Final report

on

Repair time standard for preventive maintenance of transit vehicles

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Prepared by

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ABSTRACT

This report summarizes the main findings and activities done towards the development of time standard for the preventive maintenance of the transit vehicles. In the first phase of the project, time standards were developed for the brake system component of transit vehicles and during this phase they have been extended to the preventive maintenance. Preventive maintenance (PM) is carried out periodically to ensure effective operation of the buses. A faculty from the Center of Urban Transportation Research (CUTR), along with one faculty with three graduate students from the Industrial and Management Systems Engineering Department conducted an analysis of the preventive maintenance procedure. The study was conducted at three different locations: Hartline -- Tampa, PSTA (Pinellas Suncoast Transit Authority) -- Clearwater, Lynx -- Orlando, from February 2003 to January 2004. This report describes in detail the procedure followed by the maintenance technicians for preventive maintenance of the buses. Time standards are proposed for the preventive maintenance process along with ideas and recommendations for improvement.

Acknowledgements
Special thanks go to all supervisors and technicians across the locations that participated in this study, the in-site coordinators: Bill Jones, Donna Loy, Ricky Sonny, Jon Austin, Ron Albright, and others for making significant contribution in the project. We would also like to take the opportunity to thank Robert Westbrook and Lisa Staes for initiating and supporting this effort.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND SCOPE

Due to increased competition in the US market, it is evident that businesses and industries are striving hard to survive in this market. The public service sector is not an exception. They are finding out different means in order to operate more effectively. One of the ways is to restructure themselves for increased efficiency. Fundamental tools required to increase productivity include: methods, time study standards and work design. This study incorporates principles of industrial engineering and work measurement to establish time standards for transit vehicles. Time standards define the time necessary for a qualified worker, working at a pace ordinarily used, under capable supervision, and experiencing normal fatigue and delays, to do a defined amount of work following the prescribed method.

Literature shows that typically most of the organizations are generally operating without standard at a 60% performance. When time standards are established, performance improves to an average of 85%, a 42% increase (Niebel, Freivalds, 1999). Establishing time standards is a step in the systematic development of new work-centers and the improvements in methods used in existing work-centers. Areas such as planning, control, training, and scheduling are closely related to standards functions. To operate effectively, all of these areas depend on time and operational procedures.

The objective of this study is to establish accurate repair time standards for transit vehicles in Florida public transit systems. This project develops standards in order to minimize the time required to perform tasks, continually improve reliability of services and to conserve resources and minimum costs by specifying direct/indirect materials of tools to provide repair service.

The previous report on the Repair time standard for transit vehicles describes in detail the time standard development for brake system component of transit vehicles. This phase is further extended to develop time standard for the preventive maintenance processes.

2. PREVENTIVE MAINTENANCE DESCRIPTION

Preventive maintenance (PM) is the most important activity of the total maintenance and repair done on the buses. It is carried out in order to inspect all the components of the bus and ensure that they are functioning properly. PM carried out with full efficiency will not only increase the efficiency of the bus performance but also reduce the chances for incident during its operation. Increasing the working efficiency of the parts will result in considerably less failure of the various components and hence longer working life of the parts.

There is a need for standardization of the process so that the quality of the PM can be controlled and most importantly measured. Further standardization would serve as a reference guide to carry on the PM activities more efficiently. In addition, time standard would serve as a benchmark for the skill level evaluation of the technicians and help make important management decisions.

Improvement in the availability of equipments and skills of the technicians will result in changes and further improvement of the standard already developed in this current study. Thus the standard developed in this study would serve as a benchmark for further improvement to the processes. Though the way the PM activities are carried out change constantly with the bus design, improvement in technology and availability of resources, developing standard would definitely help in making those improvement. The PM activities are performed regularly on the buses depending upon the distance traveled, route information, bus age, time intervals, and some other related factors.

As observed during the study, most of the facilities performed PM depending upon the distance traveled with some consideration to the bus age. The PM may be categorized for every 3000 miles, 6000 miles, and 12000 miles or equivalent. It may vary with the convention used at different facilities.

During the exploratory phase of this project the steering committee, comprised of members of the Florida Maintenance Training Advisory Committee, guided the Time Standard Team to start the analysis with the preventive maintenance. Three locations were invited to participate in the study. These facilities were: Lynx in Orlando, PSTA in Clearwater, and Hartline in Tampa. The preventive maintenance activities could be divided into 10 major processes. They are as shown in Figure 1.

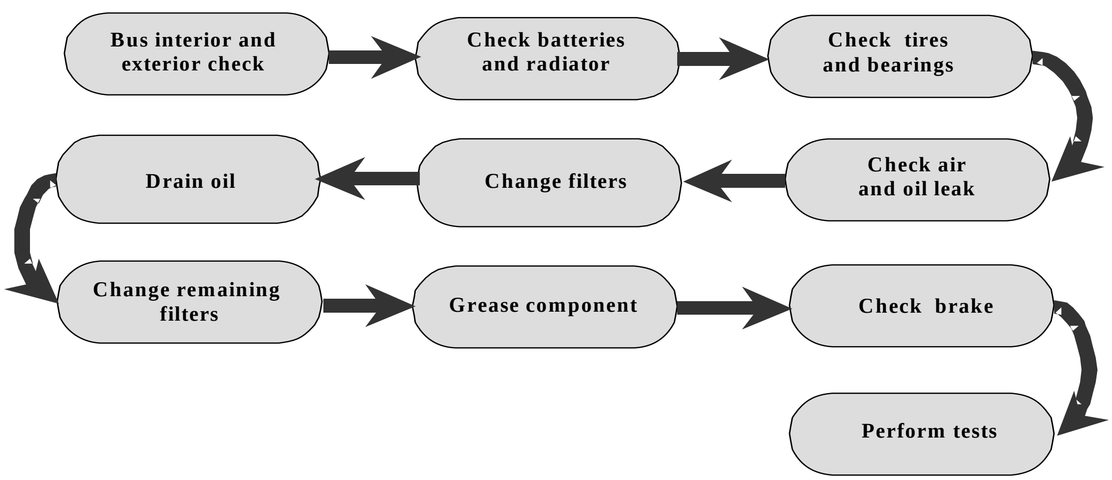

Figure 1: Processes of Preventive Maintenance

The flow chart shown in Figure 1 is the sequence of processes proposed for the design of the pilot readings. This is developed after detailed analysis of few observations taken at the three different facilities. The sequence proposed can be changed to a certain extent without altering the total time taken to complete the PM activities for developing the time standard. For example, the fuel filter can be changed before the air filter or vice versa without effecting the total time. Besides components inspected and replaced vary with the type of PM. As mentioned PM's are done on buses after 3000 miles, 6000 miles, 12000 miles and so on. These intervals may change depending upon the facilities. In 6000 miles PM, certain activities mentioned in the flow chart may not be a part of the PM process. For example, the transmission oil is not changed in PM for 6000 miles.

There are usually two broad classification of the PM, usually referred to as 6000 miles or 12000 miles and it may go to 24000 miles and so on. At some facility it is termed as A, B and C type PM with A as 3000 miles, B as 6000 miles, and C as 12000 miles or equivalent. There are some differences between the basic two PM: 6000 and 12000. The major are changing oil and filter for the transmission, differential oil, and air drier filter that are a part of 12000 are not included in 6000 or equivalent PM. A standard is developed for the 12000 miles or annual or equivalent that includes all the operations performed in the 6000 miles PM. The proposed method will serve as a standard for 6000 miles PM just by not considering the time for certain processes that are not included in 6000 miles PM as discussed earlier.

3. APPROACH

Before a valid time study could be conducted four fundamental requirements were addressed. First, because of the many interests and reactions associated with the time study, it is essential that there be full understanding between the supervisor, employee, and time study analyst. This project was strongly supported by supervisors, maintenance directors and employees. Everyone was informed of the purpose of the study and the analysts were always welcomed to the facilities.

Second, the analyst should be honest, tactful, patient and enthusiastic. He/she should ensure that the correct method is being used and should accurately record the times taken. The analysts that participated in this study possessed these qualifications. As a result, a good relationship was established between the analysts and both the technicians and supervisors.

Third, the technicians must be thoroughly acquainted with the processes. All the technicians that agreed to participate in the study were usually entry-level, they had complete knowledge of the process. Although some variability existed regarding the elements, the sequence and completion of each process was very similar.

Fourth, the technicians should assist the analyst in breaking the job down into elements, and work at a steady normal pace. Technicians assisted the analysts while dividing the job into elements. Most of the technicians worked at a normal pace while being observed. However, since time study directly affects the pocketbooks of workers, it was evident that some technicians worked below normal. Observations were adjusted with a performance factor in order to standardize the data. Taking these requirements into consideration the project was divided into 6 steps.

1. Literature Review
2. Process Study
3. Observations
4. Standard Development
5. Modification and Recommendation
6. Database Development

The following section discusses each of the mentioned processes in detail.

4. LITERATURE REVIEW

In the literature review the areas related to maintenance was researched and it was found that there was insufficient work done related to preventive maintenance. Research shows that there is considerable importance given to recording the details at the maintenance facilities and ways to cost reduction but there is dearth of its implementation. There has been little or no work done so far in developing time standard for the repair of the transit vehicles.

Bladikas and Athanassios (1986) discuss about the factors the may affect or help evaluate the maintenance policies using regression models. Bruce et al. (1986) discusses an application at the Tidewater Transportation District Commission of a framework for evaluating a transit agency's maintenance program. This method views the maintenance department's mission as a set of management activities that are associated with functional tasks that comprise the total bus maintenance process. Method is proposed to provide an overall measure of the maintenance operation's effectiveness, particularly in terms of vehicle miles per road call and vehicle maintenance cost per vehicle mile.

List and Lowen (1987) report the results of a survey sponsored by American Public Transit Association (APTA) regarding bus maintenance performance indicators and compares those results with other surveys and related projects that have been conducted in the past. The factors that account for the maintenance such as the number of road calls, miles per gallon, miles per quart of oil, miles per road call, periodic road calls, maintenance cost per mile and repeat work.

Literature conducted shows that an effort is made to integrate the maintenance activities with the operation of the transit services. Thus scheduling the maintenance so as to have lesser spare ratio has been an area of constant research. The time for the maintenance has been estimated to determine the scheduling of buses for the repair and also to estimate the number of buses that can be sent on road. However, literature generally falls short of addressing issues of determining the actual time for the repair or PM activities based on the performance level of the technicians in the transit facilities.

This research would make scheduling of buses on repair activities more deterministic thus help in better prediction. This would result in decreasing the cost and better management of public or private transit agencies.

5. PROCESS STUDY

The initial visits to the facilities by the time standard analysts were to understand the PM activities. Initially the total time to complete the job was recorded. These are termed as the pilot readings. These pilot readings are used to calculate statistically the number of reading required to develop the time standard. The total number of reading to be taken for 90% confidence is computed as shown.

Since time study is a sampling procedure, averages of samples ($\bar{x}$) drawn from a normal distribution of observations are distributed normally about the population mean (μ). The following formula was used to determine the number of cycles to be observed:

$n = \left(\frac{s t_{\alpha/2,\upsilon}}{k \bar{x}} \right)^2$ = (624.5 * 2.92) / (0.1 * 14600) = 13.55 ~ 14 observations.

A 90% confident level (1- α) was used for 10% probability of error (k). The mean ($\bar{x}$) and standard deviation (s) used were obtained from the 4 readings taken. The total number of cycles required was computed to be 13.55 observations. Since there were three participating facilities and to ensure the required confidence, it was rounded up to 14 with nearly 4 to 5 readings to be taken from each facility depending upon the availability of the buses and technicians.

After the number of observation required was calculated the processes and the sub-processes were identified and classified accordingly.

6. OBSERVATIONS

The observations were taken at all the mentioned facilities. Observations were taken in order to record the time taken to complete the job. A total of 14 observations were taken as mentioned above. While collecting the data the following inconsistencies were observed:

1. PM interval: Each participating facility had their own interval for doing the PM. Thus, the activities included in the PM were observed to have a large variability.
2. Element differences: Although every technician followed the same process to complete the PM, they had a unique method for working on it. Due to this variation, the data collection became difficult and much more challenging. However, it allowed us to identifying a combination of best practices from the various styles. Our study recommends a standard process that is based on all the best practices observed and the minimum time required.
3. Variation in treatment of processes or elements: PM activities are composed of mostly diagnostic operations or inspections. These change considerably with the

technician's skill and performance. This also introduced a great variability in the time of job done.

4. Facility Layout: Each participating facility had a different work-floor layout; hence travel times varied significantly depending on the layout. An attempt was made to develop the time standard independent of the facility layout. Thus the standard developed considered travel times in the vicinity of the bus. This might result in an actual increase or decrease in the travel times depending upon the facility design. An effort is make to develop standards independent of the facility design, yet effective.
5. Equipment: Equipment used by the different facilities for performing the operations varied. Thus the time taken by working on the commonly used equipments was considered for the standard development. This would not require any facility to buy any additional equipment for implementing the time standard.

The numbers of visits along with the number of readings taken at these facilities are listed in the Table 1. The number of visits in the first row as shown in Table 1 indicates the visits to the facilities by the analysts. The initial study was done to understand the PM process followed by the pilot readings to determine the number of readings to be taken for the time standard development.

Some of the observations taken were not considered for the standard development or were classified as invalid as more than one technician was assigned to work on the bus. The valid observations in this study were performed by a single person. It was also seen that due to some unavoidable circumstances in some of the observations, the total time taken to do the job was very long. These observations were also termed invalid.

Table 1: Summary of visits

	HARTLINE (Tampa)	PSTA (Clearwater)	LYNX (Orlando)
Number of visits	15	14	5
Number of initial studies and pilot observations	6	6	2
Number of observations for 6000 miles	3	2	2
Number of observations for 12000 miles or equivalent	1	5	1
Total number of invalid observations	5	1	-
Total valid observations	4	7	3

7. TIME STANDARD DEVELOPMENT

7.1 Introduction

All the observations taken were analyzed to standardize the procedure taking into account the various factors such as time, tool availability, facility layout and technician skill level. The focus was to get improved efficiency with reduction in the total delay and stress caused to the technicians. Analyses were done to calculate the standard time required for each operation in the preventive maintenance and then standard time was developed.

Setting Time Standards involves two complementary procedures: operation analysis and work measurement. Operation analysis is the primary technique for reducing the work involved; it studies all productive and nonproductive elements of an operation, and ensures the elimination of unnecessary movement on the part of material or technician and substitution of good methods for poor ones. Work measurement is concerned with investigation, reduction and subsequently elimination of ineffective time, which is the time during which no effective work is being performed.

Before the standards were established, an extensive and thorough analysis and review of each element was conducted. Elements were classified into five categories:

○ Operation
⇨ Transport and Travel
□ Inspections
D Delays
▽ Storage

The current process has approximately a total of 240 – 340 elements depending upon the type of PM. The complete flow process chart of the current method for one of the observation taken is shown in Appendix 1. The number of the element increases or decreases depending upon the type of PM performed.

It is important to emphasize that the time standards developed are realistic and feasible. This is supported by:

Actual readings: The standards are developed using actual data for the time required to complete work elements and tasks.

Normal pace: All the time suggested is to be performed at normal working pace, i.e., with no speed increment.

Processes: The standard times' are reduced because of alterations made to processes, instead of changing the work tasks themselves.

Worker habits: Worker habit changes, like speaking to colleagues or conferring with others while borrowing tools, have been reduced by altering the processes i.e., making them interact less frequently. Otherwise, work and basic processes of the jobs have not been altered. So, the workers will not have a problem migrating to the standards.

Facility layout: All the standards are based on flexible facility design, with no changes to it. Thus these standards can be implemented widely and effectively.

Other considerations: The approach used gives the time that is actually taken by the technicians to do the job, i.e., times are not based on the theoretic study. These are the actual time taken by the technician to do the PM.

It was observed that the total time for the PM was approximately 5 to 6 hours. To reduce the stress on the technicians certain allowances were also added to the standard time.

Allowance: Due to the interruptions that can take place on a daily basis, no technician can maintain an average pace every minute of the working day. There are three classes of interruptions for which extra time must be provided. These are: *personal interruptions* such as going for a drink or to the restroom; *fatigue* which can affect even the strongest individual and *unavoidable* delays such as supervisor interruptions or tool breakage.

The main purpose of the allowances is to add enough time to the normal operation time to enable the average worker to meet the established standards when performing at normal rate. These allowances are meant to give flexibility and justified rest to the technician and thus ensure smooth and efficient working. The total allowance assigned for this study is 15% as shown in Table 2. Justification to these allowances follows.

Table 2: Allowance factors

Type of Allowance	**Percent added to Normal Time**
Personal	5
Basic Fatigue	4
Standing	2
Intermittent Loud Noise	2
Tediousness	2
TOTAL	**15 %**

Personal Allowance: This includes those cessations in work necessary for maintaining the general well being of the employee.

Basic Fatigue Allowance: The basic fatigue allowance is a constant, to account for the energy expended to carry out the work and to reduce monotony.

Standing Allowance: This allowance generally accounts for the energy utilized in standing and gives flexibility and rest to the technician for standing continuously.

Intermittent Loud Sound Allowance: This allowance generally accounts for the sound made by the equipments used. For instance the noise made by the air gun.

Tediousness Allowance: This allowance is generally applied to elements that involve repeated use of certain parts of the body.

NOTE: The allowances established may vary depending upon the working and atmospheric conditions. It may also vary due to the facility layout.

Technician Performance Rating: The skill and effort of the technician will directly impact the actual time required to perform each element of the study. When different technicians are observed a variability factor is introduced. Even when the same technician is observed, performance might vary from time to time. For that reason, it will be necessary to adjust upwards to normal the time of the good technician and the time of the poor technician downwards.

Since most of the technicians always followed the same pace from beginning to end, it is customary to apply one rating to the entire study. Therefore, the analyst assigned a fair and impartial performance rating to each study. In the performance rating the observer evaluates the technician's effectiveness in terms of a normal technician performing the same task. For example if a technician performs below normal a performance rate of 90% to 95% will be assigned to that technician. If the technician works much faster than normal then a 105% to 110% will be assigned.

In PM, it is observed that the technicians working are generally entry-level or with very less experience. The observations made on these technicians have higher operation and inspection time as compared to experienced technicians. It is observed that the time taken would be less by 10% based on the observations for experienced technicians. Appendix 1 shows the time taken and flow of work done by one of the technicians under the study. Appendix 2 shows the time taken by an experienced technician to perform PM.

7.2 Requirements for the standard development

1. The time study was conducted for a single operator performing the PM activities.
2. The pace of the technicians was observed to determine the normal, slow or fast speed of operation. This would be based on the observing capability, knowledge of the method and analytical skills of the time standard analyst.
3. The time required to arrange for the setups will not be a part of the standards.

4. The equipment required to perform the PM should be readily available without causing the unusual delay or higher waiting time.
5. The time required to deal with the unforeseen situations arising during the PM, would be considered as foreign element and will not be accounted towards the total time taken by the technicians to perform the job.
6. Certain activities require the assistance of other technicians, waiting time for the other technicians are not considered for the total time.
7. Other tools needed for the PM such as the waste oil container should be available to the technician performing the PM as specified in setup.
8. Some of the sequence in the operation of PM can be changed as specified without affecting the total time required to do the job.
9. The time and method proposed includes the general inspection with oil and filter change. Repair activities identified during the inspection is not a part of the time standard.

7.3 Proposed time standard for the PM

In this research a time standard is developed for the PM taking into account all the PM activities. The time standards are developed in the form of modules. This is possible because PM’s are mostly composed of activities that are not necessarily dependent on any other operation. For instance, changing the fuel filter will not affect changing the coolant filter. Proper allocation of operations will definitely reduce the time for the tool setup and travel. The operations are analyzed and sequenced such as to reduce the total travel and set up time. Also taking into consideration, the flexibility the proposed method will offer to the technicians. The Annual or 24000 miles or 12000 miles or C category of PM’s usually takes about 5-6 hours as shown in Appendix 1. The method proposed for the PM takes 4 hours 12 minutes that is 16% to 20% less than the average total time as shown in Appendix 2. The proposed time includes the time for allowances and the time to note the information for any repair required or just to fill the details of the inspected part of the bus on the checklist. There is a reduction of nearly 30 minutes to 1 hour with the proposed method. This does not include the breaks for lunch. The detailed proposed sequence is shown in the Figure 2.

Appendix 3 shows the summary of the current observations and the time for the proposed method. It shows the summary for the 12000 miles PM or equivalent. It is evident from the observations that there is high variability in terms of the total time as well as the time for each process. This is due to the fact that there is a great deal of diagnostic test involved in the PM. The time for these inspections is highly variable depending upon the skill or performance level of the technicians. The technicians working on PM are usually entry-level or with a very less experience. This causes great variations in the readings. The other things that cause the variability are the availability of the tools, work bay design, and the design of the bus. All these factors when combined tend to put high variation in the readings.

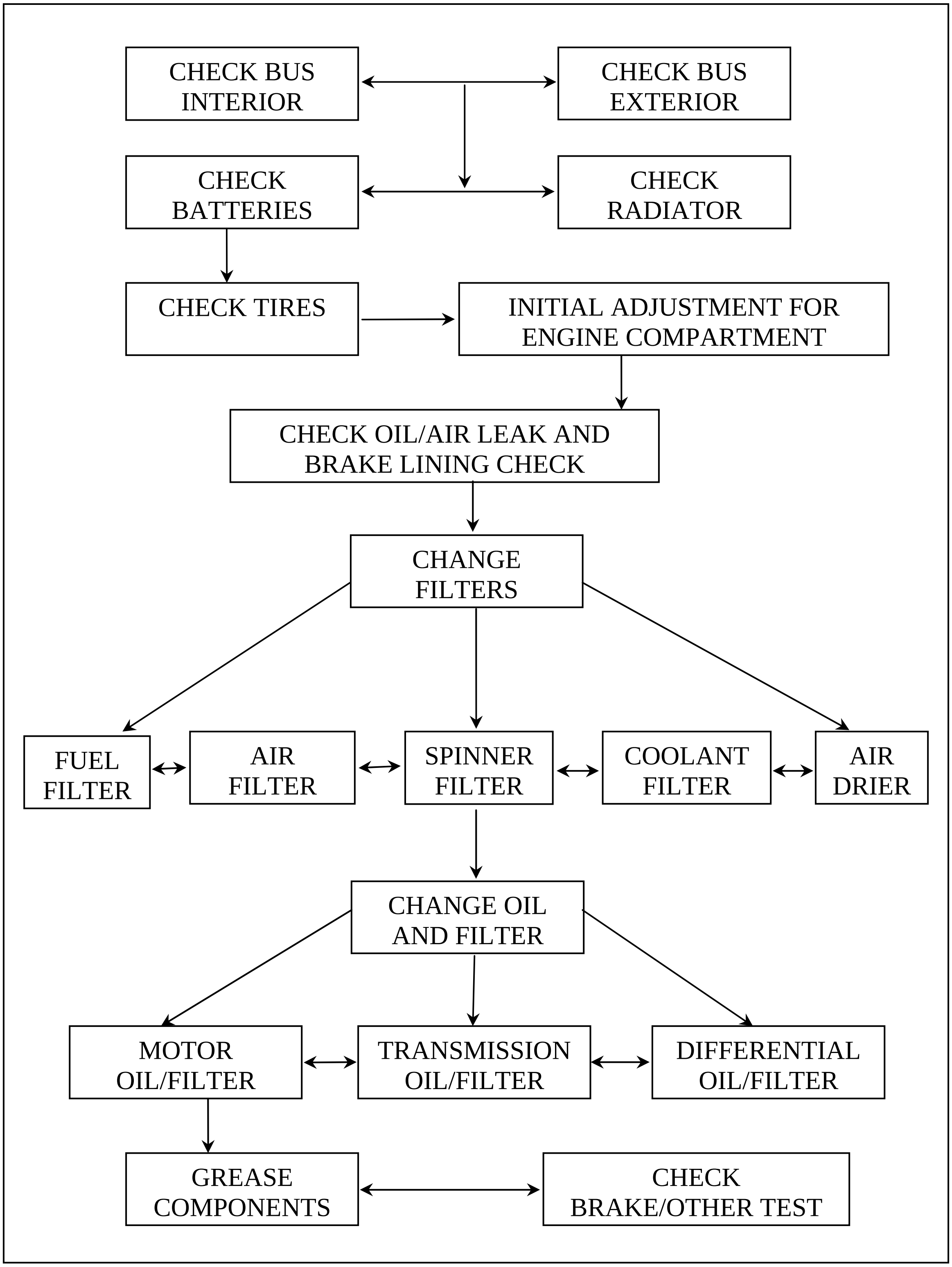

Figure 2: Detailed PM Processes

Also, as shown in Appendix 3, for some of the processes, proposed methods show a higher time than current average time. For example, Check Batteries; shows a proposed time of 18.8 minutes versus a current time of 10.7minutes. This is due to the fact that during the development of time standard, best practices were observed at different facilities and an attempt to combine them to offer comprehensive PM has been made. Some of the processes at different facilities are combined together to develop the standard. However, some of the processes that were done at some of the facilities were not considered to be a part of the standard because those were not practiced at most of the facilities listed in Appendix 4. The standards offer flexibility to be adjusted to any facility. Thus, those processes common to all the facilities participating in the study were considered in order to combine the best practices.

7.4 Effect/Comparison of the methodology and layout at different facilities

The observations were taken at different facilities to study the methodology as well as the impact of the variability of these facilities on the proposed standards. The best observed practices were incorporated into the proposed methodology. Some of the difference and factors observed are discussed as follows:

1. The technicians working on the PM are generally entry-level and so the time used to develop the time standard will reflect the time taken by the entry-level technician evaluation. That is a 90% performance rating was given to the majority of the observations taken.
2. Study shows that at some places higher importance is given to inspection of certain components like checking the bus interior than components such as checking the brakes or other equivalent components. This results in higher time to complete with less attention and time given to other important issues.
3. All the initial setup was made before starting the PM at some facility whereas some places supplied with some immediate setup and then remaining needed to be procured while performing PM.
4. The work bay for the PM of the buses differs in layout. Hydraulic lifters are used to lift the vehicle at some places whereas in pit bay, the technician has to travel to the bottom of the bus to carry out the PM. The travel time is higher in case of pit bay as compared to hydraulic lift bay.
5. Sharing of tool results in higher time for the job depending upon the tool, part availability and the number of people using it.
6. The placement of the hose pipe for motor oil, transmission oil, differential oil, and grease affects the total time for the job. Facilities with better placement of these arrangements result in faster and smoother operations.
7. Pressure cleaning may not be contingent for every PM. Pressure cleaning the bus assembly gives better visibility of the areas requiring repair or attention.
8. In some facilities, a master mechanic is responsible for the critical inspection of the major components like the motor belt, brakes, and other components. This reduces the chances of error in fault depending upon the capability of the master mechanic.

7.5 Proposed checklist

To aid the technician with the proposed method, a checklist has been developed. It was developed after taking into consideration the checklist at different facilities. It may not be suitable for the entry-level technician to work with the checklist, as it does not show the comprehensive list of all components to be checked. However, it lists down the most frequent repairs and components for inspection and part replacement based on the observations made at these facilities. The checklist as shown in Appendix 5 represents 12000 miles PM as this has most of the processes for comprehensive PM. The checklist includes the tasks that need to be performed in the sequence of operation proposed.

8. DATABASE

The Transit Maintenance Database (TMD) for the preventive maintenance phase is an enhancement of the brake system database that combines information from both systems. In this database, users can access information regarding bus maintenance time standards and bus maintenance history. It will provide information of the systems including processes and sub-processes along with the time taken for each. In addition, the database allows managers to schedule specific tasks to employees and to obtain an estimate of ending time of those tasks according to the standards previously determined. It is intended to assist managers to evaluate relative productivity or combined productivity of all employees. A users' manual is developed for better understanding of the use and working of the database.

8.1 E-R Diagram

All the tables within the database are connected so that the data can be viewed using the reports as needed. Due to the relationship among the tables, it permits enter, calculate and report information as required. This means that users can access information about employees, buses, time standards, and maintenance systems (brakes and preventive maintenance).
The relationships are shown in the Entity – Relationship Diagram (Figure 3). Explanation of each table is covered in the data dictionary.

8.2 Requirements

To use the Transit database, minimum system requirements are as follows:

Intel Pentium processor, AMD Duron or equivalent (500 MHz system speed)
64 MB RAM
At least 50 MB of free hard disk space (8 GB HDD preferred)
Microsoft Office 2000, Professional edition.
Microsoft Windows 2000 operating system
CD ROM (16x preferred)

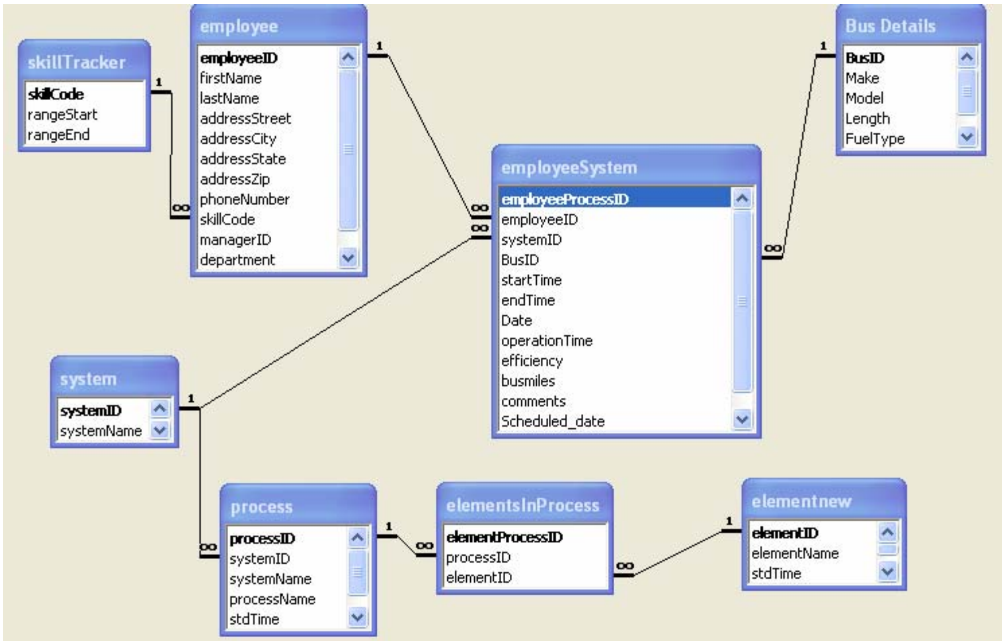

Figure 3: E-R Diagram

8.3 The interface

The database is compound by screens that facilitate the interaction between the user and the system. It mainly has three types of screens: index screen, data entry screens and the reports screens.

Index

Users will be able to navigate the database from this screen. It has icons that directs to any entry/edit or report screen, as well as to exit from the database. The screen is shown in Figure 4.

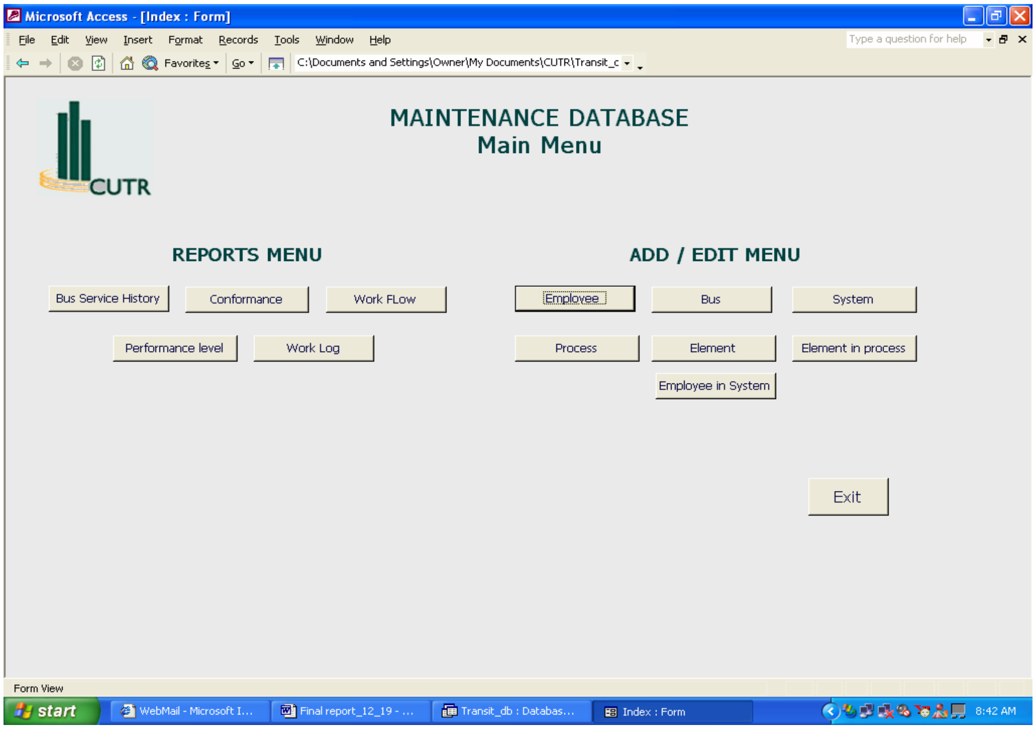

Figure 4: Index Screen

Forms

Information can be entered in the database using forms. Along with the currently used forms in the database, certain forms were added along with improved graphical interface. Some of them are as discussed as follows.

Add Employee Information: Figure 5 shows the form for the employees where information regarding the technicians can be entered or information about an existing one can be altered.

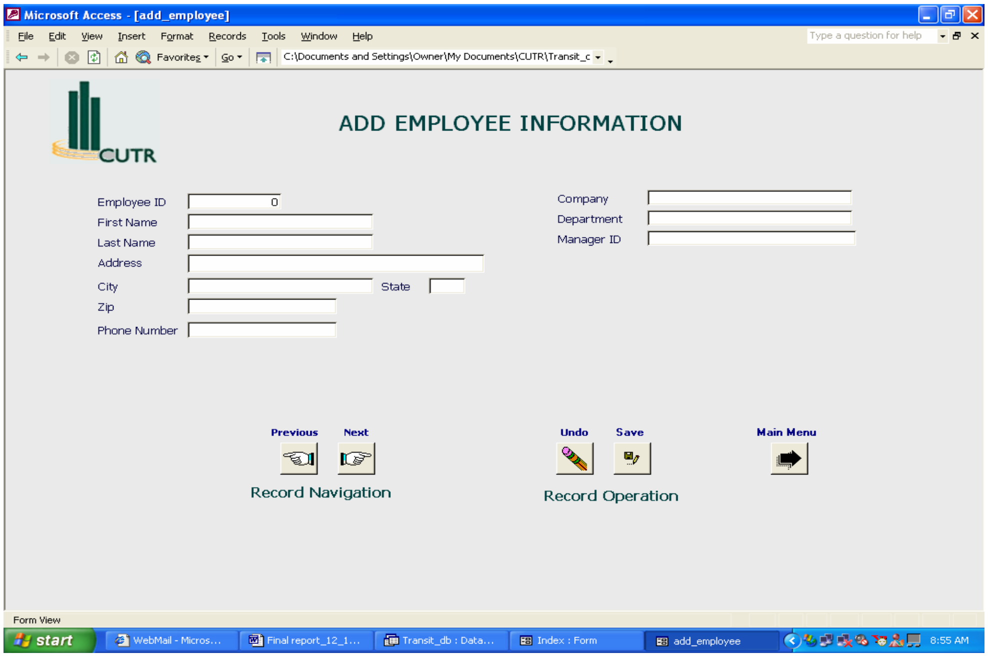

Figure 5: Add Employee in the System

Reports

The reports can be generated by the database to get the required information. In addition to the report developed for the brake system, there were additions made as described later. The reports are further described in detail in the user manual.

Conformance Report: As shown in Figure 6, this report shows information regarding the maintenance repairs done by technicians on particular buses.

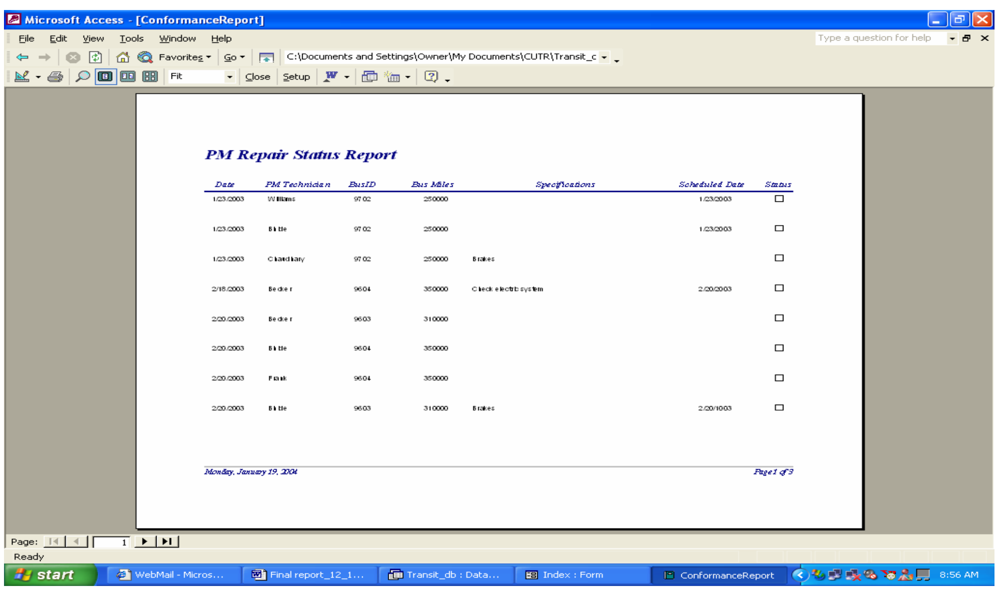

Figure 6: Conformance Report

Performance Report: As shown in Figure 7, this report shows graphic information about the performance level reached by technicians in all the systems. The number of job performed runs vertically, while the maintenance systems are on the horizontal axis. The series show the performance level reached in any case.

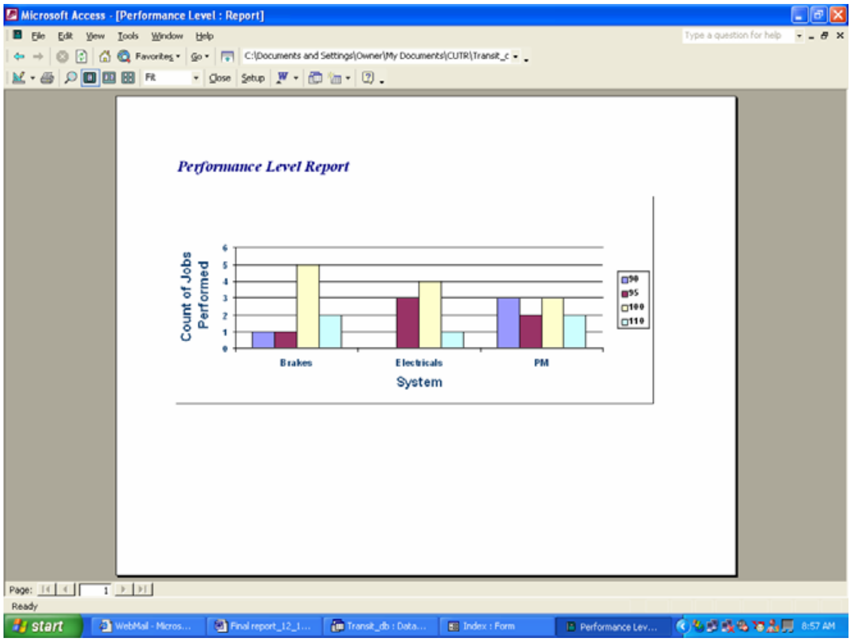

Figure 7: Performance Level Report

9. RESULTS AND CONCLUSIONS

The modifications made in the operations were negligible and the flow was changed in order to reduce the delays and travel times. Thus the method proposed mostly altered the sequence of the operations without actually changing the operations itself. Recommendations are suggested using scientific and industrial engineering skills along with other work measurement and analytical techniques.

9.1 Results

1. The delay was reduced by 80% of the average value for the delay time.
2. The processes in the proposed method are organized in a way to reduce the average travel time by 22%.
3. The total time is reduced by nearly 20% over the total average time.
4. The proposed method represents more organized way to perform the PM better understanding of the whole process.
5. The proposed method increases manageability of the tools and parts due to the predetermined sequence of flow though it offers required flexibility by modular approach. Modular approach is the representation of any process being started and

completed without being dependent on any other process or processes starting or ending time. The proposed method follows this modular approach with certain exception to better manage time.

6. Proposed method reduces redundant operations resulting from disorganized flow of the work.
7. The proposed method is aimed at performing efficiently and reducing the training time for the new technicians.

9.2 Benefits of the time standards for PM

1. Reduction on total time – The standard developed carefully considers the sequence of operation for the PM. This cuts down some of the repetitive tasks that may be very time consuming. The standard proposed reduces the total time of the PM by 20%.
2. Evaluating actual performance and productivity – The standard developed is based on the time taken by various technicians to do the job. Thus, the standard can be used as a tool to evaluate the actual performance and productivity of the technicians.
3. Determining the need for training – The standard can be used as a base for identifying the training needs. For instance, if somebody is performing at a higher total time then that mentioned in the standard suggests the lack of expertise in the area. Thus training can be provided to increase the performance of the technicians.
4. Balancing the work among the crew – The standards will assist in determining the optimum number of technicians required for completing an operation. It will also help to coordinate the allocation of tasks and assignment of jobs. Consequently, workforce utilization will increase, and unaccounted time and redundancy will decrease.
5. Comparing methods – The standard can be used as a comparing tool in the future to make further improvements in the PM.
6. Scheduling – This allows the allocation of workers for single activities and determines which personnel are available to perform unscheduled repairs or maintenance backlog. In addition, standards provide managers a better understanding of where and how all the resources are applied.
7. Assessing the need for labor and equipment requirements – When an operation is performed repetitively, the cost visibility provided by labor standards permits detailed cost evaluation and control that can result in significant savings to the company. For example, when standards are used for PM, a supervisor can review the progress of a mechanic to determine whether more time, personnel or equipment is needed for the operation.

9.3 Conclusions

1. It is seen that due to proper sequencing of the processes and the setup the travel time and delays are reduced.

2. The repetitive tasks are eliminated thus reducing the total time required for the PM.
3. In the current observations, the sequencing of the work elements is highly disorganized and so they are rearranged to give the estimate of the total time for each of the processes. This helps in evaluating the variability of each of the processes in the system.

10. RECOMMENDATIONS AND FUTURE WORK

The observation taken at various participating facility helped in developing standards and also identifying loopholes and suggesting improvements. The recommendations based on the study are as discussed.

10.1 Recommendations

1. It is recommended to pressure clean the bus every time the PM is performed. This gives better view of the fault or the repair elements.
2. Each task needs to be completed before going to the next task. Certain exceptions include draining motor, transmission, and differential oil when simultaneously other tasks can be done.
3. The parts that need to be changed should be obtained before the PM starts and hence the time for the part procurement is not a part of the standard. The set up is shown in Appendix 6.
4. A tool trolley is recommended near the repair activity place to save time for the tool placement and also repair part placement.
5. Develop an intelligent recording document or check list that will reduce the total time for making notes for the repair components.
6. Make use of a tool belt to keep all the tools that are light and most frequently used to avoid frequent traveling for the tools.
7. Use of the electric drainage pipe would decrease the time of operations like filling motor oil drainage, transmission oil drainage, and differential oil.

10.2 Future work

After the development of time standard for the PM, the study will be conducted for developing standards for other components of repair. Some of the repair components may include the engine repair or rebuilt, power transmission, ac repair, and electrical systems. Based on the current study some of the other future work will include:

1. Effect of factors on the road calls: The observations revealed that preventive maintenance activity do increase the operating efficiency of the bus transit but there are still significant amount of road calls. Some of the reasons for the road calls can be determined or the effect of the factors on the road calls can be studied by designing an experiment. The road calls may occur due to many reasons and they are recorded at the facility. Some of the reasons for the road call may be due

to the brake failure, air leak, electric system failure, transmission failure, etc. If the failure due to PM can be studied then the design of experiment can be done and the effect of these factors on the number of road calls can be determined.

2. Observations and technicians input indicated that a failure analysis would definitely help improve the PM activities.
3. Training will help improve the performances, as the technicians working are generally new or less experienced.

In addition to developing time standard for all the bus components, simultaneous enhancements to the Transit Database envisioned are:

1. Materials used for every job (as per DOT specifications): This information within the database will allow additional level of conformance by the Transit Company to mandatory component replacements for every job. For example, filters and oil replacements necessary for PM's depending on whether it is a 6K, 12K or Annual 12K preventive maintenance. This also allows for material tracking by the facility during annual inventory inspections.
2. Progress/Performance alerts: Alerts can be set and actuated depending on specific facility needs in case certain employees are performing much better or below the time standards. These alerts can be set either periodically or after a critical number of jobs performed. The idea is to dynamically assess technician performance on the fly and provide necessary training needs through training and certification programs.
3. Database training and support tools: For a database with multiple functionalities, a sound support and training manual and service is required. This can be developed and provided to the facilities at the time of installation. Also, ongoing developments can be added to the database without loss of any data.
4. Security and data sharing: Currently, most of the database or software used by a facility is used either by the managers or supervisors. The proposed Database would incorporate involvement of the Materials depots, MIS department, and other entities. Certain data may be sensitive or confidential (Employee information, performance levels, progress) and needs to be accessible only to certain people. Table sharing vertically or horizontally (only certain fields or certain relevant segments) can be set up depending on facility need

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