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Optimization of the Maintenance and Productivity of Industrial Organization

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Abstract

Industrial competition is today truly global with customers expecting to get the best product at the best price with immediate availability. Success in manufacturing, and indeed survival, is increasingly more difficult to ensure and it requires continuous development and improvement of the way we produce products. Meeting customer demands require a high degree of flexibility, low-cost/low-volume manufacturing skills, and short delivery times.

Performance and competitiveness of manufacturing companies depend on the reliability, availability and productivity of their production facilities. To ensure that the plant reaches the desired performance, maintenance managers need a good performance track on the process of maintenance and maintenance results. This can be achieved through the development and implementation of a framework for measuring the economic performance of the maintenance function. The purpose of this article is to demonstrate that the management of the maintenance function is not set in isolation but must be linked with the production function. In this article, a conceptual framework that provides guidelines for the management of the maintenance function and the proposed model of the maintenance strategy for the manufacturing industry. It aims to consolidate the objectives of maintenance and economic objectives of the company. Finally, we discuss prospects.

Keywords: Maintenance management - Maintenance processes - Maintenance model -Production.

INTRODUCTION

Competition can be found everywhere. In the manufacturing industry, not being at the forefront signifies a loss of opportunities and profits. Thus, one of the ways for a company to lead the market is by reducing waste in its operations to be able to offer products at the lowest price possible. In doing so, the company also needs to maintain their business and customer loyalty by producing good quality and reliable products. The most efficient way to improve business performance is to have an effective maintenance activity that will aid in the process of reducing cost, improving productivity, and maintaining business profile [1].

The efficiency and effectiveness of a maintenance system play a pivotal role in the company's success and survivability [2]. Therefore, maintenance activities in a company need to be monitored, controlled, and improved from time to time to produce an effective system. A suitable and effective maintenance performance measurement (MPM) is needed to monitor the maintenance activities and the planning for more successful improvement. In fact, the results from maintenance performance measurement will signify where the organization is and where it is heading [3]. It functions as a guide to gauge whether the organization is en route to achieving its goals or not.

MAINTENANCE DEFINITION

The term maintenance is quite well-defined in literature. Other maintenance related terms, however, are quite loosely defined for example, maintenance strategy, maintenance concepts, and maintenance approaches are terms that authors seem to define in different ways, and sometimes it is hard to which definition a given author refers to when using the terms. Therefore, it is necessary to describe which definitions of the terms are used in this dissertation.

According to a definition provided by [4], maintenance is "the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in or restore it to, a state in which it can perform the required function". Maintenance in its narrow meaning includes all activities related to maintaining a certain level of availability and reliability of the system and its components and its ability to perform a standard level of quality [5]. Maintenance also includes engineering decisions and associated actions that are necessary for the optimization of specified equipment capability, where capability is the ability to perform a specified function within a range of performance levels that may relate to capacity, rate, quality, safety and responsiveness [6]. [7], describes the key objective of maintenance as "total asset life cycle optimization which means maximizing the availability and reliability of the assets and equipment to produce the desired quantity of products, with the required quality specifications, in a timely manner and this objective must be attained in a cost-effective way and in accordance with environmental and safety regulation."

➢ Maintenance Types

Maintenance is classified into two main categories, which are as follows [5], [4].

- Preventive maintenance is intended to reduce the probability of failure or degradation of functioning of an item and is carried out at predetermined intervals or according to a prescribed condition.
- Corrective maintenance, similar to repair work, is undertaken after a breakdown when obvious failure has been allocated".

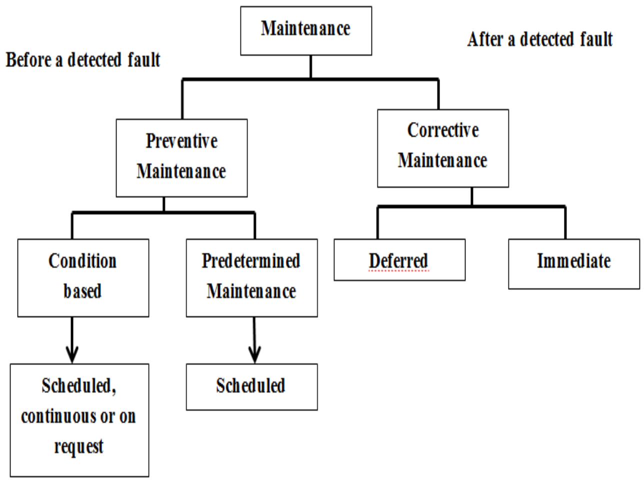

Figure 1: Represents an overview of maintenance types

MAINTENANCE MANAGEMENT MODELS

Maintenance management and maintenance strategies

[1] With increased global competition, attention has been shifted from increasing efficiency by means of economies of scale and internal specialization to meeting market conditions in terms of flexibility, delivery performance and [8]. In today's dynamic environment, a reliable production system must be seen as a critical factor for competitiveness [9]. Poor organizational competencies in managing the maintenance function effectively can severely affect competitiveness by reducing throughput, increasing inventory, and leading to poor due date performance [10], This has provided the impetus to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as condition-based maintenance (CBM), reliability-centered maintenance (RCM) and total productive maintenance (TPM), over the traditional firefighting reactive maintenance approaches [11]. The term "lean production" was introduced by [12] and by [13] in the book The Machine That Changed the World. Lean production can be considered an extended JIT that includes new intraorganizational and inter-organizational aspects [14]; [15]. Lean implementation is therefore focused on getting the right things to the right place at the right time in the right quantity to achieve perfect work flow, while minimizing waste and being flexible and able to change. Lean maintenance is a pre-requisite for Lean manufacturing

The proposed model of the maintenance management

Decision model is structured based on three basic steps; problem identification, critical component evaluation and maintenance decision as shown in Figure 2. The details of each step are described in the following sections. The main objective of the proposed model is to provide step-by-step procedure to determine the PM interval by considering the current machine state (external factor)

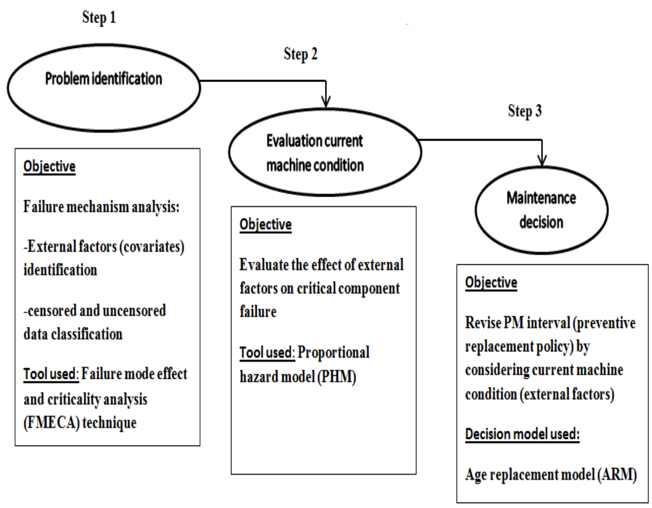

Figure 2: The general structure of the maintenance management decision model.

Step 1: Problem identification

Defining and understanding the problem accurately is the first important step of the proposed model. In reality, failure of the component is the main reason for the machine to breakdown. Component(s) failure that results in high machine downtime or cost (due to machine breakdown) is classified as critical components.

The objective of this step is to perform failure mechanism analysis in order to identify possible external factors (covariates) that contribute to the component failure and classify the censored and uncensored data. The process of this step is shown in Figure 3. failure mechanism analysis is carried out by using a well-known tool; Failure Mode Effect and Criticality Analysis (FMECA). Through FMECA, identification of the possible external factors (covariates) and classification of the censored and uncensored data can be performed systematically. Classification of censored and uncensored data is based on failure modes records and criticality index calculations.

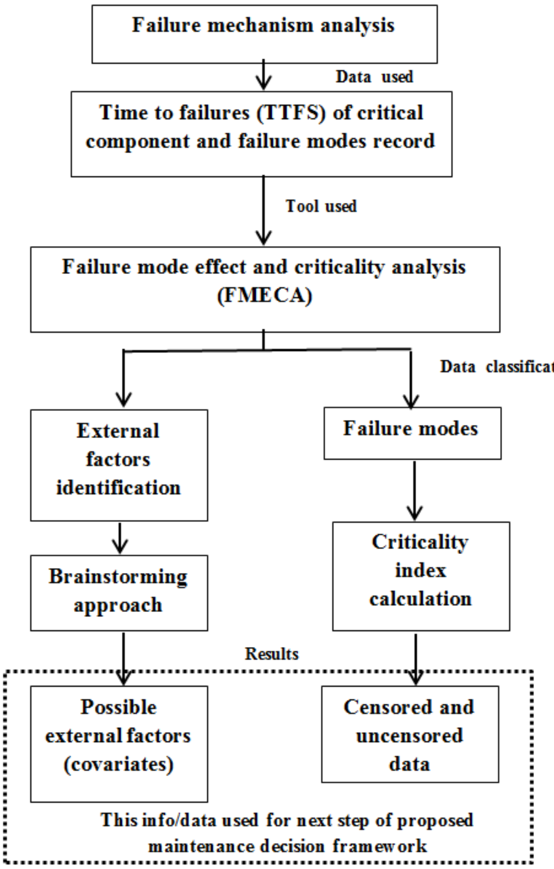

Figure 3: The process of failure mechanism analysis

The data used in FMECA are Time to Failures (TTFs) of the critical component along with failure modes records and the possible external factors (covariates) that contributes to the critical component failure. The identification of possible external factors (covariates) is carried out through brainstorming approach among experts such as maintenance technician, engineers and experience operators. The information (data) of the identified covariates and censored and uncensored data classification then will be used for further analysis in the next step of the proposed model.

Step 2: Critical component evaluation

In this step, the possible covariates that have been identified at previous step along with censored and uncensored data will be evaluated. In other words, it will determine how much (effect) the operating condition (refers to the identified covariates) contributes to the failure of the critical component based on the value of covariates parameters

Step 3: Maintenance decision

Maintenance decision is the final step of the proposed model. The first process is to test the failure times (refers to TTFs) of the critical component in terms of their trend and correlation. The result of this test is used to decide the modeling tool (either power law model or renewal model) for fitting the failure time distribution based on Weibull distribution model. Weibull distribution model is used in fitting the failure time distribution because it is flexible (versatile) distribution model and most commonly used in failure time analysis [16]. The data for fitting the failure time distribution are TTFs of the critical component along with censored and uncensored classification, which are obtained from the first step.

Description of maintenance management models

The basic concept leading to the maintenance engineering is the continuous improvement of the maintenance management process by incorporating knowledge, intelligence and analysis. They support the decision-making in the field of maintenance and are designed to enhance the global output of economic and operational result.

Due to the analysis and modeling of the results obtained in the execution of maintenance operations, the maintenance engineering permits the renovation of a continuous and justified strategy. Therefore, programming and planning activities ensure production at the lowest overall cost.

Moreover, it allows the correct selection of new equipment with minimum overall costs in terms of their life cycle and operational security (cost of inefficiency or lost opportunity cost of production). The objectives of any model of maintenance management should be determined based on the business plan of the organization. Maintenance strategies should always be aligned with the company's business plans, because the achievement of maintenance objectives depends upon it, as well as the business plan of the organization. Therefore, the maintenance and business objectives should be strongly linked together. Some of the main optimization criteria and objectives are [17]: maintenance costs (discounted), availability, maintenance quality, reliability, personnel management maintainability, inventory of spare parts, environmental impact, overall equipment effectiveness, safety/risk, number of maintenance interventions, logistics, capital replacement decisions, output quantity, life-cycle optimization and output quality.

Maintenance management is not an isolated process [17]; it is actually a linear system that depends on factors related to maintenance management, as well as internal and external factors of the organization.

Moreover, the most desirable situation is the complete integration of maintenance management in the system [18].

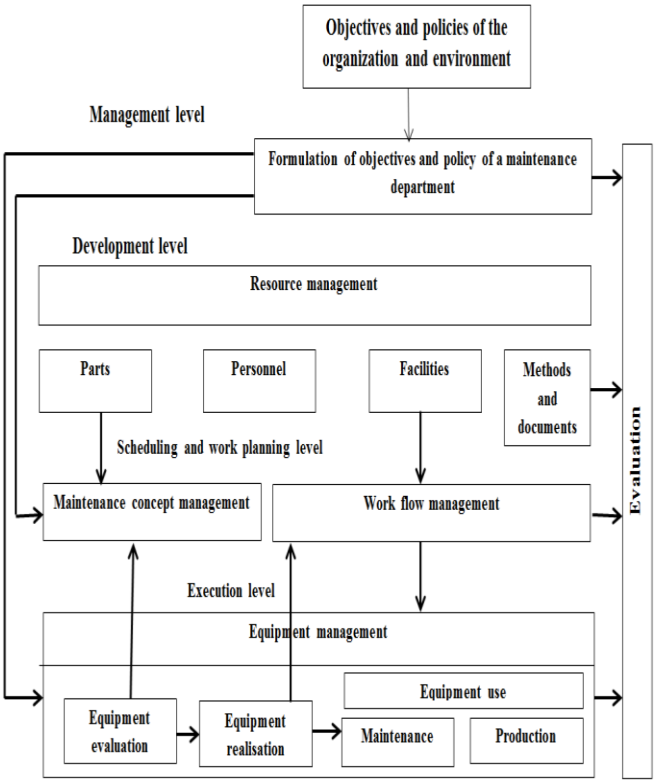

Figure 4: Maintenance management model.

Figure 4 shows the current context which frames the maintenance management and their interactions

THE RELATIONSHIP BETWEEN THE APPROACHES OF MAINTENANCE AND PRODUCTION PROCESSES

Maintenance Planning

Maintenance planning is the maintenance management activity that is carried out to prepare the maintenance plan. According to [19], the maintenance plan consists of a "structured set of tasks that include activities, procedures, resources and the time scale required to carry out maintenance". Once we make the plan, i.e. we identify the maintenance task required; we have to establish the maintenance support needs, i.e. resources, services and management, necessary to carry out the plan. Of course this support may vary according to changes in strategy, so it will have to be re-evaluated when plans are updated to meet new organizational needs. However, let us first study how to obtain our plan, our structured set of maintenance tasks for our equipment. In order to do so, we have to prioritize our equipment according to our maintenance strategy; then we may follow a combination of approaches of which the following could be of interest (Figure 5):

- Adopting manufacturers' recommendations, such as those contained in the maintenance and operation manual or similar documents, etc.;
- Relying on actual experience with the item or similar items;
- Studying and analyzing technical documentation of each item, such as drawings diagrams, technical procedures, etc., in order to improve an adapt the recommendations coming from the manufacturer to the real working conditions or maintenance special needs;
- Using maintenance engineering techniques, such as Reliability Centered Maintenance (RCM) based on a FMECA or other methods with this purpose;
- Considering regulatory and/or mandatory requirements, such as safety conditions of item operation, environmental regulations for the item, etc.;
- Other approaches

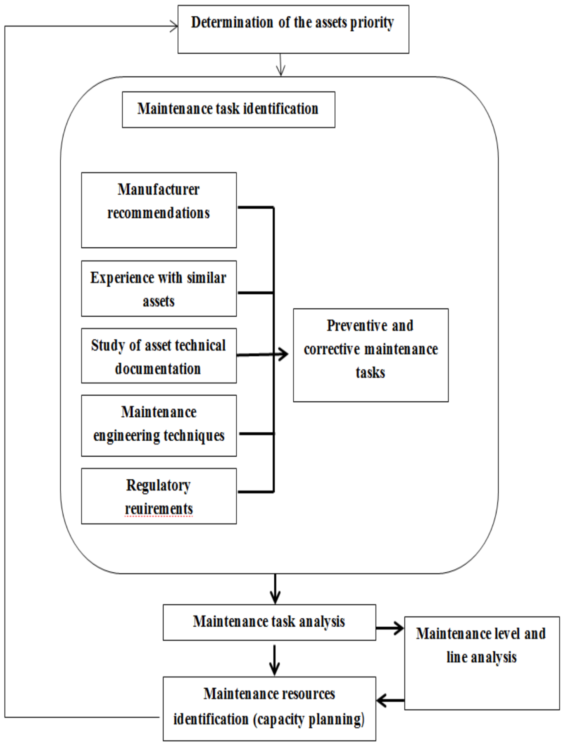

Figure 5: Maintenance task and capacity planning model

In this section we discuss articles in which maintenance (planning or scheduling) is modeled explicitly and the needs of production are taken into account. The latter however, is not modeled as such, but it is taken into account in the form of constraints or requirements. Alternatively the effect of maintenance on varying production scenarios may be considered. Following this reasoning we arrive at three streams of research. A first stream assesses the costs of downtime, which is important in the planning of maintenance. The second stream deals with studies where one tries to schedule maintenance work at those moments that units are not needed for production (opportunities) and in the last stream articles are considered which schedule maintenance in line with production. Each stream is dealt with in a separate section.

Maintenance scheduling and production

In this section we consider models where the effect of production on maintenance is explicitly taken into account. The models only address maintenance decisions, but they do not give advice on how to plan production.

The models developed in the articles in this category show that a good maintenance plan, one that is integrated with the production plan, can result in considerable cost savings. This integration with production is crucial because production and maintenance have a direct relationship. Any breakdown in machine operation results in disruption of production and leads to additional costs due to downtime, loss of production, decrease in productivity and quality, and inefficient use of personnel, equipment and facilities. Below we review articles following this stream of research in chronological order.

[20] consider the problem of determining the optimal preventive maintenance policy parameters for individual items of equipment in multipurpose plants. In order to formulate maintenance policies, the benefits of maintenance, in the form of reduced failure rates, must be weighed against the costs. The approach in this study first attempts to estimate the effect of the failure rate of a piece of equipment on the overall performance / profitability of the plant. An integrated production and maintenance planning problem is also solved to determine the effects of PM on production. Finally, the results of these two procedures are then utilized in a final optimization problem that uses the relationship between profitability and failure rate as well as the costs of different maintenance policies to select the appropriate maintenance policy.

[21] studies the problem of clustering preventive maintenance jobs in a multiple set-up multi-component production system. As far as the authors know, this is the first attempt to model a maintenance problem with a hierarchical (tree-like) set-up structure. Different set-up activities have to be done at different levels in the production system before maintenance can be done. Each component is maintained preventively at an integer multiple of a certain basis interval, which is the same for all components, and corrective maintenance is carried out in between whenever necessary. So, every component has its own maintenance frequency - the frequencies are based on the optimal maintenance planning for single components. Obviously, set-up activities may be combined when several components are maintained at the same time. The problem is to find the maintenance frequencies that minimize the average cost per unit of time.

[22] introduce the concept of selective maintenance. Often production systems are required to perform a sequence of operations with finite breaks between each operation. The authors establish a mathematical programming framework for assisting decision-makers in determining the optimal subset of maintenance activities to perform prior to beginning the next operation. This decision making process is referred to as selective maintenance.

The article of [23] deals with the problem of scheduling bus maintenance activities. A mathematical programming approach to the problem is pro- posed. This approach takes as input a given daily operating schedule for all buses assigned to a depot along with available maintenance resources. Then a daily inspection and maintenance schedule is designed for the buses that require inspection so as to minimize the interruptions in the daily bus operating schedule, and maximize the reliability of the system and efficiently utilize the maintenance facilities.

[24] examine the interaction effects of maintenance policies on batch plant scheduling in a semiconductor wafer fabrication facility. The purpose of the work is the improvement of the quality of maintenance department activities by the implementation of optimized preventive maintenance (PM) strategies and comes within the scope of total productivity maintenance (TPM) strategy.

[25] consider a plant with several units of different types. There are several shutdown periods for maintenance. The problem is to allocate units to these periods in such a way that production is least effected. Maintenance is not modeled into detail, but incorporated through frequency or period restrictions.

The relationship between Production and Maintenance

[26] describes industrial maintenance as a process that supports the production process, in which input, in the form of material and manpower, for example, is transformed into output; in effect; into finished products. Maintenance in a secondary process that contributes to the achievement of production, see figure 6

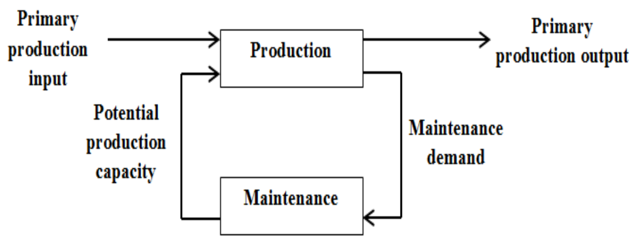

Figure 6: The relationships between production and maintenance

The planning of maintenance and production optimization

In this section we give a review of the most important maintenance decisions. In this respect we follow [27]. We distinguish between (i) the long term strategic and, maintenance concept, (ii) medium term planning, (iii) short term scheduling and finally (iv) control and performance indicators.

Major strategic decisions concerning maintenance are made in the design process of systems. What type of maintenance is appropriate and when should it be done? This is laid down in the so-called maintenance concept. Many optimization models address this problem and the relation with production is implicitly covered by them.

Another important strategic problem is the organization of the maintenance department. Is maintenance done by production personnel, in the way Total Productive Maintenance prescribes, or is there specific maintenance personnel? Secondly, where it located is, are specific types of work outsourced, et cetera. Although they are important topics, they are more the concern of industrial organization than the topic of mathematical models.

Further important strategic issues concern how a system can be maintained, whether specific expertise or equipment needed, whether one can easily reach the subsystems, what information is available and what elements can be easily replaced. These are typical maintainability aspects, but they have little to do with production.

In the short term scheduling phase one determines the moment and order of execution, given an amount of outstanding corrective or preventive work. This is typically the domain of work scheduling where extensive model-based support can be given.

We will next consider another important aspect in maintenance, which is the type done. A typical distinction is made between corrective and preventive maintenance work. The first is carried out after a failure, which is defined as the event by which a system stops functioning in a prescribed way. Preventive work however, is carried out to prevent failures. Although this distinction is often made, we like to remark that the difference is not that clear as it may seem. This is due to the definition of failure. An item may be in a bad state, while still functioning and one may consider this as a failure or not. Anyhow, an important distinction between the two is that corrective maintenance usually cannot be planned, but preventive maintenance typically can be.

The execution of maintenance can also be triggered by condition measurements, in other words, condition-based maintenance. This has often been advocated as more effect and efficient than time-based preventive maintenance. Yet it is very hard to predict failures well in advance, and hence condition-based maintenance is often unpalatable. Instead of time based maintenance one can also base the preventive maintenance on utilization (run hours, mileage) as being more appropriate indicators of wear out.

Finally, one may also have inspections which can be done by sight or instruments and often do not affect operation. They do not improve the state of a system however, but only the information about it. This can be important in case machines may start producing items of a bad quality. There are inspection-quality problems where inspection optimization is connected to quality control.

Another distinction is about the amount of work. Often there are small works, often grouped into maintenance packages. They may start with inspection, cleaning and next some improvement actions like lubricating and or replacing some parts. These are typically part of the preventive maintenance program attached to a system.

MAINTENANCE PERFORMANCE AND EVALUATION

Performance measurement is a management tool to measure the direction and speed of change done by the company. Performance measurement plays an important role for the improvement of a progress (change) towards a better performing organization. Therefore, we need to formulate appropriate performance indicators. These indicators must be directly linked with company's strategic objectives [28]. Measuring maintenance performance helps us identify the factors causing poor performance, and provides an opportunity to improve company's profits. Besides, performance measurement is also a way for the management to evaluate the condition of its systems and make a decision relating to maintenance policy adapted by the company. Maintenance activity is an activity that has a significant contribution in operation costs, approximately 30 percent of operation costs, especially if the company is implementing automated production system [29]. Here are some of the key performance measuring tools being applied in the industry, depending on the strategies adopted. Strategic TPM implementation programs have revealed a significant realization of manufacturing performance achievements leading to improved core competitiveness of organizations [30].

Maintenance performance measurement

Maintenance Performance Measurement (MPM) is defined as "the multidisciplinary process of measuring and justifying the value created by maintenance investment and taking care of the organizations stockholders requirements viewed strategically from the overall business perspective"[31]. [2] discuss the importance of MPM as follows:

- "Allows companies to understand the value created by maintenance
- Re-evaluate and revise maintenance policies and techniques
- Justify investment in new trends and techniques
- Revise resource allocations and to understand the effects of maintenance on their functions and stakeholders as well as on health and safety".

Different categories of maintenance performance measures/indicators are identified in literature. [32] classified the commonly used measures of maintenance performance into three categories based on their focus and these categories are (1) measures of equipment (2) measures of cost and (3) measures of process performance.

[33], states that "the commonly used maintenance performance indicators are maintenance process/effort indicators which are defined as leading indicators and maintenance results indicators defined as lagging indicators", as shown in the figure below.

Maintenance Performance Productivity Model: Key Performance Indicators and Operational Availability (OA)

This model helps in the measurement, analysis and the evaluation of the performance of the maintenance system. It consists of various important components or elements designed to achieve its objectives. These elements are;

Mean Time to Repair (MTTR) = Total time to repair(TRT)/number of breakdown(NOB)

Mean Time between Failure (MTBF) = Number of operating time(NOT)/Number of breakdown(NOB)

Maintenance Breakdown Severity (MBS) = Cost of breakdown repair (CBR)/number of breakdown ((NOB)

Maintenance Improvement (MI) = Total maintenance man – hour on preventive maintenance job (MPM)/total man – hours available (MPA)

Maintenance Cost Per Hour (MCPH) = Total maintenance cost(TMC)/Total maintenance man – hours (TMM)

Manpower Utilization (MU) = (Wrench time(WT)/total time available(TA))*100

Material Usage per Work Order (MUPO) = Total material cost (TMC)/Number of work order (NWO)

Maintenance Cost Index (MCI) = (Total maintenance cost (TMC)/Total production cost (TPC))*100

Overall Equipment Effectiveness (OEE)

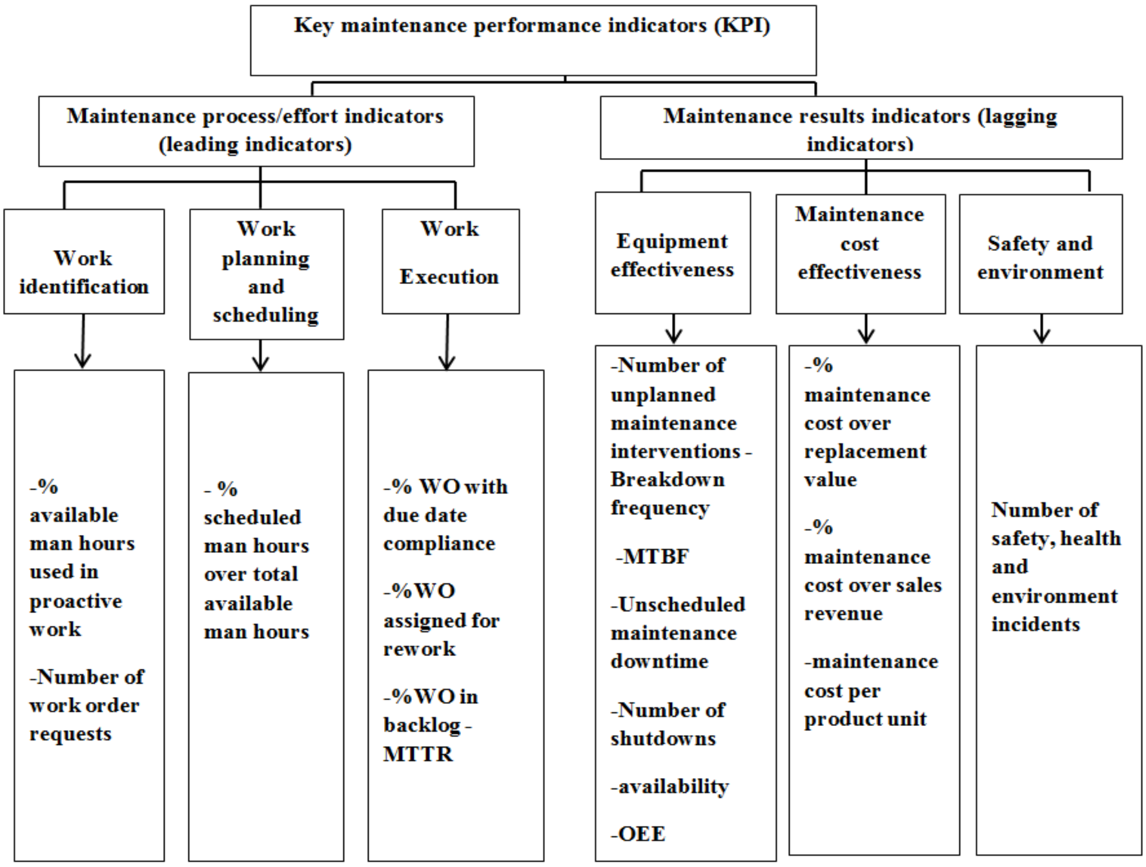

Figure 7: Key Maintenance Performance Indicators

OEE is a method to understand the performance of the manufacturing area, but also to identify possible limitations [34]. OEE calculates the percentage effectiveness of the manufacturing process. OEE is further a function consisting of the three factors, availability, performance efficiency and quality [35].

This model is also known as total productive maintenance model. It is the product of equipment availability (EA), production rate (PR) and quality rate (QR). It is an effective and efficient model developed which utilizes total productive maintenance implementation procedures for observation, analysis and evaluation of the equipment effectiveness and efficiency. It is basically aimed at maximizing the production effectiveness and the effectiveness of production plant which depends on the efficiency with which it uses equipment, materials, people and method. This is actually achieved by examining and assessing the input to the production process and identifying, eliminating the losses associated with each in order to maximize production. The standard benchmark (world class benchmark) for overall equipment effectiveness model is +85% and above [36]. The components of this model are computed as follows;

Equipment Availability (EA) =

Planned production time(PPT) – machine down time (MDT)/Planned production time(PPT)

Production Rate (PR) =

Standard time per unit (STPU)*unit produced non defective(UPND)/Number of operating time(NOT)

Quality Rate (QR) =

Total unit produced (TUP) – Defective Quantity (DQ)/Total unit produced (TUP)

The Overall Equipment Effectiveness/ Efficiency (OEE) are then computed as shown below;

OEE=EA*PR*QR

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The first metric for TPM is MTBF (Mean Time between Failures). This is measured by machine, and for this metric, the larger number the better it is. The second metric is Percent Reactive Maintenance (% Reactive). The smaller the number the better it is. World class is 20% or less reactive and 80% preventive, improvement, or scheduled maintenance. Mean Time to Repair (MTTR) is the third metric. For this metric, the smaller the number the better it is. As TPM progresses, repairs are less serious and are quicker. Tracking repair hours and showing an overall reduction is a direct cost savings. The fourth metric is Overall Equipment Effectiveness (OEE).

This is measured by machine or by process. The higher the number the better it is. World class is 85% or better. Direct financial impact can be shown as machines run faster with better quality more reliably. TPM seeks to improve the overall equipment effectiveness (OEE), which is an important indicator, used to measure TPM. An overall 85 percent of OEE is considered as world class and a benchmark for others [40]; [41]; [42]. Operational Availability (OA) - is a measure of the "real" average availability over a period of time and includes all sources of downtime, such as administrative downtime, logistic downtime, etc. It is the ratio of the system uptime to total time. Mathematically, it is given by: OA= UPTIME / OPERATING CYCLE; where the operating cycle is the overall time period of operation being investigated and uptime is the total time the system was functioning during the operating cycle. (Note: The operational availability is a function of time, t, or operating cycle.)

CONCLUSION

Performance measurement is used by industries to assess progress against set goals and objectives in a quantifiable way for effectiveness and efficiency. For the organizations industrial to stay competitive, it is imperative that they elevate the maintenance management role; from a cost center to the strategic partner in business. Performance cannot be managed without measurement; it provides the required information to the management for effective decision making. Research results demonstrate that companies using integrated balanced performance systems perform better than those who do not manage measurements

This article deals with brief description of three main outputs in the Strategy of maintenance system in industrial company. At first it describes survey of the maintenance management level in industrial enterprises that was used for definition of current state, needs of target companies and together with research of information sources for identification of potential ways of development in field of maintenance management. Second part of the article describes methodology for selecting appropriate maintenance and developed and The relationships between the maintenance and development of the organization and between the approaches of maintenance and production processes and the third part of the article describes how to measure maintenance performance indicators.

This article presents both maintenance engineering and the proposed model of the maintenance strategy to develop a simple and cost-effective approach aimed to formulate and implement maintenance strategies for the manufacturing industry.

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