal training programs from OEMs or other sources, or experience obtained from performing brake maintenance or inspection in a similar maintenance program including a commercial garage, fleet leasing company, or similar facility.

Agencies are not allowed to employ any person as a brake inspector unless evidence of the inspector's qualifications can be produced. Such evidence must be maintained for the period during which the brake inspector is employed in that capacity and for one year thereafter. Agencies are not required to maintain evidence of qualifications to conduct air brake inspections if technicians have passed the air brake knowledge and skills test as part of their Commercial Driver's License.

PART 396—APPENDIX G: MINIMUM PERIODIC INSPECTION STANDARDS

Attached to FMCSA's Vehicle Related Regulations Part 396 is Appendix G, which describes the minimum criteria needed for passing inspections. This FMCSA appendix addresses several vehicle areas including brakes, fuel systems, lighting devices, steering, suspension, frame, tires, wheel and rims, windshield glazing, and windshield wipers.

Part 396 Appendix G is extremely detailed and identifies specific defects: includes pass/fail criteria for several vehicle areas. Using brakes as an example, the table below shows a sampling of the maximum stroke at which brakes should be readjusted for bolt type air brake chambers. The requirement specifies that any brake ¼″ or more past the readjustment limit shall be cause for rejection, and that the stroke shall be measured with engine off and reservoir pressure of 80 to 90 pounds per square inch (psi) with brakes fully applied.

CRITERIA FOR MAXIMUM BRAKE STROKE

Effective area (sq. in.)	Outside diameter (in.)	Maximum stroke at which brakes should be readjusted (in.)
24	9³⁄₁₆	1¾
30	9⅞	2
36	11	2¼

There are many other Part 396 Appendix G examples where minimum inspection criteria are clearly identified. Again, agencies need to become thoroughly familiar with these requirements and ensure all PM inspections and related check list criteria are consistent with this requirement. Agencies should also consider flagging conditions that do not meet Part 396 Appendix G requirements to distinguish them as requiring repair before the bus is allowed to resume revenue service.

APPENDIX D

Sample Preventive Maintenance Update Request Form—Coast Mountain

Coast Mountain Bus Company

Update Last: Sept. 30, 2008

Request to Update Inspection Sheets	Date

Requestor Name:	Desired Effective Date:
Inspection(s) Impacted:	
SR Number(s):	

Change Requested:

Please state any known association/impacts. For example does this impact: the Work Plan; Materials Lists; Asset Components etc.

Manager Approval (Mtce.)	

For Fleet Business Support Use Only

Review of Known Impacts and the actions taken to the:

PM Schedules	
Work Plan	
SR #s	
Insp. Pt. Database	
Material Lists	
Effective Dates	
Materials Controls	
Stores	
Other	

		Date
FBS – Action Taken By	Approval – Mgr. Fleet Technical Support	

Manager's Comments:

Change to Access Inspection Database Date: ____________________

Update Last: Sept. 30, 2008

APPENDIX E

Mathematical Model to Determine Optimum Parts Replacement

Provided by Reliasoft

To determine the optimum time for such a preventive maintenance action (replacement), a mathematical model has been formulated that describes the associated costs and risks. In developing the model, it is assumed that if the unit fails before time *t*, a corrective action will occur and if it does not fail by time *t*, a preventive action will occur. In other words, the unit is replaced upon failure or after a time of operation, *t*, whichever occurs first. Thus, the optimum replacement time can be found by minimizing the cost per unit time, $CPUT(t)$. $CPUT(t)$ is given by:

$$= \frac{\text{Total Expected Replacement Cost}}{\text{Expected Cycle Length}}$$

$$= \frac{C_P \cdot R(t) + C_U \cdot [1 - R(t)]}{\int_0^t R(s)\,ds}$$

Where:
$R(t)$ = reliability at time *t*.
C_P = cost of planned replacement.
C_U = cost of unplanned replacement.

The optimum replacement time interval, *t*, is the time that minimizes $CPUT(t)$. This can be found by solving for *t* such that:

$$\frac{\partial[CPUT(t)]}{\partial t} = 0$$

APPENDIX F

Sample Preventive Maintenance Inspection Checklist—Capital Metro

Capital Metro Transportation Authority, Austin, TX
PMI Checklist Developed for Optima Buses
Section I: Road Test

Last Update 11/20/08

DRAFT COPY
PREVENTIVE MAINTENANCE INSPECTION

OPTIMA

Unit No:	__________________	Inspector/ID No:	____________________/_______
Date:	__________________	Inspector/ID No:	____________________/_______
Miles:	__________________	Repair Mech./ID No:	____________________/_______
W/O No:	__________________	Repair Mech./ID No:	____________________/_______

Instructions:

- Inspect the vehicle and compare to listed standards. Check the appropriate Pass or Fail box for each inspection item. ***If a component fails an inspection, describe in detail <u>only</u> how it failed.*** Do not suggest what needs to be fixed. On the write-up sheet, record the step number that corresponds to the failure.
- Each section must be completed entirely by the same inspector.

Explanation of Terminology

- "No loose parts" should be taken to mean that the entire assembly is secure with no loose, damaged, or missing fasteners.
- The terms "obvious" and "excessive" are used when a subjective assessment of condition must be made.

Short Repairs

When the repair can be made with the general tools and if the total repair time is less than 10 minutes.
If the short repair brought the inspection step into compliance, record what was repaired on the defect sheet.
Small repairs include, but are not limited to: Tightening screws, replacing a bulb or ground strap, etc.

Repetitive Procedures

The mechanic inspecting the vehicle should coordinate the repetitive procedures with the inspection. However, care must be taken not to let the two procedures interfere with each other. For example, do not lubricate the U-joint before checking it for play.

Special Test Equipment

- Hunter Brake Tester
- Wheel chocks to prevent vehicle movement
- Cooling system pressure tester

Recent Revisions

DATE	REVISION
11/20/08	Drain Moisture from Fuel Tank

I Road Test the Vehicle Road test will monitor vehicle engine and transmission performance while driving road test route. The operator will view the dash gauges, air conditioning system performance and braking operation.

1.	Inspect for obvious fluid leaks in parking spot Pre-trip unit for road test.	Completed ☐
2.	Clean radiator and Charge Air Cooler, if needed.	Completed ☐
3.	Steam clean, if needed: engine compartment, access door interiors, undercarriage	Completed ☐
4.	Clean batteries if needed Use cool water	
5.	Inspect insurance card *Card not expired/legible/pouch not torn*	Pass ☐ Fail ☐
6.	Inspect State Inspection Sticker *Date not expired*	Pass ☐ Fail ☐
7.	“Oil Pressure” light illuminates when ignition is turned on & remains on until started	Pass ☐ Fail ☐
8.	Listen for back-up alarm when backing *Audible from driver’s seat*	Pass ☐ Fail ☐
9.	Observe speedometer gauge accuracy *Check speed with electronic speed monitor in bus* yard [±3 mph]	Pass ☐ Fail ☐
10.	Test power of bus on Oltorf Dr. hill *Achieve speed of at least 20 mph up hill*	Pass ☐ Fail ☐
11.	Test parking brake operation on Burton Dr. hill Inspect parking brake knob *Brakes hold/no air leaks/pin is centered/No cracks in knob/securely attached*	Pass ☐ Fail ☐
12.	Test doors interlock on Burton Dr. hill With door controller in the “front open,” “Rear open,” and “Both open” positions: *Brakes must hold/accelerator must be disabled/no air leaks*	Pass ☐ Fail ☐
13.	Inspect frame alignment for dog tracking Inspect only if safety allows *Bus should track straight*	Pass ☐ Fail ☐

14.	Observe performance of: Suspension—*No bouncing/no noise/no knocking/no leaning* Brakes—*Smooth stop/no popping/no noise/no pulling* Steering—*No pulling/no noises/no play/no wandering* Retarder—*Operational*	Pass ☐ Fail ☐
15.	Listen for tightness of body components: fare box, doors, modesty panels, grab rails, etc. *No rattling/no loose parts*	Pass ☐ Fail ☐
16.	Inspect AC operation Must achieve 68° and 78° on road test No Trouble indicator lights on/good air flow/no unusual noise/fresh air duct opens and closes	Pass ☐ Fail ☐
17.	Measure braking efficiency using Hunter brake Tester Record Results:_______________ *Efficiency 70% or greater*	Pass ☐ Fail ☐ Wet ☐ Dry ☐
18.	Measure emergency brake efficiency using Hunter brake Tester Record Results:_______________ *Efficiency 20% or greater*	Pass ☐ Fail ☐
19.	*Check Transmission fluid level with engine hot* *Level full*	Pass ☐ Fail ☐
20.	Take Engine Oil Sample using Probilizer *Engine must be hot and running*	Completed ☐

The above section was completed by __________________________ / ___________
Mechanic ID

APPENDIX G

Sample Preventive Maintenance Inspection Work Instructions—LYNX

LYNX

PREVENTIVE MAINTENANCE PROCEDURES MANUAL

Lynx Vehicle Maintenance and Facilities Division
Training Section

Publication Number PMP-01-02 Revision 06

PREVENTIVE MAINTENANCE PROCEDURES

Introduction

The preventive maintenance procedures and checklists contained in this document were assembled and defined with the assistance of Lynx Technicians, Training Assistants, Supervisors and other staff employees. The process of updating this document and our Preventive Maintenance Program is ongoing. Procurement of new equipment and/or technology, failure of systems and/or components as well as other factors can effect changes in our Preventive Maintenance Program.

References for manufacture's (OEM) recommendations and the Code of Federal Register (CFR) regulations are listed in each section, throughout the document.

The practices and procedures contained in this manual are the LYNX vehicle maintenance standards for preventive maintenance inspections. The use of the PM form is considered a statement compliance with these practices and procedures.

The Preventive Maintenance Inspection schedule cycle is as follows:

Preventive Maintenance Inspection Type	Mileage
PM A	3,000
PM B	6,000
PM A	9,000
PM B	12,000
PM A	15,000
PM C	18,000

Program Goal:

Complete all scheduled Preventive Maintenance Inspections within 300 miles of its schedule mileage.

LYNX

PREVENTIVE MAINTENANCE PROCEDURES

A	Pre Shop Inspection

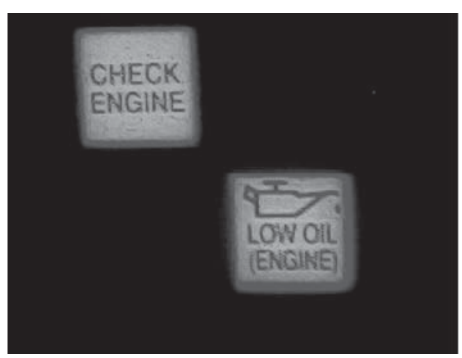
Defines the observations of vehicle condition and is performed while the vehicle is still in the parking area and while the vehicle is being driven into the Maintenance shop.

A1	Low Oil Light, Engine Light & Alarm
B	C

Check low oil light and alarm:

1. Turn the master switch to the “ON” position.
2. The oil light and Engine light on instrument panel should come on and an alarm buzzer should sound.
3. Start the vehicle and allow the air pressure build up to at least 90 PSI before moving out of the parking area.

Note! Verify fast idle operation.
Note! Place the climate control switch in the “ON” position to allow the system to run so an accurate system check can be performed later in the inspection.



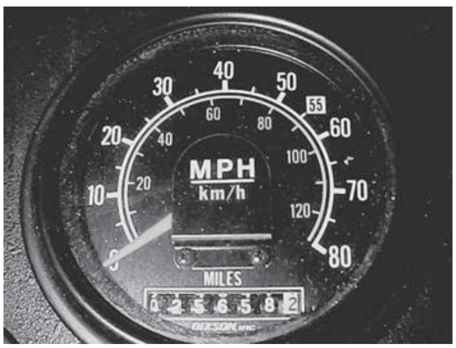
A2	Speedometer	
B		**C**

Check the speedometer condition and operation:

- Check the condition of the speedometer mounting, faceplate and pointer.
- Check the speedometer operation within the facility compound but do not exceed the speed limit while driving on the property. (10 MPH)

Note! If speedometer does not work, refer this information to the Supervisor or Lead on duty so they can research any activity generated from the operator reports of the vehicle.

References:
CFR- Title 49, Subpart G Section 393.82.



A3	Retarder Light	
B		**C**

Check the Retarder light on instrument panel for proper operation:

1. Drive the vehicle up to 10 MPH.
2. Then depress on the brake pedal. The *Retarder Applied* light should come with brake application.

A4	Speed Switch Light	
B		**C**

Check the speed switch light on instrument panel for proper operation:

Drive the vehicle up to 10 MPH then depress the brake pedal. The *Speed Switch* light on instrument panel should come on when vehicle slows down to 3 MPH.

Note! Speed switch light test applies to (**Gillig)** buses only.

Test the rear door open and interlock safety feature;
Turn the rear door switch to the open position. Rear doors should not open and interlock should not come on until vehicle slow down to 3 – 5 MPH.
Note! The rear door safety and interlock test applies to (**Gillig, Orion, and New Flyer**)

References:
Gillig- Electrical Schematic Manual: Door Interlock Section.

A5	Clean Radiator & Hydraulic cooler
B	**C**

Clean Radiator & Hydraulic cooler:

Park the vehicle out side of shop then use compressed air to blow dirt and debris out from between the radiator and hydraulic cooler coils and fins. When the radiator and cooler is cleaned out, blow out any debris from the outer perimeters of the radiator and cooler as well as the access panel grid.
Note! Use protective safety equipment such as goggles and dust/mist respirator when blowing out radiator.
Note! Do not blow out radiator while vehicle is inside the shop or while people not protected by personal safety equipment are present.

A6	Fill Windshield Washer Bottle
B	**C**

Pull the front of the vehicle into the shop and fill the windshield washer bottle with water.

A7	Low Air Warning Light And Buzzer	
A	**B**	**C**

Check the low air warning light and alarm for proper operation:

1. Pump the brake pedal to lower air pressure in air tanks, Alarm and warning light should come on when air pressure reaches between 75 – 65 PSI.

2. Check the PP1 valve for proper operation.
3. Release the PP1, pump the brake pedal to lower air pressures in air tanks, the PPI valve should pop and engage rear spring brakes when air pressure reaches between 60 – 35 PSI.

Note! Record all findings on inspection sheet.
Note! It may be necessary to chock the wheels when performing the PP1 test.

References:
CFR- Title 49, Subpart C Section 393.51.
Gillig- Transit Coach Service Manual (1999): Air System. Pg. # 168.
Orion- Bus Service Manual: Air System. Pg. # 12.66.N
New Flyer- Bus Service Manual: Warning indicators – Air Systems. Pg. # 8-64

A8	Air Gauges & Governor Cut Off	
	B	**C**

Check the air system governor cut out operation:

1. Pump the brake pedal to lower air pressure in air tanks to 90 PSI then allow air system to build pressure.
2. The air system governor should stop the system from building air when the pressure reaches 120±5 PSI.
3. The air dryer purge valve should release a burst of air once the air system reaches set cut out pressure, the air purge should not last more than 20 seconds.
4. Check cut in and build time after cut out by pumping brakes the difference between cut in and cut out pressure should not exceed 25PSI (cut in at 95±5PSI), drop pressure to 85 PSI it should take no more than 40 seconds for air to build to 100 PSI.

Note! Observe the operation of the instrument panel air gauge while performing the above test and record findings on the inspection sheet.

References:
Gillig- Transit Coach Service Manual (1999): Air System. Pg. # 163 - 166.
Orion- Bus Service Manual: Air System. Pg. # 12.1.1.
New Flyer- Bus Service Manual: Air Systems > Pg. # 8-3.

B	**Exterior Inspection**

Defines the observations of the vehicle exterior condition and is performed after the vehicle has been driven into the Maintenance shop.

B1	Outside Rear View Mirrors	
A	**B**	**C**

Check the condition of all outside rear view mirrors:

APPENDIX H

Sample Automatic Vehicle Monitoring Exception Report—WMATA

Clever Devices

Exception Summary Report

Vehicles	All Vehicles
Components	[multiple components]
Severities	All Severities
Reporting Period	07/13/2009 03:54 AM to 07/14/2009 03:54 AM

2616 2005 Orion VII 40' LF (John Deere) Four Mile

Last Occurred	Count	Component	Description	Code
07/13/09 08:13 AM	1	Engine	Engine Coolant Temperature Above 212 Degrees	
07/14/09 01:51 AM	1	Safety/Security	Brake and Throttle Interlock Exception	
07/13/09 04:22 PM	9	Fuel System	Fuel Valve Fault Signal	
07/13/09 12:11 PM	4	Brakes	Tractor Brake Stroke - Axle 1 Left - Brake overstroke: the brake rod has overstroked during a braking operation.	M253S1F4
07/13/09 03:30 PM	1	Brakes	Tractor Brake Stroke - Axle 1 Left - Non-functioning brake actuator: the brake rod has not actuated during a braking operation.	M253S1F12
07/13/09 06:00 PM	2	Engine	Natural Gas Pressure Lower Than Expected	166
07/13/09 06:00 PM	3	Engine	Natural Gas Tank Pressure Input Voltage Low	025

2617 2005 Orion VII 40' LF (John Deere) Four Mile

Last Occurred	Count	Component	Description	Code
07/14/09 01:15 AM	1	Safety/Security	Brake and Throttle Interlock Exception	
07/13/09 09:33 PM	8	Fuel System	Fuel Valve Fault Signal	
07/14/09 01:00 AM	1	ABS	Left rear wheel sensor excessive slip detected.	3+4
07/13/09 02:54 PM	2	ABS	Left rear wheel sensor speed drop-out.	3+4

2618 2005 Orion VII 40' LF (John Deere) Four Mile

Last Occurred	Count	Component	Description	Code
07/13/09 05:37 PM	7	Fuel System	Fuel Valve Fault Signal	

2619 2005 Orion VII 40' LF (John Deere) Four Mile

Last Occurred	Count	Component	Description	Code
07/13/09 04:54 PM	10	Fuel System	Fuel Valve Fault Signal	

2636 2005 Orion VII 40' LF (John Deere) Four Mile

Last Occurred	Count	Component	Description	Code
07/13/09 02:26 PM	1	Engine	Engine Coolant Temperature Above 212 Degrees	
07/13/09 10:56 PM	1	MDT	Odometer Error	
07/14/09 01:27 AM	17	Fuel System	Fuel Valve Fault Signal	
07/14/09 12:46 AM	12	Engine	Fuel Derate	086

AVM

07/14/2009 03:54:52 1 of 1 Report version 2.2.11.16696

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation