THE APPLICATION OF TOTAL PRODUCTIVE MAINTENANCE (TPM) TO OPERATIONS AND MAINTENANCE FACILITIES OF TREN URBANO; CASE STUDY: MOTOR BOGIE

by

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ABSTRACT

This work presents the development of a maintenance strategy with the objective to increase efficiency, effectiveness and security of operations and processes of Tren Urbano's Operation and Maintenance Facilities. This work will be based on a technique called Total Preventive Maintenance (TPM), an extensively proven technique that allows the development of a maintenance strategy.

RESUMEN

Este trabajo presenta el desarrollo de una estrategia de mantenimiento con el objetivo de mejorar la eficiencia, efectividad y seguridad de las operaciones y los procesos de las Instalaciones de Mantenimiento y Operaciones del Tren Urbano. Este trabajo se basa en la técnica llamada Mantenimiento Total Productivo (TPM por sus siglas en inglés), una extensa y abarcadora técnica que permite desarrollar una estrategia de mantenimiento.

To my parents . . .

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Before anything else is written, all praise is due to God, who makes our lives possible and fantastically livable each day.

During the development of my graduate studies in the University of Puerto Rico several persons and institutions collaborated directly and indirectly with my research. Without their support it would be impossible for me to finish my work. That is why I wish to dedicate this section to recognize their support.

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1 INTRODUCTION

1.1 Overview

Maintenance is one of the most important aspects and challenges of today's industries. In most companies, business suffers if maintenance is not given enough attention. In an operational system, as the one presented in any industry, a comprehensive maintenance program can be the key to success. Therefore, different programs and techniques have been developed to control maintenance of almost any kind of operational system. Maintenance is a complex issue, which needs planning and assertive awareness and training at all levels prior to the implementation of the system. The following section exposes why maintenance research is necessary.

1.2 Research Needs

Tren Urbano (TU) is the largest infrastructure project currently in Puerto Rico (PR). The TU, a heavy rail transit project, has resulted from the implementation of a state-of-the-art transit system for San Juan Metropolitan area. Phase 1 of TU includes a dual-track heavy rail line 17.2 Kilometers (10.8 miles) in length, extending from the Bayamón District south and west of the center of Santurce District, through the commercial center of San Juan and the Central Business Unit (CBU) of Hato Rey. TU is the first rapid rail transit system constructed in PR. Consequently, it is one of the principal and main service industries on the island.

The approach of TU has been to combine the strategic tools of Design-Build-Operate-Maintain (DBOM). One of the stages that has to be designed for TU's success is the operational stage. A maintenance strategy needs to be deployed for the train's operational system. The fact is that the success of operating any heavy rail system depends upon an effective a maintenance strategy.

1.3 Research Description

A maintenance strategy needs to be established to support the invention, knowledge, time and significant capital investment dedicated to this project and specifically to the design of the vehicle. The expected useful life of vehicles is 30 years if a complete revision is given every 3 months (70,000km) [TU/MIT Training/Conference, May 2000]. However, Siemens Transit Team (STT) establishes that if a revision is done only when it is strictly necessary, the vehicle useful life decreases 50 percent. Therefore, if a combination of maintenance strategies is applied in an effective way, the vehicle's useful life will increase 25 percent [Geoff McKay, 2001]. These percentages are statistical, technical and real. Statistical because they are measuring and keeping record of an issue: maintenance. Technical, because they give support to a specifically, sophisticated matter: maintenance. Finally, real, because in real life it is demonstrated that giving the adequate maintenance will give great results.

A convincing example in real life is Japan's rapid rail vehicles. Japanese vehicles were used for 15 years having a complete maintenance strategy applied. These Japanese vehicles were offered to Argentina rapid rail system. The Japanese vehicles were in

excellent conditions. Argentina knew these were used vehicles, yet they preferred these over new ones that were also offered because used ones were cheaper and accomplished quality and operation requirements as the new ones [TU/MIT Conference, 2000].

This was only a vehicle example involving foreign countries; however this is a lesson that could be learn and applied to PR's TU. TU is a new transportation system that needs evaluation and research in many of its aspects. In this research PR's rapid rail system (TU) is the one studied. TU and its maintenance strategy are the focus and both of them will be explained and described in the following section.

1.4 Maintenance Strategy

This project develops a maintenance strategy with the objective to increase efficiency, effectiveness and security of operations and processes of TU's Operation and Maintenance Facilities (O&M) located at Martinez Nadal, in Guaynabo, PR. This strategy will be based on a technique called Total Productive Maintenance (TPM), an extensively proven technique that allows developing and implementing a maintenance program.

The Japanese developed TPM in the 1970's combining American Maintenance and Japanese quality control. TPM optimizes effectiveness, eliminates breakdowns, and promotes autonomous operator maintenance through day-to-day activities. TPM has the potential of being applied to any operating system, including the TU's O&M.

TPM is a maintenance program, which involves a robust approach for maintaining facilities and its equipment. Today, the existence of diverse equipment, centralized control, few operators, high-energy consumption, shutdown maintenance and high accident and pollution risk reclaims for TPM implementation.

This research is focused in a TPM structure plan for TU's motor bogie. TPM will be recommended to actual maintenance program to increase efficiency, effectiveness and security of equipment and all its different processes. Through TPM recommendation plan, all the information about processes, parts and maintenance techniques will have to be gathered in a standardized format. In addition, TPM plan will start with upper management involving all the people working in the facility to establish a knowledge baseline. TPM will provide the environment to have a world-class quality facility. These are some of the good reasons to justify TPM.

TPM maximizes equipment's effectiveness and productivity, and minimizes machine losses; creates a sense of ownership in equipment operators through a training and involvement program and promotes continuous improvement through small-group activities involving production, engineering, and maintenance personnel.

Companies practicing TPM achieve startling results, particularly reducing equipment breakdowns, minimizing idling and minor stops, lessening quality defects and claims, trimming labor and costs, shrinking inventory, cutting accidents, and promoting employee involvement. A safe working environment is promoted that increases confidence in the plant's products.

The O&M of TU could reach all the benefits previously mentioned if TPM is implemented with discipline. Other benefits from the implementation of TPM are:

- The equipment's useful life will be longer and the equipment will not deteriorate as quickly.
- The occurrence of accidents will decrease with high probability of eliminating failures.
- No loss of time or resources and the production is effective with the possibility of eliminating defects.
- Repair costs reduction.

Over the years, TPM has been focused on manufacturing. The main area of analysis inside manufacturing is equipment. For TPM, equipment administration should be as follows:

- Equipment should operate in its maximum performance level
- It should be maintained to serve its highest required availability and performance level; and
- It should be supplied with new equipment, high performance and low life cycle cost.

TPM application must have equipment as central thought. In this research, the equipment under investigation is the Motor Bogie. Questions that must be answered about the motor bogie are:

- How can TPM improve the availability of the motor bogie?
- How can TPM contribute to energy and resource conservation and hence to the reduction in overall costs?
- How can this be achieved through maintenance-oriented plant management as part of a total system approach?

Any company that implements TPM should expect to reduce its operation costs in terms of breakdowns or defects, and at the same time increasing productivity. Figure 1 and 2 [Shirose, 1992] show just some of the benefits derived by companies that implemented TPM. These are typical results.

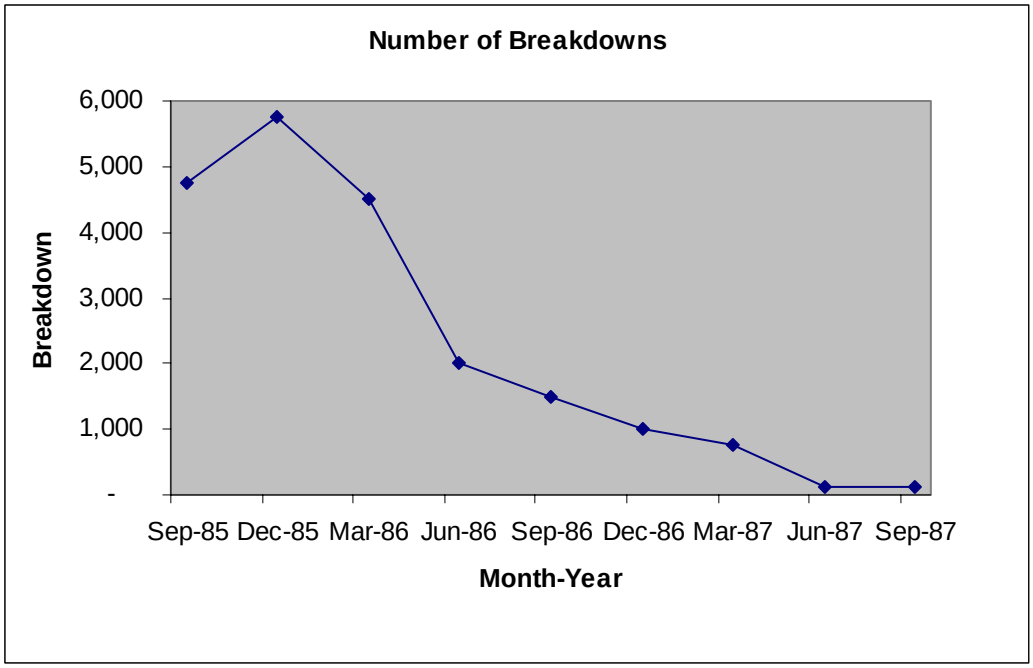

Figure 1: How TPM affects the number of breakdowns [Shirose, 1992]

Both figures show TPM Success Statistics. Figure 1 shows how TPM affected the number of breakdowns in a facility from 4,800 to 110.

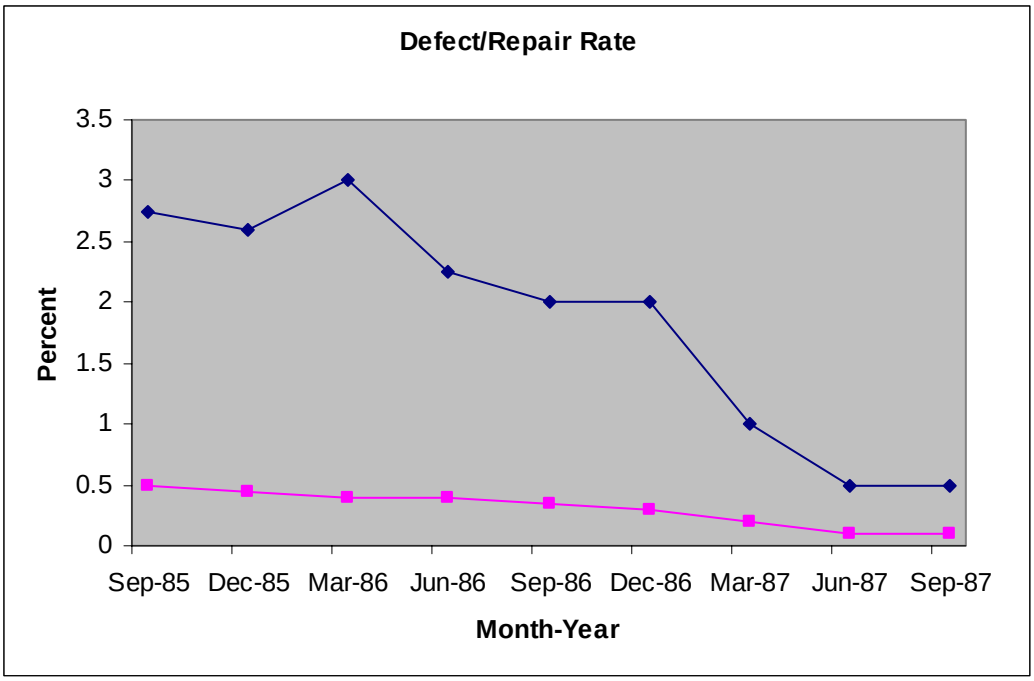

Figure 2: How TPM affects the defect and repair rates [Shirose, 1992]

Figure 2 shows how TPM affected the defect and repair rates of two different companies. Company A reduced from 3% to 0.1% their manual repairs (rework) and Company B reduced from 0.5% to 0.1%.

On both cases TPM acts successfully. These two figures only show two examples of how effective TPM implementation can be. For this research the effectiveness of TPM is based on specific objectives. The next section presents the objectives established for this research.

1.5 Research Objectives

TPM has two goals and these are: zero breakdowns and zero defects. When breakdowns and defects are eliminated, equipment operation rates improve, costs are reduced, inventory can be minimized, and as consequence, labor productivity increases. These are general objectives that were established in this research. The following are specific objectives applied to this case.

- Develop TPM maintenance strategy for the vehicle motor bogies. The motor bogie includes the traction motor, the brake system, suspension system, truck connection (cables and pipes), current collector (power pickup to the 3rd rail) and the wheel flange lubrication.
- Investigate TPM strategies for its application to the motor bogie in order to increase efficiency, effectiveness and security in the operations of TU's vehicle. All TPM's applicable techniques will be evaluated for success of the motor bogie's maintenance.
- Generate a specific format including all processes, parts and maintenance given to the Motor Bogie. This format is a complete database of the necessary information to execute the correct and complete maintenance of the motor bogies.
- Propose TPM Plan to all possible processes in the O&M of TU using the specified given format. Although this format will be specific for the motor bogie, it could also be used in any other part or maintenance process at the O&M.

- Aim for world-class quality for the O&M of TU.

All these objectives demonstrate that TPM is profitable. All the benefits received lead to other benefits, such as a skilled work force, equipment, and the factory environment necessary to survive in this age of automation and unmanned operations. All these rewards can be achieved following the established methodology and the other parts of this project, explained in the next section.

1.6 Project Report Organization

This project deals with the application of TPM to the O&M facilities of TU, focusing on the motor bogie. This document presents the proposed solution methodology, its relevance with respect to current research, results and conclusions. It also includes a group of recommendations, which specifies future work that can be done on this matter or related fields.

This introductory chapter, Chapter 1 – Introduction, provided the user with enough information on the subject; evaluated the need for a maintenance strategy and instituted the objectives of this study work.

The second chapter, Chapter 2 – Literature Review, exposes major information on TPM. Mostly, TPM had not being applied to mass transit system maintenance. However, through a technology transfer program developed with knowledge gained in manufacturing, it was possible to develop a TPM plan for the motor bogie of TU. This chapter includes general TPM definitions, and more of its benefits and rewards due to its

implementation and its origins, which are based on American and Japanese interactions. It includes more maintenance techniques that are related to a compound TPM, such as Preventive Maintenance (PM), Corrective Maintenance (CM), Predictive Maintenance, etc.

The third chapter, Chapter 3 – Methodology, provides the steps used to recommend TPM to TU's actual maintenance program, based on Nakajima's 12 steps. It describes the approach used in this research, in as much detail as necessary to illustrate the use of the particular search method selected.

The fourth chapter, Chapter 4 – System Description for TPM Application, explains the actual maintenance strategy from TU. This current strategy will be used and evaluated to recommend TPM to actual maintenance program to increase efficiency, effectiveness and security of equipment and all its processes.

The fifth chapter, Chapter 5 – Master Plan for TPM'S Implementation, shows and evidences the experimentation process followed in this research. Cased studied previously considered in Chapter 4, was modified and is presented in this chapter. Also, observations and recommendations are included in this chapter.

The sixth chapter, Chapter 6 – Conclusions, presents the conclusions and contributions delivered from this study. Also, suggests derivative works that may origin from this research, as well as modifications that can be done following TPM advantage.

TPM effectiveness can give great benefits. A review of TPM contributions and examples success stories follow in Chapter 2. This helped to select relevant performance measures that were adopted to monitor TU's Motor Bogie performance.

2 LITERATURE REVIEW

2.1 TPM Appraisal

TPM appraisals follow in this chapter. They facilitated the selection of relevant performance measures that were implemented to monitor TU's Motor Bogie performance. However, at first sight the focus was a global one; TPM was an effect of a worldwide cause.

After World War II, Japanese industries took and modified American productive knowledge and quality techniques increasing the quality and demand of their products in a considerable way. The same situation occurred in equipment maintenance. More than thirty years ago, Japan combined American Preventive Maintenance (PM) and engineering techniques to convert them into TPM. Usually, TPM isn't applied to mass transit system maintenance. However, through a technology transfer program developed with knowledge gained in manufacturing, it is possible to develop a TPM implementation to the O&M facilities of TU.

Nakajima [Nakajima, 1988] explains the course of PM to TPM. The importance of the equipment's effectiveness is evident for TPM success. TPM starts by eliminating the six major losses:

1. Loss from equipment failure

2. Loss from setup adjustments
3. Loss from brief stops
4. Loss from speed drops
5. Loss from process defects
6. Loss from startups

Operation and maintenance are inseparable and for TPM autonomous maintenance is required. Activities that encourage equipment's mainframe, promoting lubrication and promoting proper bolting should be established. General inspections must be accomplished, as well as autonomous inspection training and education. Finally, some keys for workplace management are offered. Maintenance activities ought to be standardized. There are some types of standards: equipment design standards, equipment performance standards or equipment specifications, equipment materials procurement standards, test run, and acceptance standards. There are several types of maintenance plans: annual, monthly and weekly. There are also major maintenance project plans. Each of them is developed in details. It's important to keep record of maintenance plans because they will reveal the quality of a factory's maintenance and help in future maintenance problems.

Nakajima [Nakajima, 1989] explains Maintenance Prevention (MP) as a significant aspect of project engineering that serves as the interface between project and maintenance engineering. Problems occur at startup stage and subsequent operations. The role of MP

is minimizing these problems by designing safeguards and countermeasures into the equipment before its fabrication and installation. To carry out TPM activities a company needs personnel with strong maintenance and equipment-related skills. Guidelines for recruitment are needed. Basically the operator will conduct equipment, periodically verification, scan the instrument panel and revise its lubrication. Records where completions of these practices are documented need to be audited.

TPM promotes the overlap of small groups, integrating organizational and small group improvement activity as discussed by Nakajima [Winter et.al., 1984]. Many companies have developed their own terminology and procedures for conducting small groups, categorized by Quality Control (QC) circles and Zero Defects (ZD) groups. The group goals coincide with the companies' goals, which lead to high morale that in turn conducts to high profits. Roberts in his paper [Roberts, 1997], mentioned that the goal of a TPM program is to markedly increase production while, increase employee morale and job satisfaction.

Kogyo [Kogyo, 1991] presents TPM as a combination of American maintenance practices with Japanese quality control concepts and small group activities to revolutionize plant maintenance. It is an innovative system for equipment maintenance that optimizes effectiveness, eliminates breakdowns, and promotes autonomous operator maintenance through day-to-day activities. TPM can be implemented into three different areas:

Part I of TPM: Identify the six major losses in manufacturing. Part II is reducing the six major losses. Part III: Study TPM Case Studies. These case studies describe how workers developed TPM programs in order to combat continued problems and improve plant, machine, and operator productivity and efficiency.

Peiró [Peiró, 1982] presents TPM as an application of PM, which facilitates the development of the equipment in its maximum capacity and eliminates surprising risky situations, which have a high and unexpected cost. Peiró [Peiró, 1982] also divided the TPM study in three different parts with different focuses:

Part I includes general topics of philosophy, composition and other aspects. It contains an explanation and an example of an annual-work plan and a monthly-work plan. It clarifies how to use additional assistance and how to control it. A demonstration of a Maintenance Center from the definition throughout inspections and codification is clearly explained, including formulas and processes for its completion. Finally Part 1 includes the theme: Center of Work-Control, which includes control panel formulas and distribution of assignments month by month.

Part II starts with the replacement of equipment including alternatives to consider before making a substitution: repair of the existing equipment, request for new equipment with similar characteristics to the existing one, request for new equipment better than the existing one, maintaining equipment in service or rent an equipment. It continues with the description of cyclic works, which are works to be done in an annual frequency. A formula of cyclic works including the work description is shown with required hours for

its modification. Next the equipment maintenance is presented: PM, selection criteria, maintenance action, installation of new equipment, cost, control of maintenance, including examples and others.

Part III embodies evaluation and identification of tasks or jobs, material supply and some recommendations of preventive order along with negative attitudes, advices and personal comments.

Some authors divided TPM in different features, mentioning the most important features [Nakajima, 1989] of TPM as:

1. Activities to maximize equipment effectiveness – requires complete elimination of failures, defects and other negative phenomena. Alludes to ZD and its relationship to TPM.

2. Autonomous maintenance by operators – it depends on the prevailing labor organization.

3. Company-led small group activities – people oriented management models

Nakajima [Nakajima, 1989] presents how profitable can be for a company if it implements TPM. It gives examples of TPM's effectiveness in productivity, quality, cost, delivery, safety/environment and morale. On each category the changes are positive. A complete TPM definition is given as follows:

Total Effectiveness - TPM aims to maximize equipment effectiveness (overall effectiveness).

Total Maintenance System - TPM establishes a thorough system of PM for the equipment's entire life span.

Total participation of all employees - Various departments (engineering, operations, and maintenance) implement TPM.

- TPM involves all employees, from top management to workers on the floor.
- TPM is based on the promotion of PM through motivation management: autonomous small group activities.

TPM can be "profitable TPM" and pursue optimal equipment effectiveness if:

- Accurate equipment operation records are stored so that the appropriate management and controls can be provided (with narrower targets).
- A precise scale for measuring the equipment operation conditions must be devised.

Nakajima [Nakajima, 1989] also analyzes how breakdowns and minor stoppages impede automation; a comparison between preventive medicine and PM is presented with the difference that in the last case, instead of people, it's the equipment. He mentions how useful PM can be. However, if the purpose is to eliminate breakdowns, it can't work alone. To eliminate failures, hidden defects must be exposed and equipment must be treated before it breaks down. To eliminate failures, well-regulated basic conditions should be maintain (cleaning, lubricating, and bolting), adhering to proper operating procedures, restoring deterioration, improving weaknesses in design, and improving operation and maintenance skills.

Integrating small group activities into the organizational structure is part of TPM implementation. The small group can be categorized in QC and ZD. The small group goals should coincide with company goals and the maturity of small activities can be evaluated. Top management must inspire the small group activities.

Nakajima [Nakajima, 1989] mentions the importance of the equipment in TPM implementation and success. Takahashi [Takahashi, 1990] exposes in words that equipment is the major means of production in a factory; so management must be equipment-oriented. TPM requirements are mentioned and explained in detail. Using equipment to its fullest extent, in order to manufacture the desired quality and efficiency is the first step towards maintenance-oriented plant management. TPM application must have equipment as central thought, answering: how to improve its availability, how can it contribute to energy and resource conservation, and hence, to reduction in overall costs, and how can this be achieved through maintenance-oriented plant management as part of a total system approach.

Other authors focus on other TPM factors. Gotoh [Gotoh, 1991] focuses on Toyoda Gosei Co. Ltd., a medium-sized company supplying plastic injection moldings and rubber moldings to the automobile industry. This company used TPM to improve plant availability, product quality and resource utilization. They used “small group cycle” or TPM promotion system.

A TPM Promotion Committee must be created to have closer relationship, as shown in Figure 3.

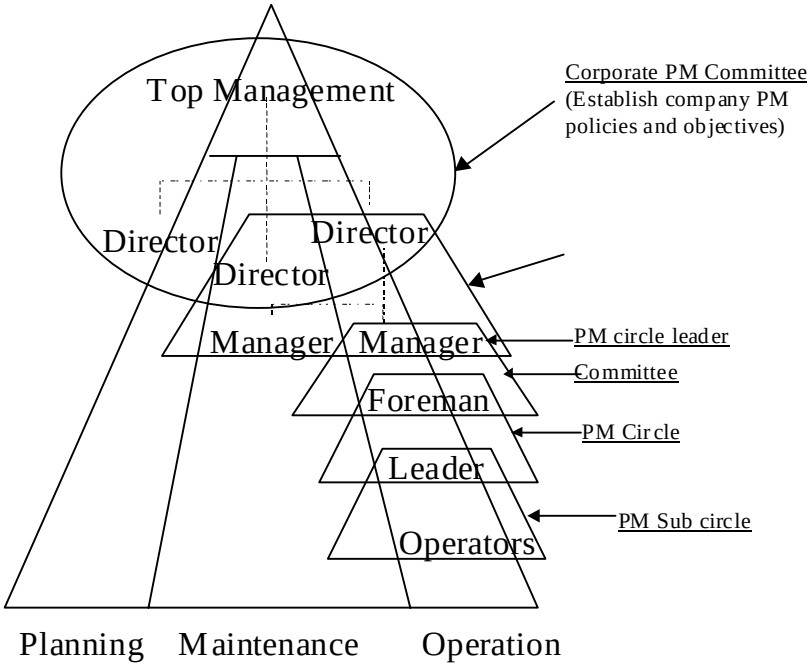

Figure 3: TPM Promotion Committee [Kelly, 1984].

TPM tries a positive investment in human resources in order to fully utilize existing equipment through improved availability, through more assured quality and through labor-saving as a result of plant modification. Kelly [Kelly, 1984] divided TPM into three different motives. The motives are:

1. Improve productivity through a highly motivated workforce; a multi-craft work or job enlargement program can be devised in which all workers are given a range of challenging jobs in an effort to develop their skills in different crafts. Having this in mind, the job would not be monotonous, repetitive or production line work.

2. The life-cycle approach that should improve overall performance of equipment. It establishes the gap or lack of information flow between those who project and design the equipment, those who manufacture it, those who maintain it and those who used it for production. The technical aspects of TPM emphasize MP, which implies the design of highly reliable and easily maintainable equipment with subsequent feedback form maintenance and operation to design.

3. The voluntary small-group basis of TPM. QC circle and ZD Group are widely practiced in Japan regardless of the size of the company. Naturally TPM followed the same route focusing small-group activity on the "5 S Activity", which means five Japanese words which means neatness, tidiness, cleanliness, stainless and orderliness.

Following the idea of a work force, TPM can be referred as *Total Productive Maintenance Team* [Tompkins, 1996], which had a tremendous role in contemporary manufacturing. Their main objective is to increase machine uptime and product quality. It entails TPM in the implementation of effective corrective, preventive, predictive, and autonomous maintenance programs, setup time reduction, tool management, visual management and housekeeping, and spare parts inventory control. TPM implementation impacts material handling, storage alternatives, to move and store tools, PM materials, testing equipment, and spare parts. It impacts workstation layout, too.

Based on the different references and studies from TPM, it has been proven to be a program that works. TPM has it motives as an approach to improve equipment performance and productivity. TPM has it uniqueness due people involvement in a

maintenance strategy. TPM has its objectives already settled: Zero Defects, Zero Breakdowns and Zero Accidents. Its direct and indirect benefits will justify its strategy implementation.

This chapter presented TPM appraisals, justified its benefits, the general objectives and methodology. Chapter 3 will present the TPMs maintenance strategy for TU's vehicle motor boogie and TPM method applied to the boogie.

3 METHODOLOGY

TPM brings maintenance into focus as a necessary and vitally important part of the business. Each publication studied in Chapter 2, explained TPM and exposed its benefits and rewards. This research provides an alternative maintenance strategy based on TPM success. Nakajima [Nakajima, 1989], one of the authors studied previously, proposed 12 steps to follow TPM implementation. The 12 Steps are presented in Table 1.

Table 1: Steps for TPM Implementation

Step	Key Point
Preparation 1. Discuss and agree with TU's management the need for TPM as the equipment maintenance program.	Top management announcement at in-house meeting; publish company newsletter.
2. Conduct TPM introductory education and publicity campaign.	Presentation; metropolitan area newspaper visibility.
3. Create a TPM promotion organization	• Steering committee and specialist subcommittees • TPM Promotion Office • Follow this research and others TPM related
4. Establish basic TPM policy and goals	• Set baselines, focus (motor bogie) and targets • Forecast effects and events
5. Draft a master plan for implementing TPM.	From preparation stage to application for PM.
Introduction 6. Kick off TPM initiative.	Invite customers, affiliates, and subcontractors.
Implementation 7. Build a corporate constitution designed to maximize equipment effectiveness.	Pursue the ultimate & innovative in equipment (vehicle) effectiveness & performance.
8. Build an early management system for new parts, equipment and processes.	Develop easy processes.
9. Build a quality maintenance system.	Establish, maintain, and control conditions for zero defects.
10. Build an effective administration and support system.	• Increase process-support effectiveness • Improve administrative functions & environment
11. Develop a system for managing health, safety and environment.	Assure an accident-free, pollution-free environment.
Consolidation 12. Sustain full TPM implementation.	• Apply for PM Prize • Aim to even higher targets

Based on Nakajima's 12 Steps, the Methodology followed for TPMs Implementation Strategy/Plan for TU Motor Boogie is the following:

1. Discussion and agreement with TU's management about a need for a maintenance strategy.
2. Develop TPM Strategy/Plan proposed for TU.
3. Focus TPM Strategy/Plan on TU's vehicle motor bogie, as requested.
4. Create TPM Organization
    a. Create TPM Promotion Organization
        i. Steering committee
        ii. TPM Promotion Office
        iii. TPM Research
    b. Establish basic TPM policy and goals
        i. Set baselines, focus (motor bogie) and targets
5. Draft a Master Plan for implementing TPM to actual maintenance strategy
6. Recommend future steps for a high-quality control stage for TPM Implementation.

These steps are key factors for TPM success. The steps were modified for TU environment. The steps can be applied to any TU resources and other key components. TPM foundations are relatively easy; it seeks to increase effectiveness and efficiency of

its atmosphere, which is the main objective of this project. The main purpose of this research was to implement TPM to specifically TU's motor bogie system and those steps will be the medullar ones to follow.

The next chapter, Chapter 4, will present TU's actual maintenance circumstances. Strategic Maintenance Plan will be based on this environment.

4 SYSTEM DESCRIPTION FOR TPM APPLICATION

4.1 Create TPM Organization

Total Productive Maintenance (TPM) is a dynamic maintenance program performed by all employees at all levels via small group activities. A TPM organization is dedicated personnel in charge of their specific regular main task inside TU such as Supply Chain Manager, Human Resource Manager, among others; plus, they are responsible for adding value to the company with TPM's development and correct implementation. This TPM organization needs to be lead by a group or team leader who has to be capable of understanding the business, the equipment and the people. This leader can be named as the Manager System Maintenance. This leader needs to report directly to the General Manager of the business center. Top Management, including General Manager and managers reporting to the General Manager, needs to be familiarized with TPM techniques and they need to be sure that there is an adequate strategy understanding for its complete success.

Figure 4 shows the Top Management Organization. Different managers in charge of different areas report directly to the General Manager. All of them are familiarized and in complete support of the TPM Strategy and Organization. Each manager has an organization focus on their specific tasks, with TPM included as part of each individual

objective. Appendix A includes organizational detail for each of the teams presented below.

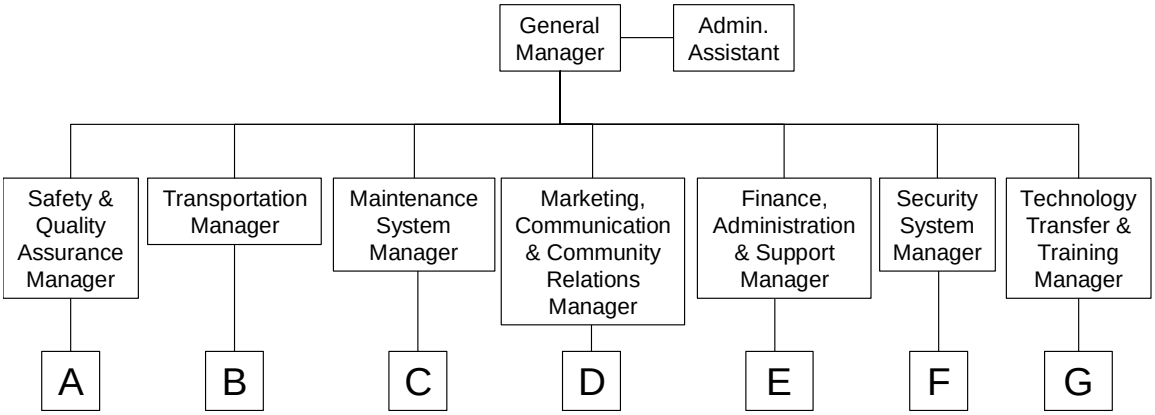

Figure 4: Top Management TPM Organization

Manager's Involvement is essential for TPMs achievement. The second part of the success is a dedicated team for maintenance execution and its analysis. For this accomplishment, the Manager of System Maintenance must report directly to the General Manager and has full responsibility for maintenance of the vehicle fleet, right-of-way and electrical power systems. This individual will oversee day-to-day operations of the system with the primary purpose of maintaining an infrastructure designed to provide safe, reliable, appealing service to the public. The position will direct resources to ensure that the infrastructure is in a constant state of good repair. Figure 5 shows the different teams that report directly to its designated supervisor who reports directly to the Manager of System Maintenance.

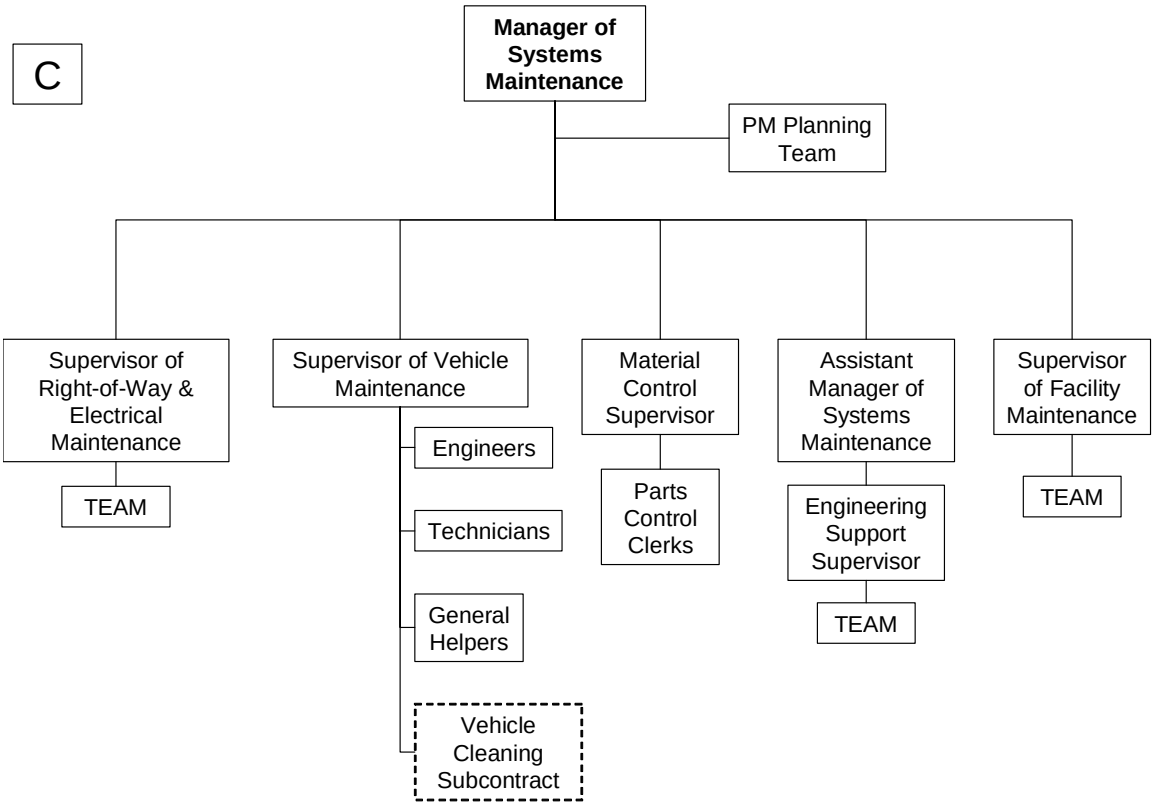

Figure 5: Manager of System Maintenance Organization

This organization is responsible for TPMs accomplishment in the business. This main team, in addition to work with TPM implementation, must have a promotion office which will acquire new resources and train them into TPM philosophy. This office must be in charge of recruitment, plus they need to follow on TPM research for continuous improvement. Notice that there are organizational boxes with dashed-lines, which means that these teams can be sub-contracted to outside purveyor. The people belonging to this team are the main characters for TPM implementation and maintenance.

Inside this maintenance organization, notice the Preventive Maintenance Planning Team (PM Planning Team). This team is in charge of analyzing maintenance messages. Also, this team, who reports directly to the Maintenance Manager, generates Work Orders which will be discussed in next Chapter 5 in detail. The PM Planning Team need to be composed by people with basic educational background, computer knowledge and experience in the O&M Facilities. Today industries called the people belonging to this team: planners or schedulers. Also, other companies required a technical/professional background such as engineering bachelor degree or three to four years of experience. This team needs to be composed by four to five engineers or schedulers who will report directly to a Master Scheduler. This Master Scheduler and his team will be responsible for the Maintenance Alert, Work Order status, that will be discussed further, and most important, the different metrics associated with the efficiency and effectiveness of the O&M Facilities that will dictate TPM success. This metrics will be presented in Chapter 5.

Having set TPM's Organization as suggested in Figure 4, and in Appendix A, and its main team explained in Figure 5, the next step is to establish what are going to be TPM Organization's goals and objectives.

4.2 Establish Basic TPM Policy and Goals

Before establishing TPM's objectives and goals, first it is necessary to define the focus and baseline. The motor bogie was selected as the focus for this study; therefore, the complete vehicle baseline needs to be identified.

4.2.1 Study TU Vehicles

The actual condition of TU's vehicles needs to be documented in order to determine performance and condition of the equipment that will be used. Table 2 shows the requirement for documentation: type, description, designer, location, and data for the equipment which will be presented in next section.

STT (Siemens Transit Team) is the manufacturer of TU vehicles. STT has workshops in Austria and Sacramento, California, where the vehicles are designed and manufactured. The rail car being manufactured for TU system is an updated version of high capacity vehicle whose design has been proved in use in other transit systems. The model selected is a steel-wheeled vehicle designed to run on steel rails in high platform boarding stations. The vehicle has multiple unit air conditioning (A/C) propulsion, cab operation, and full automatic train control capacity. The subsystems of the train (car body, propulsion system, friction brakes, and others) use service proven designs that may have found on other heavy rail vehicles operating in the United States and overseas. Building upon these subsystems, the exterior aspect of the vehicle has been adapted to meet both the Authority's Technical Provisions and Drawings, and modern aesthetic and design concepts.

The TU vehicles have integral stainless steel car body and will operate in married pairs. The vehicles were designed for high-level boarding and have six sliding double leaf pocket doors per car, three on each side. Additionally, each vehicle has doors at each

end of the cars to allow emergency transfer from one car to another. Key details of TU vehicles are summarized in Table 2.

Table 2: Summary of features of TU vehicle

Vehicle Concept:	Married pair, steel wheel on steel rail, high level boarding, 2 powered trucks per car
Dimensions [L x W x H]:	23.0 m x 3.1m x 3.8m(per car)
Rail Gauge:	1,435 mm
Maximum Grade:	6%
Minimum Curve Radius:	150 m (main-line), 80 m (yard)
Weight:	41 mt (per car)
Passenger Capacity (per car):	72 (seated), 181 total (per car, at 4 passengers per m^2, excluding the operator)
Line Voltage:	750 V DC, 3^{rd} rail
Propulsion System:	AC propulsion, regeneration capability
Power Rating:	4 * 125 kW (per car)
Maximum Speed:	100 Km/h
Maximum Acceleration:	1.35 m/s^2
Maximum Deceleration:	-1.35 m/s^2 (service), -1.55 m/s^2(emergency)
Friction Brake System:	Pneumatic, spring-applied parking brakes
Suspension System:	Primary – chevron electrometric springs Secondary – air springs
Doors:	6 double leaf pocket sliding doors (per car) 2 end doors (per car)

After staging major characteristics of the vehicle, the next step was to show in detail the motor bogie, which is the main part of the vehicle and the focus for this study. Figure 6 shows the motor bogie.

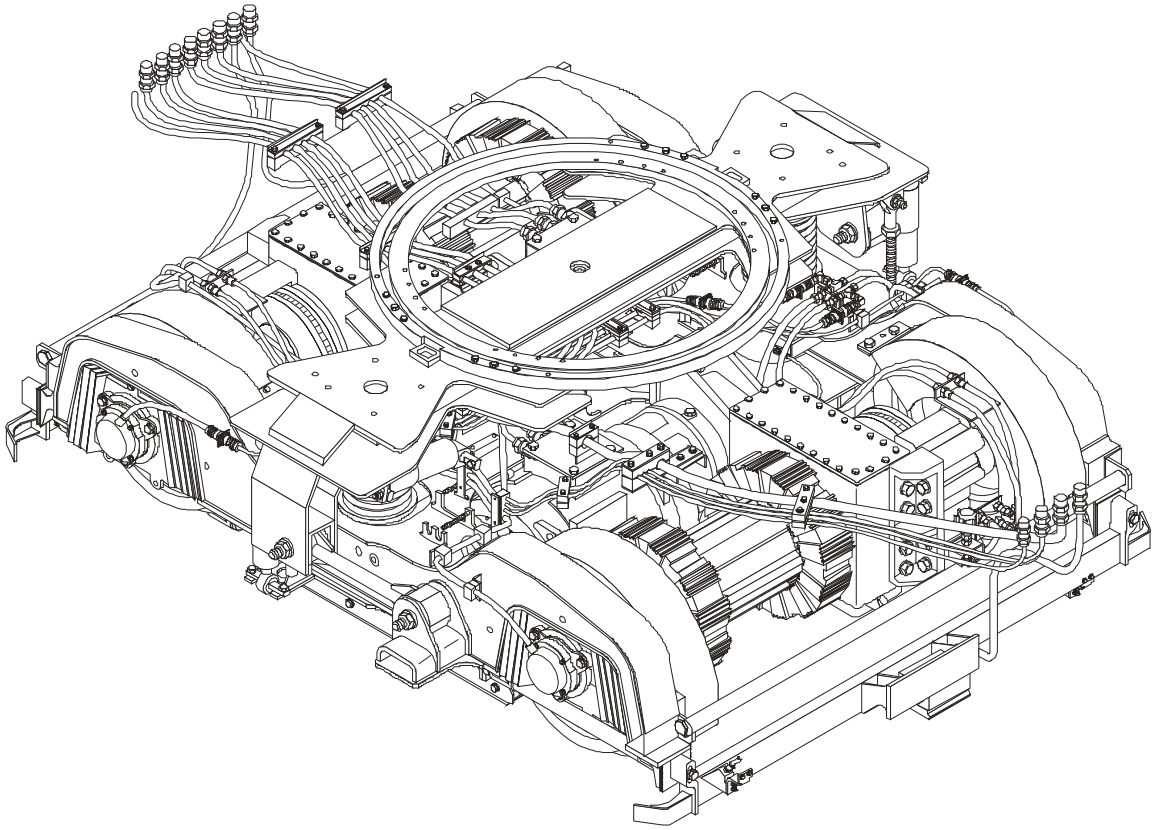

Figure 6: Tren Urbano Motor Boogie Drawing

The truck system overview or the motor bogie is composed of the following systems:

- Journal Bearing
- Wheel
- Wheel flange lubricator
- Gearbox
- Ground Brushes
- Truck Connection
- Motor
- Bolster
- Speed sensors
- Brake equipment
- Current Collector
- Axle
- Traction Motor
- Suspension
  - Primary
  - Secondary

After presenting the motor bogie's system; the baseline for this study is clear and the focus set, therefore targets can be established. The target for this study is to propose TPM as Tren Urbano's (TU) Maintenance Policy. First of all, TU's current maintenance policy was verified.

4.2.2 TU's Current Maintenance Policy

First, TU Maintenance philosophy was revised. STT developed a group of maintenance manuals based on the equipment they were buying and using. After the manuals were done, Alternate Concepts Incorporate (ACI) and PR Highway and Transit Authority (HTA) revised them. Then, when the manuals were approved and revised, a complete maintenance strategy was developed.

The development of this maintenance strategy was based on the actual equipment used in the vehicle. For all scheduled and unscheduled vehicles, tracks, and systems maintenance, the information is stored in and dispatched in the Operations and Maintenance Facilities (O&M). The maintenance areas within the O&M were organized into the following work-group areas:

- Periodic vehicle inspections and unscheduled vehicle maintenance – this area perform sporadic evaluations of the complete vehicle. Also, this area is in charge of reacting upon any impromptu event.
- Vehicle component replacement maintenance – this area requires people with technical knowledge and maintenance expertise on heavy vehicles like the ones explained previously. Most of the maintenance required parts substitution, and this team is in charge of removing and replacing components for the vehicle functionality.
- Support shops, includes:
    - Component repair shop – after part removal this area is in charge of fixing the component for its usage.
    - Electrical equipment shop – this shop contains certified electricians maintaining the vehicle electrical equipment working.
    - A/C shop – The Air Conditioner shop is dedicated personnel for the functionality of the vehicle's air conditioner system.
    - Truck shop – this division is in charge of the motor vehicle maintenance.
    - Machine shop – this group is in charge of performing changes or machining of parts or fixtures for the vehicle's adequate maintenance.
    - Parts cleaning facility – this working party is responsible of satisfactory cleaning the components that surround the vehicle. This team is the basis

to the correct maintenance provided to the vehicle and its environment for its correct functionality.

- Small article paint shop – this area is directly related to the aesthetic and appearance of the vehicles and its components. Also painting is required for the maintaining the equipment in good conditions based on its surrounding environments.

To control and monitor all different areas providing maintenance to TU, a computer program was developed by an external consulting group [FASuite Training, 2005].

This chapter presented TPMs Organization, also explained current TU Policy and Goals and how it can be related to TPM. In addition, this section illustrated the TU motor vehicle and its present maintenance policy. The next chapter presents the intention of this analysis based on TU's Actual Maintenance Policy already presented and how it can be improved applying TPM concepts.

5 MASTER PLAN FOR TPM'S IMPLEMENTATION

First, TU maintenance philosophy was verified and set as baseline in Chapter 4. For this chapter 5 the intention is to design an effective maintenance strategy in order to keep the equipment at its highest level of required performance taking advantage of current maintenance policies. At the same time, effective maintenance will optimize activities so that the system is safely and efficiently maintained in the most cost-effective manner. This strategy will improve actual maintenance program following six key steps.

5.1 TPM's Implementation Plan: Six Key Steps

The design maintenance strategy follows TPM's implementation plan. There are six basics steps recommended to have an effective maintenance.

5.1.1 Identify

Random observations have a low probability of catching a problem before it becomes expensive, it is much better to program inspections by operators who are equipment sensitive. For TU's motor vehicle, the equipment will benefit from regular cleaning, lubrication, adjustments and observations for signs of abnormal performance. These are important checkpoints for early sings of problems. Actually, TUs philosophy is just following Manufacturer's Specifications to run its vehicle maintenance, however identifying an issue in an early stage can improve considerably their maintenance strategy.

For example, a checklist was recommended to identify these issues. Table 3 shows a recommended preventive maintenance checklist for TU vehicles:

Table 3: Preventive Maintenance Checklist for TU vehicles.

Preventive Maintenance Checklist The operator will perform a comprehensive "circle check", both internally and externally, to determine the train's safe operational readiness for passenger service. Name: _____ Date:_____ Time: _____ pm ___ am___ Employee ID: _____ Vehicle ID: _____	
Initial Safety Check	
The cleanliness of the vehicles	
	Presence of require safety equipment o Fire extinguishers o Special tools
Enter the forward cabin	
	Equipment lockers o Condition o Status
Insert Specifically design security key into the master controller	
Select proper mode of operation for the circumstance	
	Examine Console
	Examine Cabin Area o Indicators: ▪ Lights ▪ Circuit breakers ▪ Switches
	Contact the OCC Line Controller o Report readiness of the vehicle for service o Request permission to move into the departure track o Wait for the information from the OCC (existing conditions, operational changer or special instructions)
	Receive permission to move
	Select automatic mode
	Prepare for a full automatic revenue service operation
Comments or any other Observation:	

This maintenance service and inspection checklist must be executed every time an operator starts an idle vehicle. These PM Checklist will include evaluation of the cleanness of the car and a pre-departure safety test and inspection. It is very easy to follow. By writing a mark, the employee or operator insures that vehicle performance will be fine. The whole checklist must be revised, and if a mark doesn't appear, the vehicle isn't ready to start and needs revision. All vehicles leaving the O&M must had the PM Checklist completed. This simple and general revision avoids failures making the system works in the best conditions at all time. And, at the same time, empowers the employee (operator) by giving knowledge of what issues to consider – TPM - and responsibility by fill-in the required personal information on checklist. Therefore, the vehicle wouldn't be affecting the motor bogie in its performance, at least the issues that were consider on the PM Checklist. This PM Checklist can be altered, however always considering safety and quality as major focus/goals.

Another way to identify an issue is using Maintenance Alerts. Maintenance Alerts are the initial point for a maintenance job. With this tool, incidents can be reported and saved in the maintenance system. Also, Maintenance Alerts can be used to report any required maintenance job to be performed. The Alert is a fundamental element for the history of events related to the vehicle maintenance. Also, it is a tool for summarize any open maintenance job. Figure 7 shows the Maintenance Alert Form for TU. It will be discussed further in detail.

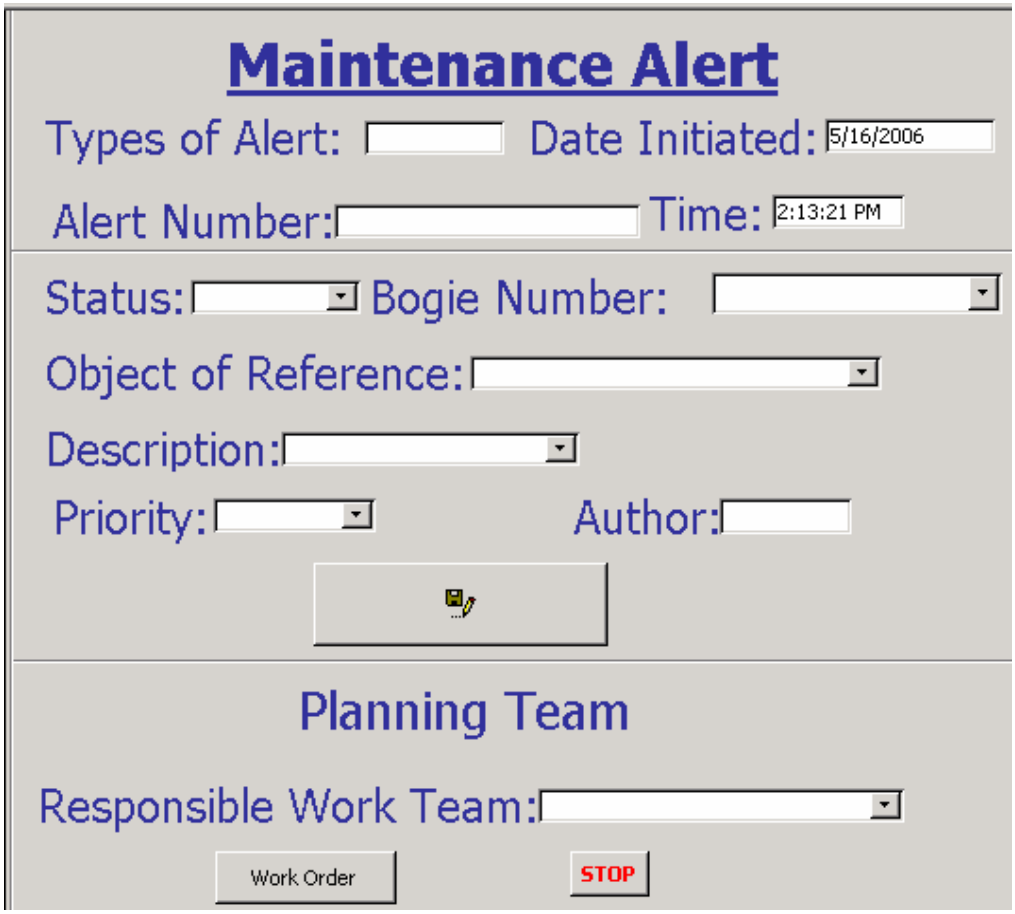

Figure 7: Maintenance Alert Form

Next is the description of each key data point that must be entered into the Maintenance Alert Form. Each area can be associated with each of the steps followed for this study. First, the Types of Alerts need to be *identified*:

- Types of Alerts – will classify the kind of incident or work that needs to be performed. The options are:

- Work Request (TU1): It is used by all areas to request to the Maintenance Department to do a predetermined activity, like an installation of new equipment or an existing one, however they are not related to any kind of problem or malfunction.
- Failure Alert (TU2): It is used to report all failures that are found during the usage and operation of any equipment under the maintenance team responsibility.
- Activity Alert (TU3): This alert must be generated by each maintenance area and it helps to document any unscheduled job during work. This unpredicted alerts are of minor significance, however they are part of the technical documentation history that must be saved. This kind of unscheduled alert must be assign to the main maintenance order being performed at the time.
- Maintenance Alert (TU4): This alert is generated by each maintenance area or department, where they emphasize all the deviations found during the maintenance order execution. This maintenance execution is out of scope of the original maintenance order. This kind of alert may generate other maintenance orders different than the one that is initially performed.

- Extraordinary Maintenance Alert (TU5): Is generated by each maintenance area. This alert assists the documentation of any deviation required from the Preventive Maintenance Routines.
- Preventive Alert (TU6): This alert is created from the Preventive Maintenance Order to associate the history of an equipment failure that will be included in the initial scope of the work order.
- Operational Incident Alert (TU7): This alert is related to incidents that are not related with the equipment operation; however the business operation may be affected by other factors.

Once the kind of alert is selected, the system will automatically assign an Alert Number. Next are the data points that must be included to complete the Maintenance Alert transaction:

- Status: Indicates the condition of the alert. They can be OPME (open message), WIPME (work-in-process message), DELME (delayed message) or CLOME (close message). If the status of the message creates an operational incident affecting negatively the business, a special instruction must be included. For example, writing RED or IMP will send a message to management of this specific alert.

- Object of Reference: This space is applicable to report an incident or an alert making reference to a specific part of the equipment or location. This is the element that will generate all future maintenance work related.
- Description: This classification will provide for a brief explanation of the alert.

Formerly the facts have been *identified*; the second part of the Maintenance Alert needs to be *planned*.

5.1.2 Plan

The second step to have an effective maintenance strategy is planning. Planning ensures that all resources necessary to do the job are accounted for. Planning includes what has to be done, in what sequence and with what skills. The Planning Executer, in most cases the planner, must be someone who has the technical skills and plant-specific experience to be credible to those executing the plan. For TU, there is a planner/scheduler that is in charge to verify that all resources are accounted for, however TPM recommend a vast knowledge of what this person is planning and a capable person of taking advantage of standards to help layout a job and estimate how long it will take. Finally, estimate overall cost, allowing cash flow and repair-or-replace decisions.

As previously discuss and showed in Figure 7, the Maintenance Alerts owners are the PM Planning Team. This team is responsible to verify the Maintenance Alert correct completion; therefore the responsible department to execute the maintenance job will be notified by this team.

This pursues the next step: schedule.

5.1.3 Schedule

Scheduling is a matter of availability, of when to do the job based on available resources. In reference with the Figure 7, Maintenance Alerts, the message is analyzed and the availability of the department in charge is verified. The Maintenance Alert needs to communicate with the Planning Team to identify the department, resources, man hours, tools and equipment needed. Then the Scheduling department will verify if it is available.

The scheduler must verify if there are mandatory jobs that will have priority. These include any preventive maintenance, the normal load of emergency work determined in the Identify Step, or any other planned work already started. Figure 8 shows the Scheduler Decision Process.

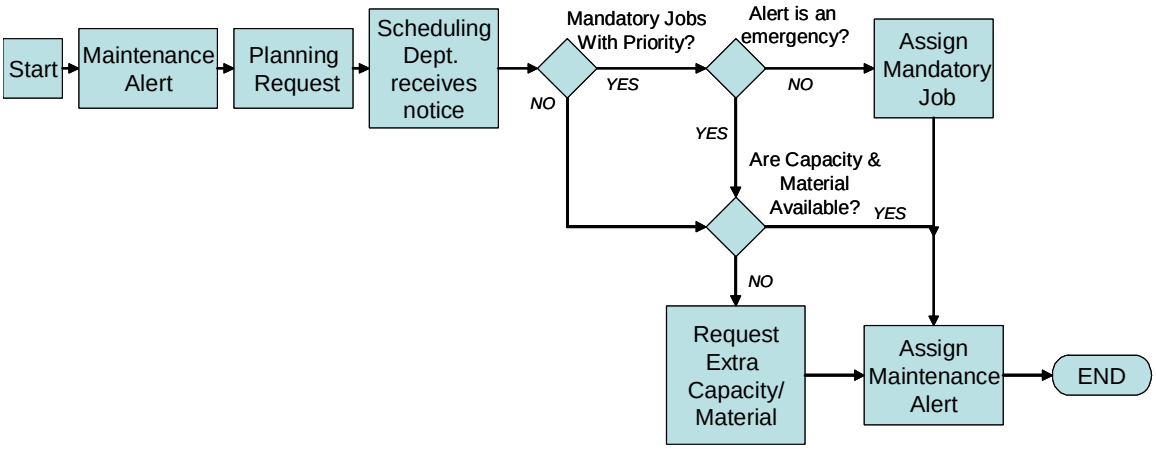

Figure 8: Scheduling Process

For planning and scheduling purposes the PM Planning Team is in charge of verifying material and capacity availability. A basic Material Requirement Planning (MRP) will be required. Many industries have automatic computer programs that will perform this analysis. However, with the job to be assigned man-hours, materials and tool required plus on-the-job experience, the work can be assigned, which brings the fourth step: Assign.

5.1.4 Assign

This assignment of the job will depend on the organization arrangements in place. TU's usually delegate the day-to-day work assignment to the area or maintenance supervisor. Following the Maintenance Alert previously showed; Planning key components are:

- Responsible Work Team: In case the data entry person has knowledge of the team in charge, this field can be completed with the responsible group to execute the task. It is Maintenance Department – PM Planning Team responsibility to verify its veracity.
- Author: the person who initiate this Maintenance Alert. This must be unique and exclusive to be able to identify the requestor if any doubts on the Maintenance Alert arise.
- Date Initiated: Date and time failure or alert emerge.

For TU, it will be helpful if the team or foreperson has a few days of planned work in advance on hand. This will allow flexibility, as emergencies, unplanned work, or crew changes occur.

Once the Maintenance Alert is allocated, the job can be executed, which is the fifth step.

5.1.5 Execute

This is where well-trained, motivated team players keep the maintenance process rotating. This team needs to be skilled people due to their contribution to: quality, cost, time and service.

For the Maintenance Alert, the following field needs completion:

- Priority – This field will assign suggested dates for the response time following the priority assign. This priority is important information related to the maintenance alert which will affect the planning closure date. The priority can be classified as:
    1. High
    2. Medium
    3. Low
- Stop: This field must be pointed if the resources or equipment assigned were not available. The PM Planning Team is responsible for this field.

5.1.6 Analyze

Finally, the sixth step is analyze, which is the most important one and basically where this project major contribution is. Thoughtful analysis of the failure, and responses to it, will lessen the chance of repeating the same mistakes. Analyze why a failure occurs can drive to one key component:

- Work Order Required: complete this field if a Maintenance Work Order is required due to the generated Maintenance Alert.

Work Order will be discussed in detail in future sections, however it is part of the Analyze step which will drive to two different TPM strategies: Corrective Maintenance (CM) and Preventive Maintenance (PM).

5.2 Corrective and Preventive Maintenance

CM consisted of repairing failed equipment, and returning the equipment to service. Minor interventions can be done, documented, and the bogie is set for service.

The following Table 4 shows the procedure that guarantees TU's equipment corrective maintenance:

Table 4: Corrective Maintenance Procedure

Steps	Activity	Owner	Safety Rules, Preventive Actions and Controls
1	Receive failure report.	Technicians (T), Maintenance Coordinator (MC) and Engineer	Guarantees that the received information about the failure is clear and precise.
2	Create a technical evaluation report.	T	Register all information that allows an effective reaction to the failure
3	Inform internal customer about failure.	MC & Eng.	Initiate programming for failure analysis based on report.
4	Work with failure and inform internal customer of any progress.	T	If there is no access to the system, the MC is responsible to provide copies of procedures to execute. The Eng. must be responsible for any required changes. Environmental, Health and Safety Rules must be followed at all times. Periodically inform to MC or Eng. of any progress.
5	Inform Internal Customer of job completion and the operative conditions.	CM or Eng.	Equipment Operative Reestablishment
6	Create an adequate maintenance order in the system, with the task and resources used attending the issue. Release Order.	CM, Eng. & T	Inputs, Resources and general failure revision. Order needs to be created.
7	Notify and technically complete Work Order & Maintenance Alert in system.	T	Document any field observation that may be the causes for failure.
8	Verify and Release to Cost Control Center (or a special order if required), the Maintenance Order.	T	Release order
9	Complete Maintenance Alert.	T	Close Maintenance Alert
10	Analyze, technical closure and Maintenance Order & Alert closure	CM & Eng.	System Closure

Corrective Maintenance main goal is to guarantee equipment adequate maintenance that supports public mass transportation for Tren Urbano. Preventive Maintenance (PM) has the same goal/objective, however it is more complicated. PM is based on documentation analysis and manufacturer specs. The following Table 5 shows the procedure that guarantees TU's equipment preventive maintenance:

Table 5: Preventive Maintenance Procedure

Steps	Activity	Owner	Safety Rules, Preventive Actions and Controls
1	Guarantee that Equipment Manufacturer's Instructions and Maintenance Instructions are included in TU's System. If the equipment is new, continue to Step 4.	Maintenance Coordinator (MC) and Engineer	Verify equipment maintenance instructions. Apply any other instruction that is necessary.
2	Improve and spread the maintenance plan with the technical data generated by the maintenance execution or the new technology applicable.	MC and Engineer	The MC and the engineer need to gather data in order to identify the process owner and others related. Technical staff needs to be informed and trained if new technology is applied.
3	Analyze statistical data from all corrective maintenance performed to equipment since the last preventive maintenance. Include a reliability analysis and recommendations from technicians.	MC and Engineer	System Corrective Maintenance Orders, list of these orders and standard analysis.
4	Release and Update Maintenance Plan.	MC, Engineer & System Clerk	Create system instruction if a new preventive maintenance is required.
5	Guarantee a schedule between Maintenance and Operations for equipment availability to execute necessary maintenance.	MC and Engineer	An ordinary or a special work instruction. Verify equipment availability for maintenance execution.
6	Revise Maintenance Preventive Order includes necessary materials and requirements. Guarantee system update if it is necessary.	MC and Engineer	Verify Instructions
7	Releaser order	MC, Engineer and Authorized Technicians (T)	Verify Instructions
8	Execute Preventive Maintenance	T and Clerks	If there is no system access, the MC, Engineer or T is responsible to provide copies of procedures

Steps	Activity	Owner	Safety Rules, Preventive Actions and Controls
			for their execution. The Engineer or MC is responsible for bring up to date any required changes. Environmental, Health and Safety Rules must be followed at all times.
9	Guarantee that internal client will be informed of equipment availability.	MC, Engineer and T	Technicians must performed equipment operational tests as required.
10	Notify into the system the assistance to the preventive maintenance order. Create an alert of Corrective Maintenance if necessary.	T	Verify instructions
11	Verify maintenance information associated with preventive maintenance.	MC, Engineer and T	General revision of inputs and resources. Verify instructions.
12	Close Order	T	Verify instructions.
13	Guarantee order content, technical and preventive maintenance order closure.	MC and Engineer	Verify instructions. Consider any obstacles for order closure.

Corrective and Preventive Maintenance are based on Work Orders. The following section explains in detail the important elements that are included in Work Orders.

5.2.1 Work Order

Maintenance Work Orders are the central element of this strategic maintenance plan. Thru Work Orders, the maintenance work is planned, scheduled, assigned, executed and analyzed registering related costs based on activities performed. Some benefits of a Work Order are:

- Planning and scheduling mechanism for complex jobs.
- Cost collection mechanism for labor, stores requisitions, purchase orders, and services to charge against a piece of equipment or production work center.

- Way to capture delays and measure productivity.
- Tool to determine and manage work backlogs.
- Means of saving equipment histories to analyze failure and effectiveness of your preventive maintenance efforts.

All maintenance work in the O & M needs to be managed by a work order. An electronic copy of the work order must be available on the shop floor at a computer workstation. Relevant maintenance history for each vehicle will accompany each work order. The work orders can be classified as:

- Periodic inspection
- Program maintenance
- Immediate repairs

Periodic inspection and program maintenance are Scheduled jobs – Preventive Maintenance. Table 3, PM Checklist, showed an example of Periodic inspections. Periodic inspections consist of required tasks that the operator had to complete before the equipment is used. In every periodic inspection same information will be required: name, date, time of inspection and the item that is examined.

The periodic inspections are a vital component of safety programs, and on manufacturers' warranty requirements. The system automatically schedules jobs for periodic inspection based on a review for inspections dates for all units. For defects and breakdowns, a work order is initiated on a computer as repairs are identified. In either

event, careful use of the work order based approach provides a complete record of all time and materials applied to each unit for each inspection and repair.

Immediate repairs are the only unscheduled jobs, Corrective Maintenance, which are usually the result of in-service failures or defects found during inspections which are not well documented in a periodic inspection.

When the whole system is functioning and the necessary information is gathered, the system automatically adjusts all future maintenance schedule dates based on the dates the work was completed. From the defect log the operator can automatically generate a work order by clicking on a check box. Except for intermediate repairs - CM, all other categories are programmed maintenance as part of the scheduled jobs - PM. As mentioned above, for all repairs, Corrective or Preventive, work orders need to be generated.

Work Orders can/will be created in three different ways:

1. Manually: By this way, the complete maintenance cycle is executed with the information provided by user or operator.
2. By a Maintenance Alert: this was discussed in previous sections.
3. From a PM Plan Perspective: The system automatically generates the order based on historical data, manufacturer's specification or data gathered.

The last two ways, Maintenance Alert and PM Plan, contain information previously created in the system which will process the information faster. The Manually Process

creation for Work Orders, that will be describe in the following section, includes the complete information process to generate a Work Order.

The first step to create an order is the access. Figure 9 shows the Access form for a Work Order creation.

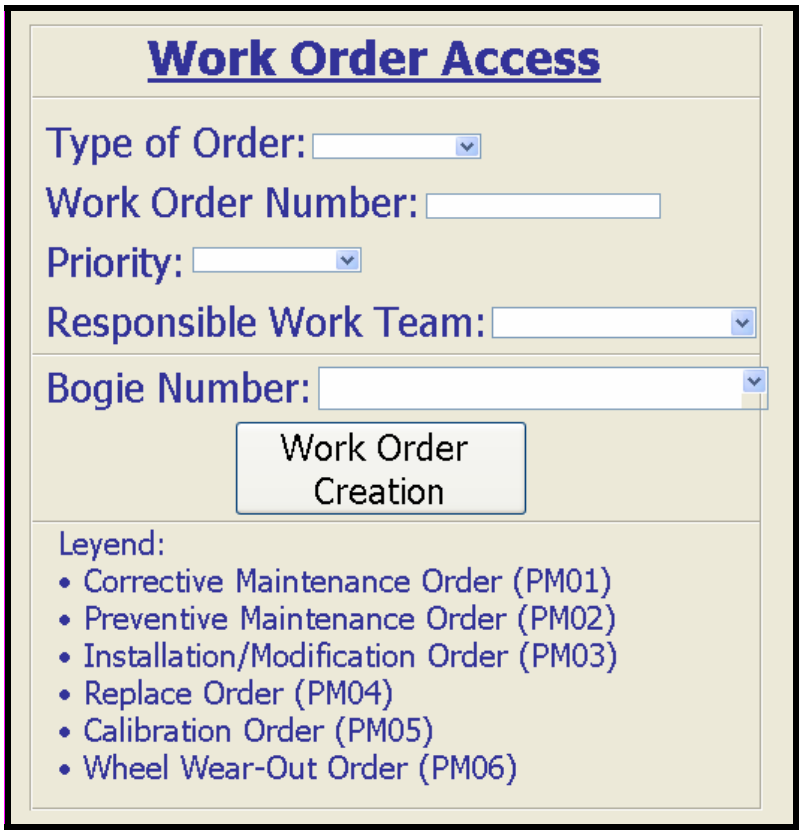

Figure 9 Work Order: Access

First the Type of Order needs to be entered; this will allow the system to classify the maintenance work that will be performed. This should be a mandatory field, not an optional one. The following are the different options that should be available in this field:

- Corrective Maintenance Order (PM01): associated to Maintenance Alerts: TU2, TU3 and TU4 that were mentioned in previous section.
- Preventive Maintenance Order (PM02): associated to Maintenance Alerts: TU3, TU4, TU5 and TU6 that were mentioned in previous section.
- Installation/Modification Order (PM03): required when an installation or a modification of one of the maintenance technical components, this one does not required any alert associated. Only require Maintenance Alert TU1 when it is requested by another area unrelated to the maintenance area.
- Replace Order (PM04): used to replace warehouse materials or components. This order should be generated by the material department, and no Alert should be associated with it.
- Calibration Order (PM05): used to maintain equipment regulated.
- Wheel Wear-Out Order (PM06): Associated to alerts TU2, TU3, TU4 and TU5. These alerts should be monitor in order to charge them to the correct department.

Then the Priority field needs to be completed. This can be an optional category; however it will allow the system to classify the job urgency.

Then the next field is Responsible Work Team. This field is associated with the maintenance department responsible of the activity that will be performed.

Based on this information, the system will allow the creation of a Corrective Maintenance Order (Work Order). This form is presented in Figure 10.

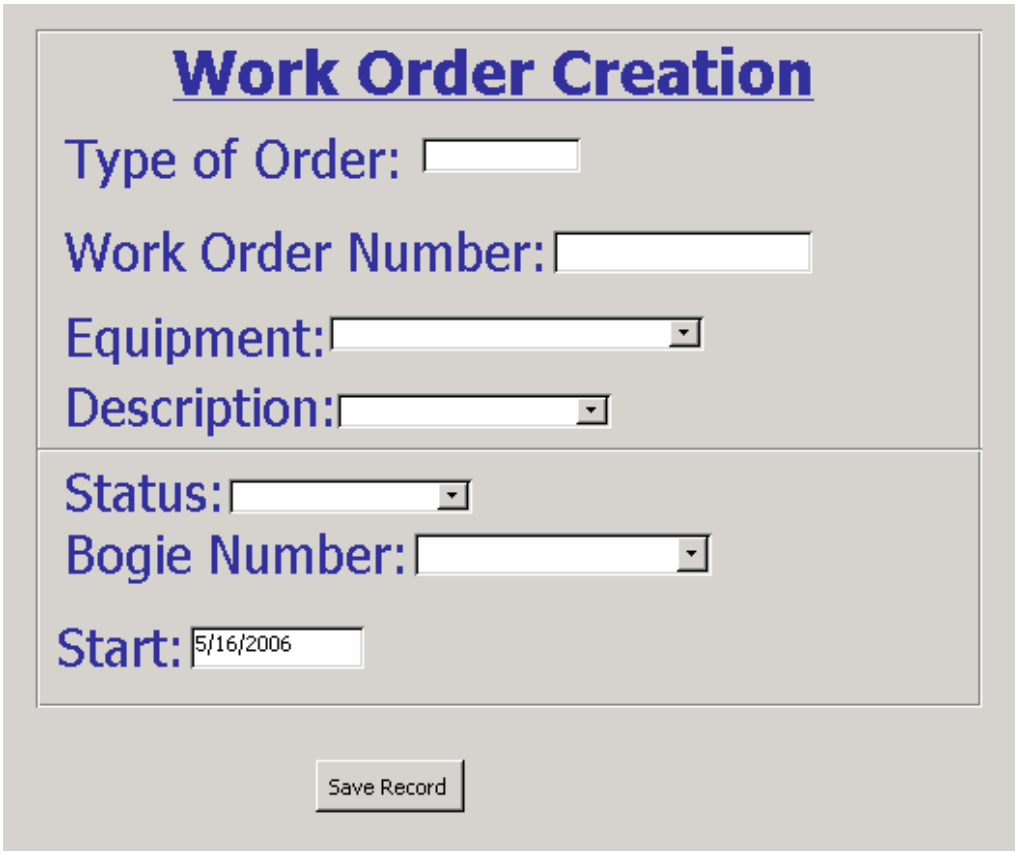

Figure 10: Work Order Creation Form

The Message field will describe briefly the objective or requirement of the order. It is recommended that this field is completed with significant information. The next field: Status, will present the current status of the order. This field can be completed as:

- OK – All resources are available
- MATM – Material Missing

- TOOM – Tools Missing
- MANM – Man Hours Missing
- SPEM – Special Information Missing

This field will show which resources are missing for the order total execution.

All statistics in the system are created in reference to an Equipment. In any case it is applicable; select Equipment based on the Work Order created. In case it is not applicable, meaning that there is no Equipment related to the Work Order been created, the field should be completed with the word “TREN”.

Start field: this field will be obligatory. The system needs dates to be able to raise an initial programming of human resource, technical resource of materials (replace and consumable) and/or tools and documentation. In case a PM01 order is been created, the system considers obligatory solely the field of extreme beginning.

After completing this information for every incident, various decisions must be taken. Figure 11 shows the decision process when a failure occurs.

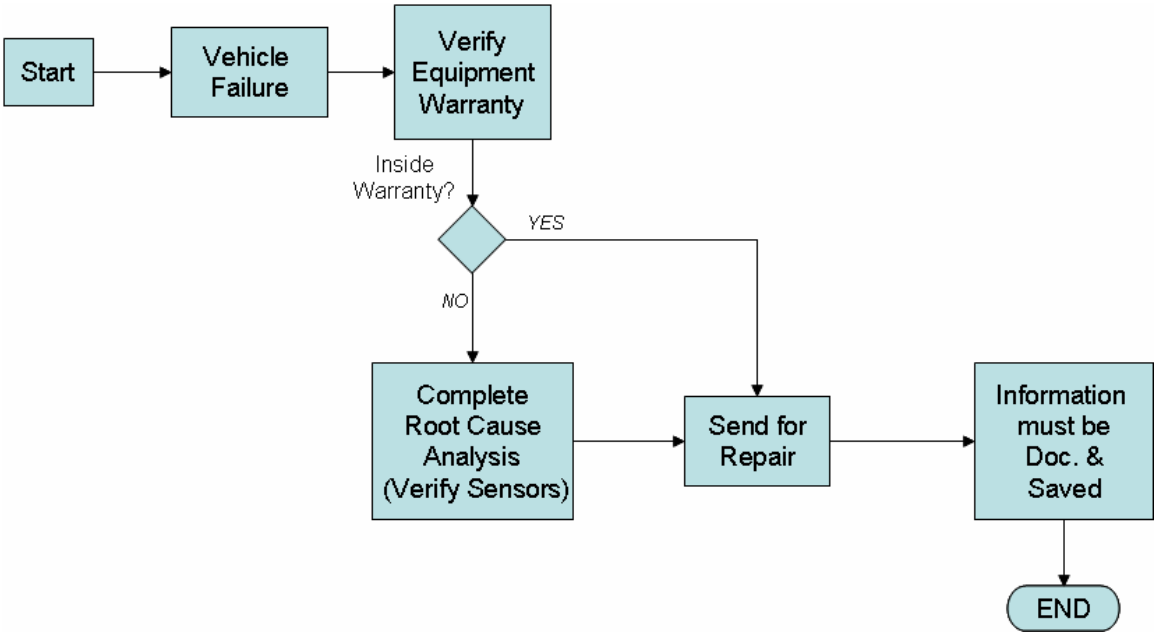

Figure 11: Decision Process for failure occurrence

After a vehicle failure, the manufacturer's specification and warranty information must be revised. If the vehicle is inside its warranty, the manufacturer is responsible for its repair, so the equipment is send for repair. Otherwise, if the equipment is not inside the warranty period; a root-cause analysis must be performed where the alert sensors located strategically in the equipment need to be analyzed and included in the PM plan. After this analysis is performed and documented, the equipment can be fixed. If the adequate maintenance can be given at the O&M the following information must be filled out in addition to the one that is already completed at the main work order:

- Technician(s) or Professional(s) required developing the job.
- Parts required
- Tools required
- Materials required
- Process or a list of task the operator may complete before the job is performed
- Operation estimated time
- Comments
- Done dates

As the work is completed the operator will use the computers workstation to report hours worked by each member of the maintenance staff. Parts, tools and materials applied in work would be included in the report. The system captures the nature of the actual work undertaken, together with unlimited comments. Therefore, a work history is accumulated on equipment and serialized components. This allow for a complete defect-repair-inspection history to be built for the equipment but also allows component history to be compiled even as the component moves for the equipment installation, to vendor repair and then back to a new equipment assignment. In addition to detail retail information, a listing of the parts and labor used for every repair is available for reporting.

All of the work orders verify the Manufacturers Specifications. Each part or equipment must be accompanied with a Manufacturers Specifications. This information must have:

- Name of the Manufacturer
- Telephone and address
- Vendor's name and contact information – e-mail address, fax, telephone
- Warranty information

Also, an equipment or component still under warranty is automatically flagged.

The system can be integrated with inventory control and purchasing. For example, components that are sent out for repair are tracked by the system. Notices for components that are overdue for returned are generated regularly and may be automatically faxed or e-mailed to the vendor. Once the item is returned, is available to be installed in another vehicle.

The system captures all maintenance and repair activity for each piece of equipment. This enables the PM Planning Team to review repair history by vehicle and identify units, which need closer monitoring. Also, by examining the past history of unscheduled repairs, budgets estimates for unscheduled maintenance can be improved. Priority of the repairs should be based on the time or duration of the amends: minor repairs first and longer repairs in last place (SPT- Shortest Processing Time).

The PM Planning Team will use the system to:

- Manage job plans for required maintenance performed on each vehicle in the fleet
- Identify overdue maintenance
- Monitor vehicle out-of-service dates
- Schedule maintenance on a time or usage basis

The system features a comprehensive user-friendly reporting and inquiry capability, allowing maintenance management and staff to sort, select, and review repair and inspection records. All reports will offer sort and selection criteria such as equipment number, date (reported, due, started, completed), type of defect-work, assignment and location. The following reports can be provided:

- Equipment history failure
- Asset maintenance and repair history
- Serialized components and repair history
- Daily inspection sheets (including tasks and reported defects)
- Defect reports (by status, type, failure, consist, date range as well as other criteria)
- Job schedule (by equipment, job type, date due, assignment, etc.)
- Work order status

- Job plan definitions
- Work order with required tasks and parts lists
- Work orders history (summary an detail) completed by period, symptom, type
- Work orders completed by work actions code, component, vehicle
- Labor hours assigned by mechanic or craft or job classification
- Labor hours worked by period and individual and activity
- Work orders with labor cost greater than $X (or any user-defined amount)
- Mechanic's comments for follow-up on incomplete repairs
- Vehicle maintenance summary: number of work orders, labor and parts costs
- Vehicles and components under warranty
- Mean time between failure

Basically all of these different reports can be generated to analyze and improve performance measurements. The following session demonstrates the different metrics that are helpful for TPM success based on the Work Orders Figures showed previously and the Micro Soft Access Tool generated for TU's Motor Bogie included in Appendix B.

5.2.2 Metrics and Recommendations

TPM Metrics or Targets are focus on obtaining a minimum of 80% of Overall Equipment Effectiveness (OEE). The OEE can be calculated as:

$$OEE = A \times PE \times Q \qquad \textbf{Equation 1}$$

- A: Availability of the machine. Availability is the proportion of time machine is actually available out of time it should be available.

$$A = (MTBF - MTTR) / MTBF \qquad \textbf{Equation 2}$$

For the Motor Bogie it is the Mean Time Between Failure (MTBF) is:

$$MTBF = Total\ Running\ Time / Number\ of\ Failures \qquad \textbf{Equation 3}$$

minus the Minimum Time to Repair (MTTR), divided by the MTBF as shown in Equation 2.

- PE: Performance Efficiency is given by:

$$PE = RE \times SE \qquad \textbf{Equation 4}$$

RE is Rate Efficiency: Actual average cycle time is slower than design cycle time because of jams, etc. Therefore, output is reduced because of jams.

SE is Speed Efficiency: Actual cycle time is slower than design cycle time machine output is reduced because it is running at reduced speed.

- Q: Refers to quality rate the percentage of good parts out of total produced, sometime called yield.

Based on the MS Access Tool developed, a series of reports can be generated. These reports will guide to basic metrics that need to be set as organizational goals for TU's TPM Organization. One of the reports can be the duration of an open Work Order, Table 6 shows an example:

Table 6: Work Order Duration Report

Type of Order	WO Number	Start	End	Duration	Average	World Class Goal
PM06	WOPM035320061713	4/1/2006	5/3/2006	32	23	10
PM01	WOPM065320061708	4/4/2006	5/3/2006	29	23	10
PM03	WOPM035320061709	4/6/2006	5/1/2006	25	23	10
PM03	WOPM045320061715	3/31/2006	5/4/2006	34	23	10
PM04	WOPM045320061716	4/9/2006	5/8/2006	29	23	10
PM06	WOPM065320061717	4/17/2006	5/4/2006	17	23	10
PM04	WOPM045320061718	4/8/2006	5/6/2006	28	23	10
PM05	WOPM055320061719	4/21/2006	5/5/2006	14	23	10
PM02	WOPM025320061720	4/23/2006	5/4/2006	11	23	10
PM01	WOPM015320061814	4/1/2006	5/3/2006	32	23	10
PM01	WOPM015320061821	4/28/2006	5/3/2006	5	23	10
PM01	WOPM015320061828	4/25/2006	5/9/2006	14	23	10
PM01	WOPM015320061835	4/19/2006	5/9/2006	20	23	10
PM01	WOPM015320061840	4/16/2006	5/2/2006	16	23	10
PM01	WOPM015320061842	4/2/2006	5/8/2006	36	23	10
PM01	WOPM015320061845	4/10/2006	5/6/2006	26	23	10

One of TU's goals should be to minimize the duration of an open Work Order. The World Class Goal is 10 days for a rapid rail maintenance system work order. With this data, a graph can be plotted and visualized. Figure 12 shows the graph for Table 6 data:

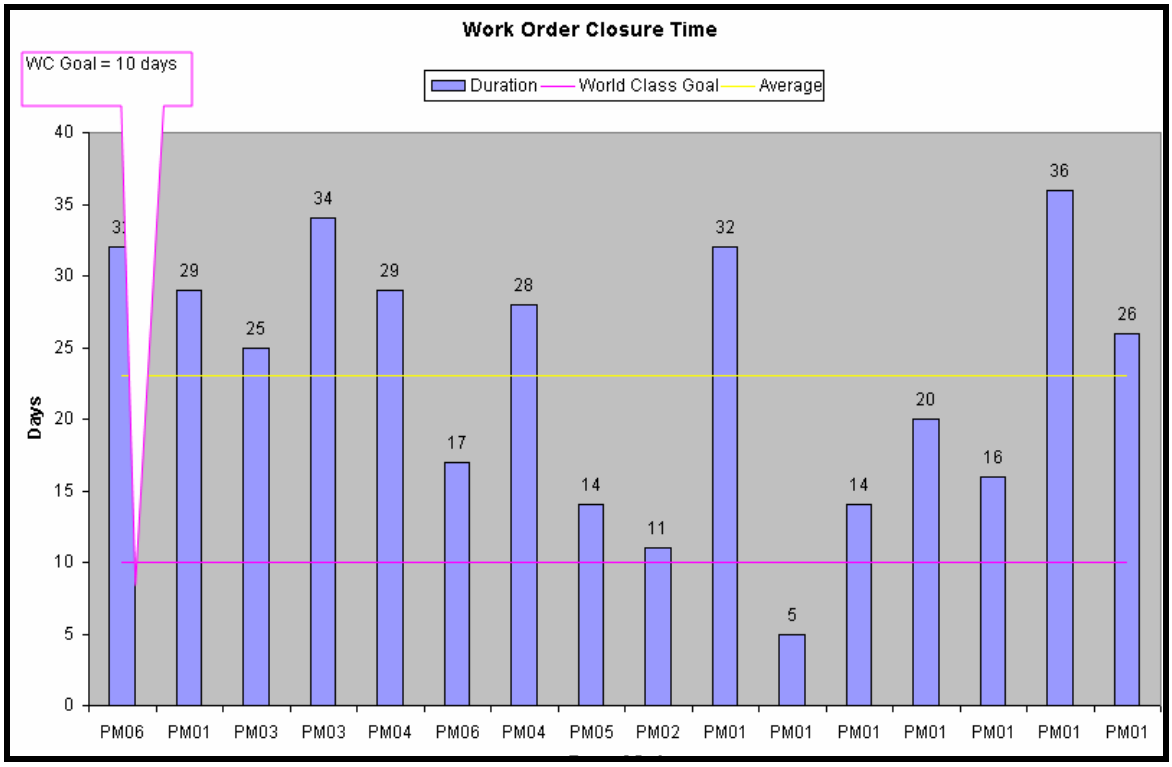

Figure 12: Work Order Duration

The Work Order includes valuable information that will help the O&M Facilitates to monitor its efficiency and effectiveness. For example Figure 13 shows the failures per the different motor bogies that exist in the O&M:

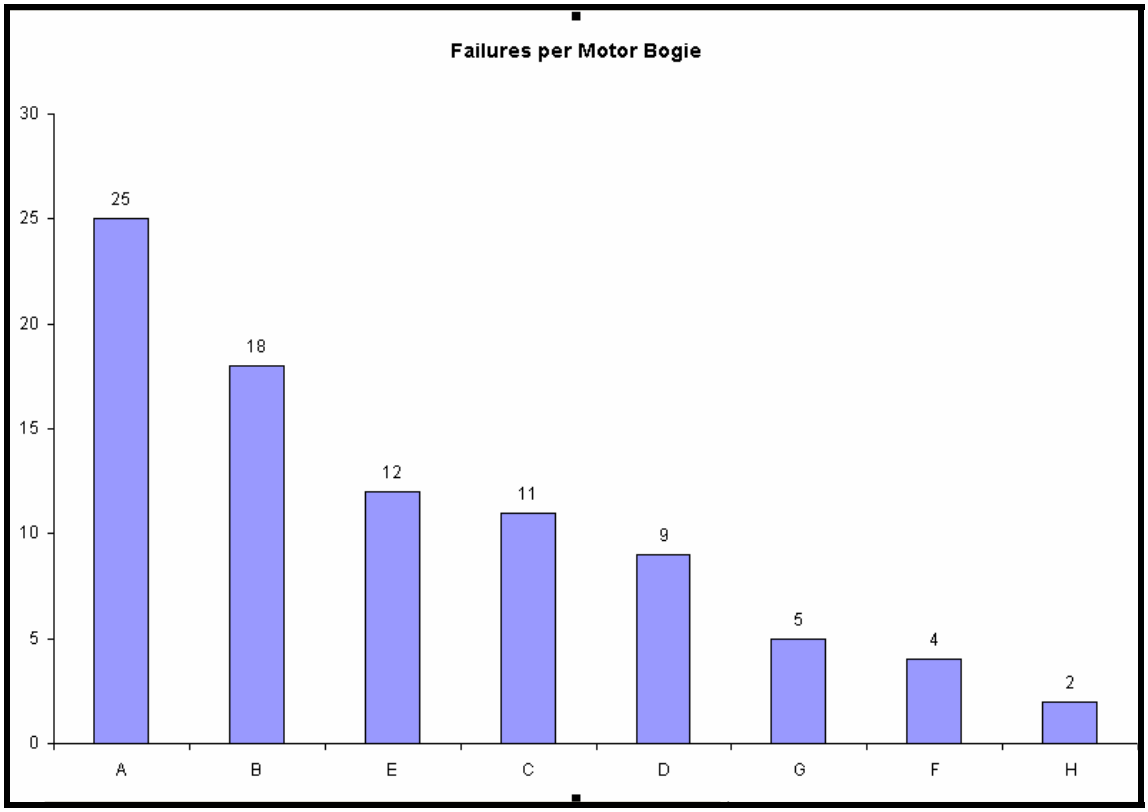

Figure 13: Failures per Motor Bogie

Analyzing this graph, the Motor Bogie A and B are the highest failure rate bogies in the O&M, therefore special attention must be provided to this Motor Bogies. The study of the different failures that occur within this bogie can help to determine the maintenance plan to be executed. For example, Figure 14 shows the failures corresponding to Motor Bogie A:

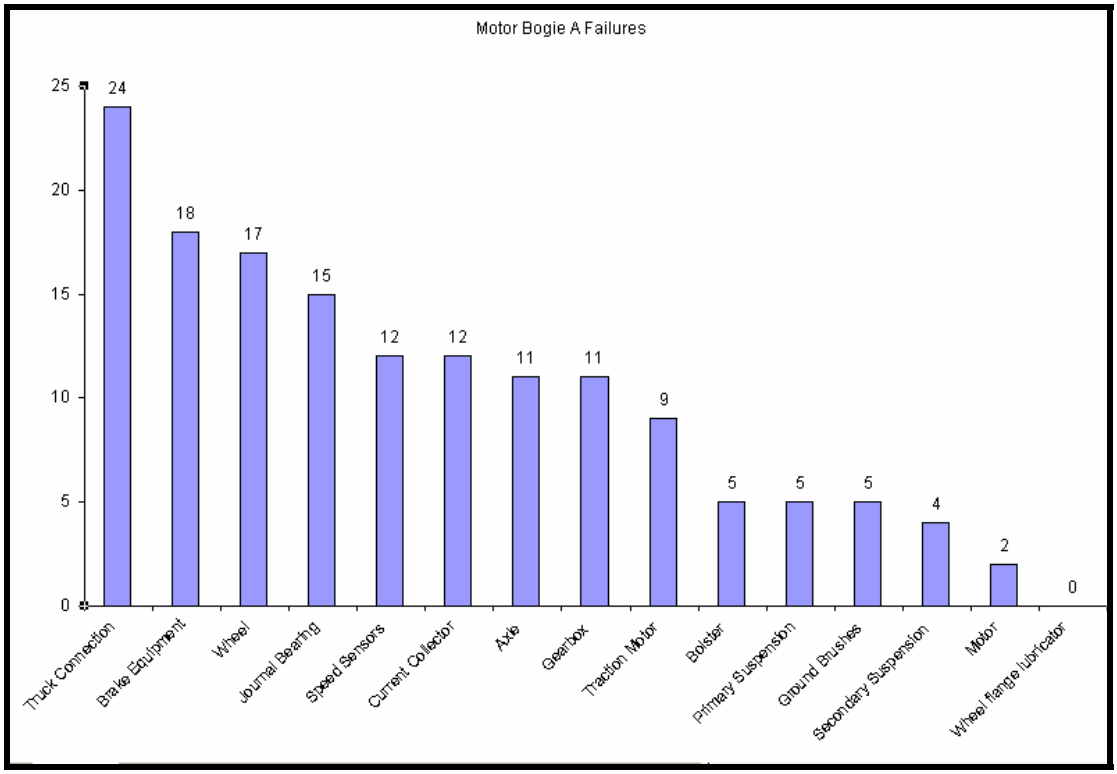

Figure 14: Motor Bogie "A" Failures

Based on this graph, the Truck Connection for Motor Bogie A has the highest failures occurrence; therefore a Predictive Maintenance strategy can be settled for this equipment. The service life of the “Truck Connection” Equipment is predicted based on inspection and diagnosis, in order to use the parts to the limit of their service life. Predictive Maintenance is condition-based maintenance; it manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system. This will monitor conditions through the system.

These are some of the different reports, graphs and analysis that can be performed based on the Work Orders information. However, these are specific metrics recommended for TU's TPM Organization in order to achieve TPM benefits. The strategy or metrics need to:

- Evaluate equipment performance through time – like in Figures 13 and 14.
- Detect repetitive failures – like in Motor Bogie "A" Example.
- Adjust its efforts on Predictive Maintenance
- Provide reports on PM, which will include PM accomplishment, costs, evolution, utilization, productivity, breakdown or stop hours (by equipment), if there's a certain tendency, and the Middle Time Between Failure (MTBF) used for the OEE Calculation which should be included in TU's Main Goals or Metrics for Improvement.
- Determine the required dedicated personnel and a number of operators.

This chapter 5 presented an effective maintenance strategy in order to keep the equipment at its highest level of performance. In addition, Appendix B includes operational manual for the tool developed in Micro Soft Access Program for TPM Implementation for TU's Motor Bogie.

6 CONCLUSIONS AND FUTURE STEPS

This applied research accomplished the development of a proposal maintenance plan for TUs Motor Bogie based on TPM. Also, this project anticipated an established TPM Organization within the Operations and Maintenance (O&M) Facilities of TU. It generates 6 Basic Steps for TPM Implementation using MS Access Tool based on the Motor Bogie Maintenance. These six steps and tool can be used for other processes or areas in the O&M facilities. Following these six steps, tool and analysis this project seeks for world-class environment for the O&M of TU.

Based on the plan presented in this project, Tren Urbano needs to combine TPM with all other strategic tools for the success of operating this heavy rail system. Once TPM is successfully attain, appreciated and implemented, the following future steps need to be present:

1. Kick off TPM Initiative in the O&M facilities - invite customers like daily riders, affiliates like any public or private transportation system, and subcontractors.
2. Build a corporate constitution designed to maximize equipment effectiveness - pursue the ultimate & innovative in equipment (vehicle) effectiveness & performance having experts in the team or doing benchmarking.

3. Conduct focused improvement activities and TPM training - project-team activities and workplace small-group activities including people from highest to lowest level.
4. Establish an autonomous maintenance (AM) program - Proceed step-by-step, with audits and verifications at each step.
5. Implement planned maintenance program - CM/PM/Predictive Maintenance
6. Build an early management system for new parts, equipment and processes - develop an easy process.
7. Build a quality maintenance system - establish, maintain, and control conditions for zero defects.
8. Build an effective administration and support system - increase process-support effectiveness - improve administrative functions & environment
9. Develop a system for managing health, safety and environment - assure an accident-free, pollution-free environment.
10. Sustain full TPM implementation - apply for PM Prize and have an internal recognition and award system.

And finally aim to higher targets; following the implementation plan, TU should progress through different phases in charting its new course for progress.

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APPENDICES

APPENDIX A – ORGANIZATIONAL CHARTS

A.1 General Manager Organization

The General Manager Organization includes all the managers that report directly to the General Manager. This is the Main Staff in the facility. Figure A.1 shows the General Manager Organization.

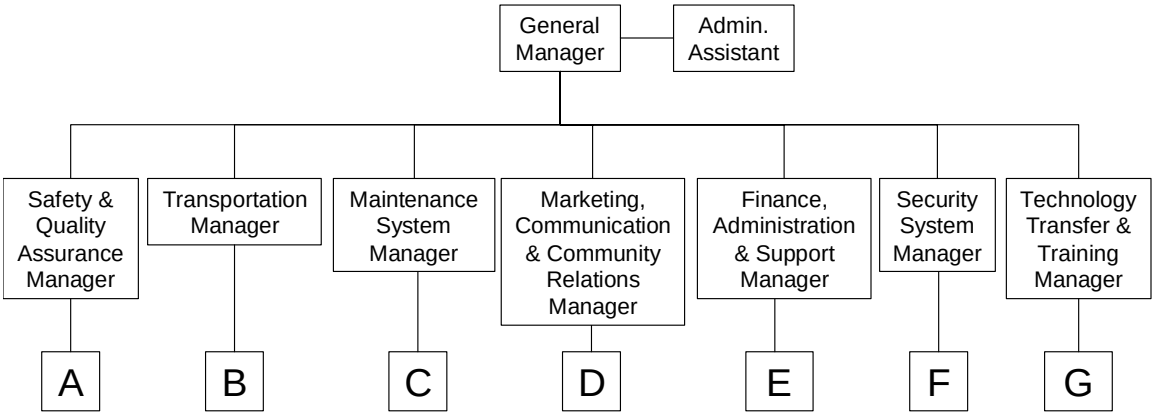


Figure A. 1 General Manager Organization.

A.2 Safety and Quality Assurance Organization

The Safety and Quality Assurance Organization has a Manager that reports directly to the General Manager. This Organization includes the Quality Organization with the Quality Engineers and Document Control Clerk and the Safety Department. Figure A.2 shows the Safety and Quality Assurance Organization.

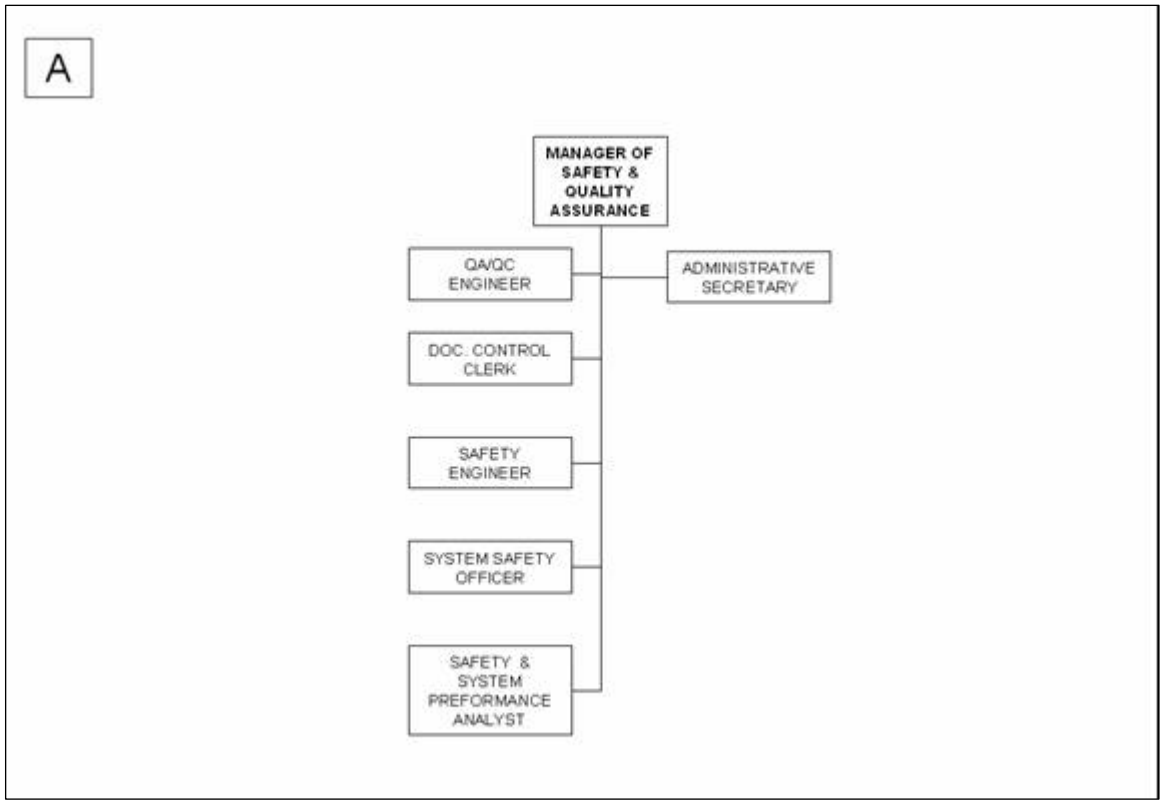


Figure A. 2 Safety and Quality Assurance Organization.

A.3 Transportation Organization

The Transportation Organization has a Manager that reports directly to the General Manager. This Organization includes the Operations and the Central Control departments. Figure A.3 shows the Transportation Organization.

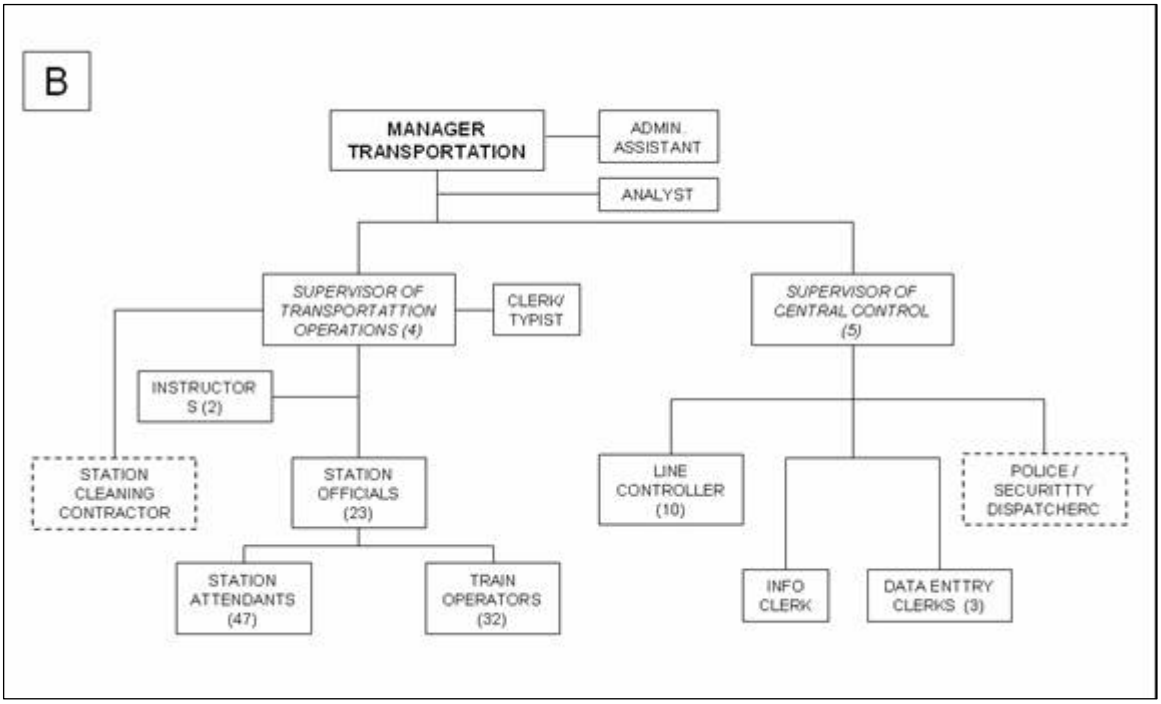


Figure A. 3 Transportation Organization.

A.4 Systems Maintenance Organization

The Systems Maintenance Organization was discussed in Chapter 4. Figure A.4 shows the Systems Maintenance Organization.

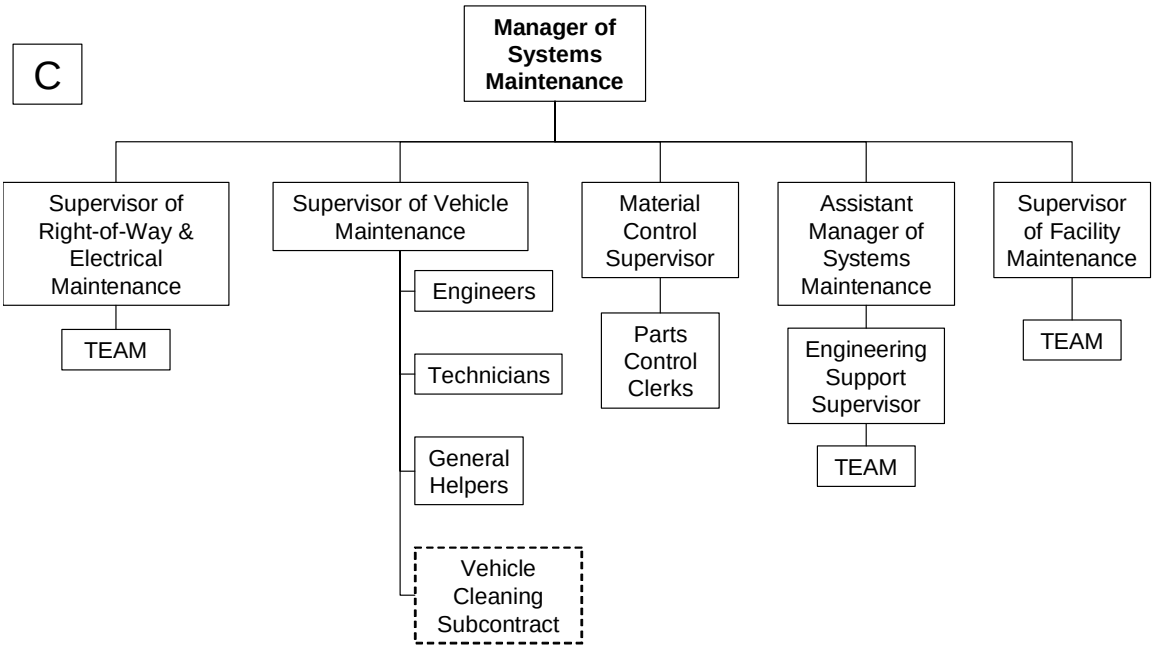


Figure A. 4 Systems Maintenance Organization.

A.5 Marketing, Communications & Community Relations Organization

The Marketing, Communications & Community Relations Organization has a Manager that reports directly to the General Manager. This Organization includes the Customer Service Department and work with subcontracted services. Figure A.5 shows the Marketing, Communications & Community Relations Organization.

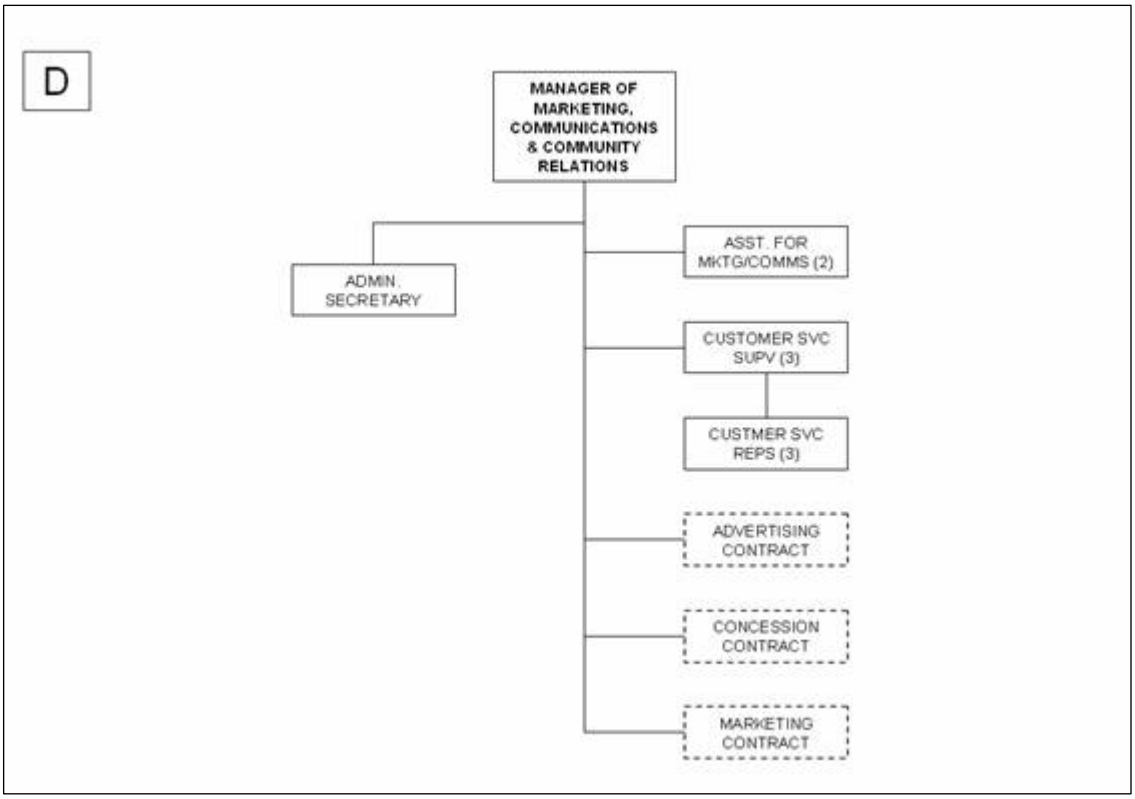


Figure A. 5 Marketing, Communications & Community Relations Organization

A.6 Finance, Administration and Support Maintenance Organization

The Finance, Administration and Support Maintenance Organization has a Manager that reports directly to the General Manager. This Organization includes the Human Resource Department, the Finance Department, the Materials and Contracts Administrator and MIS Administrator. Figure A.6 shows the Finance, Administration and Support Maintenance Organization.

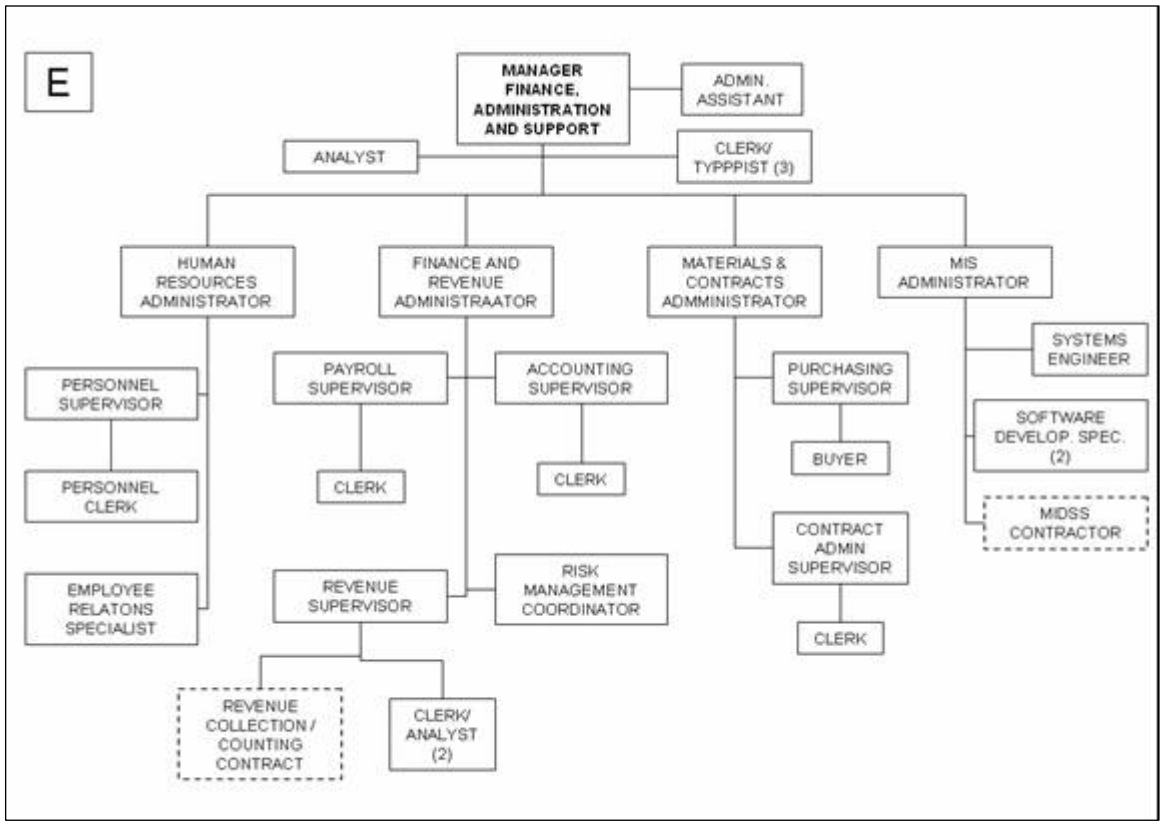


Figure A. 6 Finance, Administration and Support Maintenance Organization.

A.7 Security and Technology Transfer Organization

The Security and Technology Transfer Organization has a Manager that reports directly to the General Manager. This Organization includes subcontracted services. Figure A.7 shows the Security and Technology Transfer Organization.

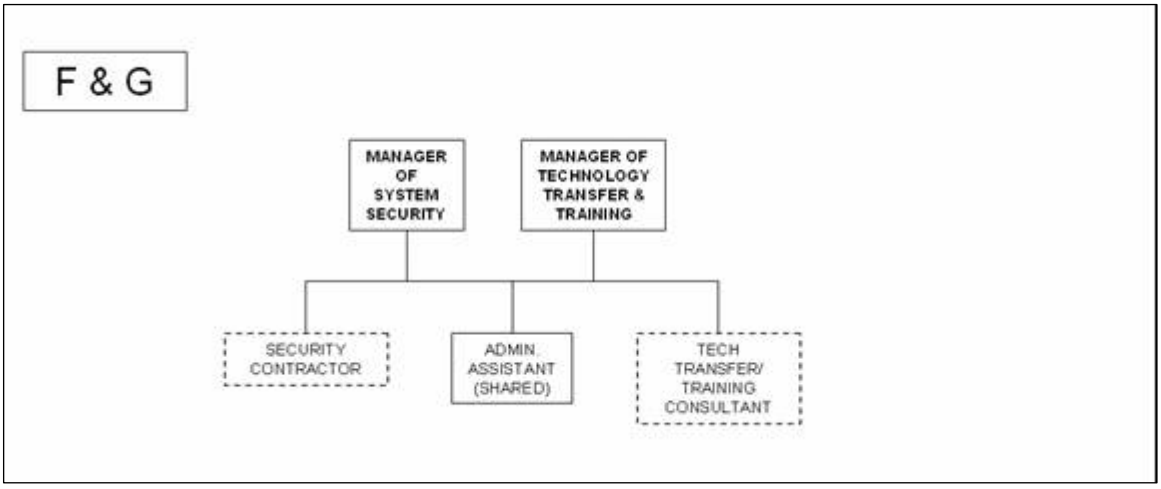


Figure A. 7 Security and Technology Transfer Organization.

APPENDIX B – OPERATIONAL MANUALS IN MS ACCESS

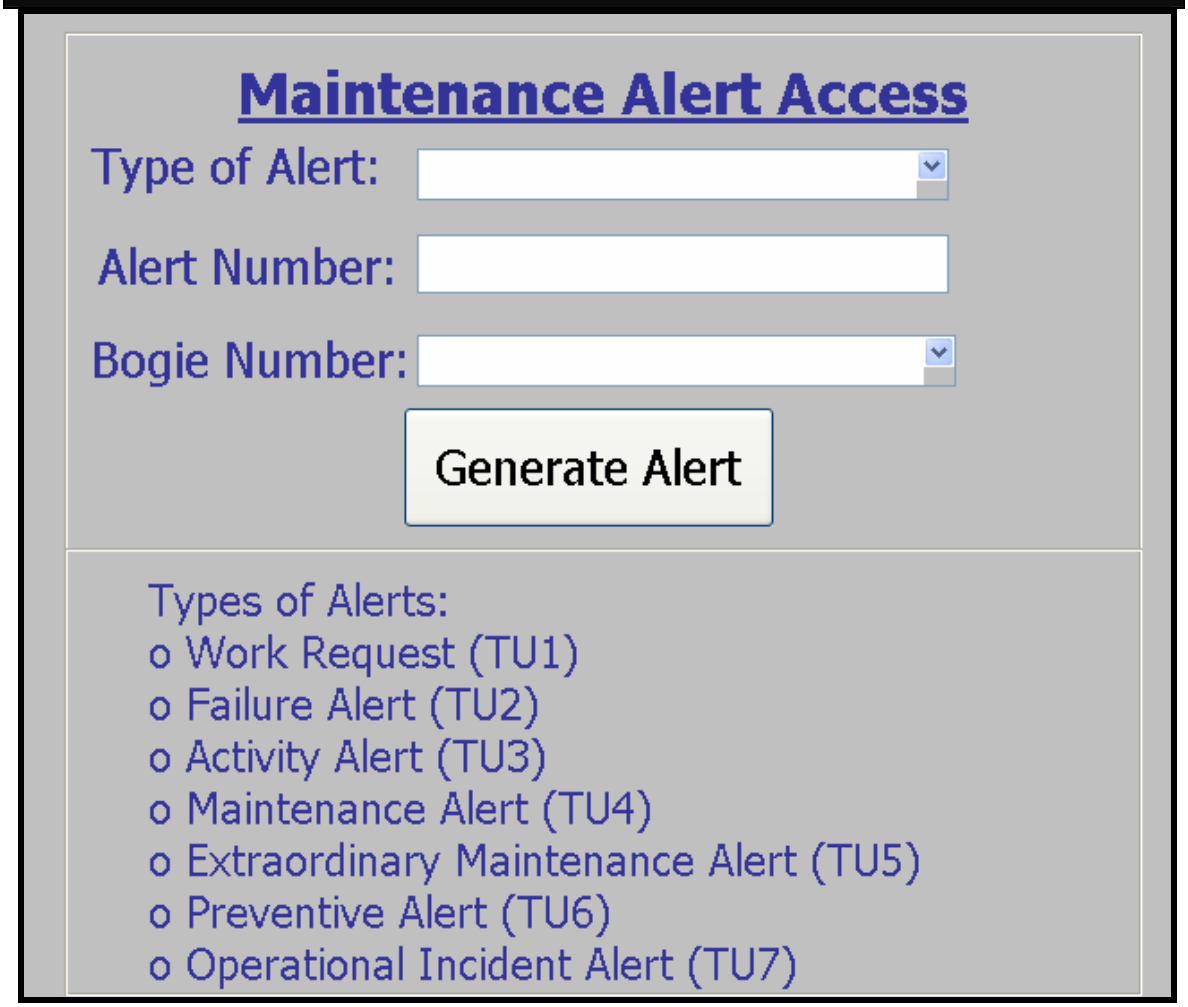
B.1 Tool Introduction

Justification
MS Access Tool was developed to gathered, document and analyzed maintenance activities in the O&M Facilities. The following screen is the tool Main Menu.
Screen View

B.2 Maintenance Alerts

Justification
Maintenance Alerts are the initial point for a maintenance job. With this tool, incidents can be reported and saved in the maintenance system. Also, Maintenance Alerts can be used to report any required maintenance job to be performed. The Alert is a fundamental element for the history of events related to the vehicle maintenance. Also, it is a tool for summarize any open maintenance job.

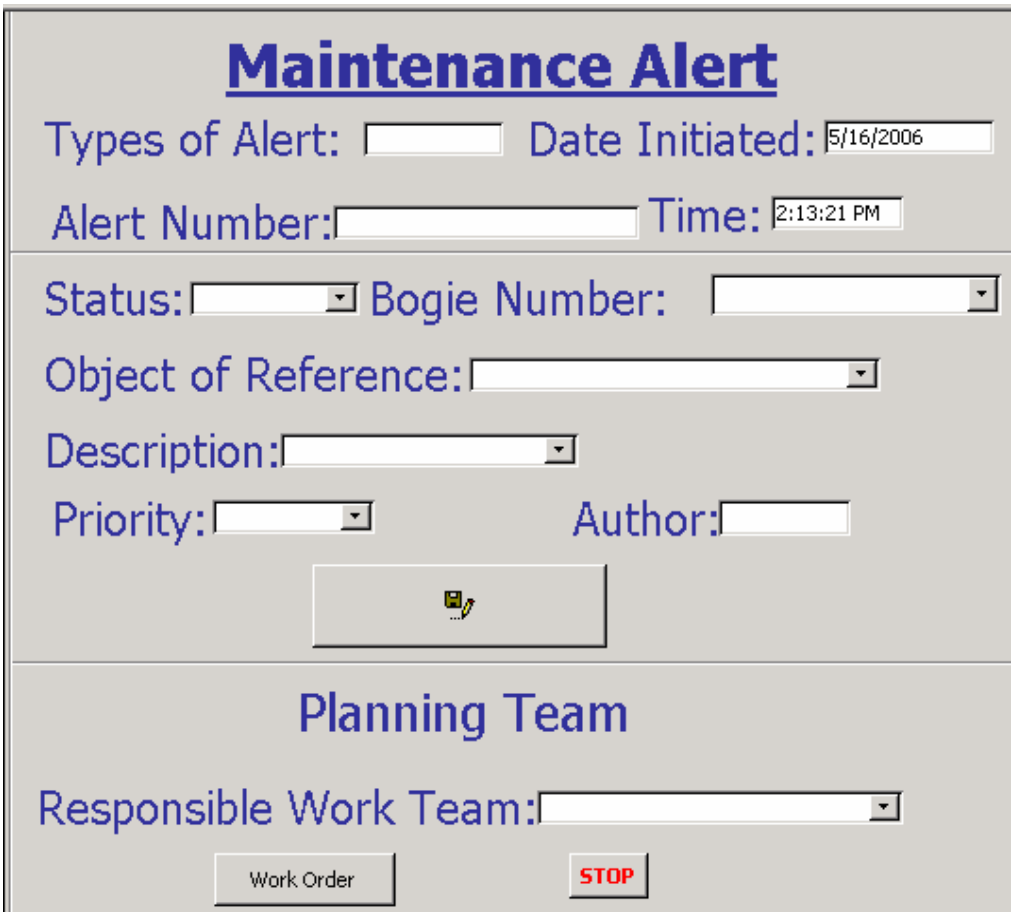
Screen View



Description
Next is the description of each key data point that must be entered into the Maintenance Alert Form. **Types of Alerts** – classify the kind of incident or work that needs to be performed. The options are: • **Work Request (TU1)**: It is used by all areas to request to the Maintenance Department to do a predetermined activity, like an installation of new equipment or an existing one, however they are not related to any kind of problem or malfunction. • **Failure Alert (TU2)**: It is used to report all failures that are found during the usage and operation of any equipment under the maintenance team responsibility. • **Activity Alert (TU3):** This alert must be generated by each maintenance area and it helps to document any unscheduled job during work. This unpredicted alerts are of minor significance, however they are part of the technical documentation history that must be saved. This kind of unscheduled alert must be assign to the main maintenance order being performed at the time. • **Maintenance Alert (TU4):** This alert is generated by each maintenance area or department, where they emphasize all the deviations found during the maintenance order execution. This maintenance execution is out of scope of the original maintenance order. This kind of alert may generate other maintenance orders different than the one that is initially performed. • **Extraordinary Maintenance Alert (TU5):** Is generated by each maintenance area. This alert assists the documentation of any deviation required from the Preventive Maintenance Routines. • **Preventive Alert (TU6):** This alert is created from the Preventive Maintenance Order to associate the history of an equipment failure that will be included in the initial scope of the work order.

- **Operational Incident Alert (TU7):** This alert is related to incidents that are not related with the equipment operation; however the business operation may be affected by other factors.

Once the kind of alert is selected, the system will automatically assign an Alert Number. Next are the data points that must be included to complete the Maintenance Alert transaction:



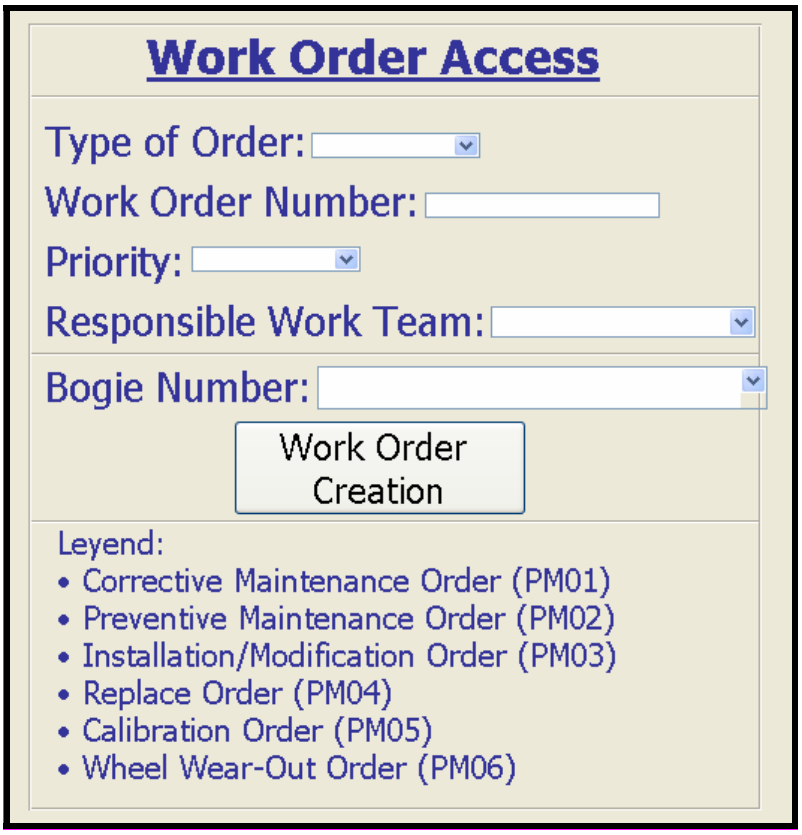
Description
Status: Indicates the condition of the alert. They can be: o **OPME** (open message) o **WIPME** (work-in-process message) o **DELME** (delayed message) o **CLOME** (close message) If the status of the message creates an operational incident affecting negatively the business, a special instruction must be included. For example, writing **RED** or **IMP** will send a message to management of this specific alert. **Object of Reference**: This space is applicable to report an incident or an alert making reference to a specific part of the equipment or location. This is the element that will generate all future maintenance work related. **Description**: This classification will provide for a brief explanation of the alert. **Responsible Work Team**: In case the data entry person has knowledge of the team in charge, this field can be completed with the responsible group to execute the task. It is Maintenance Department responsibility to verify its veracity. **Author**: the person who initiate this Maintenance Alert. This must be unique and exclusive to be able to identify the requestor if any doubts on the Maintenance Alert arise. **Date Initiated**: Date and time failure or alert emerge. **Priority:** This field will assign suggested dates for the response time following the priority assign. This priority is important information related to the maintenance alert which will affect the planning closure date. The priority can be classified as: o High o Medium o Low

Stop: This field must be pointed if the resources or equipment assigned were not available.

Work Order Required: complete this field if a Maintenance Work Order is required due to the generated Maintenance Alert.

MAINTENANCE WORK ORDER CREATION AFTER A MAINTENANCE ALERT

Justification
It is possible to create a Maintenance Work Order directly from the Maintenance Alert. The procedure is the following: From the Main Screen press the Work Order Bottom:  The system will automatically display the following screen:

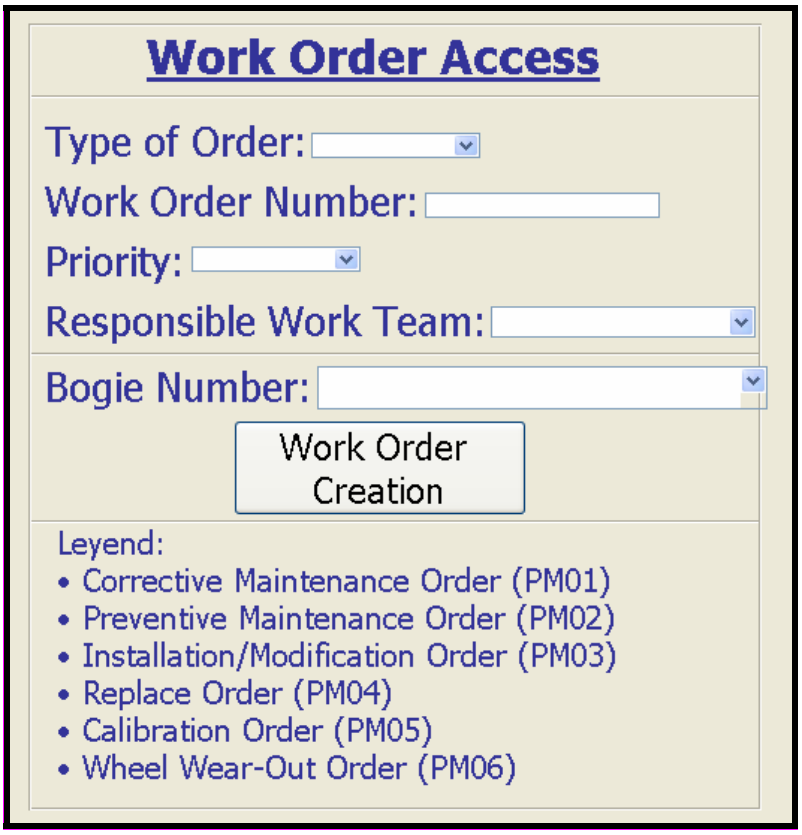


Description
Type of Order: the system will suggest **PM01** however other types will be available for selection (See Maintenance Work Orders Users Manual)

B.3 Maintenance Work Orders

Justification
Maintenance Work Orders are the main element of the maintenance system. With Maintenance Work Orders the maintenance job can be planned, executed and registered the costs encounter with the activities performed. Work Orders can/will be created in three different ways: • Manually: By this way, the complete maintenance cycle is executed with the information provided by user or operator. • By a Maintenance Alert: See Maintenance Alert Users Manual. • From a PM Plan Perspective: The system automatically generates the order based on historical data, manufacturer's specification or data gathered. Following the complete cycle for a manually order creation is included. The last two ways, Maintenance Alert and PM Plan, contain information previously created in the system which will process the information faster.

Screen View



Description

First the Type of Order needs to be entered; this will allow the system to classify the maintenance work that will be performed. Following are the different options that should be available in this field:

- **Corrective Maintenance Order (PM01)**: associated to Maintenance Alerts: TU2, TU3 and TU4 that were mentioned in Maintenance Alert Users Manual.
- **Preventive Maintenance Order (PM02)**: associated to Maintenance Alerts: TU3, TU4, TU5 and TU6 that were mentioned in Maintenance Alert Users Manual.
- **Installation/Modification Order (PM03):** required when an installation or a modification of one of the maintenance technical components, this one does not

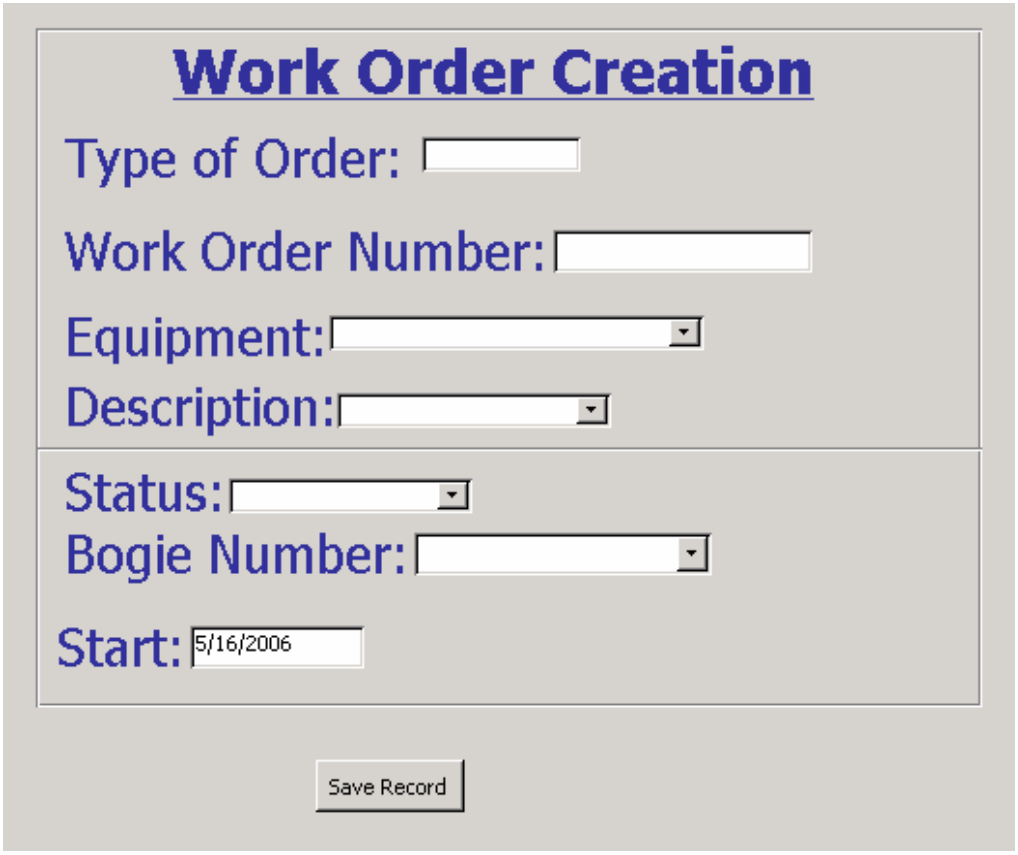
required any alert associated. Only require Maintenance Alert TU1 when it is requested by another area unrelated to the maintenance area.

- **Replace Order (PM04):** used to replace warehouse materials or components. This order should be generated by the material department, and no Alert should be associated with it.
- **Calibration Order (PM05):** used to maintain equipment regulated.
- **Wheel Wear-Out Order (PM06):** Associated to alerts TU2, TU3, TU4 and TU5. These alerts should be monitor in order to charge them to the correct department.

Priority: can be an optional category. It will classify the job urgency.

Responsible Work Team: associated with the Maintenance Planning Team, which represents the maintenance department responsible of the activity that will be performed. In case a Technical Location was selected in the Work Order Access Form, the system will automatically assign the planning team based on the Technical Location Master Files. Otherwise, this field can be registered, and assign the responsible department. Always complete this field, in order to analyze execution results per department.

Screen View


Work Order Creation
Type of Order:
Work Order Number:
Equipment:
Description:
Status:
Bogie Number:
Start:
5/16/2006
Save Record

Description
Message: describe briefly the objective or requirement of the order. It is recommended that this field is completed with significant information. **Status**: present the current status of the order: • OK – All resources are available • MATM – Material Missing • TOOM – Tools Missing • MANM – Man Hours Missing • SPEM – Special Information Missing This topic will show which resources are missing for the order total execution. **Equipment:** All statistics in the system are created in reference to a Technical Location. In any case it is applicable; select a Technical Location based on the Work Order created. In case it is not applicable, meaning that there is no Technical Location related to the Work Order been created, the **Main.Plan.Dept**. field should be completed with the word "TREN". Based on this information, the system will allow the creation of a Corrective Maintenance Order (Work Order). **Start fields**: The system needs extreme propose dates to be able to raise an initial programming of human resource, technical resource of materials (replace and consumable) and/or tools and documentation. In case a PM01 order is been created, the system considers obligatory solely the field of extreme beginning. For the other classes of orders, it is obligatory to register the end date.