Developing a Maintenance Strategy: A Case Study in an Automotive Assembly Plant

by

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ABSTRACT

This thesis examines challenges in adopting world class maintenance practices. Specifically, it describes research conducted regarding efforts to enhance the equipment efficiencies within a mature automotive assembly plant. Although the policy deployment of other goals and objectives were considered successful, the plant's efforts to adapt some of the world class maintenance practices did not work so well. As part of the policy deployment, a preventive maintenance team was formed to improve up-times of specific equipment. This thesis explores the reasons behind the difficulties in planning and implementing change in maintenance systems.

This thesis presents recommendations on developing a more effective maintenance strategy, based on the research and prevalent theory related to cultural change, project management, team formation and world class maintenance systems. It also suggests mechanisms available to leadership for cultural change and describes tools to build commitment towards a shared vision.

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1. Introduction

1.1 Thesis Objectives

This thesis describes the current status of maintenance management practices at an automotive assembly plant and compares it to world class maintenance systems. In addition, it explores barriers to improvement in a mature manufacturing site and possible solutions on how to overcome them. This will be used to develop an effective maintenance strategy.

1.2 Problem Statement

What are the issues that impede implementation of world class maintenance systems in a mature manufacturing plant, and what are the possible solutions?

1.3 Thesis Organization

In chapter 2, I briefly explain the Amcar Operating System[1] at Amcar and how implementing world class preventive maintenance practices fits into meeting Amcar's corporate objectives. Chapter 3 contains the background of Fitchburg Truck Assembly Plant (FTAP) where most of my research was conducted. Chapter 4 describes specific characteristics of world class maintenance management systems and compares them with that of FTAP. A preventive maintenance team was formed at FTAP to implement world class maintenance systems and improve efficiencies of nine equipment types. The development of this team and its barriers to progress will be discussed in Chapter 5. This chapter will also include my analysis of the team and discuss some reasons for the difficulties the team faced in forming the team itself and in meeting its goals. Chapter 6 covers the issues that are seen in implementing changes in maintenance practices based on literature and interviews with plant personnel. Recommendations on how to approach implementing maintenance follows in Chapter 7.

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[1] The name of the company and the names of individuals associated with this automotive company have been disguised to protect confidentiality.

2. Amcar Operating System (AOS)

In this chapter I will briefly explain the history behind the Amcar Operating System and some fundamental principles of AOS. This is to show the connection between Amcar's corporate objectives, AOS and the maintenance management system.

2.1 Amcar Operating System as a Corporate Strategy

Amcar formulated their mission in 1993: "To be the premier North American car and truck company by 1996, and worldwide by 2000." The Amcar Operating System was developed as part of a manufacturing strategy. It is the development of a total production system that is analogous to the Toyota Production system. Amcar wanted to unseat Toyota as the world's top quality manufacturer. AOS, which began in 1994, lays out Amcar's manufacturing philosophy and shows how designers, engineers, factory workers and suppliers can change the way they operate to build quality cars. The goal is to make the highest quality cars and trucks at the lowest cost.

The need for an operating system was recognized during a brainstorming session called by Amcar CEO Robert Schulist in the summer of 1994. Schulist wanted his management team to come up with a plan to make Amcar the world's top automotive company. Dennis Johnson, the Executive VP of Manufacturing, convinced Schulist that manufacturing should be Amcar's priority and that Amcar needed to learn from Toyota's manufacturing excellence to become the world's best auto company.

In the summer of 1994, the Manufacturing College (which later evolved into the Amcar Operating System department) arranged a session to teach the Toyota Production System (TPS) to Dennis Johnson and his Vice Presidents using the Harvard Business Review case study on Toyota Motors Manufacturing, Inc. (The case study describes Toyota's response to a seat defect problem.) Subsequently, Johnson taught the plant managers. He called a strategy session asking the senior executives whether Amcar should implement TPS and how. A group of senior executives studied this and the Amcar Operating System was their answer on how to get there.

Johnson organized the people who worked directly with him and they set out to develop the Amcar Operating System. An AOS department, located at corporate headquarters was formed to design, coordinate and roll-out training. Initially they focused on providing training to executive management on the Toyota Production System. Since then, the scope of the department has expanded to include plans to train the rest of the organization.

2.2 Amcar Operation System as a System[2]

AOS literature stresses understanding AOS as a system and the importance of recognizing the relationships between interdependent elements of a system. Johnson emphasizes that AOS is different from other initiatives in the past because "it takes stand-alone single initiatives, which in many ways have become just buzz words (such as PM, Robust and Capable, Level and Balanced Schedule, SPC), and weaves them together into a system."[3] The mutual impacts of those changes within the system must be considered. In the past, Amcar tried to adopt many tools, assuming that the tool represented an entire system. The comment below was typical of the way in which new Toyota type programs were attempted to be instituted throughout the company. Harry A. Lawrence, Vice President of Finance, Strategy and Planning comments, "For example, after many trips to Japan, we saw Statistical Process Control (SPC) charts, and said that we should put SPC charts in place. We even put measurements in place to measure how many SPC charts we were using. We thought that SPC charts were the answer, but failed to understand that charting, in itself, does not drive improvements. We need to have a system in place that supports improvements."[4] The process to chart was learned but not how to manage using the charts.

AOS is said to be dynamic in that it evolves through the design, development and roll-out of AOS classes, and through the process of implementation. It is continually being redefined, as the organization learns what works and what does not.

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[2] Taken from AOS course books

[3] Taken from AOS course books

[4] Taken from AOS course books

2.2.1 Amcar Operating System Subsystems

The AOS identifies four subsystems that deliver results in safety, quality, delivery, cost and morale:

- **Human Infrastructure** This subsystem stresses the importance of human resource management. An organizational culture that supports lean manufacturing is critical to the success of AOS. Therefore it is necessary to continually attract needed talent, and develop employees. Worker participation also becomes essential. AOS particularly emphasizes the large role that managers as leaders in change have to play to create an environment that is conducive to lean manufacturing. This is why, to change behavior in lower levels in the organization, Amcar's plan is to start with the executive and upper management and then move down the organization. Throughout the phases of development and implementation of AOS, the AOS department and management need to identify and address the organizational barriers that resist change.

- **Leveled and Balanced Schedules** Capacity and process planning, production planning and scheduling and material flow planning all support this subsystem. To achieve leveled and balanced schedules would involve effective planning and scheduling and improving manufacturing capability (such as preventive maintenance) to meet customer demands so that it can build to schedule just-in-time.

- **Value-Added Activities** Material flow planning, waste identification and elimination, best practice sharing and standardized work support this subsystem.

- **Robust and Capable Processes** An in-control process is essential to lean production. This subsystem has four support processes: standardized work, robust product and process design, quick problem detection and correction, and total productive maintenance.

There are tight interdependencies among the four such that all need to be addressed if results are to be obtained. The subsystems play a considerable role in enabling or supporting each of the other subsystems. Conversely, if one is not operating well, it can

play a significant role in undermining others. For example machine downtime must be minimized in order to meet a just-in-time production schedule.

The enablers for meeting the goal are correct behavior of management coupled with training and communication. Also, support processes and tools need to be developed to execute those processes in a methodical manner. Proper measurements (of process and results) need to be made to ascertain that what should be done, is actually being done.

2.2.2 AOS Four Basics

There are four AOS basics that support the Robust, Capable and In-Control Processes subsystem. These concepts are usually the first to be implemented at the plant level. Preventive maintenance falls in one of the categories. The four AOS basics are:

- **5S** activities are very popular in many factories in Japan. It promotes basic housekeeping and orderliness in the workplace. The 5S stands for [5]:

  Seiri: Keep only needed material at the job site; remove unnecessary items immediately.

  Seiton: Store materials in an orderly fashion.

  Seiketsu: Observe overall cleanliness; in neat and clean surroundings it is more obvious when something is wrong. This promotes quick problem detection.

  Seiso: Clean tools, equipment, and job site whenever necessary; clean equipment works better.

  Shitsuke: Practice self discipline.

  It can also be interpreted to mean : sift, sweep, sanitize, sort, and standardize.

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[5] Shiba, Shoji, A New American TQM Four Practical Revolutions In Management, Center for Quality Management, Boston, MA, 1993, pp. 490

- **Standard Operating Procedure (SOP)** is part of standardized work. Each work station has a step by step description with a diagram next to it on how the worker should perform the operation. The SOP's are written by hand so that it can be updated easily. For instance, if a quicker, easier way to complete a job is found, the SOP is revised. It promotes controlled change, so that all the operators who are at the station need to buy in and agree to change before the SOP is altered. It is useful for communication, continuous improvement and variation reduction.

- **Preventive Maintenance (PM)** promotes proactive behavior. This is leveled and balanced scheduling of equipment maintenance which contributes to leveled and balanced scheduling of production. Up-time of machinery can be increased by enhancing the operators' and skill trades' awareness of the equipment for which they are responsible. In addition, root cause analysis, prevention and fixes to equipment downtimes also lead to improved performance.

  Preventive maintenance is a part of total productive maintenance. Total productive maintenance is a system that focuses on optimizing equipment effectiveness and includes preventive maintenance, predictive maintenance and operator involvement.

- **Statistical-Process-Control (SPC)** highlights problems. By having workers on the floor use it, they can detect and correct problems faster. It is also a good measurement tool for continuous improvement, as it provides feedback on process changes and variability. Variation reduction will lead to better manufacturing processes.

Standardized work, productive maintenance and robust product and process design lead to in-control processes. However some problems do arise and when they do, systems that they have in place such as SPC and 5S will allow for quick problem detection. To correct the problem, root cause analysis tools are used.

2.3 Amcar Operating System Implementation Strategy

AOS is being driven through the organization through cascade learning and teaching, which start with management from the very top and will eventually work its way down. The

concepts of the Toyota Production System and current trends in world class manufacturing are taught both as philosophy and practice. Dennis Johnson is the first student of each course. Then, he teaches to his immediate reports-the vice presidents. The vice presidents in turn teach to their subordinates, which are the plant managers. The plant managers take the learning and hold classes for their direct staff members.

It is up to the discretion of the plants to cascade teach beyond the plant manager's staff. The Fitchburg Truck Assembly Plant, on which much of the research for this thesis was based, decided against it because the material was written for executives and was not considered appropriate for middle to lower managers and hourly employees. The classes for middle/lower management and hourly employees are more tool or implementation focused rather than systems/theory oriented. The classes for them are usually shorter, more implementation focused and often given by AOS specialists at the plant or from an outside instructor. At the Fitchburg Truck Assembly Plant, the AOS "Preventive Maintenance Topic Focused Training Class" which explains some of the management tools and practices used by many plants that have world class maintenance systems. The class was taught to the AOS Specialist, a tooling engineer, a quality manager, the preventive maintenance coordinator, and a cross section of maintenance area managers, supervisors and skilled trades through several sessions in 1996 by external maintenance experts.

AOS is considered an evolving system, which will be continually changing and improving based on the learning derived from discussion and implementation. The AOS training books are often a description of world class principles on manufacturing but do not explain how to achieve it given the current status. This is left to the plants to find out what the best method for implementation is, given the particular constraints and opportunities in each plant.

In each plant, AOS Specialists are responsible for coordinating the AOS classes and facilitating workshops. In addition, they are coaches on AOS concepts to other people in the plant. The AOS Specialists report directly to the plant manager. They work with the plant manager and staff to plan and implement AOS principles at the plant level. Amcar did not want outside consultants implementing AOS in the plants and felt that it would be best

to implement using internal people, usually selecting from within the plant itself. The AOS specialist goes through intensive training from the AOS department to become an expert in AOS.

The Toyota Production System is a rigid system. Amcar has the advantage of being able to assess the change and take what will work at Amcar. It is a judgment call as to what to customize and what to copy. There are two modes of implementation-the learning lab line and AOS workshops.

The workshops are "Kaizen type" continuous improvement sessions, usually involving a small group, and are more task focused to solve immediate problems. About 57 workshops were held at the Fitchburg Truck Assembly Plant in 1996.

Learning laboratory lines are actual operating sections of manufacturing where AOS principles are tried out. It is a pilot area for AOS principles. Middle management and hourly employees that are associated with the learning lab line are usually the first ones to be trained on AOS concepts and tools. The learning lab line is usually for slow and potentially difficult implementation. Workers test their ideas and taught concepts in the learning lab lines. It is a "sandbox" for employees to play in and learn how to implement the four basics and beyond and address barriers.

PDCA or the Plan-Do-Check-Act process is taught and practiced in classes. It is an important part of the Toyota Production System and hence the Amcar Operating System. PDCA symbolizes the principle of iteration in problem solving-making improvement in a step-by-step fashion and repeating the improvement cycles many times.

Plan: Determine analytically and quantitatively what the key problems are with an existing process and how they might be corrected.

Do: Implement the plan.

Check: Reflect on the process as a feedback loop. Understand what worked and what did not work quantitatively and analytically.

Act: Modify the previous process appropriately, document the revised process and standardize it.

The AOS classes not only provide information about the Toyota Production System but try to enforce the "plan," "do", "check" and "act" parts of the learning process as well. The learning labs provide an opportunity to "do" what is being taught. A following course is usually held more than a month after the previous one, and part of the following course is allotted for reflection and feed back to their bosses on the principles from the previous course and the status of implementation.

After the concept or idea is tested out in the learning lab lines, the learning is then used to implement in other areas. There are three objectives for the learning lab lines. One, it is to teach in a real situation how AOS should work, two, it will help draw attention to areas that are barriers to AOS implementation and three, the learning can be transferred within the plant faster than across plants. NUMMI and Saturn have been experimental plants that were supposed to be model plants for GM. However GM so far has had trouble spreading that learning to other plants. By having the learning labs within each plant, organizational learning can take place faster. Harry A. Lawrence, Vice President of Finance, Strategy and Planning, said, "There are some projects happening in each plant, but it's not a silver bullet and the changes must be thoroughly understood or else they can be misused. We don't want to go too fast. If we take the learning laboratory lines and really turn them into the idealized state, those examples of what can be done will be more effective teachers than anything else we could do. Actions speak louder than words and a living example of what can be done is powerful."[6]

New maintenance practices that are taught in AOS classes are expected to be tested out first in learning lab lines to find out what works and what does not. Then what works is to be proliferated to other areas within the plant.

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[6] Taken from AOS course books

2.4 Conclusion

The Amcar Operating System is a corporate manufacturing strategy, and maintenance is an integral part of the Amcar Operation System. There are many examples of unsuccessful cases in which plants have tried to implement lean manufacturing without having all the necessary ingredients in place. A successful implementation of a robust maintenance system is one of those necessary ingredients for success.

3. Fitchburg Truck Assembly Plant (1996)

This chapter will describe some background of Fitchburg Truck Assembly Plant (FTAP), on which this research was based.

FTAP is situated in Canada and was built in 1976. FTAP is Amcar's only manufacturer of large vans. While the plant capacity is rated at 120,832, the plant produced 74,363 vans and wagons in 1995 and was estimated to put out 86,081 in 1996. It produces an average of 424 vehicles a day.[7] The plant runs two production shifts, and the night shift and weekends are mostly reserved for maintenance or repair work. The manufacturing processes are mainly manual with very little automation. For example, it has 228 manual weld gun stations and only 16 welding robots.

Approximately 1900 employees worked at FTAP in 1995. 4.6% of them were salaried. 9% were female, and 15.9% of management had college degrees. The hourly employees are represented by Canadian Auto Workers' union.

3.1 Organizational Structure[8]

The Fitchburg Truck Assembly Plant is divided into three areas: body-in-white, paint and trim/chassis/final. There were two business center managers, reporting to the plant manager, in 1996. (See Figure 3.1) One business center manager was in charge of both body-in-white and paint, and the other was responsible for trim/chassis/final. Each of the business center managers had several production and maintenance area managers reporting to them. The production and maintenance area managers in turn had several first-line

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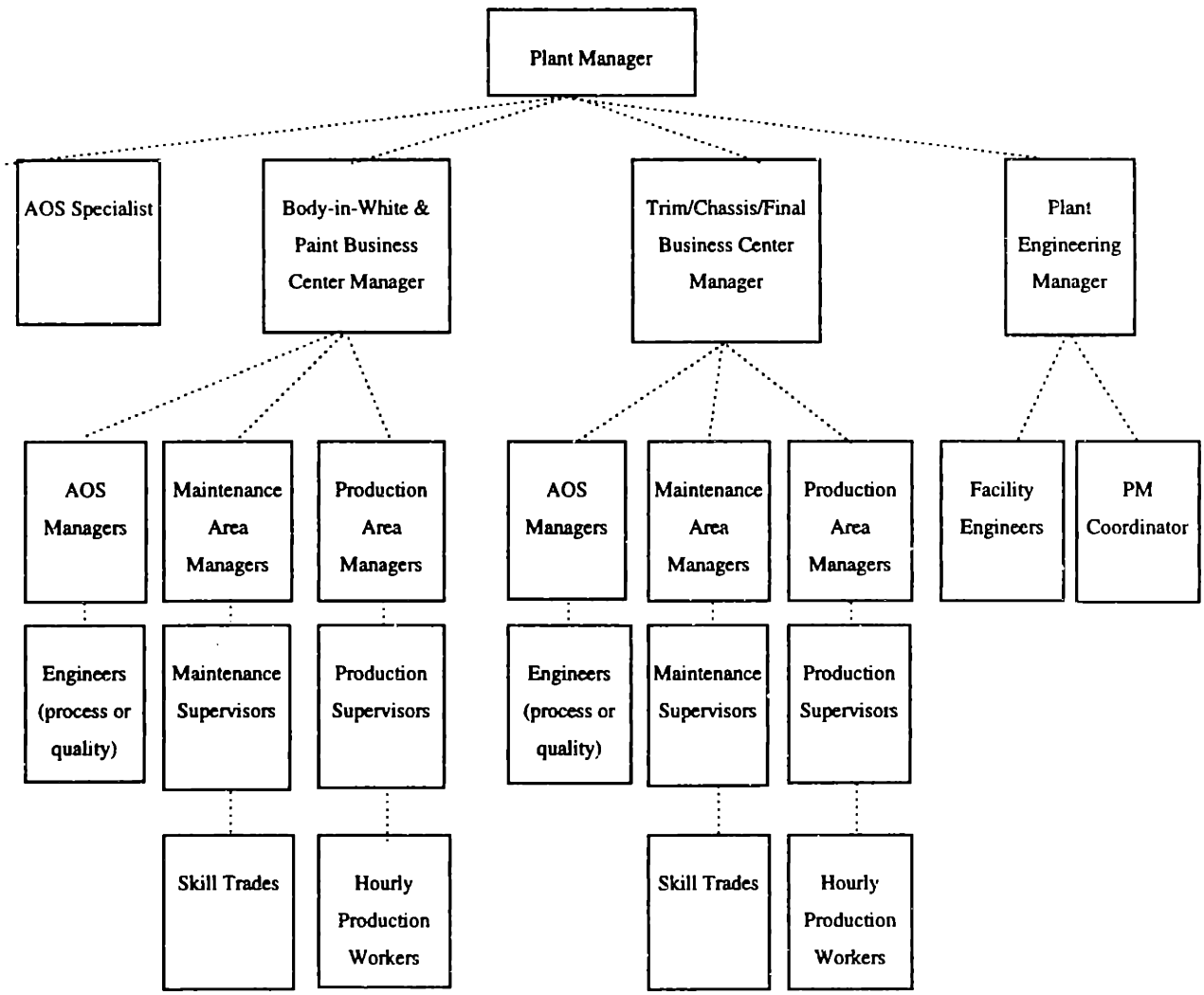
[7] For comparison, this plant is about a mile away from a sister plant re-tooled in 1983 which makes the popular minivans. The plant assembles about 1200 units a day. It is expected to run at full capacity by the end of 1996.

[8] This organizational structure was changed in 1997. In 1997, the maintenance organization was centralized and merged with the plant engineering group. It reported to the plant engineering manager and no longer to the business center managers. In addition, the position of business center manager for paint was created and filled.

supervisors reporting to them. The production hourly workers worked for the production supervisors, and the skill trades people worked for the maintenance supervisors. The engineers reported to "AOS Managers." AOS Managers were each responsible for the quality and reliability of a certain group of related processes and reported to one of the two business center managers.

Figure 3.1 Abbreviated schematic representation of organizational structure (November, 1996)



3.2 Policy Deployment

Amcar's "policy deployment" is analogous to the Japanese Hoshin planning. Policy deployment is part of the Amcar Operating System, and it refers to a specific process in which corporate and plant goals and objectives are developed. Policy deployment offers a process to focus on a critical few areas in which the company or the plant must achieve "breakthrough" strategic improvements, in order to achieve its mission. Once top management defines key objectives, it then "cascades" those objectives to the next layer of management. The individuals who are closest to the problem define the most appropriate strategies to achieve the objectives. After the objectives and means are cascaded from top to bottom, the plans are adjusted, incorporating the inputs and "rolled up" from bottom to upper management.

FTAP was the first plant at Amcar to use Policy Deployment as part of the annual goal setting process in 1996. See Appendix A for FTAP's Policy Deployment Plan 1996. The plant manager and his staff spent the first three months carefully deciding and planning on which strategic initiatives to focus. The policy deployment was introduced to the rest of the organization in April during a series of Town Hall meetings which included all salaried employees. As can be seen on the second page of the plan, the PM program was part of the policy deployment. During this time, plant manager and his staff asked the employees to give inputs or voice concerns about any part of the policy deployment plan. After the plan was finalized, the policy deployment plan was linked to the individual appraisal system. These managers in turn appropriately incorporated their objectives into their subordinates' individual objectives.

3.3 Learning Laboratory Lines

The following sections are written to illustrate some of the AOS changes that were happening at FTAP at the time of the research.

3.3.1 Cowl Line

The first and main learning lab line is located in the cowl line of body-in-white. The body-in-white includes all the processes before the vehicle is painted. The cowl line is where the

front part of the van structure is assembled. It had four robots and about fifty portable guns in 1996.

The line runs differently from other lines. It has a "team leader" on each production shift. The team leader positions were created in early 1996 by redeployment, after a 5 day workshop in the cowl line which freed up two production workers by rearranging work stations. A team leader is an hourly employee who obtained the position by bidding through seniority. The team leader monitors the progress of the group. This person addresses any operational problems including incoming material shortages and quality problems. He/She also monitors quality and output schedule, and coordinates training of new workers. This person reports to the production supervisor and does not have any formal authority to discipline the workers. The team leaders calls a meeting every Tuesday and Thursday 10 minutes before the second shift break with the production workers and maintenance workers, who were assigned to that line, to discuss operational issues and other relevant news. The production supervisor attends as well and works closely with the team leader to make sure the meeting runs smoothly. By the end of 1996, it was still like an announcement type meeting, and not an interactive one, but the team leaders hoped that this will change over time as people in the team began to feel more comfortable in giving inputs and voicing concerns in front of the group.

There were four additional major changes in the cowl learning lab line.

1. Some concepts of standardized work and 5S were implemented. Each station has a work procedure which was written by the production workers themselves. Also, fixtures were thoroughly cleaned and painted.

2. A 5 day productivity improvement workshop resulted in streamlining some operations in the cowl line which then led to the elimination of two operators which then allowed for two positions for team leaders to be created.

3. A 5 day workshop was held to look at how material was delivered to the area. This workshop involved material handing supervisors, two operators, and production supervisors. The number of pieces in each container was decreased to reduce inventory,

and the containers were raised in platforms such that the operators could reach into the containers more easily. Also if there were more containers than were permitted it would be noticeable because they would not be on designated platform.

4. A team meeting area for operators and skill trades was created through a workshop that involved a material handling supervisor, production supervisors and some operators from the cowl line. Some stock was moved to create space, and layout had to be designed.

3.3.2 First Leg of Trim Line

In 1996, management identified the need to improve material delivery to the production workers in the trim area. The first leg of trim became the second learning lab line to implement world class production principles. This area was advantageous because there was not much heavy process equipment to be moved and it was a highly visible area to the rest of the plant. In addition, the labor union had requested that management look at the area because it was congested with both operators and high levels of parts inventory. The AOS Specialist facilitated the workshop and the workshop included production and material handling supervisors, production and material handling coordinators, and two skill trades who were dedicated to this project. The coordinators were hourly employees. A consultant who was knowledgeable in the Toyota Production System initially helped the group to re-layout the operations and material handling so that operator motion and parts inventory would be reduced. Parts were brought to a centralized area and repackaged into smaller containers which were then distributed to the stations that needed them. Large racks were replaced with slanted roller racks on which the containers were placed so that the operators could easily access the parts which were now in smaller containers. The stations were set up such that empty containers could also be easily detected by material handlers.

They worked on the area section by section. At first the group worked in a workshop in a conference room to re-lay out the area on paper, then implemented it on the weekend. After a while they became familiar with the process and for the remainder of the project, they were able to execute what needed to be done on the floor, without paper, by talking with

people and changing things even with the production running. The result was a more safe and ergonomically-friendly area for the operators, with better quality, less rework, and improved productivity. This was well accepted by both management and floor personnel and was regarded highly successful.

3.4 Conclusion

There were much activity at Fitchburg Truck Assembly Plant, in 1996, to implement some of the concepts of the Amcar Operating System. A new way of setting goals in the plant was used at FTRAP to involve more employees in the goal setting process so that there would more probability of success with the projects. Moreover, much effort had been in standardized work process in production and in inventory reduction particularly in the learning lab line, with positive results. Maintenance work practices at FTAP will be covered in the next chapter.

4. World Class Preventive Maintenance and Current Status in Maintenance at FTAP (1996)

The maintenance system is one of the most important long term ingredients in the plant's life. The number of skilled workers tends to increase with automation, while the number of operators decreases. The need for adequate technical skills to quickly troubleshoot equipment that is growing in complexity becomes more critical. As a result, systematic methods for reducing equipment downtime and for quickly spreading and applying that learning become important.

PM techniques become more necessary than ever to ensure quality, timely delivery, low cost, safety and pollution prevention, particularly in lean manufacturing. The Toyota Production System which is characterized by automation and just-in-time production, in particular requires a robust PM system, because there is minimal inventory between stations. When equipment breaks down frequently or there is a high rate of repair time and frequency, downstream operations stagnates.

In this chapter, I will describe some of the common characteristics or elements of maintenance that are found in many world class manufacturing plants. I will also compare their strategies and practices of FTAP in 1996.

4.1 Strategy

Nippondenso has always had a very defined corporate maintenance strategy. Nippondenso is a part of the Toyota automobile group and the largest manufacturer of automobile electric parts in Japan. About 1969, management at Nippondenso developed the TPM or "Total Productive Maintenance" because maintenance of complex equipment was becoming a problem as operations were becoming automated. All employees participated in developing TPM in small groups activities. From 1969 to 1971, the company worked on implementing the TPM program, and in 1971 it was awarded the "1971 Distinguished Plant Prize," or the PM Prize for its results. TPM is essential to sustain just-in-time production system and takes on goals of zero losses and waste, meaning zero failures and zero defects.

The general characteristics of TPM are:[9]

1. Aims at maximizing overall equipment effectiveness (including quality, up-time and production rate).

2. Establishes a total system of PM that includes all employees from engineering, production, maintenance, including hourly production workers and maintenance technicians.

3. Promotes PM and Kaizen (continuous improvement) activities using small group autonomous activities.

Amcar also has a strategy of implementing a systematized preventive maintenance system that incorporates many of the world class maintenance practices as part of the Amcar Operating System. There are efforts to implement varying degrees of world class preventive maintenance practices particularly in the learning lab lines. However Amcar has no defined maintenance corporate strategy for the company. FTAP in 1996 did have an annual improvement goal of improving up-times of some target equipment sets and improving quality rates for weld defects, as part of the policy deployment. However, FTAP does not have a defined plan or means on how it will achieve the up-time goals.

4.2 Human Resource Management

At Nissan's Yokohama engine plant, 20% to 30% of maintenance is done by line workers. The plant's formal maintenance group handles periodic, scheduled work. The distinguishing feature of TPM that is missing from other maintenance systems is the "autonomous maintenance by operators on the line." Many companies with world class maintenance systems have moved away from trade specialization and have broadened the scope of job assignments, which means a change in the concept of craftsmanship. "Specialization have led in workers lacking in responsibility, having insufficient

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[9] Plant Engineering, March 13, 1986

understanding of overall production systems, and having excessive idle time due to personnel changes."[10]

In companies that have adopted TPM, pre-shift inspection includes 5's activities, checking for oil leaks, wear levels and, where needed, undertaking simple maintenance and repairs. This activity is usually done by production workers. Inspection of control panel indicators follows the start of the operation. This is also usually handled by production line employees. Only when there is a problem is the specialist or maintenance called. Accident or equipment breakdown generally require maintenance specialists. Nissan cross-trains production line workers and maintenance specialists. At its Iwaki engine plant some 15 maintenance specialists per shifts are assigned to the production line to help raise workers' maintenance skills. Through this interchange, the ratio of " indirect" workers (to direct production workers) is 33% of levels at other Nissan engine plants.

At FTAP, maintenance is responsible for the health of the machine and therefore it checks for oil leaks, wear, and needed repair during the night shift. Production workers do almost no preventive maintenance tasks. Due to labor union contracts, the division of labor means that production workers cannot do skill trades' work and vice versa.

4.3 Planning and Scheduling

Planned maintenance is most commonly done when facilities are idle. Nissan, however, tries to schedule maintenance for days when the plant is running production. Maintenance works on holidays only for sudden breakdowns or time-consuming repair jobs. Otherwise, maintenance is usually planned three months in advance, and only after the production and maintenance groups meet. The situation is similar at Mazda, where 75% of all maintenance is handled during regular plant hours.

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[10] Takahashi, Yoshikazu, and Takashi Osada, TPM: Total Productive Maintenance, Asian Productivity Organization, Tokyo, Japan, 1990, pp. 11

At FTAP, the production shifts are usually reserved for reacting to break downs and small maintenance work. Each skill trade person is dedicated to a certain group of equipment. During that time their major responsibility is to react to breakdowns. The night shifts and the weekends are then reserved for inspection, preventive maintenance, construction, and for time consuming repairs.

4.4 Maintenance Tactics

Maintenance tactics of companies that have exhibited robust maintenance systems have moved away from reactive maintenance to preventive maintenance, predictive maintenance, condition based maintenance and even maintenance prevention. Pre-shift inspection of control panel indicators, process/equipment parameters monitoring, vibration analysis and thermography are examples of predictive and/or condition based maintenance. Maintenance prevention refers to having equipment designers and engineers focus more on maintainability or parts robustness.

At FTAP skill trades do many inspections during the maintenance shift (third shift). In addition, they change the tips of weld electrodes at some preset interval. Thermography is conducted to detect hot spots in weld cables or electrical connectors. However there is almost no inspection of control panel indicators or process parameter monitoring except in the paint area.

4.5 Performance Measures

Toyota integrates TPM into its regular maintenance plan which involves a functional team comprised of six departments including production planning and safety. The team uses the equipment maker's recommended schedule, along with a detailed running history of the machinery and an outline of the plant's production plan. Performance targets are based on company historical data and industry benchmarks.

Some performance measures used by top manufacturing companies including Toyota are Mean-Time-Between-Failures, Mean-Time-To-Repair, and Overall Equipment Effectiveness and are explained in the following:

4.5.1 Mean-Time-Between-Failures

Mean-Time-Between-Failures (MTBF) is the average time intervals between breakdowns of equipment or components.

$$\text{Mean-Time-Between-Failures} = \frac{\text{total available time}}{\text{number of occurences of particular type failure}}$$

Total available time is the time that the machine could run during a shift or other time interval, assuming there is no downtime. By analyzing the frequency of occurrences of breakdowns, engineering modifications may be carried out to respond to unexpected failures and extend the useful life of parts and components. It provides a prioritization of areas for improvement and reduction of maintenance requirements. It also provides information of points at the machine to be inspected or replaced and helps determine a useful preventive maintenance program. It can also be used for engineering data for reliability and maintainability design.

4.5.2 Mean-Time-To-Repair

Mean-time-to-repair (MTTR) provides data on the recovery time of a equipment that needs maintenance work or repair. It is calculated as follows:

$$\text{Mean-Time-To-Repair} = \frac{\text{total recovery time from a particular type of failure}}{\text{number of occurrences of that type failure}}$$

Training program (technical skill level), maintenance methods, communication methods (recognition of a failure occurrence), parts procurement or fabrication time, and response time to the site all effect the mean-time-to-repair.

4.5.3 Overall Equipment Effectiveness[11]

The best indicator for equipment effectiveness would be to use OEE, or overall equipment effectiveness. This measures the impact of equipment related losses. The OEE tracks losses through measuring three critical factors: availability, performance efficiency, and quality rate.

OEE = Availability x Performance efficiency x Quality rate

Availability includes machine breakdowns and setup/adjustment losses. Performance efficiency tracks minor stoppages and speed losses. Quality rate measures product defects and rework.

4.5.4 Cost Reporting System

Successful companies categorize the cost of maintenance by equipment, area, equipment type, or by similar parts. A meaningful cost reporting system not only keeps information about the labor and material expended, but focuses on the "total cost of maintenance." This would include costs resulting from poor maintenance and malfunctioning equipment, such as the cost of downtime, substandard product, and lost opportunities or customers.

Many maintenance people at FTAP told me that they had a good system because the percentage of preventive maintenance tasks completed was over 90% and because of the shear volume of preventive maintenance that was done at night. This is not a good indicator. It fails to measure the effectiveness of PM's themselves.

Moreover, very few stations collect equipment history and downtimes. Only the tire machines, the major framer and cowl framer robots, and some manual weld guns had records of equipment history. Equipment history is useful for identification of repetitive

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[11] Robinson, Charles J., and Andrew P. Ginder, Implementing TPM The North American Experience, Productivity Press, Portland, OR, 1995, pp. 125-150

problems and for training. Trending and analysis would provide information where resources should be allocated to improve up-time. It is also helpful in communicating between shifts, between production and maintenance, and between supervisor and floor workers. The difficulties have been due to suspicion that upper management will use the information for disciplinary purposes. In addition, the skill trades and even some of the maintenance supervisors feel they should be "fixing" pieces of equipment that are down instead of doing "clerical work."

FTAP does keep track of maintenance costs by labor and material expended. However it does not examine the cost of downtime or defects per type of failure.

4.6 Information Technology

While computers are helpful in establishing an information database and for organizing that information that is easy to use, retrieve and store, it is important to note that the computerized system in itself is not the solution. The effective use of *any* information system is the solution. Effective use of information requires discipline. Accurate lists of equipment and spare parts must be complemented by well-defined standardized maintenance procedures.

Currently, most maintenance records at FTAP, when they are kept, are kept manually, but there is a plan to install a computerized "total maintenance system" in the near future. If properly used, this would allow quick access to data on equipment breakdowns, maintenance work schedules and maintenance instructions. In addition, it has the future capability of being linked to parts inventory. However, the challenges of this information technology are installing the system, training people on how to use it and actually having the people use it. While some skill trades people have welcomed the computerized system, others feel intimidated by the technology that they are not familiar with. The benefit from the computerized system can only be as good as the information that is entered into it and its use. The implementation of IT in maintenance will have to be performed cautiously, taking into account the skills and motivations of the users.

4.7 Employee Involvement

Nippondenso believes in total employee participation in the PM process. The health of the machine is not only a maintenance function but everybody's responsibilities. In addition improvements are mostly driven through small "autonomous" work teams that include production line workers and maintenance technicians.

At FTAP, there are some signs of employee involvement in maintenance issues. For example, a task force to improve weld quality included a skill trades person which proved very helpful because that person was very familiar with the equipment and its problems. There is another example where some skill trades' inputs are sought when new equipment sets are brought in. However there is no formal and systematic process in which skill trades people are involved in improving the long term effectiveness of the equipment that they are responsible for maintaining and repairing.

4.8 Reliability Analysis

4.8.1 Failure Database

An equipment history documents the complete performance and repair history of a machine. The value of maintaining history will provide information for improving equipment effectiveness. It is necessary to understand maintenance activities that come up in actual situations, analyze their problems, define specific areas, and make proposals for improvements. MTBF is a form of maintenance records. However MBTF itself is a waste of time if the information is not used. This is why some skill trades people feel that writing down repair history is a waste of time—the information is not being used for analysis and improvement.

4.8.2 Root Cause Analysis

5 Why's are used as a tool for root cause analysis and as part of a continuous equipment improvement process at Nippondenso as well as many other Japanese manufacturing plants. When a breakdown occurs, the maintenance supervisor or skill trades person fills out a "5 why form" that asks the question "Why?" five times to uncover the root cause of the problem. It is also being used at FTAP when there is a stoppage and production is directly

impacted at FTAP. This is filled out mainly by the responsible area manager or supervisor in maintenance or production. Management of root cause analysis and charting of downtimes are primarily the responsibility of the preventive maintenance coordinator, who is just one person in the entire plant.[12] However in the majority of cases the skill trades or production line workers are not involved in the 5 why process. In addition, the 5 Why's are not available to the skill trades to read. Therefore the learning is not shared. The form is treated like a report to superiors but not used as tool for sharing the learning.

In addition it is difficult to do root cause analysis when there is minimal equipment history. Skill trades people at FTAP would be more interested in keeping equipment history if they can be part of a group that analyzes and decides how to fix recurring problems. Then they will realize the usefulness of keeping the equipment history, and by seeing successes in improving equipment effectiveness over which they had some control, they will be even more supportive about changes in maintenance management systems.

4.9 Process Analysis

At Nippondenso the process, in which maintenance system works, is evaluated by reviewing its performance against cost, delivery and quality expectations. This I believe is essential to complete the Plan-Do-Check-Act cycle and to look at the system as a whole and see which processes need to be improved. This "check" which includes reflection of its performance allows organizations to continuously improve its strategy and practices. FTAP could use this to evaluate its own maintenance processes or methodology and see where it should focus its efforts in.

4.10 5S

5S promotes safety, efficiency, quality, equipment efficiency, morale, and reduces cost. Activities can be to clean up oil leaks which may enhance equipment efficiency and create a

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[12] In 1997, this responsibility for root cause analysis was decentralized and pushed down to the maintenance supervisors who were closer to the problems than a single preventive maintenance coordinator for the entire plant.

safe environment for the workers. In addition, elimination of grime and dust can often lead to better equipment performance and quality and therefore a reduction in cost. An orderly display of parts and tools can expedite repairs and reduce the risk of using the wrong parts or tools by mistake. Moreover, a clean and tidy environment promotes morale as well. It is relies on total employee participation and each individual worker takes on assigned responsibilities.

"...5S management is not something that can be accomplished through the contributions of a few extraordinary talented people. Rather, it can be successful only through individually motivated initiatives that apply to all employees with regard to order, tidiness and cleaning. It should be distinguished from a type of hypothetical management that merely promotes increased use of an equipment cleaning crew."[13]

While in Toyota everybody takes part in 5S, this is not true in FTAP. The fixtures and the robots are not cleaned by the operators or the skill trades. This is said to be the work of the janitors, due to the division of labor from local labor contracts. These people are for the most part responsible for keeping the plant and its equipment clean.

In addition, 5S is meant to instill order and discipline in the workplace. This cannot be achieved when only a part of the organization is responsible for it. Also the operators' awareness and ownership of the equipment is not enhanced.

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[13] Takahashi, Yoshikazu, and Takashi Osada, TPM: Total Productive Maintenance, Asian Productivity Organization, Tokyo, Japan, 1990, pp. 122-131

Figure 4.1 Comparison between World Class Maintenance and FTAP

	World Class	FTAP
Maintenance Strategy	Clear and defined.	Some objectives defined; No clear plan.
Human Resource Management	Production workers do routine maintenance work.	Skill trades do all maintenance work, including basic inspection.
Planning and Scheduling	Maintenance is done during regular production shift, as much as possible.	Most maintenance work is done on night shift, when production is not operating.
Maintenance Tactics	Focus on preventive, predictive and condition based maintenance.	Focus on reactive and preventive maintenance. Some predictive maintenance and condition based maintenance. Not much focus on process parameter monitoring.
Performance Measures	MTTR, MTBF, OEE	% of PM's completed. Production schedule conformance measurement. Some downtime loss and cost measurement.
Cost reporting system	Examines "total cost of maintenance."	Labor (including overtime) and material cost (including scrap), divided by number of vehicles produced. Productivity numbers closely monitored.
Employee Involvement	Autonomous work groups	Some involvement by skill trades in decision making.
Reliability Analysis	Root cause analysis	Some equipment history kept and analyzed. Some root cause analysis practiced.
Process Analysis	Part of maintenance management system.	No formal systematic process.
5S	Total involvement	Involvement by only select groups (e.g. janitors)

4.11 Conclusion

FTAP is making some progress towards improving preventive maintenance practices. However it still needs to capture some of the essence of world class maintenance systems. See Figure 4.1.

5. Development Of A Preventive Maintenance Team: A Case Study

The following chapter is about a preventive maintenance team that was formed to improve maintenance and the problems it faced during the planning and implementation. The AOS is a learning process with many experiences that may seem at first like failures but the learning can be used by the team, the organization, and others as valuable classes in planning and implementing change. The purpose of this case study is to understand lessons learned from the experiences, and investigate ways to improve on the situation and ways to prevent problems from reoccurring.

5.1 The PM Team

5.1.1 Preventive Maintenance Team Is Formed.

The Preventative Maintenance Team was formed in August of 1996. The need for better preventive maintenance was emphatically voiced by the plant manager's direct staff during the time when policy deployment was being written in the January to March time frame. The urgency and importance of improving preventive maintenance were first initiated by the staff members, not from the plant manager. The policy deployment was introduced to the rest of the organization in April during a series of Town Hall meetings which included all the salaried employees. To align the goals of the plant with the incentives of its employees, one of the five goals and the objectives of the business center managers' performance appraisal was to be based on the effectiveness or improvement in the nine equipment sets. These nine equipment sets were chosen by the plant staff and maintenance managers, taking into consideration which equipment needed to be improved and what specific maintenance skills needed to be further developed for the new upcoming launch. Subsequently, the objectives in the policy deployment were rolled into the maintenance area managers' and maintenance supervisors' goals and objective performance expectations.

The PM team was only one of several teams that were set up to achieve plant's objectives. For instance, there were teams set up for Plant Manager's Staff Team, In-system Damage Team, and Management-Union Relations Team. The teams had a kick off session off-site, that were filled with classes and activities on team building and organizational change.

From interviews with the then plant manager it was intended that the team work to improve up-time of eight key equipment types[14] by implementing world class maintenance practices where appropriate. A "team" was set up so that people would work together towards a common goal, giving them also an opportunity to use some of soft behavioral tools, that had been taught by an outside organizational development training and consulting group called Change Management Consulting, or CMC.[15] Critical members such as the maintenance area managers were strongly encouraged to join, and others signed up voluntarily. A CMC consultant was to attend the meetings to help with the process of forming successful teams and running meetings effectively.

The maintenance needed to be improved for 4 reasons:

- The launch coming up the following year would be the biggest that the workforce had experienced since the plant had been built in 1976, with capital expenditures of about 200 million dollars. There would be a significant increase in robot technology for which the skill trades had to be trained to operate and troubleshoot. The 1998 launch would require a four fold increase in robots in body-in-white, from 16 to 56. Historically the skill trades performance during launches had not been stellar, and management was concerned. In 1994, 6 robots were installed in the framer and the plant took approximately a year to bring the framer to operate reliably with the expected up-time. This difficulty was attributed mainly to deficient skills of the skill trades that were needed to keep the new automation running. There was no question among the plant manager's direct staff members that the maintenance system needed to improve significantly for the plant to have a successful launch.

- While many maintenance personnel in the plant considered them among the best in the corporation, the maintenance practices at the plant were still far from world class, in

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[14] Nine equipment sets were initially identified, but one equipment type was removed from the plant later on.

[15] The name of the training and consulting group has been disguised.

terms of standard operating procedures, documentation, root cause analysis and employee involvement in continuous improvement and TPM, where operators do basic maintenance.

- Since the plant would like to win the business of a new product, the plant manager wanted to demonstrate the plant's capability with improved maintenance. High quality and up-time of equipment would help demonstrate the plant's ability to run a new product. Maintenance was an important ingredient to the future of this plant.

- Preventive maintenance is part of the basic foundation that is needed for a successful lean manufacturing system. A solid preventive maintenance program was necessarily a requirement of the Amcar Operating System.

Team members consisted of three maintenance area managers (one from each of the three areas -- body-in-white, paint, and trim/chassis/final), one maintenance supervisor from body-in-white, the preventive maintenance coordinator, the plant engineering facilities manager, one tooling engineer who worked primarily in trim/chassis/final, an industrial engineer for the maintenance department, a production area manager from body-in-white, a production supervisor from body-in-white, and the business center manager who was in charge of maintenance, production and quality of both body-in-white and paint. The business center manager, who reported to the plant manager and who was the highest ranking member, was the leader of the group.

Several participants felt that although they were not forced, they were heavily pressured into signing up, particularly if they had received performance feedback from their managers that they needed to improve in their behavioral skills. Many felt that this was another "CMC" thing that was just to get the group together and talk. The PM coordinator however felt hopeful that finally improvements in maintenance would be made. In addition, the leader was uncertain at first whether his primary role was to improve the behavioral skills of the people in the team by empowering them and educating them, or whether to achieve hard results through this team.

There was much pessimism about the team particularly within the maintenance organization about how serious upper management felt about preventative maintenance for the following reasons: 1) Previous plant managers had not placed much emphasis on preventive maintenance. 2) Up until then the maintenance department felt they had been neglected and previously the first thing in cutting costs had been to cut labor in the maintenance department. 3) Also the plant manager was expected only to remain for 2-3 years at the plant so, for many, this drive for better preventative maintenance was expected to only last that long. The people had seen so many projects come and go initiated by previous plant managers. 4) Many were confused about importance of this team relative to the overall objectives of the plant. Since joining was voluntary, how important was this? Was this just an exercise in teamwork or was this team to really produce solid results? 5) The available statistics indicated that the downtime of their 8 robots in body-in-white was less than 5%, and completion of the preventative maintenance overall was around 90% which to them meant that they were up to world class standards. Although downtime of other equipment was not measured, the area managers felt it was also very close to 5%. They felt that to improve these numbers would be very difficult.

5.1.2 The First Two Meetings (August 7 & 21, 1996)

The first two meetings were held in the maintenance meeting room during the summer shutdown. The PM coordinator initiated the meetings to discuss how PM could be improved. There was much confusion whether the PM team was supposed to set the meetings themselves, or if CMC had to be there to facilitate the meetings. The PM coordinator felt that he did not need CMC to improve maintenance, and therefore he called the meetings. The first two meetings were not facilitated by CMC and had low attendance. The business center manager did not attend. From these two meetings, it was decided that instead of trying to tackle all eight areas at once, the group would prioritize the equipment types in order of greatest need for improvement. Then the group would address the equipment set with the most problems in maintenance. The portable weld guns were picked as first priority for improving maintenance.

5.1.3 Third Meeting (September 11, 1996)

The CMC called this PM Team meeting. The business center manager ran the meeting. The meeting was held in his office as was most subsequent meetings. Most of the members showed up and maintenance issues were discussed. However, what was discussed and agreed upon in the previous meeting was not followed. It was determined that the members did not know what maintenance methodologies were being used outside his/her immediate functional group and that world class maintenance practices were not clearly understood. To address the first issue, a walk-through of all the key process equipment types was scheduled and conducted at the next meeting.

5.1.4 Fourth Meeting (September 16, 1996)

A walk-through was held to establish a baseline and show best practices and problems that each area had seen in improving maintenance. There were log books that documented the cause of breakdown in the learning lab line in body-in-white that the hourly workers were using. In the paint area, the paint automatic sprays were shown. Training of skill trades on troubleshooting was an issue that the paint area was currently addressing. To accommodate training, an electrician was added during each of the production shifts. In addition, to increase response time to breakdowns, one radio had been issued to the electricians in paint in each production shift. In trim/chassis/final, the tire machines were shown to the group. The machines had PM check sheets near them that were kept current and closely monitored. In addition, the location for oilers was available on a chart so that PM's could be done more easily and thoroughly. The hourly workers who worked on the tire machines were also documenting downtimes.

5.1.5 The Plant Manager's Walk-through (September 19, 1996)

The plant manager knew that follow ups to projects were critical. He called for an update to the progress of maintenance. Therefore he arranged for a walk-through of the plant to see how far along they were in improving PM's. The maintenance supervisors and maintenance area managers from all three areas, and the business center manager from Body-in-White took the plant manager around the plant to show him the maintenance status. When he finished the walk-through he told the leader of the PM team that there

were very little data collection of equipment downtimes and where there was downtime data there was very little analysis of that data. The PM's were far from world class and there was much room for improvement.

The maintenance area managers and business center managers were visibly upset by this negative evaluation by the plant manager. The maintenance area managers in particular had been proud of their preventive maintenance program. They insisted that their preventive maintenance system was one of the best in Amcar, and many from other plants within Amcar had come to benchmark their system. They had 90% completion of all their PM's and 95% up-time on their robot equipment. The maintenance department was clearly frustrated. They felt that, given the situation they were in with low investment from the company to upgrade to new machinery, they were doing fairly well.

However, one thing was clear from the walk through by the plant manager. He was serious about wanting to see some improvement in the maintenance management system.

5.1.6 The Fifth Meeting (October 2, 1996)

This was the first meeting that I attended and was also the first meeting after the plant manager's walk-through. This meeting and all subsequent meetings until the rest of the year, except one, were held in the leader's office. We met on average once every other week. There was never any question who the leader was. The leader was always in front of the office and set up the agenda at the beginning of the meeting. During the meeting the maintenance area managers and I updated the group on what came out of the meeting with the consultant from Toyota. I had previously set up the meeting with the consultant because the maintenance area managers wanted to know how FTAP's maintenance differed from world class maintenance systems. The consultant had advised that the team begin with cleaning the pieces of equipment.

We then brainstormed ideas and barriers to an effective PM. Ideas were written on the board:

a) Copy a process that had been successful in the past in improving up-time. This involved measuring downtime and causes for downtime. Then a root cause analysis would be conducted on downtime. This process had been used successfully in improving the up-time of the framer during the last major launch.

b) Form a training committee for skill trades for maintaining equipment. This task had already been assigned to a person outside the PM team.

c) Monitor up-time, mean-time-to-repair, mean-time-between-failure, tip levels, quality. Many pieces of equipment were not being monitored. Some members felt that having measureables and monitoring them should be pursued. (This would be the first stage of a.)

d) Address union issues. One person felt that the team should include union representatives and hourly people.

e) Maintain a clean environment. Much of the equipment problems was said to be caused by a dirty environment. The Toyota consultant had said that the equipment should be kept clean.

f) Implement visual management and standard operating procedures for maintenance.

g) Improve weld gun up-time and weld quality and prepare for weld equipment installation during 98 launch. The weld quality needed to be improved, now that new weld standards had to be maintained, as mandated by corporate. (Soon after, another team was put together to address this issue.)

h) All the plans should be consistent with the framework of the Amcar Operating System.

Each member of the group was asked to sign up for an item and to come up with a plan on how to address that issue.

5.1.7 The Sixth Meeting (October 10, 1996)

At the next meeting, we heard from the leader that the plant manager had wanted to see a plan on improving maintenance. He also intended to do a follow up walk-through soon. The business center manager from trim/chassis/final was there also listening on the progress of the PM team. Although he was not responsible for the progress of the team, he was responsible for the progress in maintenance in his area. There was added interest in the PM team, subsequent to the plant manager's walk-through and feedback. The union and three other hourly skill trades people had been invited by one of the maintenance area managers who had signed up to work on labor union issues during the last meeting.

The members presented each plan and the team gave inputs. The people responsible for planning for the "Visual Management and Standard Operating Procedure" had taken the series of AOS PM classes which taught world class PM systems and methodologies. Therefore they had come up with an extensive plan virtually copying the recommendations from the AOS PM course book. After the meeting the members of the team were confused how these plans were all going to fit together and how the members would find time to accomplish them all.

The members who were not from body-in-white wanted a plan that would encompass all of the three divisions, not just one. One even said that this would encourage healthy competition among the areas. One person after the meeting told me that he was upset that the group was spending too much time on improving union-management relations. He felt that it was not a union management meeting but a PM meeting, and that the focus should not be to improve union-management relations but to improve up-time. He remarked that there was another "CMC team" already set up to improve union-management relations.

5.1.8 The Seventh Meeting (October 23, 1996)

From this meeting on until the end of the year, there was no first line supervisor in any of the meetings. They were too busy on the floor.

At this meeting, self assessment and peer assessment on behavioral skills were conducted by CMC. Each member received an assessment of oneself and three other members. This

was done so that members could track their own trends on behavioral skills throughout the year. Although scores were confidential, people were visibly uncomfortable about rating each other in the same room at the same table sitting shoulder to shoulder. One person later expressed discomfort about rating peers, saying that peers should not be rating each other. After the questionnaires, the team moved on to reviewing the plans. The plans had been revised according to the inputs that were generated from the previous meeting.

The team had to decide its next step. One of the maintenance area managers felt that it should focus its efforts on working with the union because they were the major roadblocks to progress. He burst out with profanity saying that the team had not accomplished anything for several meetings now. Another member was adamant that the group should work on implementing the Toyota-style Total Productive Maintenance. He had already brought a "business plan" that he had copied from the TPM book. Some people in the group did not understand TPM, but they did not ask the person to explain. People began interrupting each other. Another person was saying that the AOS classes encompassed most of the items on the board and therefore we should follow the AOS manual. Only two people in the group had taken the AOS PM class, and therefore other people did not know what he was talking about but were unwilling to admit ignorance. I said that we should follow AOS PM classes or TPM, but that the commitment from the team was critical to make it successful because to implement it would be time consuming and difficult. I suggested that we pick something small and gain some momentum. Nobody replied for a moment. Then two members stated that the task was not so formidable and that all of the above projects could be executed all at once. For others, the fact that many were unfamiliar with TPM or AOS-PM made them uninterested in the plan. People were becoming frustrated because others were not acknowledging their own inputs. Nobody was listening. They were all talking. There were many side conversations about what each one thought should be done. In addition, people were frustrated because the team had not "done" anything. There was no clear plan to which the team as a whole could agree.

Finally, when the meeting time was up the leader was visibly exasperated. He said, "Let's **do** something." He proposed that the team begin with cleaning the cowl framer fixture,

which was a tool in body-in-white that held the parts together as the robot welded the parts. The confusing thing was that one of the plans did include cleanliness. However that plan was not even mentioned. The plans people had prepared for the meeting were discarded. Many felt that getting their hands dirty and doing something meant that the team was productive, whereas mere planning meant that the team was not being productive. The leader told the PM coordinator to set it up on a Saturday to clean the fixture. The team would come in on Saturday.

The people from engineering and production were confused why they were on the team and what their roles were. In addition, there was some resentment in the group that a business center manager who did not have much experience with maintenance was the person assigned to lead the group. Moreover, those people who were not part of body-in-white felt resentful that the team seemed to be concentrating only on equipment in body-in-white and not the other areas.

5.1.9 The Eighth Meeting (November 2, 1996)

The team assembled in the cowl area. There were no union member or hourly people in that meeting. Some members, including myself, had thought that we were going to actually observe the equipment being cleaned. However, the cowl framer had already been cleaned the night before the meeting. The cowl framer was visibly cleaner. A couple of members were assigned to work with the janitors and their supervisors on a procedure and a schedule for cleaning. One of the maintenance area managers came up with the idea of setting up a procedure so that operators and/or janitors could tag if a problem with the equipment was noted. It was noted that the janitors needed to be involved and so it was decided that a janitor would be invited to the next meeting.

At this time the plant manager was assigned to a different project and left the plant relatively quickly. The plant manager had lasted less than a year at the plant. A new plant manager came to the plant. From the time that the announcement was made that the plant manager was going to leave to actual departure date took less than a month.

5.1.10 The Ninth Meeting (November 13, 1996)

There were no janitors at the next meeting. There was still no hourly or union representation either. There had not been much effort from the group to include them in meetings or in conversations. At this meeting, the leader kept coming in and out due to a large breakdown in paint. Even when he was at the meeting, he was answering his radio, looking at his computer terminal and pacing up and down. The maintenance area managers were going in and out of the meeting due to some urgent issue as well. There was frustration among the other team members because, due to poor planning and lack of communication, some of the fixtures were not cleaned properly, and had a production supervisor not caught a potential problem, shift start up for that morning would have had problems. The ice that was needed for cleaning had not been ordered. The procedures for cleaning which some felt were supposed to be written by the janitors themselves had been written by the janitors' indirect supervisor and an industrial engineer. In addition the janitor's direct supervisor was not informed about the PM team and its purpose in cleaning. He was on night shift and could not attend the PM team meeting. However he had informed one of the maintenance area managers that there was no way all the fixtures could be cleaned as scheduled.

Also, action items which were assigned to people were not being done. A member was supposed to invite a janitor to the meeting but had not done so. The tags had been ordered but there was no mention when they would be coming in. The team debated the meaning of the standard operating procedure for cleaning and who should be writing it. Those people who were more familiar with the AOS concepts felt that the standard operating procedures should be written by janitors themselves. Others felt that the supervisor or the industrial engineers could write it. The members once again were interrupting each other and voices were raised, trying to debate how standard operating procedures should be written. The meeting concluded with assigning two people, who knew the methodology in which standard operating procedure should be written, to meet with the janitors, their supervisor and industrial engineer to explain the process to them.

The production supervisor and production area manager met with the janitors the next day. The janitors were a couple of hours late and their supervisor did not show. The janitors had also brought the union steward with them, just to make sure that the management were not trying to take advantage of them. The concept of writing a standard operating procedure was explained to them. The janitors agreed to meet in a week after they had settled on a routine in cleaning.

Outside the meetings, people were unhappy about the progress of the team. They were very busy with other work to do and felt that there really was no point to the meetings. Except for a few members, it was obvious that nobody was spending much time on the project. In addition, everybody was confused where this team was heading.

It is interesting that the group's lack of progress was largely blamed on the leadership of the team. Several of the members indicated that the leader "is losing control" of the meetings and that he should be making decisions while seeking inputs from the team members. The general attitude was that the direction should be set by the leader but that was not happening. Therefore they felt that this was causing much discussion and no real action.

5.1.11 The Tenth Meeting (November 27, 1996)

This meeting was scheduled to go over the codes of behavior. CMC felt that codes of behavior for the meeting had to be established so that what was acceptable and what was unacceptable would be set, such as not interrupting each other. However only one person other than myself showed up. The CMC people had asked that the leader not to attend so that other members of the team could have a chance to voice their feelings freely. Also it is worth noting that by CMC's request, the location of the meeting was to be held away from the leader's office so that at least there would be less appearance of an hierarchical structure in the team. When I asked other members why they had not attended, two people said that they had been too busy, one person had been on vacation, another person made a decision not to attend the meetings anymore, and another two said that they had been unaware of the time of the meeting.

This was the last PM team meeting. The PM team did not meet again.

5.2 Analysis of the PM Team

The rest of the chapter will try to analyze the PM team and find out what factors may have contributed to the apparent problems the team was experiencing. The reader should also understand that organizational development is a difficult and time-consuming process. I used two frameworks to analyze the team-one is "Ingredients to effective work groups" and another is "Problems in Entering a New Group; Self Oriented Behavior." I also discuss difficulties and improvements in policy setting and deployment.

5.2.1 Ingredients to effective work groups [16]

In "Leading Groups in Organizations," Hackman and Richard Walton talk about the necessary ingredients of effective work groups. They say however that there are multiple ways that these ingredients can be provided, and a virtually unlimited number of ways effective groups can choose to operate when they are present. The ingredients are 1) clear, engaging direction 2) an enabling performance environment and 3) adequate material resources.

5.2.1.1 Direction/Purpose

The purpose was to increase up-time of nine pieces of process equipment by 5%, as it was written in the policy deployment. Until the plant manager's walk-through, members had not known that the PM team had anything to do with meeting the objectives stated in the policy deployment. In addition it was to give the members an opportunity to use the "soft" tools provided by CMC and to show them that cultural change was necessary for long term performance improvement in the maintenance of equipment. However what is evident is that the members were confused about the purpose. Nobody in the team could crisply articulate the purpose of the team. Was CMC the main purpose or improvements in

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[16] Hackman, J. R. and Richard E. Walton, "Leading Groups in Organizations," Designing Effective Work Groups, Jossey-Bass Publishers, London, 1986

maintenance? What is the connection between CMC conducted behavioral peer feedback activity and the preventive maintenance team? While the plant manager understood the connection, most members in the team did not see or accept the connection. The meetings were very frequently referred to as the "CMC" meetings, which to most were lower in priority than other tasks they had to fulfill. Organizational development activities are considered an add-on to their jobs, and not integral to their line of work.

The plant's Policy Deployment, as it was written, had only the business center managers (one of which was the leader), maintenance area managers and the maintenance supervisors responsible for reaching these objectives. Therefore with the exception of the maintenance area managers and supervisors, success or failure in achieving the goals was not directly consequential for the team and its members. The people who were not in the maintenance organization felt that they were helping the maintenance organization although it was not their direct responsibility to show progress. For the maintenance organization, it was easier to go around the team and put in improvements themselves without buy-in from the group. They knew that their performance review will be in part based on the improvement in equipment up-time. PM team was only a time sink and hindrance to them. They did not agree with the direction that the group was heading, and they were becoming increasingly frustrated.

In addition, membership except for the maintenance area managers was on the most part voluntary. If it is voluntary, then is the purpose really important to the plant? This gave a flavor of doing something over and above what was required of them-like an extracurricular activity.

The team needed a clear sense of what is expected and why it is important to the overall plant objectives. While details do not have to be completely specified, an overall direction for performance of the PM team would have helped focus the team.

The plant manager recognized that improving the maintenance system would involve addressing the human side and the cultural barriers to change. Therefore he brought in process consultants to help address the issues. However the process consultants could only

help if the group wanted their help in sorting out its problems. The team largely felt that "soft" issues are not important, and therefore process consultant could not assist. The business center managers, particularly the leader, should have managed the confusion and problems, and worked with CMC and the Toyota consultant to clarify any confusion. In addition, they should have spoken with the plant manager openly about their concerns.

5.2.1.2 An enabling performance situation

Groups have to overcome three "hurdles" to achieve their goals. First, they must exert enough effort, second, they must bring adequate levels of knowledge and skill, and third, they must employ task performance strategies. Hackman and Walton refer to these as "process criteria of effectiveness". There are three leverage points, other than issuing pure exhortation and ultimatum, to help address these "hurdles".

A group structure that promotes competent work on the task. Particularly important structural features include:

- ***Task structure.*** The task must be clear, consistent with the direction of the group and must be a meaningful piece of work. The task must be set such that the members share responsibility and accountability and must provides many opportunities for the team to learn how well it is doing. It was unclear how each member of the team would be held accountable for failing to perform in the PM team.

- ***Group composition.*** There should be as few members as possible to get the work done and should have among them the talents required by the task. What job needs to be done and who are the people needed to do it? Many, particularly the maintenance area managers, felt that the group composition was incorrect. Membership needed to include, from the beginning, hourly skill trades and maintenance supervisors whose commitment was needed to implement most of the maintenance improvement projects.

- ***Core norms that regulate member behavior.*** There were no known repercussions for not attending a meeting or for interrupting somebody while speaking. Many disagreements were not aired or dealt with explicitly in group meetings. For example,

the maintenance area managers in paint and trim/chassis/final were unhappy that the team seemed to be focusing on body-in-white improvements. Critical assumptions such as membership and vision/objectives of the team were never challenged. In addition, while many felt the AOS would be unsuccessful due to the lack of commitment by the unions, they were afraid to voice this concern.

Only one person besides myself showed up to the codes of behavior meeting. This shows a lack of commitment from the team members to make this team work. This emphasizes the fact that process development consultants can only be useful if the team members accept the consultants and their inputs.

In addition, the team had different mental models on how the decision making process should be conducted. For example, the leader felt that the process should be based on consensus. Some of the members felt it needed a "benevolent dictator" who would make the "right" decisions after listening to the inputs of the members. The plant manager brought in CMC to work on these issues. CMC should have foreseen the confusion and addressed it.

An organizational context that supports and reinforces excellence. The organizational context can create significant conditions for team effectiveness.

- ***The reward system.*** The reward system should provide recognition and other positive consequences for excellent team performance. The team was unclear as what exactly it was accountable for as a team. This also led to confusion as to what exactly the rewards would be for the team as a whole if it showed improvement. One thing that did help was when the plant manager went on a walk-through to see how maintenance had improved. The plant manager's behavior indicated how important he felt that preventive maintenance was to the plant. However the group that showed the plant manager its maintenance status was not the PM team but the maintenance supervisors.

  There was also a perception that what occurred on the plant floor was far more pressing and important than the meetings. The first line supervisors and the hourly employees

whose participation and buy-in were critical were not required to attend the meetings, and there were not repercussions for missing the meetings.

One of the most important things that is missing is the lack of constant leadership. Although this plant manager had been very interested in improving both cultural change and maintenance, the members of the team and the rest of the maintenance department were not sure how long this interest would last, considering this plant manager was not expected to stay very long at this plant. So there was perhaps some pessimism whether this long term project was going to last very long, and whether the rewards, which would require many risks and devoted time, could be reaped from this project.

It would be untrue to write that there were no rewards to being on the team. The improvement in the behavioral skills may certainly have helped the next performance review for several people. For the production supervisor and production area manager, with increased up-time of equipment there would be increased production. For tooling engineers, with better maintenance this would mean that they would be less called on for help. For the industrial engineer, there may be some productivity benefits to this project. Also, everybody was concerned about the longevity of this plant.

- ***The educational system.*** The team should be provided with technical assistance regarding any aspect of the task for which members do not presently have adequate knowledge, skill and experience. Only a few members in the team had taken the AOS PM classes, so this created a language barrier between those who had taken the class and those who had not. Also, the cascade AOS teachings never reached the members of the team, except the leader. The term, Amcar Operating System, was heard by most, but several, particularly in maintenance, did not know what it really meant. The Amcar Operating System was considered by many as additional work and not an integral part of their every day way of work practice. Some training or coaching on the Amcar Operating System, world class maintenance systems, long term and short planning and on project management would have been helpful.

- ***The information system.*** Support staff to collect up-time data and analyze them were only partly available through an outside vendor. The preventive maintenance coordinator did collect up-time data and analyze them but he was usually very busy and his data was many times late. However, whether this was a serious roadblock to team performance is uncertain to the author.

- ***Available, expert coaching and process assistance.*** Coaching and consultation can help remedy coordination problems and building commitment. They can also provide additional technical and process assistance. If needed, they can help solve implementation problems and foster creativity in strategy development. Although help was available, it was rarely used. Culturally many people at the plant do not like asking outsiders for help. Therefore the technical consultant in particular was not utilized to the fullest extent, although he was available to help. In addition, it was felt that the technical consultant would not understand and would not be empathetic towards the cultural situation at this plant. The process consultant, or CMC, did attend the meetings, but many felt these "soft" issues were just a waste of time.

5.2.1.3 Adequate material resources

The single issue on which the maintenance area managers felt most strongly was their lack of labor resources. They felt that the upper management did not understand their need for more resources, particularly more supervisors and skill trades people, to accommodate the additional work that had to be done for this project. Maintenance area managers felt that they could not meet their objectives given the present manpower numbers. Whether their need is justified or not, I cannot answer. However this feeling among maintenance managers that upper management does not "care" about its needs somehow has to be resolved. This further gives evidence that there was a lack of debate and dialogue, which led to a clear miscommunication with the plant manager and the maintenance organization. The plant manager felt that the need for more resources were being met as much as was possible, by one, the addition of two more supervisors, two, there were 20 more skill trades people in the maintenance department than were allocated by productivity targets, which

then had to be offset in labor in other department, and three, the maintenance department was allowed to run $20-50,000 over budget to do weekend work. The maintenance managers felt that this was not enough given the labor contract and the age of the machines.

5.2.2 Problems in Entering a New Group; Self Oriented Behavior [17]

In Process Consultation, Its role in Organizational Development Volume 1, Ed Schein discusses the process of building and maintaining a group. He writes that when two or more people come together to form a work-task oriented group, there will initially be a period of essentially self-oriented behavior. As self-oriented behavior declines, members begin to pay more attention to each other and to the task at hand. The following section discusses the self-oriented behavior and how the challenges the PM team faced includes the initial team forming phase of self-oriented behavior.

Schein identifies four issues in self oriented behavior in team formation: identity, control and influence, needs and goals, and acceptance and intimacy.

5.2.2.1 Identity

One of the first and foremost issues that a member entering a new group must decide is what role or identity the member should have that is acceptable to both the person and group. Each member needs to answer, "Who and what am I to be in this group?" Every member of the group had a problem with establishing expectations about individual roles in the group. What were the roles of the people outside the maintenance organization? Should these people just provide verbal assistance and guidance or should they be a part of the decision making process? What was the role of the leader? Should the leader be the dominant aggressive leader, the humorous tension reliever, facilitator or the quiet listener? What roles should each maintenance person play in the team? Should they be the drivers of the team?

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[17] Schein, Edgar, Process Consultation, Its Role in Organizational Development, Addison-Wesley Publishing, NY, 1988, chapter 4

5.2.2.2 Control, Power And Influence

Another issue is the distribution of power. The meetings were mainly held in the leader's office. The plant as a whole has a hierarchical, functional structure. There were several levels of hierarchy in the team. The amount of control and influence will vary from member to member and often from time to time. People will test each other out and experiment with different forms of influence in early meetings. It is evident that the members were unsure about participative involvement in decision making and involvement. To what extent the leader should be using his power and authority? Also how much power and influence should the maintenance area managers and the PM coordinator have on the team? Should they be internal experts in the process? These questions needed to be resolved during the early phase of the team formation.

5.2.2.3 Individual Needs and Group Goals

The third issue is the team members' concern that the group goals will not include his/her personal goals and needs. The members in addition may be hesitant about expressing personal needs and goals and may adopt a "wait and see" attitude. If the leader of the group responds to the pressure and sets the goals, that person is only partially solving the problem because that person cannot be sure that the goals that he/she sets will include all the members sufficiently to get them committed to the task. In the PM team, there was much dissatisfaction among the members who were not part of body-in-white because they felt the team was only working on body-in-white issues and their needs were not being addressed. This led to minimal support for the team from members outside the body-in-white area. In addition if the individual needs of some members were to react quickly to issues on the floor and the group goal was to make long term improvements, there will be tension among the group. Until member needs are exposed and shared and then to some point met, it is not possible to have valid group goals.

5.2.2.4 Acceptance and Intimacy

This can be a source of tension until workable norms have been established. It is obvious that there was not much acceptance and intimacy within the group. There were not many instances of harmonizing or compromising among group members during the meeting. There was tension in meetings and a reluctance to admit ignorance or lack of knowledge.

5.2.3 Problems in Policy Deployment

The following section describes the problems and lessons learned in setting and deploying policy. [18]

1. The need to change or to improve has to be felt particularly by those who are expected to implement. The policy was accepted by the middle-lower management as something that they felt they had no control over to change and did not agree with, although they initially had a chance to express their concerns at the town hall meetings. At Hewlett Packard where policy deployment is successfully used, many of the policies are revised by the organization before it is finalized. This brings much more acceptance and commitment into the policies as it becomes "personalized." Much time should be spent building a shared vision by working together to establish the need for change and agree on a plan.

2. Periodic reviews are necessary to make sure that communication is working and expectations and concerns among those involved are addressed. Milestones and "catch-ball" are required throughout the planning and implementation process to ensure that progress is being made, plans are adjusted if needed, encouragement and

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[18] While FTAP clearly had problems with meeting the preventive maintenance objectives in the policy deployment, other initiatives in the policy deployment plan seemed to have worked fairly well. For example, the AOS work in trim for station re-layout was so successful that it became the internal benchmark for station redesign for Amcar. In addition, FTAP was the first where much of the engineering pre-production prototyping was built adjacent to the plant and, for some processes, in the production plant using existing processes. It was useful in identifying problems early before the launch of the product.

support are given, and the barriers to progress are being addressed. Even when plant managers change, long term efforts such as changing maintenance practices need to be fostered consistently and persistently. These periodic reviews need to continue even with leadership changes.

3. Policy deployment also requires a certain type of environment to work. There is a need for open relationship where people are not afraid to express their concerns or disagreements. In addition, the fear of admitting ignorance or failure only causes people to merely execute what is asked of them and saying what they feel their bosses want to hear and not expressing what they really think. In this case the members did not bring up major areas for concern during the town hall meetings. Moreover, the PM group was afraid or reluctant to approach the plant manager and give truthful updates on their progress. Even when it was evident that the goals and objectives of the preventive maintenance system would not be met, nobody within the plant was willing to update the plant manager.

5.3 Conclusion

Many managers at the plant told me that, due to the cultural barrier among hourly people and the local labor laws, the maintenance management system could not be improved. This is in my opinion only partly true. The other part was that the people in the PM team had difficulty working together towards a common goal, due to unclear goals and lack of skills, accountability and motivation. This needs to be resolved even before it tries to overcome the cultural barrier among skill trades.

The situation was made worse because members in the group felt that addressing some of the "soft" issues was not helping solve maintenance issues. The connection between these organizational issues and barriers to progress in maintenance systems needs to be internalized by those involved. In addition, while process consultants could only be useful if the team wanted to be helped in the first place.

6. Barriers to World Class Maintenance Practices

This chapter is based on interviews with the maintenance department, including more than 30 skilled trade people, on maintenance and the Amcar Operation System. In particular, I focused my interviews in the learning lab line which was where much of the implementation efforts were taking place.

Barriers to implementation can be divided into task oriented problems and relationship oriented problems, although the two are often closely related. Task oriented problems include a person who does not share in the view that some crisis needs to be prevented or a problem needs to be solved. There is no apparent gain in this task for that person or group in question, and therefore there is a lack of task related motivation to support the implementation. Relationship oriented problems are associated with the person involved who fails to be motivated because of the relationship he/she shares with the person asking to the completion of the task. Trust is essential but absent in this case.

6.1 Relationship-based Problems

6.1.1 Loss of Power and Control

"AOS is too rigid." Some skill trades were concerned that the standard operating procedure would restrict their work.

Some of the first line supervisors and area managers felt that their control over their subordinates was being lost. They were upset that upper management kept saying listen to the hourly workers but nothing was being said to listen to concerns of the lower management. Also the union seemed to be gaining more power after every contract which made implementing AOS more difficult.

Some supervisors were upset that they are being increasingly forgotten. They used to be asked to give input and approve new equipment sets that were brought into the plant but more and more this function was given to hourly employees. One person felt that since the supervisors were the ones who were ultimately responsible for the equipment they should

be the ones involved in the equipment approval process during launch. In their view, they were doing more administrative work and losing control over their area of responsibility.

6.1.2 Management and Labor Relations

It was not surprising that the one area where least progress was made was where very little trust existed between management and the workers. Managers were trying very hard to implement downtime information data collection in the paint area. However they met much resistance. The paint area is considered one of the most complex and critical areas. This was because if there was stoppage in the line, many cars could get stuck in one of the e-coat tanks and be destroyed. In addition, the equipment shut downs and start-ups were very complicated and required much expertise from particularly the electricians. Therefore the electricians tended to be more experienced and there was less rotation with the other areas. The supervisors, who were relatively new with less than a year at the plant, were dependent on the electricians. Hence the electricians held a lot of power in the area, and they were very suspicious about the motivations behind management to implement AOS. For the electricians in the paint area, AOS was a win-lose situation. Most of them were very opposed to AOS. They felt that it was the management who was trying to exploit them by eliminating jobs and then adding more work to those who remain. The skill trades people did not see much benefit in data collection because they had their own informal communication system from shift to shift. In addition they felt it was the supervisors' job to write reports on downtimes. "What will the supervisors do if we do their jobs?" In the past, the electricians told me that there had been an instance when somebody from management had told the electricians they were not working hard enough based on the fact that the equipment failure documentation did not contain many breakdowns.

6.1.3 Fear of Admitting Ignorance Or Showing Disagreement

Although their inputs were sought when the plant manager's staff were working on the policy deployment plan, the maintenance area managers and supervisors failed to voice that they did not believe that they could attain the preventive maintenance goals. Some felt they felt "forced" to agree with the goals by "upper management" despite the fact that they did

not feel they could meet the goals. In the same way, some of them felt that they were forced to join the PM team.

I believe much of this is caused by communication breakdown or lack of relationship building in the organization. I believe that this fear of repercussion or embarrassment from telling the truth is a major culture problem in this plant. People, particularly in the middle to lower management levels, do not feel comfortable about bringing bad news to their bosses or being completely open with them about their own concerns. This subsequently leads to misunderstanding, unmet expectations and suspicion in relationships. Subordinates may wish to withhold information or feelings from their bosses because they do not wish to expose themselves or to be punished for saying possibly unpleasant things or things they believe others do not wish to hear. Often subordinates will respond only with vague statements that "everything is all right" because they do not wish to be embarrassed in front of their peers by admitting problems. Consequently, for problem solving, such an organization can be ineffective and even counterproductive, and becomes a severe inhibitor to becoming a learning organization.[19] Even if the current stream of plant managers insist that they are open to suggestions and feedback, the people who report to them do not believe this if there has been a long history of plant managers who managed in an authoritarian manner. It will take time and consistent reinforcement of behaviors to change this view.

6.2 Task-oriented Problems

6.2.1 Lack of Goal Setting and Planning

The following comments were given by managers and supervisors when I asked about the status of maintenance:

- Some did not know what the goals were. Is it up-time? World class maintenance? Visual Management? What does he [plant manager] want? (Notice that there is much

[19] Schein, Edgar, Organizational Psychology, Addison-Wesley Publishing, NY, 1988, page 155

emphasis on what the plant manager wants, not what the plant needs. This hints at a very hierarchical structure.)

- Many did not know whether they achieved their goal or not, because they were not collecting downtime data from equipment sets.

- Most did not know how to achieve the goal and had no plan.

Several area managers and supervisors felt that they did not agree with the metrics that were "thrust" upon them. They did not see the need for calculating MTTR (mean-time-to-repair) and MTBF (mean-time-between-failure), and they felt that the numbers gave useless, misleading information, particularly MTTR. Some skill trades people who were collecting the data did not know what it was used for. They felt it was useless and was probably for upper management. This indicates a lack of understanding for the metrics that were set to achieve goals in improving equipment up-time.

6.2.2 Lack of Buy-in To Improving Maintenance Through Adopting and Adapting World Class Methodologies.

The lack of support or motivation to work towards the plant goals of improving maintenance was very evident. The following statements summarizes their sentiments:

- Several supervisors felt that AOS was just a waste of time with just more paper work. They just saw it as more work without gain. They did not see why they had to do some of the things they were told to do, such as post up PM sheets. The skill trades people also did not see much benefit from charting or checking off PM when they are completed. "Charts are a waste of time. They mean nothing to me. I am here to fix machines not make pretty charts."

- According to several managers the time pressures on the floor were too great for them to work on improving world class maintenance practices.

- The plant was at 95% up-time already which was world class and therefore it would be too difficult to improve. The percentage of completed PM's was higher than 90%,

which was much better than the other Amcar plants. Some supervisors and even managers felt that there was no real need for a PM team. The up-time was good enough compared with other Amcar plants.[20]

- Given labor relations, they did not feel that some of the world class maintenance practices could be implemented at the plant. Managers felt that as soon as there were lay-offs because of efficiencies that were gained, the hourly people and the union would no longer support the effort.

Many were pessimistic about the constancy of purpose. The current plant manager was not expected to remain for very long. Therefore there was widespread feeling that AOS itself was not going to last very long. Putting much time into this may be just a waste. "We have had a zillion plant managers, each bringing their own pet projects. AOS is an example."

It is apparent that much time needs to be spent publicizing and educating the people who are affected by AOS. The people collecting the data need to be informed how the data is being used and how they can play a part in systematically solving problems. Also in many cases the tools are not being used properly. The PM sheets that were posted were not checked, and therefore unmarked PM sheets frequently went unnoticed in the learning lab line. In addition, if even the maintenance management does not believe in the benefits of MTTR and MTBF, is it reasonable to expect that there will be much buy-in from the people on the floor?

6.2.3 Lack of Training

One of the maintenance managers said, "Leaders were saying, 'Go implement AOS,' but really nobody knows what AOS is. Management told us to establish MTTR, MTBF, go

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[20] As only 3 equipment sets were collecting any downtime data, it was uncertain what the downtimes were for the rest of the equipment sets in the plant. Also it is very difficult to compare performance among plants. This plant was highly manual with very few robots. Also this plant only produces about two thirds the full capacity due to low demand for the product, with takt time of about 2 minutes which is very slow compared with modern automotive plant facilities.

clean machines but really nobody knows why, or what AOS even is... Somebody said you've got to clean everything. But nobody told us why the equipment had to be clean. How clean is clean? Nobody had defined it. Why are we cleaning? The [AOS PM] focused training is a bit late. AOS started last March. It should have come earlier. Wouldn't it have been better to establish what we want to do first and determine where we are going? We should have had a business plan on preventive maintenance. AOS will not be successful because it is not being handled properly. AOS was supposed to be cascaded down so that the implementers were supposed to get the training too. How come the higher ups are getting the training but the actual implementers are not? Isn't it more important for the implementers to have the understanding and reasoning to implement?"

However one of the area managers disagreed. He said that there was no need for anybody else to tell them what to do. They could figure it out themselves. Besides even if they did ask, he doubted that the plant manager would tell them how to implement it. Either the plant manager did not know how to implement or expected them to figure it out themselves.

Only the business center managers had received the formal AOS teach courses. While some middle managers in production had AOS classes, almost none of the middle to lower managers had any sort of AOS training. The topic focused PM training was provided to some managers and supervisors, although this should have been provided much earlier, before the PM team was even formed. However even this does not give the students an overall systems view on AOS. This seems to indicate that upper management feels that middle to lower management just needs to worry about implementation, and not understand the need to implement at all or how their work fit into the framework of AOS.

6.2.4 Lack of Worker Involvement

The success of implementation is highly dependent on how the plan and execution of that plan is accepted by those who are affected. In addition, changing to world class maintenance standards is a long term strategy which involves fundamental changes in the way employees think and operate at work. Therefore participative decision making and

planning become critical. More buy-in would be possible if more participation was encouraged in the decision making from the supervisors and hourly employees.

For instance, supervisors from the night shift did not even know that there was a PM team. They felt that they were not being involved in the decision making of implementing world class preventive maintenance although they were on the shift when most the PM's were being performed.

Town hall meetings for maintenance were held for some time but from the perspective of the skill trades people nothing came out of it. When town hall meetings were held and some concerns were voiced, managers did not address the problems. For example, they raised an issue that operators were resetting steppers which affected weld quality negatively, but this was not addressed. The skilled workers perception was that town hall meetings were not really to get them involved but that management had their own agenda.[21] When the skill trades workers' needs were not aligned with what management wanted or thought was important, they felt that management would ignore their inputs. In addition, the town hall meetings were on the most part not publicized very well, so some did not even know that it was going to be held. After a while, town hall meetings for skill trades disappeared.

Formal root cause analysis of downtimes was done mostly by supervisors and area managers, with minimal involvement from hourly employees. Meetings on downtimes had poor attendance by supervisors and management. The hourly employees were not invited to these meetings. In addition, the PM team made only minimal effort to include participation from the workers and from the union. Ideally, the team should have included the workers from the beginning, so that they could have been part of the team forming process. Since decisions would most closely impact them, their involvement would have helped in gaining acceptance from the workers during the try-out period and implementation. Only one supervisor was included in the team. This supervisor attended the meetings intermittently. It was obvious by the problems that occurred in trying to clean some of the fixtures that

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[21] This issue was addressed several months later by the weld quality improvement group.

there was insufficient communication between the PM team members, and the supervisors and hourly workers, inside and outside the meetings.

6.2.5 Firefighter-hero mentality

"I feel a high whenever I'm at a[n equipment] breakdown. I like having a lot of breakdowns because it makes me feel useful." When there is a major breakdown, a small group of maintenance workers crowd around the piece of equipment. The size of this group increases as the impact to production increases. The number of maintenance supervisors also grows and so do the number of maintenance area managers who come to see if they can somehow lend a hand. The effected production supervisors and area managers look on. When there is an extended breakdown, even the business center manager comes over to check on the status. This is high pressure time, and those workers that are able to troubleshoot the problem are commended by management. Also they are recognized by their peers for their technical expertise and their rapid response. People are rarely rewarded for maintaining pieces of equipment that have good up-time. This has the potential for acting as a disincentive for improving downtimes. Whether this is true in this plant is uncertain to me.

6.2.6 Job Elimination

The goal of AOS is to improve productivity and quality. Everybody, management and hourly employees who were interviewed, were sure that people would be laid off as a result of AOS. As up-time increases, less people would be required to maintain and repair the machines. Managers were concerned that as soon as some hourly workers were laid off, others would refuse to support AOS.

Several first line supervisors felt that their jobs were going to be reduced as worker involvement increased. They could see that already there were not as many supervisors as there had been before. In many cases, they felt more unprotected than the hourly employees because at least the hourly workers had the labor union behind them.

6.3 Conclusion

As shown above, this plant faces many challenges, some task related and some cultural related issues, in improving maintenance practices. These barriers will need to be addressed in developing a strategy for improved maintenance.

7. Strategy for Improving Maintenance Practices

Any project that requires cultural change will be challenging and time consuming, with no simple solution. The challenges with implementing change in maintenance practices particularly in a brown field such as FTAP are numerous and difficult, and I cannot even pretend to have all the answers. The shear number of publications written about change management and about implementing total productive maintenance bear evidence that this is not a simple problem with a simple solution. It is also worth noting that FTAP is not unusual in its problems with change management. In this chapter, I offer some suggestions for upper management based on my observations and literature search.

7.1 Some Mechanisms Available to Upper Management for Cultural Change in Brown Field Organization

In this section, I discuss mechanisms that are available to the leadership to change an organizational culture, using Shein's Organizational Culture and Leadership.[22] Some mechanisms are already at play at FTAP.

7.1.1 Change Through Organization Development-The Creation of a Parallel Learning System

Many managers and supervisors in maintenance feel that AOS will fail. In addition many of the hourly workers do not see AOS improving maintenance practices but merely adding more work for them. By using the learning lab line, people involved will be able to see where AOS fails and where AOS is successful. In addition, successes seen in the learning lab line has made it easier to proliferate to neighboring areas, where skill trades people through routine rotation have been able to spread the learning. The learning lab line is then also a good way to publicize AOS.

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[22] Schein, Edgar, Organizational Culture and Leadership, Jossey-Bass Inc., San Francisco, CA, Second edition, Chapter 16

In order for AOS to be successful using the learning lab lines, there has to be constant activity and change in the learning lab line with attention and publicity given to the efforts and achievements of those involved. If there is no change, or change is slow with very little improvement, then the learning lab line becomes "proof" to the pessimists that AOS does not work. Failure is only temporary as long as there is persistence to make the system better. Many skill trades people were asking what fundamental improvements AOS have achieved. All they see is their work has increased and how their control of how they work was becoming restricted.

7.1.2 Change Through Technological Seduction

Amcar uses educational interventions to introduce both social and technical concepts and methodologies to bring about cultural change. Amcar uses many concepts from Senge's The Fifth Discipline to change the way people think and work.[23] They are taught to challenge their mental models and become systems thinkers. They are encouraged to develop their own personal mastery and also a shared vision among groups, organizations and communities. In addition, the Toyota Production System concepts and language are taught and enforced. The hope is that gradually people will develop a common frame of reference that will eventually lead to common assumptions. As the organization builds up experience and resolves crises successfully, new shared assumptions gradually evolve.

The danger of employing this strategy is, if the change is too esoteric or out of the cultural context of the environment to which it is introduced, then the change isolates some groups of people. It creates a language barrier for people who do not understand or who have not been exposed to it. It can even become threatening for these people because they feel that they are not a part of this change. Some maintenance managers were unimpressed by the organizational learning teachings and felt it was a waste of time. The language and concepts must be appealing and be taught to all levels of the organization so that they can relate to the change and understand it.

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[23] Senge, Peter, The Fifth Discipline, Bantam Doubleday Dell Publishing Group, Inc., NY, NY, 1990

7.1.3 Change Through Systematic Promotion

Amcar as a corporation and FTAP as an individual plant use systematic promotion of subcultures to proliferate the "AOS" culture. The VP of Manufacturing has set up the AOS system so that there is a AOS specialist in each plant. This person who is in charge of organizing, teaching and implementing AOS reports directly to the plant manager. This signifies that the VP of Manufacturing is serious about AOS. The plant manager at FTAP has consistently rewarded people who implemented AOS concepts. The upper management now needs to promote AOS implementation in maintenance by consistently rewarding those in maintenance who take risks, apply effort, and improve maintenance practices.

7.1.4 Managed Change Through Infusion of Outsiders

At FTAP, there are some signs that it is trying to inject some outsiders that will be change-agents. This occurs during the hiring process, when people with experience in the Toyota-like production system are given priority over people without the experience. In addition, outsiders (some within Amcar and some from outside Amcar) are brought into jobs below the top-management level and are given the opportunity to educate and reshape management's thinking. This will be very helpful in that this will be "showing by doing." Also, without having to wait for teachings and policies to cascade down the organization, which tends to lose information in the process, planting members who share the same vision as the leader can be more effective and faster. However, attracting new talent to an under-invested plant that manufactures a mature product with low technology is challenging. In addition, this person needs to be able to speak in both languages and fit into both cultures. This person will need to fit into the existing culture and influence the members with whom he/she works, and yet be able to be an outsider enough to be objective and see where the organization needs to go.

In addition, consultants are available at Amcar by the AOS department to the plants to help people learn about how Toyota runs their manufacturing systems. However, the consultants are not being used effectively particularly by the maintenance department. This may be due to the fact that there is a tendency to dislike asking outsiders for help or admitting ignorance about a particular subject. In order for the maintenance to be a learning organization, it

cannot be afraid of admitting ignorance or getting help where available. Upper management should take a lead in demonstrating that admitting ignorance is nothing to be shameful.

7.1.5 Change Through Turnarounds

Change through turnarounds involves several conditions for change. First is that the organization must recognize that some of its past ways of thinking and working are indeed obsolete and must change. The organization must be "unfrozen". This could be driven by external realities that threaten organizational survival. However the threat must be real because otherwise it will be perceived as just a motivational tool.

If some parts of the organization can be "unfrozen," change is possible if there is a turnaround manager or team with a consistent and clear sense of direction for the organization, a model of how to change culture to get there and the power to implement the model. This is difficult because, while Amcar is trying to incorporate the positive aspects of the Toyota Production System, it does not know exactly what the model looks like, since Amcar does not want to just blindly copy Toyota. As the Amcar Operating System gathers growing enthusiasm, there is also increasing diversity and polarization which leads to conflicting visions. As the PM team experienced, there were different mental models of what the approach and ultimate goal should be for the PM team. If there is not a sufficient ability within the organization to inquire into and harmonize diversity, the vision will no longer be shared, and conflicts will limit the growth of enthusiasm. The visioning process during this change process should involve an inquiry process which will lead to redefining and clarifying the vision.

7.1.6 Change Through Coercive Persuasion

Use of coercive persuasion strategy can be dangerous because plant managers have not lasted very long at the plant and, in the past, policies have not lasted very long. The essence of this mechanism is that the turnaround manager retains his/her power indefinitely, thus preventing members of the organization from developing a strategy of just waiting until he or she is gone. Unless there is seamless continuation of leadership at the plant manager

level, people in the organization will be in a "holding pattern." History at FTAP makes it difficult for leaders to use coercive persuasion as the main strategy, and it will only bring compliance and subversive resistance. In addition, the hourly workers are on the most part protected by the labor union. Moreover, many employees will soon be retiring and may therefore opt to wait it out until retirement which will undermine the coercive persuasion strategy.

7.1.7 Change Through Reorganization and Rebirth

FTAP should not use reorganization and rebirth strategy which is a process in which most employees are replaced on a large scale with other people who are new to the organization and who share the leader's vision. The culture is destroyed by physically destroying the organization. This would not be consistent with Amcar's belief that through persistence and education, it can slowly but permanently transform a brown field plant like FTAP. This "wipe-out and start-over" process of change is often traumatic for many people involved. Therefore it is not commonly used as a deliberate strategy, but it may be appropriate if economic survival is at stake.

However this method could be employed to a smaller degree. An organization can provide awareness or behavior-modification training but whether fundamental values that individuals hold can be changed is questionable. When all else fails, the leader may have to consider replacing them. This does not have to mean demotion or termination, but may mean that they are transferred laterally to other positions that are less likely to bring about conflict.

7.2 Relationship-based Solutions

7.2.1 Consistency in Leadership

FTAP has had 12 plant managers in a period of 20 years. While AOS has a good vision, it requires capable and visionary leaders who are in top positions for long periods of time to make it work. Plant managers need to cultivate and maintain relationships with their people which is difficult to do if plant managers work there for only a couple of years or less. There is a strong need to build trust among the workers before long term change occurs.

There needs to be a better system for continuing policies even when plant managers change, particularly if the change that is required is as big as AOS. Otherwise, the organization will be confused and only pay attention to short term goals and not long term ones. The prevalent feeling at FTAP is that AOS is just the flavor of the month. This will only breed compliance and not commitment to company goals.

7.2.2 Maintenance of Relationships and Supervision

Just as equipment needs maintenance, so do humans. Consistent and persistent follow-up is needed to see if the team and the maintenance organization are moving towards the plan. According to interviews with supervisors and middle managers, management spends little time discussing with subordinates about the progress towards meeting goals and objectives. Management needs to spend more time with its subordinates, discussing long term plans and progress and how each one is contributing, or *not* contributing, to the plants' goals and objectives. They need to also provide coaching and feedback. This would also allow plans to be modified or adjusted according to progress.

7.2.3 Relationship Building Through Dialog and Inquiry

With the help of Process Consultants the maintenance organization and other groups with which it works can learn about the essence of dialogue and inquiry. Peter Senge advocates Personal Mastery, System Dynamics, Mental models, Shared Vision, and Team Learning in his book, The Fifth Discipline. Improving relationships between management levels, between management and labor, and between functional areas is important to improving maintenance. Breaking down distrust can begin by initiating dialogues between groups that are focused on a specific problem, such as a specific equipment problem. However it is essential to have somebody who can "translate" Peter Senge's language to maintenance talk and teach them how to apply it. The technical jargon of The Fifth Discipline such as mental maps and "right hand column and left hand column" do not sound useful to maintenance's work function.

7.2.4 Treatment of Outsiders

An organization that does not like outsiders cannot be a learning environment. If the group does not know how to do something internally it must look externally. Technical experts in world class maintenance systems were available but not used effectively. Organizational development consultants should help the organization create an environment in which people will accept outside expertise that it does not have itself. In early 1996, there was an example within the plant where it was successful in using outside help. The first leg of trim which was driven mainly by the production group was able to significantly improve material delivery and station layout through the use of a consultant who knew the Toyota Production System well and who could help the group. It seems that this group were more receptive to outside help.

7.2.5 Redefinition in Roles and Relationships

The transition to new roles needs to be nurtured by upper management so that it is not too traumatic for those involved. In addition training should be provided so that needed skills can be developed. Jobs are being redefined continually in the change process. The new or changed responsibilities cannot be achieved at one time. For example see Figure 7.1 which describes new job roles for autonomous maintenance. Having consistent leadership is important for this reason as well. In addition, these roles have to be structured and introduced in such a way that there is an incentive for them to assume these new roles. For instance the supervisor cannot perceive his new role as a loss of power to skill trades people and his job reduced to mere administrative work. He needs to see his job as one that gives him more influence such as organizing small group activities and driving continuous improvement projects by communicating performance results to his group.

Figure 7.1 Autonomous Maintenance Work Activity Changes (Adapted from Implementing TPM The North American Experience by Charles J. Robinson and Andrew P. Ginder)

Job Title	Present Work Responsibilities	Additional Responsibilities After Autonomous Maintenance
Production Operator	Operate machine. Report machine malfunctions.	Accept ownership of machine. Maintain machine cleanliness. Maintain organized work environment. Perform machine checks and simple PM tasks. Log and trend machine performance. Participate in small group activities.
Skilled Trades Person	Perform machine checks/adjustments. Replace worn parts. Lubricate machine. Respond to machine shutdowns. Repair/replace broken components. Rebuild/overhaul machine.	Maintain and review equipment histories, including performance. Analyze equipment failures for root cause identification. Specify equipment modifications to increase performance. Interface directly with machine suppliers to increase performance. Specify PM requirements. Train production operators in PM activities. Participate in small group activities.

Plant Engineer	Specify machinery changes. Interface with machine supplier. Specify new machinery. Specify PM tasks. Specify part requirements.	Define plant engineering strategies. Coordinate operating philosophies. Benchmark equipment performance. Participate in small group activities.
First-line Maintenance Supervisor	Manage PM tasks. Coordinate breakdowns. Conducts root cause analysis. Monitor equipment performance.	Lead small group activities. Consolidate equipment performance measureables. Communicate performance results to plant management. Communicate plant management's strategic intent to small groups.
First-line Production Supervisor	Manage production operators. Manage production schedule.	Lead small group activities. Consolidate production performance measureables. Communicate performance results to plant management. Communicate plant management's strategic intent to small groups.

7.3 Task-Oriented Solutions

7.3.1 Goal Setting and Planning

Getting buy-in begins with effective policy deployment. Setting goals and purpose are important for the preventive maintenance team and the maintenance organization as a whole. Extensive time must be spent on the problem formulation and establishing the need for change. The time spent here will help bring commitment from the people responsible for bringing about the change. The policy deployment relies on open communication between boss and subordinate so that realistic goals are set, expectations are clear, and commitment for the program is built.

Workshops may be helpful initially to get people together to discuss problems in maintenance and formulate a plan. A similar workshop at FTAP in 1995 was held to formulate a business plan for 1996 cost improvements. It was a 3 day workshop of 40 people, including supervisors and area managers. This led to a cost reduction of 7.9% in 1996, as opposed to the 2.9% in 1995. This workshop was a critical contributor of achieving the cost performance. See "Preventive Maintenance Workshops" in Appendix A which describes an example on how workshops could be used to improve preventive maintenance.

7.3.2 Flexibility

Many people in the maintenance department including skill trades people feel that AOS is rigid and inflexible. Implementation within this culture will involve selling and negotiating, particularly with the hourly employees. Forcing the maintenance organization to conform to all the rigid maintenance practices in Toyota will lead to resistance. While intent on not losing the essence of the maintenance practices, managers should be flexible in the implementation and practice of some of the world class maintenance tools. The maintenance department should be allowed to have some control over how the implementation is done. FTAP will not need to copy exactly how other plants are implementing AOS, because being the only producer of big vans, not much coordination is needed. However what is more important is that there is a standard within

the plant across departments. This way the learning can be shared within the plant more easily. It is up to the leader of the team and the AOS specialist, with guidance from the plant manager, to determine what is flexible and what is not, so that the meaning is not lost.

7.3.3 Worker Involvement

Worker participation is important for maintenance because their acceptance in the program is needed for success. However worker participation should be handled in a very careful manner not to threaten or alienate middle to lower management. Middle to lower management need to be strategic and tactical planners. In addition their relationship with the factory floor workers largely determines whether the program will work. There should be a clear understanding by management which types of decisions will be made in a participatory manner and which types will be made by a select person or group.

7.3.4 Incentives

There needs to be added incentives for participation in the PM team and implementing world class preventative maintenance practices as a team. For example, the plant manager should at some frequency attend the team meetings to show encouragement and endorsement in the process. There should also be incentives for managers to implement AOS. Even when plant managers change, people need to be consistently rewarded for types of behavior and results that Amcar wants to develop. They should not only be rewarded for taking the class or attending a workshop, but should be rewarded for the results that are produced from the class and the workshops. In addition, supervisors should not view AOS as eliminating their own jobs but they should view AOS as a way to get their jobs done more effectively and efficiently, or even get promoted in some cases.

In addition, skill trades should have incentives to support and participate in the AOS implementation. This may include management giving systematic recognition, or providing skill trades more control over how the maintenance work is managed or coordinated. In addition, they can be given some control over how the change process is handled. (This matter should be handled gingerly, because the first line supervisor's role should be clearly

defined so that they do not feel left out.) When improvement is shown from the change, the organization should celebrate its success.

Recognition should be given to those who put in long term fixes, instead of people who put out the fires. Root cause analysis should be the driver of recognition and not short fixes of breakdowns.

7.3.5 Implementation team with the right people.

The team should focus on one area, or at most one area per division, with a **small** core group with the ***right*** members, not just available members. The right members should include some first line supervisors and skill trades people. The plant manager should give the team the power to make changes but ask for progress at an agreed upon frequency. He/she should be clear what results are going to be expected and **why**. The team needs to develop into strong believers in the program, who can also influence, teach, negotiate and sell the program to the rest of the organization.

In addition, at a minimum there should be an expert in world class maintenance who is a vital member of the team who can provide technical guidance into the team. This expert who is chosen to be part of the team may be picked from within the plant or externally. Whether chosen externally or internally, this person should be well liked and respected by the maintenance staff. If internally selected, this person could learn from an outside consultant (such as the ones available through the AOS department) who is experienced in world class maintenance practices. This person should also go through intensive training on AOS / PM implementation by visiting other plants with good maintenance practices. Choosing from within FTAP, or preferably within the maintenance organization, would be more attractive than searching externally because the person may be more accepted by others. However, if a person cannot be chosen internally, then an outside consultant can be a member of a team, though special care must be taken to properly assimilate the consultant into the team, and avoid using the consultant intermittently or sporadically without building a long term (though not an overly dependent) relationship with the consultant.

7.3.6 Fear of Job Elimination

I believe that people cannot take part in projects they feel will negatively effect their own or their peers' livelihood. If job elimination is the motivation behind projects, then the projects cannot be based on employee-involvement. If employee involvement is absent, then long sustainable changes towards world class maintenance systems cannot be achieved.

7.3.7 Training

The area managers need to take the basic AOS classes that illustrate the AOS framework so that they understand how preventative maintenance fits into AOS and so that they see the importance of their work in reaching corporate goals. Preventative maintenance is one of the most fundamental building blocks of AOS. The middle managers' understanding of and commitment to AOS are critical in the process of change. They need to buy into the AOS concepts before they can coach and encourage their subordinates in AOS implementation.

In addition, they need to take a more active role in teaching and training of the world class maintenance practices to the lower level management and hourly employees. Their participation in the AOS PM class was positive in that it indicated to their subordinates that the managers cared enough to take the class with them. The class was also helpful in that the homework forced area managers to work with skill trades people and it provoked much discussions and feedback about the maintenance organization. The leaders in the maintenance group should take more steps in sending out a message that they do believe in AOS and take it seriously. Some of the negative impression that many of the skill trades have about AOS comes from poor execution of AOS tools and misunderstanding of AOS from middle management. For example, breakdown time recordings and chartings are considered a "waste of time" by skill trades because they do not know how it is being used, if at all. Also some tried to force the implementation without consultation with the skill trades which only brought resistance.

Some form of AOS cascade teaching to the middle managers and lower level managers will be helpful in 1) internalizing the teachings 2) forcing those who are teaching to walk

the talk (role modeling). 3) signaling to subordinates that their subordinates also feel that it is important, 4) teaching in a language that the subordinates can relate to, and 5) teaching managers to take on the role of teachers and coaches. By teaching they will come to know that their roles are changing. They are to become coaches and coordinators in the change process.

Some training or best practice sharing on improving middle to lower management skills in planning, management, leadership and implementation may be helpful. Also some training in labor relations management should be offered. In this case inserting role models into the organization would be very advantageous as well so that people could actually see some of the concepts and skills in use.

7.4 Conclusion

For implementation of better preventive maintenance, the important elements to success are:

- Realization that "soft" organizational issues are just as important as hard technical issues, if not more so, to successfully adopt better maintenance practices in brown field manufacturing organizations. Relationships and building trust are critical to achieving success. In addition, fear or reluctance to discuss bad news in an open manner can hinder progress.

- Management's role is to clearly define the maintenance organization's purpose and expectations and to make sure the incentives are clearly aligned with the plant's goals and objectives. It should also request for periodic updates to monitor and provide encouragement.

- World class maintenance cannot be exactly copied in this organization. Coercion will not work, because it will only bring compliance or subversive resistance. Acceptance and understanding in the changes by the organization are more important than exactly copying world class maintenance practices. Also, labor union contracts prohibit some work practices that are considered world class maintenance practices. Flexibility is key.

- Constancy in leadership is necessary for long term sustainable change. The AOS framework is a good start but leaders are needed for implementation. Leaders need to stay in one plant long enough to establish relationships and trust among the employees and the union. Only this way will leaders be able to implement long term changes. The seeming paradox is that stability is needed for long term changes. No number of process development consultants can substitute for leadership.

The value of Plan-Do-Check-Act is persistence and discipline. I believe that this is a simple but a powerful asset that many of the plants with world class manufacturing systems have. There are no quick fixes. The learning comes from past experiences and from learning from others' experiences. The PM team was the first step towards implementing change in maintenance practices on a wide scale. It was not a failure if the members learn from what happened and try again incorporating the learning that they experienced. It was a failure, if there was no learning from this effort and if no more effort is spent in further improving maintenance practices by making systems changes.

Appendix A. FTAP Policy Deployment (1996)

(Robust, Capable & In-Control Processes)

Staff Ranking	Core objective	Management Owner[24]	Implementation Strategies	Measurement	Target[25]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
1	1997/1998 Launch		1) Organizational structure to support coordination of current and new model activities.	Number of people -systems coverage Product / Process issue resolution as related to current & new		S,Q,C
			2) Pilot builds at FTAP: F1, (P0, C1, and PVP)-including workforce, pilot facilities, support infrastructure.	MTS regarding: BITS/CN's- QTY/Resolution Workstations ergonomics/safety		
			3) Launch curves-1997 & 1998			

[24] Names have been removed.

[25] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Robust, Capable & In-Control Processes)

Staff Ranking	Core objective	Management Owner	Implementation Strategies	Measurement	Target short term; long term	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
2	PM Program	(Body in White/Paint Business Center manager)				
		(Business center manager, Human Resources Manager, a maintenance area manager)	1) Establish trades training committee to develop training to address immediate needs and prepare for 1998 MY technology. Implementation includes needs assessment, timing, procurement of budget and deliverables, and joint elimination of obstacles	▲ - MTTR ✓ - Weld audit (penetration) ▲ - # hours bypassing primary equipment	5% ; 20% 10% ; 50% 5% ; 20%	S, Q, C, D, M
		(Maintenance Area Managers)	2) Improve up-time on key processes Supv1 Supv2 Supv3 Framer Cowl Weld guns Booth Conv. Trim hoist Tire machine Rolls Fill Equipment	▲- MTBF ▲- # of PM sheets improved ✓ - PM completion ✓ - Hours B & D short shift	5%; 10% 10%; 25% 95%; 100% 95%;100%	S, Q, C, D, M
		(PM Coordinator)	3) Effective downtime analysis and root cause analysis by center/major equipment	✓ - % up-time ▲ - Average time to close open corrective action	5%; 10% 5% ; 25%	Q, C, D
		(PM Coordinator and Maintenance Area Managers)	4) Implement computerized PM system providing flexibility (in activities, frequency), on-line completion and updates.	Exclusive operation of PM program with computerized system	0%; 100%	C, D, M

✓ = Existing measurement

▲= New measurement

FTAP Policy Deployment (1996)

(Robust, Capable & In-Control Processes)

Staff Ranking	Core objective	Management Owner[26]	Implementation Strategies	Measurement	Target short term; long term[27]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
3	Continuous quality improvement					
			1) Identify critical processes by zone based upon First-Time-Capability and external indicators.	SPC for controllable processes		Q, C, D, M
			2) Repair and inspection reduction	# of repairmen		Q, C
			3) Bi-weekly quality initiative meeting	0-2 MIS warranty, IQS, CSA, Spec J.D.Power		Q, C, D
			4) Measure First-Time-Capability and establish plans for specific issues	True Zone First-Time-Capability		Q, C

[26] Names have been removed.

[27] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Robust, Capable & In-Control Processes)

Staff Ranking	Core objective	Management Owner[28]	Implementation Strategies	Measurement	Target short term; long term[29]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
4	Reduce process variation					
			1)VRT for BIW parts	-# open issues -Open: closed ratio		Q, C, D, M
			2) BIW dimensional control of build variation	CII Door warranty 0-2 MIS C/100		Q, C, D, M
			3) Five critical processes plant wide • Weld penetration • LLL cowl framer up-time • Interior rear trim panel "v" gap • Weather-strip right front door • Exterior molding fit	Variation (as defined by process owner) • Chisel check • % up-time • Q.A. Line (C's)/day • Cert line (C's)/day • Q.A. line (C's)/day		Q, C, D, M
			4) Develop and implement measurement strategy for the 98 van • Measure F0/F1 build • Launch DEA by 4/15/96 • Data management system installed by 97 V-1 • Perceptron launched by 97 V-1	• Support pilot timing • Time to launch • Time to launch Time to launch		Q, D, M

[28] Names have been removed.

[29] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Human Infrastructure)

Staff Ranking	Core objective	Management Owner[30]	Implementation Strategies	Measurement	Target short term; long term[31]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
5	Improve employee relations & morale		Communication plan 1) Establish cross-divisional comm. team. 2) Town hall meetings (hourly) 3) Town hall meetings (salary) 4) Skip level meetings (hourly & salary) 5) Video presentations 6) Paycheck messages 7) Vanews 8) Amcar employee network 9) Culture feedback surveys	% improvement culture survey (use 1994 as a baseline)		S, Q, C, M
			Employee involvement 1) Absenteeism program 2) New hire orientation Study/Propose 3) Quality circles Study/Propose	Percent absent/# of absenteeism		S, Q, C, D, M
			Miscellaneous 1) Company store 2) Open house 3) Cafeteria upgrade 4) Communication center Study/Propose	Subsidy reduction		M

[30] Names have been removed.

[31] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Human Infrastructure)

Staff Ranking	Core objective	Management Owner[32]	Implementation Strategies	Measurement	Target short term; long term[33]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
6	Canadian Auto Workers' Partnership Plans		1) Effective negotiation preparation -Name technical advisor for local negotiations -Review/evaluate current local agreement/past practices -Formulate management proposals with expected benefit -Review anticipated union demands and formulate management position	Establish team Weekly meetings Weekly meetings Weekly meetings		Q, C, D, M
			2) Insourcing vs. outsourcing -Review outsourcing criteria with staff -Evaluation of current/anticipated sourcing initiatives -Review sourcing plan with CAW -Establish joint sourcing committee	Monthly meetings Monthly meetings		C, D, M

[32] Names have been removed.

[33] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Human Infrastructure)

Staff Ranking	Core objective	Management Owner[34]	Implementation Strategies	Measurement	Target short term; long term[35]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
7	Improve salary effectiveness		1) HRM committee -Cross-functional development -Diversity planning -Development needed plans	Bi-monthly meeting # moves # openings/placements completion of plan		Q, C, M
			2) Needs assessment and training -Salary training program to be developed/implemented -Current needs/'98 needs	Committee established Training begin		S, Q, C, D, M
			3) Communication/awareness -Salary town hall meetings -Skip-level meetings -Change management consultants -Interim appraisal process	# meetings Monthly meetings Bi-Annual meeting Feedback meeting		S, Q, C, D, M

[34] Names have been removed.

[35] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Value-Added Activities and Human Infrastructure)

Staff Ranking	Core objective	Management Owner[36]	Implementation Strategies	Measurement	Target short term; long term[37]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
8	AOS implementation and training		1) Conduct 36 workshops to support A) 1998 process B) Learning Lab Line activity C) Creation of focus area D) General topics as developed	# Done pre-production # Done trim # Done LLL # Done general		S, Q, C, D, M
			2) Develop administrative Standard Operating Procedures Develop production process Standard Operating Procedures	Attribute charts Attribute charts		Q, C, D, M
			3) AOS executive education and LLL implementation	% Complete on Gantt chart on LLL		Q, C, D, M
			4) Rear seat central material area (CMA) Department 9721 central material areas (CMA's)	# Hours of material on the line # Hours of material on the line. Number of work stations revised. Number of container pack sizes changed.		S, M
			5) A) 9721 Focus area to be developed as ideal area for material delivery, central material area, and station layout. B) Improve FTC in 9721 C) Implement CMA to support 9721 focus area	CAW buy-in to support concept in other areas. TBD # Hours of material on line # Container pack size changes		

[36] Names have been removed.

[37] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Value-Added Activities)

Staff Ranking	Core objective	Management Owner[38]	Implementation Strategies	Measurement	Target short term; long term[39]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
9	Disciplined cost improvement process		1) Bi-weekly cost meeting - area managers present activity progress on business plan initiatives	Weekly cost package business plan work sheets		C
			2) Absenteeism/SPA/vacation control initiatives. Initiate plan to level out requirements and address high absentee levels.	Weekly absentee report. Weekly cost package. Absentee allowance		S, Q, C, M
			3) Track open season training moves and do a classification audit on open season completion	Weekly tracking report - status on % completion. M/P authorization report		C
			4) I.P.M boards for key operations show standard vs. actual and calibration requirements where applicable	Monthly IPM usage report		Q, C
			5) Standard Operating Procedure M/P controls	M/P conciliation report		C
			6) Pay as paint initiative addressing IPM for all elements used in phosphate & E-coat will continue	Bi-weekly phosphate chemical and e-coat paste & resin usage		Q,C,D

[38] Names have been removed.

[39] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Value-Added Activities)

Staff Ranking	Core objective	Management Owner[40]	Implementation Strategies	Measurement	Target short term; long term[41]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
10	WCB cost reduction					
			1) Establish a committee to review WCB program on a monthly basis	# of meetings		S, C, M
			2) Support and implement applicable initiatives of the business process redesign	# of initiatives implemented		
			3) Institutionalize regular analysis of top 10 injury producing operations	# of injury reductions by operations		

[40] Names have been removed.

[41] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Value-Added Activities)

Staff Ranking	Core objective	Management Owner[42]	Implementation Strategies	Measurement	Target short term; long term[43]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
11	Total capital BICS, special and new model spending		1) Bi-monthly project meetings	Financial commitments		C
			2) Monthly accrual spending	CIMS		C
			3) Submit all projects for approval	# written		C

[42] Names have been removed.

[43] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Value-Added Activities)

Staff Ranking	Core objective	Management Owner[44]	Implementation Strategies	Measurement	Target short term; long term[45]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
12	Daily operations for safety, quality, delivery, cost and morale		1) quality improvement measured by division, zone, in JD Power categories	0-2 C/100 warranty CSA P/100 Spec (reduce range) IQS		Q, C, D, M
			2) Cost improvement of 6% in M/P, O/T, OME, scrap, IPM	Weekly cost package		Q, C, D, M
			3) Volume (per day) achievement	Assembly Paint (main line) BIW (main line) Framing		Q, C, D, M
			4) Improve plant, division, zone "true" FTC levels	Cert line Rolls KD Chassis Trim Paint W/ & W/out metal BIW w/door fit, metal		Q, C, D, M
			5) Improve key process indicators	To be defined by CBM's		Q, C, D, M
			6) Improve safety program	Annual safety audit; safety talks JHSC audits, Supervisor manual audit Job hazard analysis; Supervisor training		Q, C, M

[44] Names have been removed.

[45] Target numbers have been removed.

FTAP Policy Deployment (1996)

(Level & Balanced Schedules)

Staff Ranking	Core objective	Management Owner[46]	Implementation Strategies	Measurement	Target short term; long term[47]	Improvement Focus (S = Safety, Q = Quality, C = Cost, D = Delivery, M = Morale)
13	Complexity reduction					Q, C, D
			1. Identify a complexity task force at FTAP to interact with complexity team	Part numbers or operator decisions reduced. Manpower reduced through complexity		

[46] Names have been removed.

[47] Target numbers have been removed.

Appendix B. Preventive Maintenance Workshops

Workshops will be very time consuming and in this case resource intensive, but workshops may be necessary to periodically remove people from their day-to-day activities and bring attention to problems that have long term impacts. It will allow attention and time for people to focus on maintenance problems. While workshops themselves are not the answer to better maintenance practices, they may help create an environment in which such goals and objectives can be achieved. It may even necessitate a person dedicated to purely coordinating activities and training, and providing information and answering questions and concerns about the team and its progress to other people in the plant. Implementing a preventive maintenance plant-wide cannot be taken lightly as if it were an extracurricular activity, a side job that needs to be accomplished. The following are some suggestions based on research and on interviews with consultants and AOS specialists.

B.1 Preparation

Preparation for the workshop would be done by the maintenance managers and supervisors, a AOS specialist, Toyota maintenance experts, and process consultants. The need for such improvement must be established through preliminary data collection achieved from benchmarking, the changing external environment and an assessment of the internal systems. Convincing themselves that change is necessary through data analysis and research is very critical but lacking in the PM team case. The managers and supervisors should be well trained in world class maintenance systems and have a vision of what the ideal state should look like. One or two sets of equipment which have in the past shown troublesome up-time problems are chosen for the project. Nine sets of equipment may be too many for the group to handle all at once. The group could begin with one or two sets of equipment and then when the group gains momentum it could move on to other areas. Preliminary analysis of what equipment is the most troublesome should be done before the team is formed. This could be based on failure to meet delivery schedules or some major quality problem. For the first team of this sort, the problem should be well defined and

clear. It should also be considered feasible in the view of maintenance managers. This will help bring more sense of purpose to the team itself. The maintenance manager and the maintenance supervisors responsible for those equipment sets should lead the group with the help of the AOS Specialists and consultants.

To kick off the project, the plant manager should be present to show the importance of the project and his/her endorsement. There should be team building exercises, or "ice-breakers" such that every member can feel relaxed and integrated. If the consultants are to be used, then they should be part of the team or at least present during the workshops. It is important that people in the group understand that the current state of the maintenance needs to improve. A feeling of need and urgency to improve has to be established by doing a gap analysis between the current state and what is needed to remain competitive in the environment.

B.2 Team Member Selection

The chairperson could be a person of the highest rank and with the best leadership style. However there also needs to be a technical expert on world class maintenance systems in the team. Those people who have the necessary skills or those people who are stakeholders in the change should be carefully selected and approached to join. For the most part, it should not be voluntary. Selection should be handled such that it will be considered an opportunity for recognition and an honor. However if the person refuses he/she should not be forced to join.

The members of the group should include the maintenance manager, first line supervisors and some skill trades people from the focus area. It is also recommended that an engineer who is closely familiar with the equipment and the process is also a part of the team. It is important that the first line supervisors are involved in these meetings and are part of the design and implementation. This way they will not feel that they are losing control over decisions that affect their own jobs. The AOS Specialist who is experienced in giving workshops in the plant should also be part of the team. Operator involvement in the meetings and implementation may be useful, but this must be handled carefully because it

may drive skill trades people away in fear that their skilled jobs may be taken away and given to operators. Having production supervisors in the group may even be necessary especially if the project is going to need the help of the production group. Labor union representatives should be invited and if they do not show interest they need to be repeatedly encouraged to come. If they do join they should also be integrated as an important member who is vital to its success. Also having some members, who are potential role models and who share in the vision part of the team, will also be advantageous. Ideally the members of the team will become "change agents."

B.3 Initial Workshop Meetings

It is important that the stakeholders' needs are identified up front so that the team can build commitment to the program. The initial workshop itself should generate a rough plan on what needs to change and how. If training is needed, then it should be provided. Training does not necessarily need to occur all at once at the beginning but can be arranged piece by piece as the need is identified. However the organizer should be careful that the members can communicate using terminology that they can all understand. The "AOS" speak may not be familiar to everybody and may isolate those who do not understand it.

In some groups the roles of individual members are obvious. In this case, it may not be so clear, as was evidenced in the PM team case. This may lead to initial jockeying for power and influence and particular roles by each of the members. However, as the team develops, it may be advantageous to establish needed roles for task completion and to discuss desired roles by individuals and work to meeting the needs of the task and the members.

It is essential to establish a supportive relationship-building environment that allows people to admit they do not comprehend something or voice concern when they do not agree with the direction. Process consultants should be able to assist in this. The plan that is generated should be flexible to changes.

The essence of "craft pride" among skill trades could be preserved by allowing for each of the skill trades to be represented within the team. They will then have their own identity by trade.

B.4 Policy Deployment

The goals and plans then are presented to and reviewed by the upper management for approval. The goals and plans are written into policy deployment with the name of the team next to it. The upper management should ask pertinent questions to the team to satisfy itself that the team has thought the problems and the plans through thoroughly. It should be clear at this point to everybody involved in the team what goals are expected to be achieved and that each member will be responsible for the attainment of the goal.

B.5 Communication With Environment

The team needs to manage communication between it and the environment well. The process of information exchange with the environment may mean that "the group will need to filter, classify, and elaborate information to ensure internal comprehension and external acceptance."[48] This function involves finding out what others' messages mean to the group and in formulating its own messages to the outside in terms that others will understand, accept and even support. This becomes particularly necessary when there are other people who are closely associated with the area in which the team is working on but who are not part of the team. For instance, a maintenance supervisor who is not the core member of the team may feel excluded from the decision making process and may not support the team's efforts.

B.6 Data Driven Problem Solving

The problems should be approached in a data-driven matter as much as possible. Technical experts within the team can use this opportunity to show how analysis and charts can improve equipment performance. Losses should be categorized to find out which are the top losses. Then some top losses should be analyzed and possible solutions or further testing should be discussed. Could better maintenance fix it? Can a better design of the equipment fix it? Then there should be a decision as to what losses and what fixes to try

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[48]Schein, Edgar, Process Consultation, Its Role in Organizational Development, Addison-Wesley Publishing, NY, 1988, pp. 54

out. A process of Plan-Do-Check-Act should be used. An iterative process to try out one or a few possible solutions, and then take measurements to see if the problems are fixed. If the problems are not fixed then alternative solutions are explored. The cycle begins again.

B.7 Team Sustaining

Good project management is vital to the success of this project. Milestones and relevant measurements to progress should be set so that problems or delays can be identified more quickly. Large milestones can be marked by celebration and recognition. The upper management should request presentations from the teams on a frequent basis so that there is good communication or "catch-ball" between it and the team. The presentations should not have an atmosphere that it is trying to "check-up" on the progress. If this is the case many will try to hide problems due to the pressures of trying to only bring good news to their bosses. This is a time when the team gets to show what worked and what did not and the challenges or barriers it is facing to achieve its goals. This could also be an opportunity to show support and encouragement.

Flexibility is key. The Toyota Production System is in many ways a highly disciplined and a regimented system. It is doubtful that such a system can work at this plant, because this will be construed as loss of control for those involved. This will only lead to compliance or even resistance. Some tools will need to be adapted to the plants' needs and constraints, and what fits its culture.

With time, some people will leave the group, and some will join. The team should manage the process in which the group brings in new members and releases members who leave. Socialization activities, indoctrination, training and rites of entry will occur around new members. Rites of exit will occur for the departing member, depending on the conditions in which they are leaving. These processes need to be effectively managed so that the group can maintain and develop despite the flux of members.

Appendix C. Welding[49]

Welding is an important process in automotive manufacturing. The welds join metal parts of a vehicle together, providing structural integrity which ensures safety for passengers. In addition improper weld location and weak weld quality can make cars "squeak and rattle." First I will briefly describe some of the basic concepts behind how a spot weld is made. I will then explain some elements that are required to produce quality welds, with a particular focus on maintenance.

C.1 Definition of a Weld

Resistance spot welding is a process for joining two or more metal parts together at a point by pressing two pieces of metal together while an electric current is passed though them.

C.2 Spot Weld Fundamentals

The weld is made by holding the parts to be joined together under pressure and passing an electric current through the metal at the pressure point. The current passing through the point melts the metal, and if pressure is maintained after the current is stopped, the molten metal solidifies, forming a metal "nugget" at this location. (See Figure C.1) The size and the structure of this nugget determines the strength of the weld.

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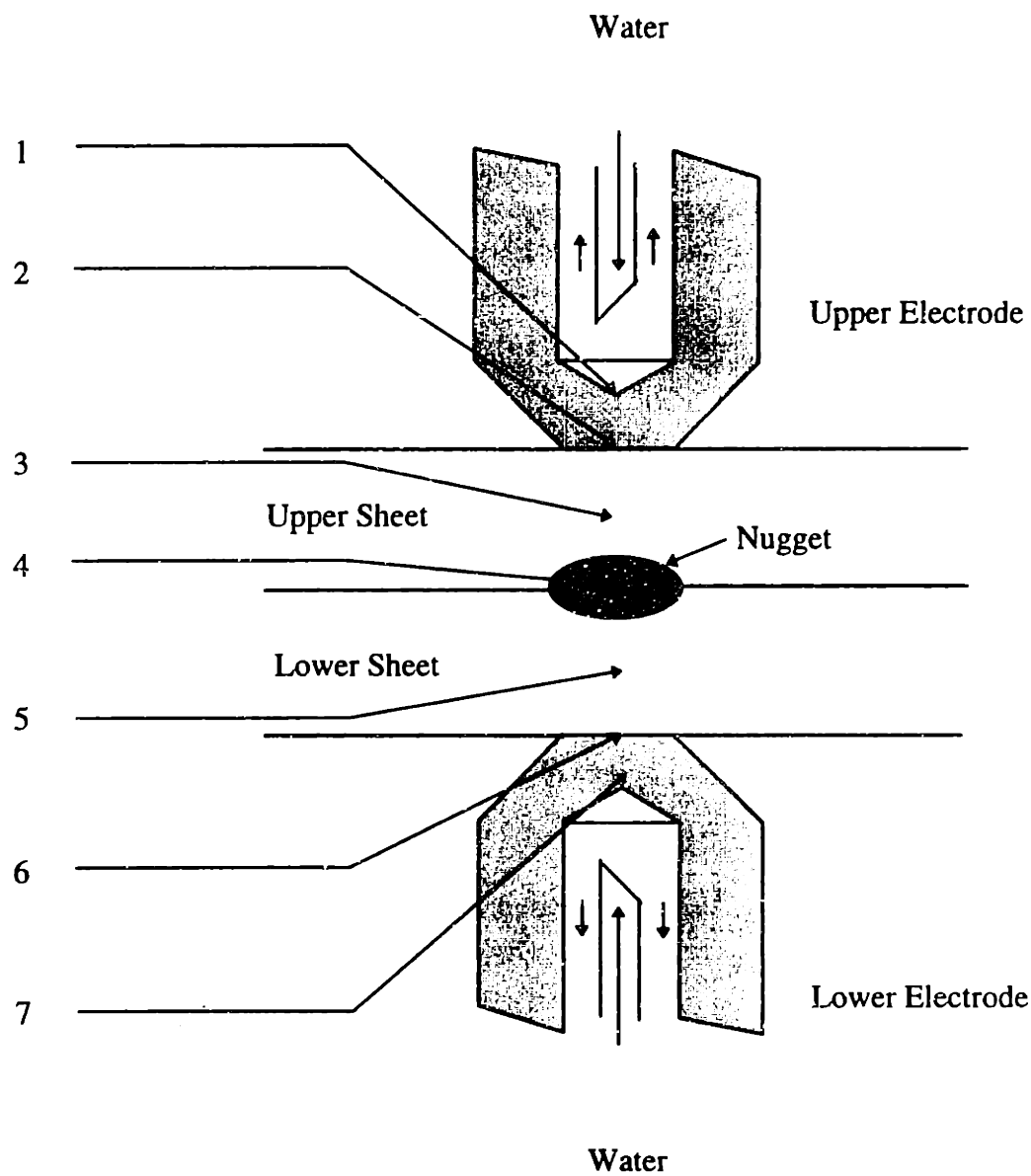
[49] Vecchio, E. J., editor, Resistance Welding Manual, Volumes 1 and 2, Resistance Welder Manufacturer's Association, Philadelphia, PA, 1972

Figure C.1 Schematic Diagram of Resistance Spot Welding The numbers indicate various points of resistances.



$V=IR$ and $H=I^2R$, where V = voltage, I = current, R = resistance, and H = heat. Heat is produced in a conductor when an electric current is passed through it. Current flow is the same throughout the circuit. Therefore heat will be generated in each of these sections in proportion to the resistance of each.

Figure C.1 shows a schematic diagram of the weld setup. There are seven resistances connected in series, as follows:

1. Upper electrode.

2. Contact between upper electrode and upper sheet.

3. Upper sheet.

4. Contact between upper and lower sheets (interfaces).

5. Lower sheet.

6. Contact between lower sheet and lower electrode.

7. Lower electrode.

As electrodes clamp the metal sheets together, the weld current starts. Heat is produced in a conductor by the passage of an electric current. Since V=IR, for a constant voltage the current flowing through any circuit is inversely proportional to the resistance in that circuit. If greater current is required, resistance must be reduced or the voltage must be increased. As current flows through the electrodes, most of the heat is generated at the interfaces. Welding heat is desired only in point 4 and the heat needs to be reduced as much as possible in other areas. For maximum efficiency, one would want a high current flow in the circuit with minimum resistance lost in the circuit other than the point of desired weld interface.

C.3 Variables

The heat produced to melt the interface between the two electrodes can also be expresses as $W=I^2Rt$ where W is the heat in watt-seconds, I is the current in amperes flowing through the weld, R is the resistance in ohms, t is time in seconds. Time, current and pressure make up three principle factors in resistance welding.

The heat generated is proportional to the square of the current. The current must be well controlled.

There are three separate time intervals in a weld cycle -- squeeze time, weld time and hold time. Squeeze time is the time interval between the closing of the pressure switch and the starting of the weld current. If squeeze time is too short, the weld current is started before adequate electrode force can be attained and will lead to arcing, metal expulsion and/or rapid electrode deterioration. On the other hand, if the squeeze time is too long, production will be lost. Weld time is the period during which the weld current flows and heat is generated. If the correct current is applied for the correct weld time, a weld nugget of the right size will be produced. Hold time is the duration in which the weld current stops and the electrodes are retracted from the metal sheets. With the electrodes held in place, they help to take heat away from the weld because of their high conductivity and the cooling water in the electrodes. If this time is too short, the molten nugget will not solidify sufficiently before the electrode force is removed. The surrounding area around the nugget is unable to absorb the heat and the cooling of the weld is retarded which effects the metallurgical structure and composition of the weld. This leads to a weak nugget. This time becomes more important if the sheets do not fit together (which is referred to as poor "fit-up") and there is a counter force in the material tending to pull the nugget apart.

The pressure applied by the electrodes holds the metal together during the weld cycle. It also provides a forging action. A decrease in pressure results in an increase in effective heat. This is because the resistance is increased at that location. However if the pressure is too low, molten metal discharge, poor metal surface condition, extreme electrode wear and a reduction of cross material flow across the interface will result. Therefore the resulting nugget will be a weak one.

C.4 Weld Quality Checks

Chisel checks and weld destruct testing were conducted at FTAP to ensure weld quality.

Chisel Checks: This test consists of driving a wedge between the interface of the welded parts and adjacent to the weld. The metal parts are bent until the material yields or bends sharply at the point of the weld. If the weld nugget holds then it is called acceptable.

Advantages of this test method:

- Less costly. The material is useable after testing.
- Faster information. It is relatively easy and quick to conduct this test. Quality inspectors can check material in the line quickly. The bent part is then hammered to original shape.

Disadvantages

- Less accurate because the actual nugget size cannot be determined through this method.
- The product may be damaged by prying open the interface between the two sheets.
- Some welds are inaccessible after they are assembled.
- Some metal sheets are too stiff and the chisels cannot drive a wedge between them after they are welded.

Weld Destruct or "Peel Test": This consists of chiseling, prying or pulling welded assemblies apart and evaluating the quality of the resistance spot weld by measuring the size and looking at the condition of the "button" pulled from the thinnest gauge steel being welded. The size and condition are compared with weld standards given the thickness of the sheets and type of alloy.

"Stick welds" lack the specified nugget diameter and show little or no evidence of fusion at the weld interface. The nugget looks porous at the interface and is brittle and weak. These welds also lack in penetration. "Substandard Fusion" refers to welds that have a fusion area that is less than the minimum nugget size as specified.

Advantages of this test method:

- The actual measurement of the weld size provides a better indicator of the weld strength than the chisel check test.

- The weld destruct can check certain welds that chisel check cannot. For example, the weld may not be accessible, or the weld material may be too stiff to pry between the two interfaces.

Disadvantages:

- This method is more costly than chisel checks. The tested material is discarded after use. It is therefore performed less frequently than chisel checks because the testing requires that the material be destructed and discarded at the end.

- Time consuming. Destructing an entire vehicle can take weeks.

- The peeling/prying action may deform the weld interface such that the button may appear artificially larger.

C.5 Weld Quality Problems

When the weld integrity is in jeopardy according to preset weld quality criteria, the response is different depending on severity. If safety is in question, the vehicles with the problem are contained. Otherwise, the equipment, fixture and the operation are checked, and the problem is corrected.

Not all weld quality can be attributed to maintenance. Weld quality is dependent on 1) design of parts, weld equipment and fixtures, 2) process optimization and sensitivity to process variation, 3) operation, and 4) maintenance.

C.5.1 Design

Design includes design of equipment, fixtures and parts. The design of equipment and fixtures directly affects weld quality. No amount of good maintenance can correct a poor design. Sometimes poor design can make it difficult for operators to place welds correctly. See "Operation."

C.5.2 Process Parameter Settings and Process Capability Studies

Instead of reacting to problems after they are already created, it is advantageous to put in systems that will detect a potential weld problem before it occurs. However it is difficult to troubleshoot equipment when there is no process parameters, such as current, force and time, are available. The process parameters under which acceptable nuggets of the correct size and strength can be produced should be available when a new process is introduced or a new equipment is installed in the plant. If the correct variable settings are not available to skill trades people, they will tend to "tweak" the parameters when welds fail.

The correct variable settings should be found first using recommended standards which are based on ideal conditions supplied by welding manuals and by testing out given the actual set up and materials to be welding. The robustness of the weld process can be determined conducting a capability study. This capability study would include testing out the life of the electrode tips and provides data as to when to dress and change electrode tips, based on the settings and the number of material that has been processed. In addition, variables should be varied to find out the robustness and sensitivities of the process. From this statistical process control can be applied to find control limits of each variable.

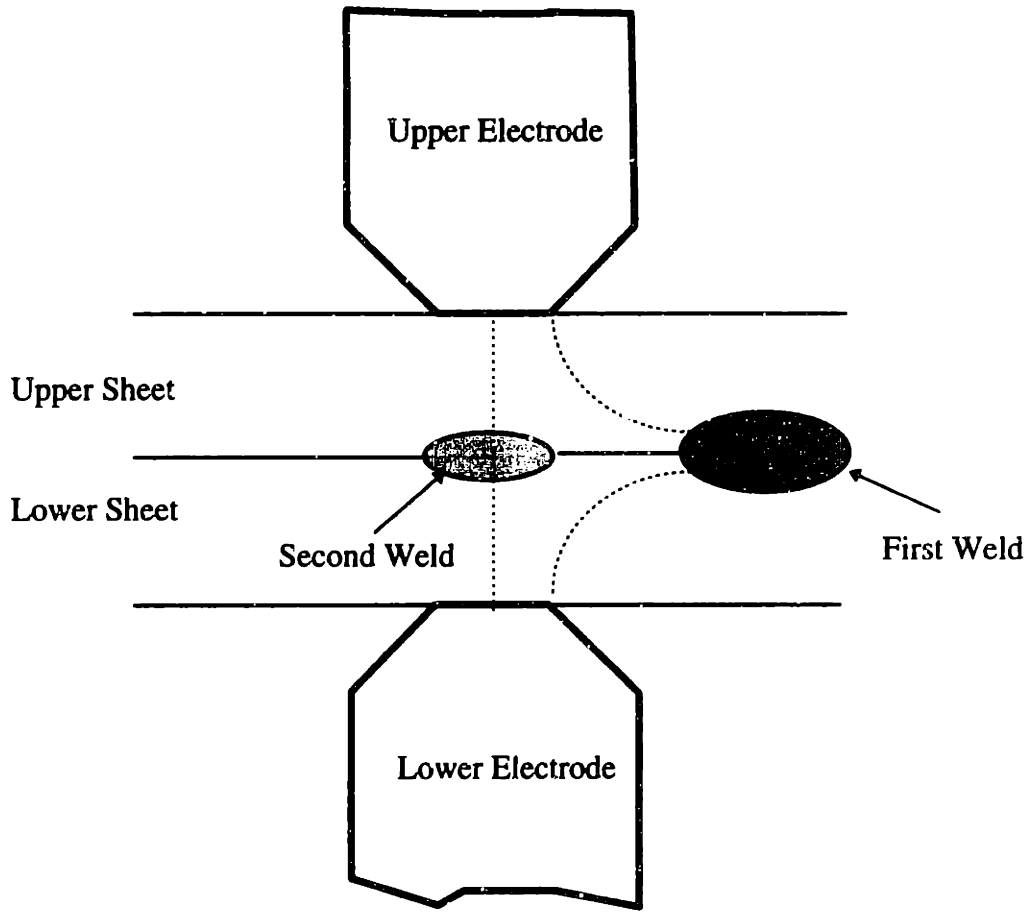
The stepper schedules and maintenance frequencies are set after the equipment during launch at this plant. It may be more advantageous to use metal sheets of the same material or better pilot/test subassemblies from stamping plant if available to determine approximate maintenance schedules, which is what Toyota does. This way problems could be worked out before launch and not during launch. This would lead to better preparation for launch.

C.5.3 Operation

Many times maintenance is called for weak welds even if the true cause turns out not to be a equipment maintenance related problem. The following are two examples how the welding operation can welding quality.

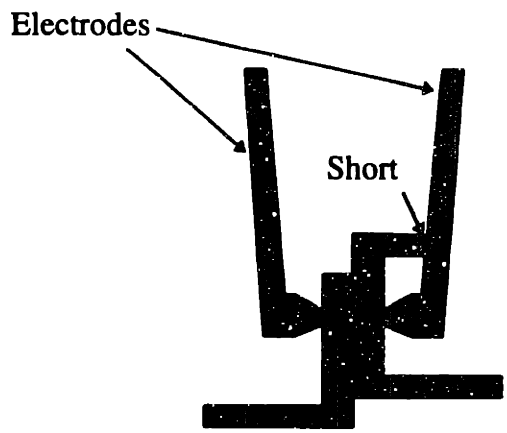
1. If the welds are placed too close together, shunting occurs. This occurs because the lowest path of resistance is through the previous weld immediately adjacent to it. See Figure C.2.

Figure C.2 Shunting Effect (Adapted from Resistance Welding Manual, by RWMA, 1956, PA, third edition, page 9)



2. Shorting occurs if one of the electrodes touch any metallic parts that will create an alternate current path. The current travels through it without going between the two electrodes. The resulting weld will be weak. (See Figure C.3.) This could be due to poor design as well.

Figure C.3 Shorting Effect



C.5.4 Maintenance

The maintenance of the weld equipment and fixtures are critical to the quality of the weld. Below are some common problems found with maintenance and recommendations.

C.5.4.1 Electrode Tip Maintenance

Configuration

It is important to make sure that the correct electrode tips are used for the application. Electrodes come in various sizes and shapes and are made of different alloys. The sizes and shapes are dependent on the metal being welded and the design of the body section. In addition, the electrode tip selection depends on electrical conductivity and mechanical strength. This is because the electrode tip must be able to endure considerable stress at very high temperatures.

Electrode Cooling

The water is transported to the electrode tubes through a cooling tube. The water flow and the correct placement of the cooling tube are essential to the cooling mechanism which affects weld quality. If the electrodes are not cooled properly, the following will result: 1) The electrodes will deteriorate faster and hence tip change will need to be performed more frequently. 2) The electrode pressure to the metal sheets will decrease 3) the current

density will decrease and 4) the weld quality will not be optimal because the weld itself will not be cooled.

Proper electrode cooling is needed to extend the service life of the electrodes. However even with the proper cooling, the heat resulting from the weld process and the process pressure result in eventual electrode tip wear. The electrode tips "mushrooms." The increased surface area of the electrode tips lead to deteriorated weld quality. This is because, as the surface area increases, the needed process pressure and current density to the weld area decrease. Therefore the electrodes are refaced or "dressed" down to the original shape and eventually replaced after repeated use.

Steppers

As electrode tips mushroom, weld quality deteriorates. Steppers are used to provide more current. It continually steps up the current incrementally after a preset number of welds. The parameters for steppers are critical in maintaining good welds over the life of the electrodes. However while the steppers provide more current to the electrodes it still does not compensate for the decrease in electrode tip pressure. As the electrode tip mushrooms or gets larger in diameter, the electrode tip pressure needs to be increased to make a good weld. Steppers only help to lengthen the tip life time and are not a complete solution.

C.5.4.2 Some Recommended General Maintenance

- Always set the weld settings to an agreed upon standard. Obtain approval from plant and manufacturing engineering personnel before making any changes to the schedules. For example increasing heat to compensate for a potential fit-up problem is not fixing the root cause of the problem. It will also lead to faster electrode deterioration because the electrode tips will mushroom faster due to the increased heat.

- Check critical parameters such as current and force at some frequency to make sure that the welds are getting the correct input variables. The settings should be verified to ensure that none has been altered accidentally.

- Adhere to the tip change and dress frequency. Electrodes should be allowed to make a specified maximum number of welds then maintained by refacing or replaced. The building of excess or unpredictably high inventory could lead to poor welds, unless the maintenance of the tip change and dress frequency is based on the number of the welds made and not time based.

- Electrode caps should be dressed in a drill press or lathe. Do not use a file. The surface alignment and area are critical to weld quality. Using a file will not produce desirable results.

- Never replace an electrode cap unless the correct water tube has been inserted. Some water tubes were found missing or broken at FTAP. Water tubes are important for cooling of the electrode tips. A correct maintenance procedure needs to involve consistently checking that the correct and non-defective water tubes are being used.

- Oilers are needed for lubricating moving parts in a portable gun. If the parts are not properly lubricated, it will lead to accelerated breakdown. Or worse, the pressure of the electrodes may not be high enough due to lack of lubrication. It is important to visually check that the oiler is being dispensing oil. If this cannot easily be done, an indicator line could be drawn on the oil port to show where the oil should be filled to and that the oil level should be decreasing with continued usage.

- While most inspections at FTAP rely on inspection, it is difficult to see if a cable is becoming worn. What would be more effective would be to measure the current carrying capability to the electrodes by use of an ammeter or to detect the gradual increase in resistance in the cables by use of an ohmmeter. This would well complement the thermography that is being used monthly to detect hot spots in connectors.