Methodology for Identifying Performance Metrics and Monitoring Maintenance Effectiveness

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Abstract: **- Over the past hundred years maintenance management had to rapidly change to keep pace with the increase of complexity in manufacturing processes. In the Beginning, equipment maintenance was reduced to optimize the corrective activities in order to minimize downtime. Good performance was dictated by the ability to reduce time to repair. Therefore, the main focus was put on improving human technical skills as well as troubleshooting effectiveness. Most current maintenance programs focus on achieving the main goals of maintenance operations: increasing mean time between failures, reducing time to repair and minimizing costs. Some researchers have focused on optimizing these variables. Detailed analyses have been conducted in the fields of equipment wellness, spares administration, planned maintenance and structured organization. Still, many organizations fail to fulfil today's ambitious objective of guaranteeing operations while achieving high reliability and maintaining safety. A comprehensive method of maintenance assessment that considers key factors and indicators that influence the main goals of maintenance is still sought after. This paper discusses a new approach to performance-based maintenance management. The objective is to determine an integrated reliability management system that provides a method of aligning maintenance operations with the business strategy and monitoring performance of key technical, human and organization goals over time**

Keyword: PM, RCM, TPM, Goal Tree, Pillars.

I. INTRODUCTION

Over the past hundred years maintenance management had to rapidly change to keep pace with the increase complexity in manufacturing processes. In the beginning, equipment maintenance was reduced to optimize the corrective activities in order to minimize downtime. Good performance was dictated by the ability to reduce time to repair. Therefore, the main focus was put on improving human technical skills as well as troubleshooting effectiveness. When reactive maintenance was organized in such a way that failures were immediately found and solved, the need for availability improvement led to preventing failures to occur. The concept of preventive maintenance changes the way of managing maintenance. The objective moves from reactive to proactive maintenance. This means staying ahead of the problem through programmed inspections to find potential failures and eliminate them before they manifest. Different preventive maintenance programs have been implemented. Initially, fixed schedules were developed. These methods did not consider the equipment usage pattern. Consequently, frequent interventions in low utilization equipment represented a waste of resources, while failures still occurred in equipment with higher utilization. In order to develop a customized plan a more careful analysis was needed. This analysis should define the optimum maintenance schedule for each equipment. With customized planning, resources were allocated more efficiently. This led to significant cost reduction and availability improvement. The significant increase in competitive products generated the need to reduce costs and increase quality and reliability. Old techniques were no longer suitable in the new continuous improvement era. One of the initiatives that arose was the Total Productive Maintenance (TPM). TPM has the objective to prevent failures and quality defects, minimize equipment losses and improve equipment cycle life. The active participation of every part of the organization is the key ingredient for TPM success.

Consequently, production personnel participate by conducting inspections and minor interventions on their own equipment. This self-directed maintenance helps detecting equipment malfunctioning in an early stage and provides with important information to maintenance department. Additionally, maintenance force can be assigned to more critical tasks now that minor repairs are handled by production personnel. This innovative approach to maintenance management was a breakthrough. Still, there was a sustained increase in automation and therefore the need for more skilled technicians to ensure equipment performance. Clearly, organizational goals included the reduction of product indirect costs and in most cases hiring was unaffordable so new alternatives in maintenance operations had to be studied. The most recent advances in maintenance management

include Design for Maintainability (DFM) and Reliability Centered Maintenance (RCM). DFM is a proactive approach that aims at reducing the frequency of required repairs, the time to repair and the amount of preventive maintenance interventions. The goal of Design for Maintainability is maintenance prevention.

RCM started from the aeronautical industry. Thorough analysis conducted on a group of aircrafts under different maintenance schedules concluded that increasing the frequency of inspection does not necessarily reduce the number of failures. On the contrary, after overhaul the aircrafts would show an increase in the probability of failure due to infant mortality. Additionally, it was found that most failures are related to random events such as poor maintenance practices, overload or improper equipment operation. RCM methodology is based on choosing the most important systems and determining their potential functional failures. With the aid of Failure Mode and Effect Criticality Analysis (FMECA) the most critical causes of failure are identified and an appropriate maintenance plan is developed to control them. This approach admits the "run to failure" option for those equipment failures that will not represent a significant safety or economical concern on production. The previous discussion shows that maintenance practices evolved to a focus oriented approach where resources are put were they are more needed. Still these initiatives are being implemented among many industries with different levels of success. Evidently, there are other factors making the results widely vary not always properly considered. Success or failure in maintenance management depends on how technical, human and organizational factors are considered. This study will focus on how to integrate these factors and methodically define a set of performance indicators to monitor maintenance operations effectiveness.

II. METHODOLOGY

The Balanced Scorecard concept will be used to determine the maintenance strategies. This concept will help define the fundamental pillars upon which the overall maintenance operation rests. From these basic pillars, a group of attributes will be derived using a hierarchical decomposition such as the Goal Tree Analysis. Successful implementation and monitoring of these few attributes will lead to more effective management of maintenance operations.

A set of metrics must be selected to lead the attributes implementation. These indicators need to monitor the maintenance strategies in such a way that any deviation from the objectives can be detected and immediately corrected. The problem resides in that no attribute can be fully monitored by an isolated metric. As such, a set of indicators would be needed for this purpose. The assignment of each metric to an attribute must be determined through expert judgment. The Analytic Hierarchy Process (AHP) is a powerful tool to formally bring expert judgment to define relevance and importance of each metric to the fulfilment of the attribute.

A. The Balanced Scorecard

The Balanced Scorecard is a management system that enables the organization to align their vision with the strategy and translate it into action. Its main purpose is to define a set of metrics that will closely monitor the organization performance. The structured methodology allows us to understand the key aspects in maintenance operations preventing the uncontrolled and unfocused selection of performance indicators. In this paper a model of the Balanced Scorecard has been developed in context of a complex manufacturing plant. The first step in developing the Balanced Scorecard is to define the vision of maintenance operations.

This is defined as: Attainment of high performance of people, equipment and processes in maintenance. This ultimate goal is to be accomplished through a methodical strategy that must consider all different aspects of the organization. Therefore, the strategy will be decomposed into fundamental pillars.

When selecting the pillars, the first and basic aspect to consider is repairs management. Once a failure occurred the cause must be effectively found and solved. Therefore, the reactive pillar goal must focus on reducing the downtime through minimizing the time to repair. In order to prevent failures to occur in the first place, the focus must change from a reactive to a proactive approach. The proactive pillar will aim at reducing the amount of failures through appropriate maintenance planning. The goal is to maximize the time between failures.

Having good reactive response and effective preventive maintenance (PM) plan is not sufficient without the necessary tools and spares. The logistics pillar must ensure resource administration including materials, equipment, spares and energy consumption. Therefore this fourth pillar goal is to guarantee resource availability with minimum cost. Even with good planning and having the necessary tools and spares, maintenance personnel must have the appropriate skills to do a quality job. The goal for the training pillar is to prepare personnel for their job requirements.

Finally, it is important to keep in mind that all maintenance related activities are planned, performed or controlled by individuals. Without personnel motivation maintenance results are in jeopardy. people pillar is probably the most critical because it is present in all other pillars. Its goal is to increase personnel motivation and performance in order to get the best out of each employee.

Table 1. Fundamental pillars of the strategy

PILLAR	SCOPE	GOAL
REACTIVE	Repair action after the failure occurs	Minimize time to repair
PROACTIVE	Planning and monitoring actions to prevent failures	Maximize time between failures
LOGISTICS	Tools, spares and equipment and their availability	Guarantee resources availability with minimum cost
TRAINING	Technical and interpersonal training	Prepare personnel for their job requirements
PEOPLE	Personnel involvement, human performance, safety and workforce planning	Get the best performance out of each employee

In order to fulfill the overall vision each of the five goals must be realized. It will be considered that each pillar has the same relative importance with respect to the vision accomplishment.

B. Goal Tree Analysis

The next step in the balanced scorecard definition is to translate the strategy into action. Goal Tree Analysis (GTA) m is the means used in this paper to perform a hierarchical decomposition of each of the strategic goals. The purpose of the decomposition is to arrive to the lowest measurable function, whereby obtaining the fundamental attributes. In this way, each general goal can be easily managed through the analysis of this few attributes. This simplification is valid given that GTA carefully breaks down the high level goal into subsequent sub goals so that success of all sub goals will guarantee the main goal accomplishment.

The higher level represented by an oval is the ultimate goal which is decomposed in lower level sub-goals until the lowest possible decomposition is met. The shaded blocks represent these fundamental attributes. Note that logical connectors are used to show in which way the combination of various attributes will lead to the goal accomplishment. The AND gate implies that all attributes must be satisfied in order to guarantee the goal success. On the other hand, OR gates indicate that the goal can be met if at least one of the success paths underneath is achieved. Considering this, we must refer to “alternatives” rather than sub-goals given that not all the attributes need to be necessarily met to ensure success at a higher level.

C. Five strategic pillars

1) Reactive Pillars:

These processes include, backup systems, redundancy, standby equipment and bypass procedures The decision to launch the alternative process will be based on the repair time estimate, the time to switch from normal to alternate operation and the potential loss of production the alternative process represents. Therefore, good communication between maintenance and production personnel is essential to make the best decision. At the same time, clear procedure must be in place to perform a quick change over. An important part of having an effective alternative process in place is its reliability. Stand by and redundant equipment must be in good condition when needed. Even though these installations are rarely used, it is important to have them under planned maintenance. Note that in order to have a good maintenance plan the reactive goal must be satisfied.

2) Proactive Pillars:

All planned activities are considered including preventive, predictive and self-directed maintenance, programmed replacements and projects implementation. The latest refers to improvement modifications conducted with maintenance department budget. Preventive, predictive and replacement programs are effective if there is a dynamic schedule oriented to prevent the loss of the system function. This is the objective of Reliability Centered Maintenance (RCM). The plan must be routinely evaluated and adjusted based on failure history, condition-based techniques and root cause analysis among other reliability tools. This resource optimization needs appropriate data collection and analysis so having a reliable Computerized Maintenance Management System (CMMS) is essential. Planned interventions also need to consider equipment availability.

This is especially important when production systems are in continuous operation. In many cases production patterns must be adjusted to support the PM down time. Planning ahead of time production department will ensure an effective intervention without significant production loss.

3) Logistics Pillars:

This pillar focuses mainly on materials, parts and tools availability but it also includes energy as a resource to be administrated. As mentioned earlier, the objective is to ensure resource availability with minimum cost.

In the presented approach, logistics pillar goal will be accomplished by ensuring equipment, parts and tools availability, optimizing energy consumption and minimizing maintenance inventory. The first condition can be satisfied not only by guaranteeing the part is in stock, but also weather this part is available immediately.

Having the part somewhere in a chaotic store will make the repair ineffective and increase the mean time to repair (MTTR). Therefore, great effort should be invested keeping a clear and properly identified storage area. This may include the development of equipment drawings / sketches and a reliable inventory system, as well as applying Visual Factory (VF) procedures. Lack of proper stores administration result in parts unavailability. If storages do not provide with the necessary parts, technicians would start keeping basic spares at hand leading to personal storages generation. In order to ensure the part is in stock when needed, it is essential to conduct adequate planning. Basically, this includes the part list derived from a close analysis conducted in the early design and installation phases.

4) Training Pillars:

Training is a highly important activity that is usually underestimated. The general believe is that time spent for training is time lost, given that many courses are ineffective and after some weeks the student would probably forget what he was taught. The problem is that this statement is generally true because of the lack of proper planning.

Training must be a “just in time” activity. This means that the person should receive the course when he or she would get the best out of it. For this purpose, a tool known as training matrix is used. This matrix will relate each employee with the skills and training needed for their job positions. Having defined the matrix, a customized training plan is easily constructed considering not only the courses applicable to the position, but also the adequate level according to the employee’s expertise.

Training courses are grouped in four different categories: knowledge base, on the job training, attitudinal and lessons learned. On the job training focuses on skills and tasks directly related to the person’s daily activities. Generally, these courses are taught by more experienced co-workers and are carried out in site. This type of training is especially applicable for new employees or when the person is assigned to a new position. Lessons learned courses are designed to expand individual experiences to the rest of the workforce.

The objective is to prevent errors experienced in one application to occur in another one as well as share the best practices among the department. Together with the course definition, there must be material preparation and people organization. The course can be prepared within the organization or it can be outsourced. There are advantages and disadvantages in both approaches. Internally designed courses are generally more applicable to the organization needs given that they are customized. But a lot of effort is demanded to prepare the material and installation and usually lack of quality and proper learning methods. On the other hand, external courses are designed by qualified training groups.

Additionally, given that many agencies and most manufacturers provide with a set of courses for different customers, they already have the materials and installations ready to use so the course is available immediately. Yet, these courses not always fit the organization particular needs, are less applicable and many times useless. Another disadvantage of external course is that when there are budget cuts, the organization cannot afford contracting external training.

Moreover, considering that it is common that the students must attend classes off site overtime is a must which is usually unaffordable in times of recess.

5) People Pillars:

People pillar focuses on getting the best out of every employee. The first sub goal is to increase employee’s motivation. From this perspective, defining challenging objectives is an important aspect for self-esteem.

Additionally, good communication of these objectives as well as departmental and organizational objectives is essential to make the employee understand and become part of the company’s vision. But sharing the goals with the employees will make no difference if there is not an established recognition plan that would reward the individual that actively participates in the results improvement. Independence and self-actualization are two parameters that must be analyzed when assigning roles and responsibilities. Individuals that are overqualified for their job position will find it difficult to learn something new leading to loss of motivation. But if they are under qualified, they will feel frustrated also leading to motivation problems. In conclusion, the supervisor must ensure that the person is comfortable in his position.

Another sub goal in the people pillar is increase management involvement Note that the term involvement was chosen instead of commitment. Managers can be fully committed to the Organization’s objectives but they need to communicate this commitment to his subordinates in a clear and consistent way.

III. PILLARS DEPENDENCY

One important characteristic is that most trees end with fundamental attributes that are common among pillar GTs.
The reactive pillar is in order to ensure an effective action, tools and spares must be available. This can only be done through the logistics pillar. Similarly, personnel competence will be enhanced through proper training as well as personnel morale will depend on the success of the people pillar. This means that the achievement of reactive pillar is directly dependent on logistics, training and people pillars.

This dependency is repeatedly seen in most pillars as represented in Figure 2, showing a feedback process. Note that reactive depends on all other pillars, while training is completely independent. The evident interdependency among five pillars determines the importance of achieving all the goals simultaneously. This conceptual result reinforces the assumption of assigning equal importance to each pillar

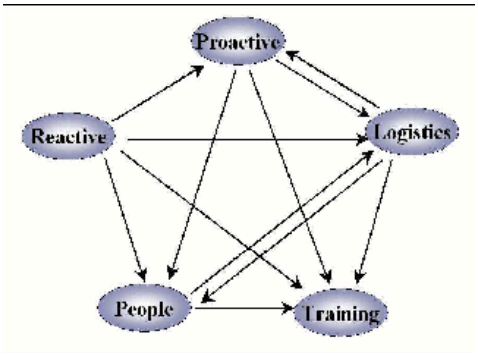

Figure 2. Pillars interdependency

After developing the GTs for each of the five fundamental pillars a group of attributes was derived. Many of these attributes are replicated in more than one pillar showing that there is a close interdependency among the pillars. Moreover, the presence of closed feedback loops indicates the importance of focusing on all pillars simultaneously in order to ensure optimal maintenance performance. It is observed that most attributes share the same indicators. This means that a variation in a single attribute can modify more than one performance indicators. Also, each metric depends on the success of a number of attributes from different pillars.

Therefore, the metrics and attributes show a many-to-many relationship. Decision makers are encountered with this complex model often. The GT decomposition followed by the application of the AHP helped clarify the model dependencies. An important advantage of this methodology is that GT decomposition provided with a general model for maintenance operations. The model can be further customized by applying the AHP to fit particular applications.
This study provides a complete and integrated methodology for maintenance related activities. The systematic development of the goal trees allows identification of all the main attributes that should be in place for reliable and safe operations. At the same time, the qualitative hierarchical arrangement of the metrics provides a means of selecting those that will better monitor maintenance performance. A case study was performed and results are consistent with expectation. Most of the resulting metrics are suggested by maintenance management literature. This practical application derived these metrics in a methodic way and at the same time provided with relative weights for each of the five pillars of the strategy.

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