Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 6, No. 2, 2021
www.scholink.org/ojs/index.php/se

Original Paper

Productivity Improvement with Equipment Owner TPM Management at Toyota Manufacturing USA: Highly Reliable Production System for Expanding Global Production

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Received: March 7, 2021 Accepted: March 20, 2021 Online Published: March 23, 2021

doi:10.22158/se.v6n2p31 URL: http://dx.doi.org/10.22158/se.v6n2p31

Abstract

The equipment reliability plays a critical role in business success because degradation in equipment condition negatively impacts plants' output. When Toyota Motor Corporation operates overseas plants, equipment reliability management is one of the most important hurdles for global production which has to be overcome. It is important to develop an equipment reliability management program to minimize support from Japan to let overseas plants become self-reliant.

This article explains how the Advanced TPS can be applied specifically to the equipment reliability process with equipment owner Total Production Maintenance (TPM). This business process focuses on managing equipment reliability to meet the business goals of Toyota Manufacturing USA.

Keywords

Equipment Reliability, Advanced TPS, Equipment Owner

1. Overseas Plant Challenge

Toyota Motor Corporation (Toyota) set the standard in manufacturing industries for producing products in the quickest and most efficient way because of the Toyota Production System (TPS) (Shigeo & Andrew, 1989). When Toyota builds an overseas plant, the TPS has been implemented to optimize the production process. It has successfully reduced manufacturing lead times, reduced work in process, and improved work environment and manufacturing operation. Yet the overall plant performance continues to face a major challenge due to poor performing equipment (either not meeting capacity requirements or overspending in maintenance to achieve required performance levels). When the authors compare equipment performance and maintenance costs to Japan plants, the authors recognized that there is a huge opportunity to improve at equipment management process and control (Womack, Jones, & Roos, 1990).

At the plant start, the equipment performance management relays on reactive work requests and time-based Preventive Maintenance (PM) suggestions from the Original Equipment Manufacturer (OEM). The original way of thinking about equipment reliability simply has meant adding more PM to equipment with issues, ordering more spare parts for critical equipment because of long lead time. The result was spending too much money on the known issues but still suffered with other acute reliability issues. The maintenance budget continues to rise and reliability decreases.

The equipment reliability process is based on know-how from different resources, including equipment co-operational suppliers and skilled engineers and team members. In plants overseas, these resources are not always readily available. Managing equipment performance in overseas plants to meet business goals and market demand (quality, availability, safety, environmental integrity and cost per unit) is challenging. It is important to develop an equipment reliability management program to minimize support that comes from Japan to let each of the overseas locations become self-reliant. Luckily, the business model of TPS can be utilized to greatly improve equipment reliability management.

2. Advanced TPS for Maintenance Management

The TPS is frequently modeled as a house with two pillars. One pillar represents Just-in-Time, and the other pillar represents the concept of Jidoka. Jidoka is "Building in Quality" at the process and Just-in-Time is building what is needed, when is needed in the amount needed. Toyota has always had the philosophy of stopping the line when the defects are found; this can be done by anyone who sees a discrepancy with a known standard (what should be happening within a process). The lines can also be stopped by machines which are called "poka-yoke" (fail-safe devices), in order to ensure a defect is not passed on. One way Toyota looks at this perspective is to ensure that Jidoka is within each process on the line through a process called "Jikotei Kanketsu" (JKK), literally meaning—"Building in Quality with Ownership". Ownership is defined in JKK as understand all the "Necessary Conditions" and "Process Criteria" so that zero defects are passed on. If team members understand these perspectives then they are more apt to understand when the process is not to standard and to be able to countermeasure the discrepancy through problem solving or "Plan, Do, Check and Action" (PDCA) thinking (Williamson, 1997, Rodrigues & Hatakeyama, 2006). Originally these concepts are focused on utilizing these concepts in manufacturing quality control process. After the authors study deeper into these concepts, the authors found that they fit very well with equipment reliability management process. By utilizing Advanced TPS thinking, the authors have raised the standard of maintenance management to match manufacturing in order to achieve optimal performance of equipment that directly contributes to achieving company goals.

2.1 Just-in-Time

The essential of Just-in-Time is “The Right Work at the Right Time”. There is a huge opportunity to eliminate waste when implementing the TPS concept through proactive equipment reliability process. By closely reviewing the original PM setup and equipment failure history, maintenance work is found to be wrong. The wrong work is a combination of work done that is too much too early, or too little too late. Either way there is a significant negative impact to the plant due to downtime or maintenance cost (labor and parts). In a reactive environment, the focus of maintenance work is repairing failed equipment. In a proactive environment, the focus on maintenance work becomes inspection of equipment heath to enable proactive intervention prior to failure. To transit to a proactive equipment reliability program, effective work of identification capabilities is needed.

The right work is the minimum amount of work necessary to ensure the equipment provides the necessary level of performance. Since there are many operational factors contributing to equipment failures, even the OEM cannot provide a fully accurate maintenance frequency. It is important for plants to identify the correct maintenance frequency based on the Condition-Based Maintenance (CBM). Other techniques such as equipment heath monitoring are installed to allow us to intervene prior to loss of equipment function. The authors also utilize communication within plants to identify new failure patterns. Work identification is the cornerstone of reliability improvement and represents a fundamental shift from conventional time-based maintenance (TBM) to an equipment reliability approach to maintenance. The Point of Failure (PF) curve in Figure 1 shows how equipment deteriorates over time, or cycles, and where team members can provide an additional line of detection should failure initiate between Predictive Maintenance (PdM) collection dates (Okogbaa, Huang, & Shell, 1992). Most cases when a team member is able to identify the function issue at Stage 3, the time loss is inevitable. It is important to identify the deviation of equipment health condition at Stage 1. One important note is the time span of each stage can vary on the same equipment due to operational conditions that change and other variables. An appropriate change management implementation approach must be used. The method is to follow up and define special maintenance frequency after each change point.

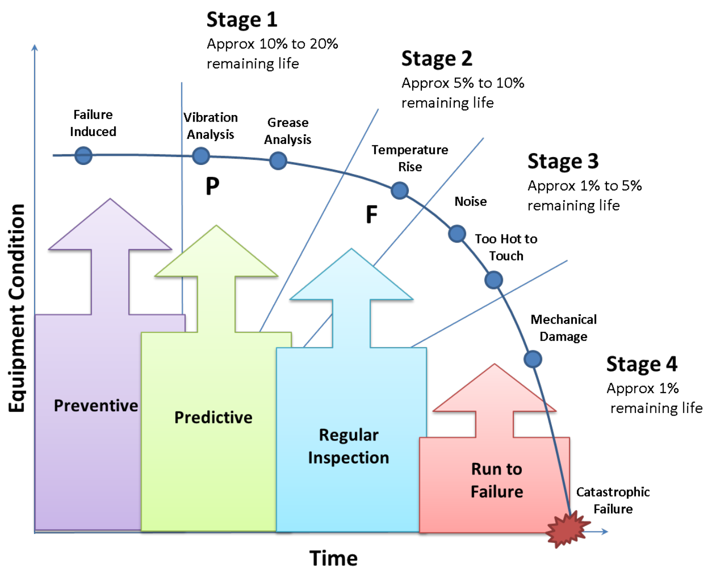

Figure 1. Equipment Health Condition Based on Different Type Maintenance Work

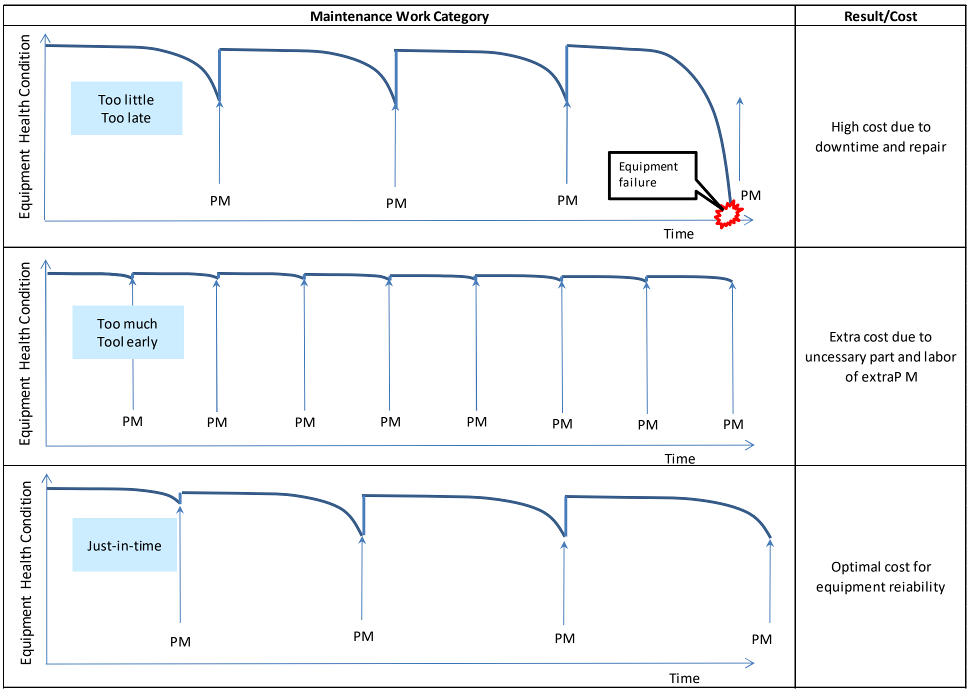

Figure 2. Time based PM vs Just-in-Time PM

The authors can utilize this equipment health condition pattern to exam how maintenance work is set up, as shown in Figure 2. When the maintenance work schedule is inadequately set, with some disturbance from various changed operational conditions or deviation from standard on previous maintenance work performed, equipment failure can occur between regularly scheduled maintenance activities. Or, the opposite may be true, in that some of the equipment has extra maintenance work planned. This ends up with adding an extra labor and material cost. Besides the cost, it also creates a negative impact to wrench time. In a highly automated plant with Just-in-Time delivery like Toyota, the wrench time is limited because all equipment needs to operate together. If too much wrench time is spent on unnecessary maintenance work, some necessary work will be cut off or postponed. This could affect other equipment reliability and even lead to equipment failure. Another common reason for extra maintenance work is because the work is not set up properly. For example, a contact surface under heavy load may not retain lubricant very well. Performing extra lubrication PMs can improve the condition slightly but adds cost (labor and grease cost). An auto greaser can greatly reduce maintenance work and increase the equipment lubrication condition significantly which improves equipment reliability. All maintenance work should be tied to a failure mode (root cause). Understanding the function of each piece of equipment (down to the component level) and its performance requirements can have a profound effect on how that equipment is operated and maintained, thus affecting the overall reliability of the equipment. This can be a challenging task and needs to involve an equipment expert because they know best what the equipment must do to achieve the operating targets. This is the key to Just-in-Time maintenance. The maintenance team member conducts the work each time and feeds back the equipment condition to the planner to adjust the maintenance work frequency and improve maintenance method. If there is a known change point, proper maintenance work needs to be scheduled to check and correct equipment condition.

However, sometimes an unknown change point is introduced into equipment. The quality of each maintenance work performed can very. These factors have a direct impact on the equipment's health condition. The authors need introduce another pillar of TPS, "Jidoka", into the equipment management process to ensure equipment reliability is maintained.

2.2 Jidoka

"Jidoka" (Ohno, 1988) plays an important role in the equipment reliability process through the whole life of equipment, as shown in Figure 3. The first step of "Jidoka" in equipment reliability is process that simply delivers the inherent capability of the equipment "by design" to meet the equipment performance requirements. From design, build to buy off, the plant needs to get involved to make sure the equipment meets all specification. Any "quality" gap needs to be corrected immediately before or during installation.

The second step is the equipment maintenance is able to sustain the inherent capability of the equipment. Deterioration begins to take place as soon as equipment is commissioned. In addition to normal wear and deterioration, other failures occur. The failure happens when equipment is pushed beyond the limitations of its design or operational errors occur. It is important that equipment is able to autonomously detect abnormal conditions and stop. But the common standard "build in" abnormal detection (protective system) is only to detect failure condition (Stage 4 in Figure 1). It does not help to improve the equipment reliability because when the equipment stops, the time loss is already happening. There is a proactive strategy to test the equipment to find the failure, which is called detective maintenance (Cândido & Parra, 2018). The test reveals whether the equipment, component or protective system is in a working or failed state. Detective maintenance tasks are only applicable to items in one of two discrete states, they are either working or have already failed. This method is great for corrective maintenance but lacks the capability to predict a potential issue. Equipment health condition detection methods need to be added to identify an equipment issue before it creates an equipment breakdown to prevent time loss. Most of the equipment health monitoring can be conducted with commercial off-the-shelf technology, such as vibration analysis, temperature monitoring, current monitoring and grease contents monitoring. For some applications that were previously performed by humans, automatic trend monitoring system has been developed to achieve "Jidoka", such as chain stretch monitoring. These predictive monitoring methods provide us important trend data to indicate equipment health status, predict equipment lifetime and guide us to improve the maintenance work that improves equipment condition (Okogbaa, Huang, & Shell, 1992).

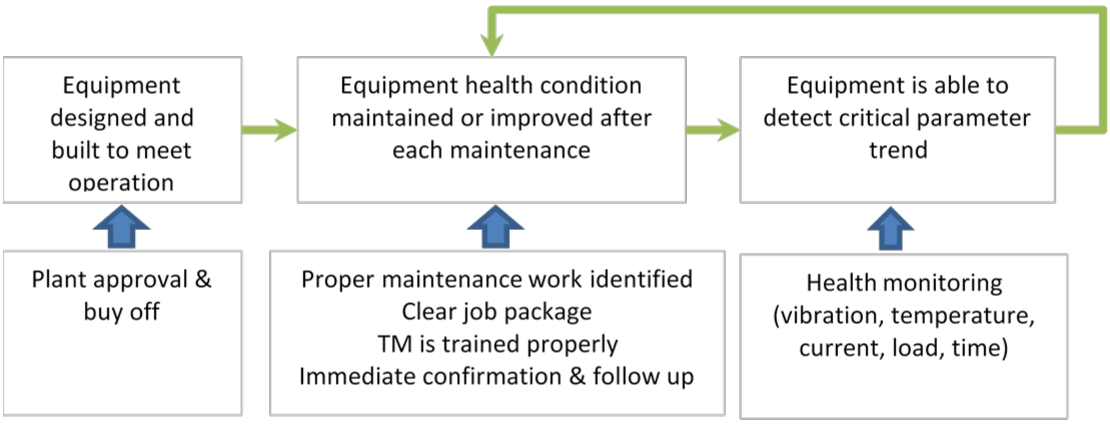

Figure 3. Maintenance Jidoka through Equipment Life

The third step is to make sure each maintenance task achieves "build in quality". In other words, the team member is capable of conducting the maintenance work without introduce failures that could cause equipment issue in certain defined time period (PM frequency) (Williamson, 1997). This requires a clear job package to indicate what to check, how to check it and how to judge the result. The standardized work is developed by the equipment expert but can be used by any team member or contractor to conduct without mistakes. The work needs to be confirmed immediately to demonstrate it is done properly. Sometimes follow up work is required also because equipment failure ratio follow the "bath-tube" pattern after each change point.

3. Equipment Ownership Based upon Total Productive Maintenance (TPM)

Introducing the TPS into equipment management requires the development of equipment reliability process and formal business process to sustain it (Sharm, 2019; Roup, 1999; Peng, 2012). The authors utilized the TPM method with focus on equipment expert development through an equipment ownership system to enhance the work identification process. With this right process in place, people ensured to doing the right things to maintain equipment in ideal condition.

3.1 TPM Process

The basic principle of TPM is to empower employees to get involved with equipment improvement in order to prevent unplanned equipment downtime and minimize waste (Shen, 2015; Windle, 1993; Williamson, 1997). With the objective to lower costs and improve return on assets, the basic equipment care philosophy is about "autonomous maintenance" (Wayne, Kennedy, & Fredendall, 1995; Cua, Mclone, Roger, & Schroeder, 2001). While this concept of basic care is a valuable starting point towards optimizing equipment performance at optimal cost, it falls short in the technical validity of the equipment reliability program due to Overall Equipment Effectiveness (OEE) (Sharm, 2019). The TPM utilizing way to make the transition from reactive to proactive is to enhance the work identification process. Rather than relying on our current program of reactive work requests and mostly time-based PM (Wu & Seddon, 1994; Khanlari, Mohammadi, & Sohrabi, 2008), the authors have developed a process that is based on an understanding of the relative risk of the equipment, followed by a technically sound failure analysis using a formal work identification methodology, to understand all the equipment's failure modes. Using one or more of these work identification methodologies, the authors then define, for those failure modes that will be managed through the maintenance function, the complete equipment reliability program, or the list of tasks that will be used to mitigate the consequences of those failures. These TPM tasks are health based, requiring that the authors define normal and abnormal values, and corresponding alarms. With this process the authors maximize the extent to which our maintenance function is proactive, and the authors therefore improve the bottom line through improved reliability. The output of this proactive process is optimal equipment reliability at optimal cost. The core concept in TPM equipment reliability process is providing a sound technical basis to focus on the right work at the right time.

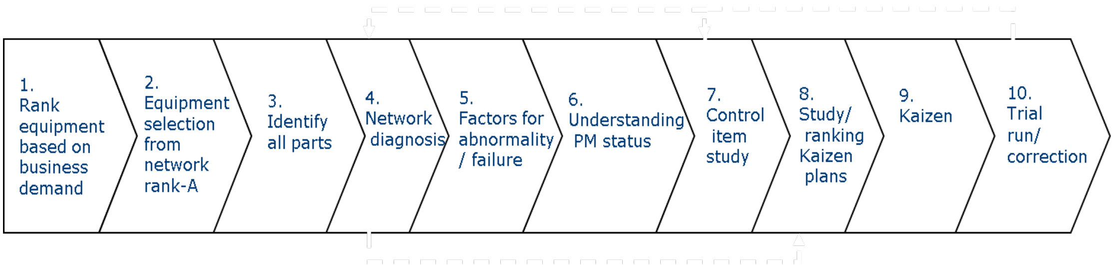

Figure 4. TPM Process Flow

The TPM process starts with identification of equipment performance requirements based on business goals, as shown in step 1 in Figure 4. Next, it determines the equipment that are most critical when they fail, and where the risk is highest in terms of impact on business performance. For this equipment, the authors establish specific performance targets. This stage focuses maintenance reliability improvements on the performance targets of critical equipment that contribute most to the company's success, as shown in step 2.

The failure identification stages identify and prioritize gaps in performance by conducting specific component level performance analyses. The failure mode and impact to business is identified for each component, as shown in step 3 to 4. Then the authors identify all contributing factors to equipment abnormalities, as shown in step 5. Before any improvement, the authors study the original maintenance PM work to identify the gap between scheduled work and all potential failure causes. If work is not set up to point to any failure mode, the authors identify them as waste, as shown in step 6 and 7. The study includes an assessment to determine gaps between the current and future state and identifies specific opportunities for improvement. The countermeasure or improvement plan is also included with cost and justification.

One of the toughest challenges on the road to improved equipment reliability is to determine the prescription of proactive work that should be done to maintain the equipment so that they deliver the necessary reliability at optimal cost. This task is known as "work identification", and it is the essential element of an effective equipment reliability process. In stage 8 & 9, the appropriate work identification strategy is followed to understand and address all causes of failure for the equipment under consideration.

The resulting equipment reliability program includes mix of PM, detective maintenance, PdM and some run-to-failure decisions based on their business impact. The outcome of the work identification element is the right work at the right time (the right work defined in terms of the tasks and the timing for conducting them). The process is self-sustaining, with opportunities to continuously improve and evaluate the overall effectiveness of the equipment reliability process as well as revisit reliability programs and continuously improve, as shown in step 10.

3.2 Equipment Ownership

The key element to implement and sustain the equipment reliability process is ownership from maintenance and management. An equipment ownership system was developed to implement and sustain TPM. Each piece of equipment in the plant is assigned to the team member who has the most experience with it. The management of this team member and supporting engineer own this equipment as well. This equipment ownership drives reliability from the floor level to management and who monitors progress of reliability by establishing targets for improvements and measure progress with Key Performance Indicator (KPI). The equipment owner is working with his management and support to address the major issues regarding equipment reliability to achieve breakthrough performance.

This system maps the tasks required to manage and execute the equipment reliability process to the roles required in the organization and to the responsibilities of those people associated with equipment reliability. The goal is to ensure that improved equipment performance is achieved and sustained. The output of the equipment ownership system is a clearly defined role with descriptions and associated responsibilities. Everyone must focus on executing the equipment reliability process. The authors start by analyzing the business process tasks, and then identify the duties required for each role to ensure that optimal equipment performance is sustained. Equipment ownership system utilizes four KPI, including Man, Method, Machine and Material, to indicate reliability status of each piece of equipment, as shown in Figure 5.

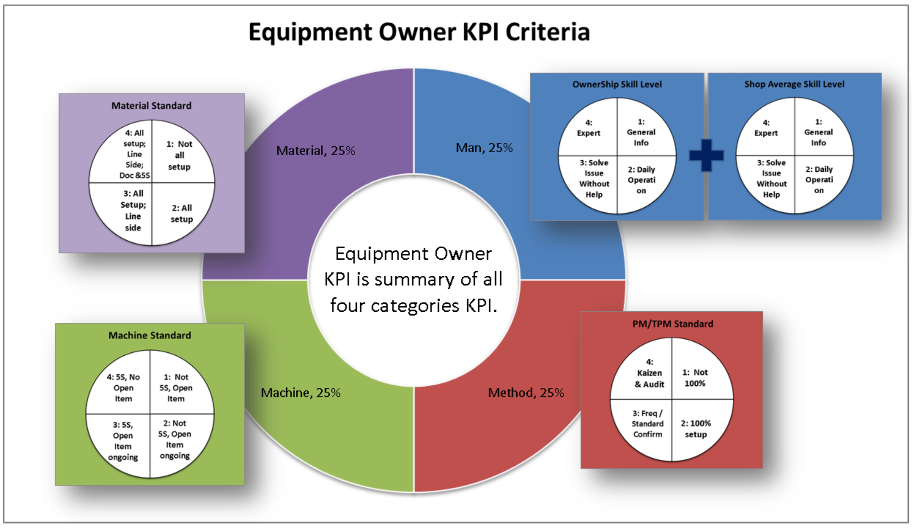

Figure 5. Equipment Ownership System KPI

3.3 Man

This indicator is to judge the team member's capability to identify work to improve equipment reliability. The owner of the equipment can dedicate his time to learn the equipment and understand the reality of how equipment fails. The goal is to develop the equipment owner to become an expert on their specific equipment. With experience and training, the team member learns to manage equipment health and learns how to maintain it to ensure optimal reliability. The knowledge from these equipment experts is formalized and made available through the TPM process. During the development of the TPM process, these team members will be asked to contribute their knowledge of the ways the equipment fails and the ways that have found to detect or prevent failure. In the context of a well-defined failure analysis, their knowledge is captured, formalized by linking proactive tasks to specific failure modes as the TPM is defined and deployed. This knowledge is also leveraged across all employees and even across other overseas Toyota plants.

3.4 Method

This indicator is to judge the development level of the TPM process. It is based on the development status of the TPM packages which have defined components, failure mode and factors, PM procedures, PM improvement, kaizen and other items required to ensure equipment reliability. With TPM packages maintenance work can continue to improve and reduce the potential for lost time, lost knowledge, and maintenance induced failures. It indicates the level of "right work at the right time" (preventive, predictive, detective maintenance) utilizing a technically sound process.

3.5 Machine

This indicator is to judge the equipment health status. The TPM package identifies the work to ensure equipment reliability. These works (inspection, PM, health monitoring) feedback health data of the equipment and based on this data obtained through the equipment health status. Mean-Time-Between-Failure (MTBF) is a commonly used equipment reliability indicator which demonstrates the result of equipment reliability management process. The authors do not use it directly in our system, but the authors do use it as reference to ensure the reliability process is heading in the correct direction. All the failures that have occurred are carefully studied to find out the root cause. The authors identify or develop the proper way to prevent recurrence. These countermeasures are also used to kaizen the TPM process so that the improved equipment reliability can be sustained.

3.6 Material

This indicator is to judge the spare part status of the equipment. Accurate part list ensures integrity of the equipment reliability process because our TPM process is based on failure analysis of each equipment component. Spare part management is also critical to achieve the TPS target. The essential of this indicator is the correct part with correct amount to achieve optimal maintenance cost. The quantity of each spare part is based on lifetime, quantity in service, lead time and cost. For overseas plants, because many spare parts are from Japan, it is important to predict part service life to control the order timing in order to achieve optimal cost. The part exchange history is also required for this indicator in order to provide good reference for future equipment reliability improvement activities.

4. Example: Equipment Ownership in Toyota Motor Manufacturing, Texas, USA

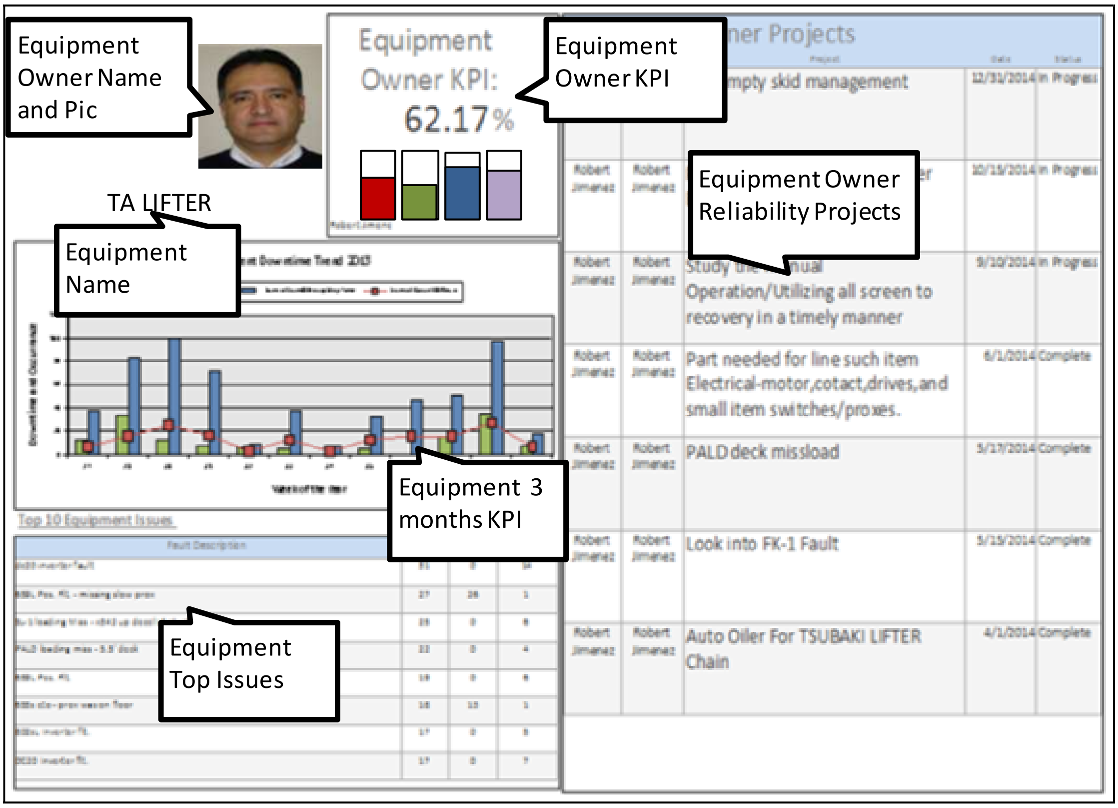

Figure 6. Equipment Ownership Tracking Document

Figure 6 shows an example report of equipment owner to reflect the equipment overall health condition. Each piece of equipment is tracked with this report to indicate improvement trend. Management utilizes equipment owner KPIs to adjust strategy and priority to ensure the plant equipment reliability is being improved and sustained.

5. Conclusion

The authors have confirmed the equipment owner TPM system is effective and proactive to improve equipment reliability, thus, improving business performance over time. This method is feasible and has a low cost. The equipment owner TPM can achieve the optimal equipment reliability, which means that for the least possible cost, the authors achieve the level of required performance from our equipment in order to meet our business goals (plant or company level goals).

The process is self-sustaining, with opportunities to continuously improve and evaluate the overall effectiveness of the equipment reliability process as well as revisit reliability programs and continuously improve. These activities optimize the effectiveness of the TPS.

This study contributes to the equipment reliability management issue and the productivity improvement strategy by proposing how to engage employees to improve equipment performance. This study is also expected to contribute to the extension of TPS concept in other words Advanced TPS in real manufacturing environment.

Acknowledgement

This equipment owner TPM process was developed at Paint Department in Toyota Motor Manufacturing, Texas, USA. The authors sincerely express our gratitude to Rob Franklin (General Manager), Kevin Voelkel (President) and Kirk Kohler (Vice President) for their guidance and support.

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