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The Role of Analyzing Maintenance Performance Indicators in Evaluating Production Processes

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Abstract— *The use of non-financial indicators alongside financial indicators has become widespread in evaluating the performance of industrial facilities to keep pace with industrial development and continuous change in the manufacturing environment. Non-financial indicators depend on measuring operational performance, while financial indicators are a translation of return results and measurement of operational performance. Industrial companies rely on analyzing the results of these indicators to evaluate the performance of production operations and follow up on the progress of their work and the extent to which the goals that have been set have been achieved by identifying the gap between the achieved and the targeted. In addition to determining in which direction the change in the production process is moving and its pattern through comparison between. Actual indicators and target or benchmark indicators. The results of analyzing these indicators are used to rationalize management in making decisions to address deviations and fill gaps to improve performance and prepare future plans. The paper aims to highlight the importance of performance indicators in evaluating production processes through a study based on the descriptive and analytical approach based on data, research, reports and studies with performance indicators. Study and analyze the results of studies conducted in some local and international facilities. The study was limited to evaluating the indicators of the maintenance function as it is one of the important functions in the production process. In addition to its influential role in cost, quality, safety and performance, and its role in maintaining equipment to achieve productivity and conserve the resources used. The study showed that the maintenance performance indicators in the company under study are unsatisfactory, as the total number of stops in one line reached an average of 55 days per year, and the availability of another factory did not exceed 60% during the period from 2007 to 2015. Accordingly, the company needs to take procedures and measures such as: preparing and implementing good maintenance plans, following modern maintenance methods, and training workers.*

Keywords— *Performance, Indicators, Evaluation, Process, Decisions Making.*

I. INTRODUCTION

New conditions, industrial development, and change in the modern manufacturing environment imposed the use of non-financial indicators alongside financial indicators to evaluate the performance of production operations to keep pace with the changes taking place. Using only financial indicators no longer fulfills the required purposes. As financial indicators are used to deal with results and returns, in which corrective measures are taken after, the problem occurs in the event of deviations or gaps. In most cases, corrective action is delayed, resulting in financial losses or other losses that may amount to the loss of the facility its competitive advantage. This requires the use of indicators that work to avoid problems by taking preventive measures, or to deal with the problem immediately after it occurs by taking quick corrective measures. This led to the emergence of new indicators known as non-financial indicators that aim to deal with problems that financial indicators alone were unable to detect and explain. Non-financial indicators depend on measuring operational performance, while financial indicators are a translation of return results and measurement of operational performances. The study aims to highlight the importance of integration between financial and non-financial indicators in evaluating the performance of an industrial facility. The study was limited to maintenance as it is a major function in the production process and affects quality, safety, cost and performance. The values of maintenance indicators will be analyzed to identify the reasons for the gap between the achieved and the targeted or benchmark values.

Zaidi Abdel Salam's study [1] addressed the importance of using quantitative methods in rationalizing maintenance decisions regarding maintenance cost indicators analysis or maintenance management performance indicators. The study concluded:

- The company's focus on the strategy of planning and implementing preventive and corrective maintenance work. Giving priority to preventive maintenance, which represents the largest proportion of total maintenance costs. The researcher attributed the high cost of preventive maintenance to excessive consumption of spare parts.
- The percentage of corrective maintenance cost is considered a small percentage of the total maintenance cost, which gives the company the opportunity to increase corrective maintenance work for some non-critical equipment, which contributes to saving parts consumption without affecting the readiness of the production facility.

Ghaith's study [2] dealt with measuring maintenance performance indicators at the bar rolling mill in the Libyan Iron and Steel Company. The study concluded:

- The average time between failures for the first and second production lines is 15.6 hours and 16.96 hours, respectively. Which indicate low lines reliability.

II. RESEARCH OBJECTIVES

The paper aims to highlight the importance of calculating and analyzing maintenance performance indicators in:

- Determining the level of performance of the maintenance function and its impact on the performance of the production process.

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- Rationalizing management in taking preventive measures and quickly taking corrective measures based on early signals through analyzing performance indicators.

III. PERFORMANCE MEASUREMENT SYSTEM

Performance measurement systems consist of performance indicators, standards, and measures that include planning, observation, and control with the aim of achieving the organization's goals. The performance measurement system is considered necessary to discover gaps and achieve control over operations in order to improve the organization's operations and achieve its strategic goals in light of the competition facing its products and services. The organization must begin by choosing indicators that describe and reflect the strategic objectives; A balanced distribution of metrics shows the overall performance outcome. The use of non-financial measures alongside financial measures has become necessary to address this problem. Non-financial measures do not mean replacing those measures with financial measures, which focus on the value of outputs and the cost of inputs [3]. Rather, these operational measures are considered "non-financial supplements that are useful in isolating any deviations due to changes." in prices than those due to changes in production efficiency, meaning determining the ratio of outputs to inputs that are consumed as a result of improved production. There are two main reasons why non-financial KPIs are important: They help to clarify and provide indications for financial KPIs. They can be easily linked to certain aspects of the overall strategy of the company or institution [4].

A. *Type of Indicators*

The indictors are divided according to their importance to the process.

Key performance indicators are a measure based on quantitative or qualitative standards that provide the opportunity to verify the changes that occur in various aspects of organizations' activity compared to what is planned.

The performance indicator is a measure to identify the change that occurs in any activity of a specific program, determines the size and direction of that change, and gives early warning of what will happen.

An indicator is a quantitative or qualitative factor or variable that provides an easy and reliable way to measure achievement or to detect changes associated with a development intervention or to help estimate the performance of an intervener.

B. *Benefits of performance indicators*

- Identify and measure organizations' progress toward their goals.
- Correcting organizations' weaknesses and strengthening their strengths.
- Pointing out the challenges facing organizations and how to confront them.
- Identifying the opportunities available to organizations and how to seize them.
- Monitor performance and identify problems facing it.

C. *Classification of indicators*

Indicators can be classified into leading and lagging indicators. Both scientific performance indicators (leading indicators) and results indicators (lagging indicators) are important for measuring the performance of any process.

1. *Leading indicators*

Leading indicator warns the user if goals are not reached before there is a problem. It is one of the statistical series that accurately shows the arrival or decline in performance before it is determined by the general economy. So the leading indicator acts as a guide to performance if the tasks and functions of the operation are performed well and alerts the person in charge of the process of the necessity checking the status compared to the reference status.

2. *Lagging indicators*

Demonstrating whether the outputs or results have been achieved, in addition to build a relationship or link between leading and lagging indicators. This link make it possible to control the process under study. In order to achieve the purpose of using these indicators, they must be chosen according to the strategy of the company or facility.

IV. VARIOUS ASPECTS RELATED TO MAINTENANCE

A. *The concept of maintenance and its types.*

The modern definition of maintenance states that maintenance is a combination of administrative, financial, and engineering applications that are applied to physical assets, tracks their economic life cycle, and is concerned with the specifications and design of the plant, equipment, and buildings to ensure their reliability and perform the necessary maintenance for them, as well as paying attention to their erection and installation, ensuring their suitability for use, making modifications to them, and replacing them. Depending on the data obtained through feedback on its design, completion and costs [5]. Figure (1) shows the types of maintenance

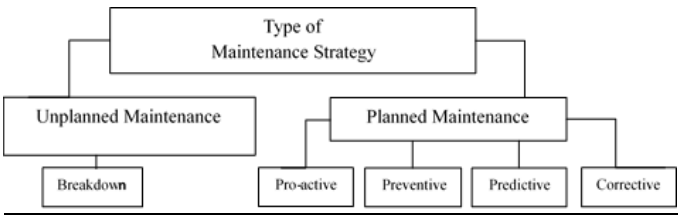

Fig. 1. Type of maintenance [6]

B. *The importance of performance indicators in maintenance*

The success of maintenance work depends on the success of maintenance work management, and performance measurement is considered a basic principle of management Maintenance Function Well-defined performance indicators should help identify gaps between required performance and Actual performance provides indications and indications of the extent of progress and progress towards closing these gaps.

C. *Maintenance performance indicators*

Maintenance performance indicators include maintainability indicators, leading and lagging indicators.

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1. MAINTAINABILITY INDICATORS

It expresses the equipment's ability to be maintained after a failure occurs to return it to service. Maintainability is desirable, and therefore management officials seek to obtain high values in maintainability indicators [7]. Figure (2) shows the sequential states that repairable systems go through

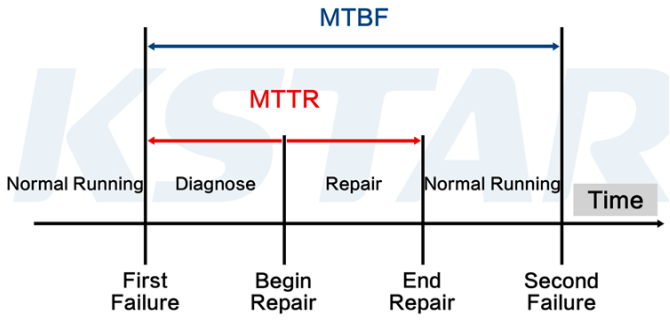

Fig. 2. The sequential states that repairable systems [8]

- Mean Time between Failure (MTBF)

This indicator is considered important in evaluating maintenance performance, as it measures the average time between failures that occur in the equipment or its repairable parts. The high value of this indicator indicates a high efficiency of the equipment in producing products in the required quantity and quality. It is calculated according to equation (1)

MTBF = operation time / no of failures……...……. (1)

- Mean Time To Repair (MTTR)

It is the average time required to repair the equipment or its repairable parts after the failure occurs, and it is calculated according to equation (2)

MTTR=(total downtime /number of failures or repairs) ..... (2)

The average time required to repair equipment is considered a measure of maintenance capacity and an important factor for performance. The average time required to repair equipment is considered a measure of the production path. The decrease in average repair time indicates the efficiency of the maintenance teams as well as the tools used to quickly repair failures.

- Failure rate

It is defined as the reciprocal of the mean time between failures, and is symbolized by the symbol (λ). The percentage of probability of failure occurring is one of the most important indicators for analyzing the reliability of equipment, as it determines the percentage of failure. Equipment failure according to the failure rate that has been in operation for a certain period at any future moment. The failure rate is calculated through equation (3).

λ =1/ MTBF……(3)

- Availability (A)

It is the ratio between the actual time to operate the equipment and the planned time for operation, and it is also expressed as the ratio of the average time between failures to the total time between failure plus the average repair time. It is calculated using equation 4).

Availability (A) = actual operating time /planned operating time …… (4)

- Time loss

The time loss is the time lost from the planned operating time (in which the equipment is not used), and it depends on how long the failure lasts. The longer the failure time, the greater the time loss and it is calculated according to equation (5).

Time loss = planned operating time − actual operating time..... (5)

- Time spent on maintenance

This indicator aims to determine the percentage of time spent on maintenance out of the total time. It expresses the extent to which all maintenance activities can be carried out if the maintenance work carried out is part of preventive and corrective maintenance. It is important that most of the maintenance work carried out is among the scheduled targets, given that its cost is monitored, which contributes to increasing the effectiveness of maintenance and the indicator is calculated according to equation (6).

Time spent on maintenance = Total time spent on maintenance / Total time allocated for maintenance …… (6)

2. LEADING INDICATORS

They warn the management if goals are not reached before there is a problem. In addition, they act as guild to performance to performance to comply with the plan according to scheduling. The leading indicators include:

- Maintenance work rate indicator

It is expressed as the ratio between the time used to carry out preventive and corrective maintenance to the time available for maintenance and is calculated from equation (7).

Maintenance work rate indicator = total preventive and corrective maintenance time)/time available for maintenance.....(7)

- The percentage of preventive maintenance work indicator:

The indicator measures preventive maintenance actual time compared to the schedule time and thus measure the efficiency and skill of the maintenance crews. A low value of the indicator indicate that the tasks were completed according to the planned time and reflects the efficiency of the maintenance teams. Monitoring changes in this indicator, helps in preparing training plans. It is calculated from equation (8).

The percentage of preventive maintenance work.= Number of preventive maintenance events / number of scheduled preventive maintenance events.....(8)

- Time allocated for corrective maintenance indicator:

It represents the breakdown maintenance work that are performed on the equipment with the aim of returning it to its operational condition. A complete maintenance is performed or the necessary repairs to return it to the condition before the failure occurred. It is calculated according to equation (9)

Time allocated to corrective maintenance indicator = total time allocated to corrective maintenance / total time used for maintenance .....(9)

3. LAGGING INDICATORS

It is concerned with monitoring the returns or results achieved from maintenance performance indicators such as the number of breakdowns, breakdown times, and availability of

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equipment. The most important lagging indicators are the following:

- Maintenance personnel cost ratio indicator.

The maintenance personnel cost ratio index is calculated through equation (10)

Maintenance personnel cost ratio index = labor costs / total maintenance costs ..... (10)

- Spare parts cost indicator

The spare parts cost index for a production line or factory is calculated through equation (11).

Spare parts cost index = Spare parts costs / Total maintenance costs .....(11)

V. Study Case

Maintenance performance indicators that were calculated in previous studies or will be calculated by the above-mentioned equations will be analyzed for steel bar mill.

- Bars rolling mill

The mill consists of two identical lines, each with a design capacity of 200,000 tons annually of rods and. The mill operates in 3 shifts, 8 hours a day, 300 days a year. The factory contains [9]:

i. Reheating furnaces with a capacity of 80 tons/hour
ii. The primary rolling stage includes 8 horizontal rolling mills
iii. The intermediate rolling stage includes 6 horizontal rolling mills
iv. The final rolling stage of the rolling, which includes 10 rolls.
v. The final finishing stage of the bars.

Table (1) shows the performance indicators of linear maintainability

TABLE 1. Maintainability Performance Indicators

Item	Line 1		Line 2	
Year	2015	2016	2015	2016
MTBF	15,6	16.96	39.18	29.50
MTTR	21.2	17.4	19.43	15.08
Availability (A)	84%	81%	82%	79%
Failure rate (λ)	0.0664	0.060	0,04	0,04
Lost time	102	96	110	91

By researcher based on [2],[10] ,[11], [12]

From Table (1), it is noted that the average monthly time loss is 110 hours for the first line and 91 hours respectively. Thus, the average annual stoppages based on the average monthly time loss is 55 days for the first line and 45.5 days for the second line in the year 2016, respectively, as a result of breakdowns and repair time. The percentage of l stoppage time based on the "assumption of 300 days available for operation" is 18.3% and 12.4% for the first line and the second line, respectively.

- Leading indicators

Table (2) shows the leading indicator for the mill

TABLE.2. the leading indicator for the mill

Indicator (%)	2015	2016
Maintenance work rate	170%	180%
Preventive maintenance	35%	21%
Corrective maintenance	65%	79%

By the researchers based on [10] , [13] , [14]

From Table No. (2), it is clear that the percentage of maintenance work is very high as a result of the high rate of corrective maintenance and the low rate of preventive maintenance, which led to an increase in the number of breakdowns and repair time.

- Lagging indicators

Table 3. Shows the lagging indicators for the mill.

TABLE.3. Lagging indicators for the mill

Indicators	2015	2016
Maintenance personnel cost ratio	42.5%	50.60%
Spare parts cost	49.3%	49.1%
Total maintenance costs	Not available	20%

By researchers based on [13], [14]

From Table.3. It is clear that the cost of maintenance personnel is high as a result of maintenance personnel performing overtime work after the general shift and during weekends and holidays to repair faults. High parts costs due to the use of spare parts for corrective maintenance, which confirms the predication by leading indicators.

VI. Conclusions

The study showed the importance of non-financial maintenance indicators in analyzing operational performance and providing information for financial indicators. For example:

- The percentage of maintenance cost in the bar rolling mill is 20% of the production cost, which is considered relatively high.
- The percentage of maintenance work in the Bar rolling mill is up to 180% as a result of high and low rate of corrective and preventive maintenance respectively.
- The total time for maintenance breakdowns in the bar rolling mill up to 55 working days per year, which represent 18.3% of the available time for operation.

Maintenance performance indicators are unsatisfactory as a result of Poor preparation and planning for the planned maintenance which led to:

- exceeding the specified time for maintenance
- Repeated occurrence of the same equipment failure as a result of temporary repair due to a lack of spare parts,
- failure to address the causes of the problem, exceeding its expected lifespan, lack of expertise to address some chronic problems,
- focus on corrective maintenance rather than preventive,
- not using new methods of maintenance, such as monitoring the condition of equipment.

The values of lagging indicators confirm the prediction by the leading indicators.

VII. Recommendations

• Attention should be paid to planned maintenance, implementing modern methods of maintenance, treating the causes not the symptoms, training workers and raising their efficiency in the field of maintenance.

• Applying non-financial indicators alongside financial indicators in industrial facilities

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• It is necessary to include an indicator of indirect maintenance costs, such as production losses as a result of time lost in repairs and breakdowns, in addition to time losses as a result of producing products that are rejected or do not conform to specifications.

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