EVALUATION OF MAINTENANCE PERFORMANCE USING KEY PERFORMANCE INDICATORS

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الملخص

المحافظة على الاصول الصناعيه أصبحت اليوم أكثر صعوبة وحرجة للغاية خاصة بالنسبة للصناعات التى تعتبر أساسية مثل قطاع النفط فى ليبيا. الغرض من هذه الورقه هو إختيار أو إستخلاص مؤشرات الأداء الرئيسيه (KPIs) التى يمكن أن تستخدم لوصف عمليات الصيانه فى الخط وتقييم فعاليتها.

جرى الإعتقاد بأن مؤشرات الإداء الرئيسيه مفيده لأدارة مهام الصيانه. ولكن حالياً لا توجد مؤشرات أداء رئيسيه معياريه لتقييم أداء الصيانه، ولهذا تم إختيار وفحص وتحليل مؤشرات أداء رئيسيه من خلال دراسة حاله دراسية نفدت فى إحدى الشركات النفطية الكبرى.

أوضحت النتائج أن متوسط تكلفة الصيانه الفجائيه تساوى 31% ومتوسط تكلفة الصيانه الوقائيه تبلغ 44% من تكلفة الصيانه الكليه، وأن إنتاجية العماله تساوى 98% خلال فترة الدراسه. ومن الملاحظ أن الشركه تدرس بجديه المحافضه على إستخدام متطلبات وتوصيات المقاول الأكثر المعدات الحرجه من حيث نوع الصيانه وقطع الغيار وتنفيد أعمال الصيانه وأى مساعدات فنيه اخرى. وهذا هو السبب الرئيسى الذى أدى إلى منع الشركه من أن يكون لديها برامج سيطره جيده لأعمال الصيانه ووضع ميزانيتها وكذلك تحسين مهارات موظفيها.

كما كان لذلك عظيم الأثرعلى إعداد برامج التخطيط وتطبيق برامج الصيانه الوقائيه التى سوف تزيد الوقت المتوسط بين حالات الفشل للأجهزه وتسمح لها بتوفر مستمر وتقلل من وقت توقفها وتخفض من تكاليف تشغيلها. نستنتج من الدراسه أيضاً أن الشركه عموماً ليس لديها أسلوب عام لتقييم أداء الصيانه وأن تكلفة الصيانه منخفضه نسبيا مقارنة بتكلفة فقدان الإنتاج.

ABSTRACT

Maintaining the asset in the industry today is becoming increasingly critical, which is particularly true for the capital-intensive process industry (oil sector) in Libya. The purpose of this paper is to select or extract the key performance indicators (KPI's) that can be used for describing the maintenance work in the plant and evaluate its effectiveness. It is believed that KPI's are useful for managing the maintenance function, however currently there are no standardized KPI's available for assessing maintenance performance.

The selected KPI's are tested and analyzed through a case study carried out in one of the major oil companies, from which the input data are collected to represent the most capital - intensive process industry. The results show that the average of breakdown maintenance represents 31% and the average cost of preventive maintenance is equal to 44 % of the total maintenance costs with a labor productivity of 98% during the studied period.

It is also noticed that the company is highly considering and remain using the contractor's requirements and recommendations for most of the critical equipment, with regard to the type of maintenance, spare parts, maintenance work execution and any other technical assistance. This prevents the company from having to have an inline maintenance control program for budget, cost and involved personnel skills. This will have a great effect on the successful planning, scheduling and implementing of a good preventive maintenance program which will reduce the overall equipment down time and will increase the mean time between failures, providing good and continuous equipment availability at lower operating costs. The company in general has no common approach of assessing performance of its maintenance function, and the maintenance cost are relatively low compared to the cost of lost of production

KEYWORDS: Preventive Maintenance; Reliability; Maintainability; Availability; Preventive Maintenance Indicator; Labor Productivity Indicator.

INTRODUCTION

As industry becomes more capital intensive, the relative cost of assets increase give more importance to maintenance function, maintaining or increasing production rate requires higher plant and equipment availability. The maintenance function has becomes more specialised and costly, many organisations have realised that there is a lot of money can be saved by managing the maintenance work in an effective way. Presently there is some dissatisfaction with the measures and indicators used currently to monitor the maintenance work. It is believed that many useless key performance indicators (KPI's) are extracted and presented, while other more important ones are overlooked. KPI's are indicators that are usually used to indicate and evaluate the performance of maintenance function within a company. The most appropriate way of achieving this is to convert as much as possible to costs as this is easily communicated and understood at any level of management.

Among maintenance managers in general, there is also a belief that economic evaluation is the only way through which they can communicate with business oriented people in top management, as they generally do not grasp the implications of technical measures for example, an availability of 97% on a certain piece of equipment may mean little to a manager, where as a figure of how much money this unavailability costs the company may be easier to comprehend. Effective key performance indicators are a valuable tool to activate corrective action often however metrics are worthless since they do not provide useful indications of performance, particularly when this performance is below acceptable levels. A realistic period must also be used for each metric- in some cases this may be one hour while in others it could be one year [1]. For this reason the selected KPI's should be the most important performance measures to provide useful information, and to represent the concerned condition through reliable data analysis.

MAINTENANCE OBJECTIVES

The objective of any plant's maintenance is to improve its availability and safety by preventing or reducing to a minimum the equipment breakdown and to maintain the equipments running in a satisfactory condition for normal operation and emergency use [2]. The maintenance contributes to profitability through:

- Extended life of assets
- Improved reliability and availability
- Enhanced and consistent product quality
- Continuity of production and supplies
- Quick response and repair times

Plant productivity improvement concerned with improving (preventive, corrective and predictive) maintenance servicing to reduce failure occurrence. Preventive maintenance servicing is concerned with providing the equipment checks and interventions according to the manufacturing servicing instructions and operations requirement including environmental concern [3].

Failure reduction or avoidance strategy starts with the equipment design phase (Reliability Concern), but what we are considering here is the failure as a consequence of operations, this becomes the primary responsibility of preventive maintenance. To develop an effective strategy for failure avoidance we need to know when the item or equipment is about to fail, so the repair or replacement action could be scheduled with minimum operation interruption before failure actually occur.

The management of maintenance is the same in principle as that of any other function, the manager wants to know his targets and the extent to which they are being met and therefore; performance measurements provide valuable information and means to control his department activities to stated objectives. Maintenance represents a significant portion of cost of providing a service; this portion of cost is continuously increase due to the fact that the big scale equipment and facilities invested can not hold their expected availability because of insufficient maintenance.

TYPES OF MAINTENANCE

There are two types of maintenance, these are:

a- Planned Maintenance (Preventive maintenance)
b- Unplanned Maintenance (Break-down maintenance)

When maintenance is done before the equipment breakdown or failure with the objective to prevent the failure is called preventive maintenance, and when maintenance is done after a breakdown or failure of equipment with the objective to bring back the equipment into operation is called breakdown or failure maintenance. The evaluation of preventive maintenance program should be performed regularly by concerned manager with the support of the technical and engineering group to address the overall effectiveness of the program in improving the equipment, plant availability and reducing the maintenance cost as well. The efficiency of the preventive maintenance shall be evaluated to improve the reliability of the equipment by studying and modifying the failure mode (failure is the loss of component or equipment to perform its function). System effectiveness is a measure of the ability of the system to achieve a set

of specific requirement; it is a function of availability, where availability can be enhanced by reliability, maintainability and maintenance performance.
Reliability is defined as a probability that a given system operating under a given condition will continue to operate according to its specifications for a given period of time [2, 4].

Maintainability is the probability that a particular repair can be performed within a given time, in practice, the maintainability of a system is typically characterized by its mean time to repair MTTR [4].

Availability of the equipment is defined by the probability that equipment will be in service during a scheduled working period [4]. Availability defined by the following equations [2]:

A = Uptime / (Uptime + Downtime)

A = MTTF/ (MTT F + MTTR)

Where, MTTF denotes the mean operating time to failure, and MTTR denotes the mean time to restore or repair.
Or

A = MTBF / (MTBF + MTTR)

Where, MTBF denotes the mean time between failures and MTTR denotes the mean time to repair.

The availability can be improved by improving (increasing) the up time (MTTF) or by keeping a minimum failure rate; this can be obtained by a proper maintenance system (improving maintenance resources and maintenance technique).

Mean Time between Failure (MTBF), Mean Time to Failure (MTTF), and Mean Time to Repair (MTTR) are equipment management metrics used to assess reliability, maintainability and identify problems, Figure (1) showing the relationship between MTBF, MTTR and MTBR

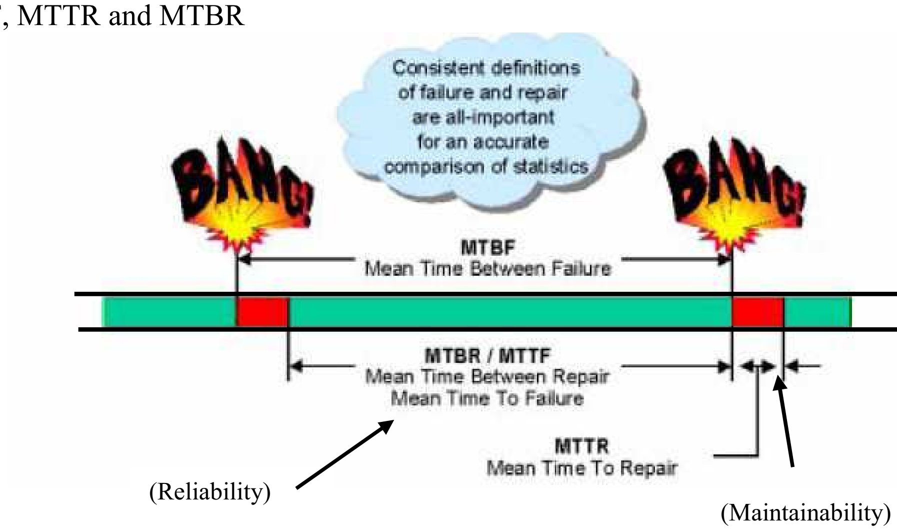

Figure 1: Relationship between MTBF, MTTR, and MTBR [5]

MAINTENANCE PERFORMANCE MEASUREMENTS

Measurement of maintenance performance is aimed at expressing in value the result of maintenance effort and also at increasing the productivity of plant through feed back of such evaluation to the decision makers and job controllers at various levels of the plant management.

Measuring maintenance performance requires defined objectives to be set. These objectives are then analyzed in terms of measurable parameters which can be evaluated through the use of performance indices to figure out whether the objectives have been met or not. The purpose of measuring maintenance performance can be summarized as follows:

- To define the operational goals of maintenance department and to determine the performance against these goals for possible evaluation of maintenance activities.
- To establish priorities for the improvements of maintenance techniques based on numerical values for performance, so that more effective maintenance activities may be developed by taking the right decisions at the right time.
- To raise the moral of the maintenance department, it has been treated as a subsidiary department of secondary importance.
- To detect weakness in the administration of the maintenance operation and its supporting systems, as well as the operating system and to correct the weakness.

MAINTENANCE KEY PERFORMANCE INDICATORS (KPIS) [6]

The problem in many organizations is that the information collected from business processes is used only for the sake of measurements, not for change or signal to identify ineffective or failed strategies. If the idea is to use KPI's that will identify work process improvement areas which are aligned with company objectives, then the objectives must be well defined and understood.

From the equipment prospective, the objectives are usually related to reliability, availability, maintainability, and cost saving. Usually the objectives are related to improving maintenance and operations work process and maintaining assets for continuous production, additionally other objectives related to information and personnel training. Based on that, the following KPIs are selected and used to evaluate the maintenance performance:

The Overall Equipment Effectiveness (OEE)

Maintenance effectiveness should be primarily measured with the OEE metrics of Total Productive Maintenance (TPM). The strengths of OEE lie in its simplicity and supporting quality management, continuous improvement and internal efficiency measurements. The goal of combining the OEE calculation and investment costs of the machines is to maximize the utilization of the constraining bottleneck machine of a production line, i.e. the efficiency of the machine in respect to the investment costs. Otherwise the productivity improvements could be lost because of production bottlenecks. It will be misleading focusing of OEE on achieving the maximum performance from a machine regardless of what the performance requirements are. In addition, the costs of quality losses, performance losses and availability losses are not financially comparable.

Overall effectiveness metrics are top-level industry measures used to evaluate operating and quality performance. Overall Equipment Effectiveness (OEE) from Total

Productive Maintenance (TPM) is a common metric used to measure production effectiveness.

OEE is the product of normalized availability (uptime), production throughput (yield) and first-run-quality. OEE is a measure of process and equipment effectiveness when the equipment is scheduled to run. In terms of OEE, "world class" performance is said to be 85 % percent or greater for continuous processes and 80 % percent or greater for batch processes [7]. When demand exceeds capacity, any reduction in OEE represents lost profit. The most central objective of TPM is the maximization of the overall equipment effectiveness (OEE), which is calculated by:

OEE = Availability (%) x Performance (%) x Quality (%)

Where:-

$$\text{Availability }\% = \frac{\text{Total Available Time - Actual Down Time}}{\text{Total Available Time}} \times 100$$

$$\text{Performance }\% = \frac{\text{Output (in MSCF) x Time To Produce The Output}}{\text{Total available Time - Actual Down Time}} \times 100$$

MSCF is defined as millions of standard cubic feet of compressed gas.

$$\text{Quality }\% = \frac{\text{Total Production - Defective Products}}{\text{Total Production}} \times 100$$

Maintenance Cost indicators

The selected cost indicators are:

- **Cost of Maintenance Break down;**

This is the average cost of breakdown computed from historical data of the system or similar system. This includes cost of man hours and cost of spare parts.

$$\text{Average Cost Of Breakdown} = \frac{\text{Direct Cost of Breakdown}}{\text{Total Maintenance Cost}}$$

This index indicates the influence of preventive maintenance when the plant has been operating steadily for a period of time. As more preventive maintenance introduced, so the value of this index should be reduced.

- **Cost of Preventive Maintenance**;

This is the average cost of preventive maintenance which includes material, labor and other indirect costs. This is also an accounting parameter.

$$\text{Average Cost Of Preventive Maintenance} = \frac{\text{Cost Of Preventive Maintenance}}{\text{Total Cost Of Maintenance}}$$

This index is used as indicator of the extent of preventive maintenance. In continuous process industry the value of this index exceeds 60%.

Workload indicators (Labor productivity)

$$\text{Labor Productivity} = \frac{\text{Time Recorded on Maintenance Job}}{\text{Time Estimated For The Job}}$$

Or

$$\text{Labor Productivity} = \frac{\text{Total Worked Hours}}{\text{Total Available Hours}}$$

Data Collection and interpretation

The data was collected from reviewing the existing maintenance records and maintenance cost documentation. Also data gathered from the computer maintenance management system (CMMS) which are actually in use. And conducting a serious of interviews, and discussion with maintenance staff and others concerned in finance cost control, material purchasing, and operations personnel and finally by direct observation through the use of the author self experience.

The data in Table (1) summarizes the historical records of one Turbo- Gas Compressor unit (TC1) for the last seven years:

Considering ideal time = time in hours required to produce 10 MMSCF (targeted daily production) of the compressed gas a day without stoppages of the equipment = 24 hrs. While the best time to produce 10 MMSCFD is approximately 24.2 hrs (on average as several stoppages of minor nature has occurred) = 24.2 hrs. We assume that the gas quality is not changed by the compression process, and any losses or wastage of gas being recorded.

Table 1: Turbo compressor historical data records (TC1) (ENI Oil Data)

Equipment		TC1 Turbo- Compression package			
Year	Total working time (days) I	Planned down time (days) II	Total time available (days) III	Actual downtime (stoppages) (days) IV	# Average Gas Prod. Capacity (Compressed Gas in SCF) V
1997	362	0	365	3	9.4
1998	362	0	365	3	9.4
1999	363	18	365	2	9.6
2000	364	0	365 ♥	1 ♥	10
2001	363.5	0	365	1.5	10
2002	364	10	365	1	9.8
2003	361	25	365	4	9.2

Notes:

Average gas production capacity (Compressed gas) = 10 MMSCF/day.

♥ Best of the best records.

Before starting the calculations let us denote VI by the quality of gas, VII by the loss or wastage of gas, and VIII by the number of hours (amount of time) required to produce ten millions of standard cubic foot of compressed gas a day.

OEE calculation (Best of the best target)
Using the data in Table (1) we find the following:

OEE = Best Availability (%) x Best Performance (%) x Quality (%)

Best OEE (Overall Equipment Effectiveness) = 66.3%
This result taken as an example for the year 2000, the rest of the results are shown in Table (2)

Table 2: OEE Calculations

Year	1997	1998	1999	2000	2001	2002	2003
Availability	99.1%	99.17%	99.45%	**99.72%**	99.58%	99.72%	98.90%
Performance	62.84%	62.48%	64 %	**66.48%**	66.57%	65.2 %	61.67%
Quality	100 %	100 %	100 %	**100 %**	100 %	100 %	100 %
OEE	62.3 %	62.3 %	63.6%	**66.3 %**	66.3 %	65.0 %	61.0 %

Cost indicators

The collected cost information from maintenance department at the ENI oil company data table shows the costs of man-power and spares, preventive and breakdown maintenance work expenditure during the studied years.

Table 3: Maintenance costs

year	Man-power cost. (USD)	Spare parts and consumable cost. (USD)	Logistic support cost (USD)	Preventive Maintenance cost (USD)	Breakdown maintenance cost (USD)	Total maintenance . Cost (USD)
1997	1,330,000	1,597,000	735,000	5,870,000	4,270,000	13,802,000
1998	1,040,000	1,829,000	626,00	,010,0005	3,6 70,000	12,175,000
1999	860,000	820,000	390,000	4,404,000	3,5 00,000	9,974,000
2000	8 90,000	1,090,000	400,000	6,383,000	3,800,000	12,563,000
2001	870,000	950,000	390,000	4,3 38,000	3,210,000	9,758,000
2002	7 45,000	1,950,000	398,000	4,2 50,000	3,1 50,000	10,493,000
2003	1,168,000	1,740,000	410,000	5,480,000	3,780,000	12,578,000
Total				35,735,000	25,380,000	81,343,000

Breakdown Maintenance Indicator (BMI)
This index indicates the influence of preventive maintenance when the plant has been operating steadily for a period of time. When an effective preventive maintenance introduced, the value of this index should be reduced. It is known as the breakdown maintenance severity**.** From the data in Table (3) we find that:

$$\text{BMI} = \frac{\text{Average Cost Of Breakdown}}{\text{Average Of Total Maintenance Cost}} \text{x}100 = 31\%$$

Preventive maintenance indicator (PMI)

$$\text{PMI} = \frac{\text{Average Cost Of Preventive Maintenance}}{\text{Average Total Cost Of Maintenance}} \text{x}100 = 44\%$$

Preventive maintenance indicator (PMI)

$$\text{Average Cost Of Preventive Maintenance} = 5{,}105{,}000$$

$$\text{PMI} = \frac{\text{Average Cost Of Preventive Maintenance}}{\text{Average Total Cost Of Maintenance}} \text{ X100} = 44\%$$

Labor productivity Indicator (LPI)

The Maintenance sections annual worked man hours against the available hours are as follows:

Table 4: Maintenance sections annual worked vs. available man hours

Year	Mechanical Hrs	Electrical Hrs	Instrument Hrs	Inspection Hrs	Total W. Hrs	Available Hrs
1997	130,000	60,000	50,000	120,000	360,000	403,910
1998	110,000	55,000	50,000	100,000	315,000	334,565
1999	116,000	40,000	45,000	65,000	264,000	270,000
2000	80,000	37,000	42,000	42,000	201,000	211,400
2001	75,000	40,000	42,000	50,000	207,000	260,000
2002	75,000	39,000	40,000	42,000	196,000	219,550
2003	80,000	35,000	42,000	40,000	197,000	250,267

The labor productivity can be measured for the year 1999 as an example as follows:

$$\text{LPI} = \frac{\text{Total Maintenance Worked Man - H} = \text{ours}}{\text{Total Maintenance Available Man - Hours}} \text{x}100 = 98\%$$

CONCLUSIONS

1 The best OEE obtained during the studied period (1997-2003), equal to 66.3% (the ideal OEE is 85%). OEE above 60% is considered competent; however consideration should be given more to the equipment performance and availability to improve the overall equipment performance.

2 The cost indicators show that the average break down maintenance cost equals 31% of the average total maintenance cost. And the average preventive maintenance cost equals 44% of the average total maintenance cost.

3 The level of manpower utilization are satisfied as shown in the labor productivity indicator 98 %.

The above selected indicators give an indicative impression to the maintenance performance and it is clearly identifies the area of concern where the organization management should interfere for proper decisions. Some of these areas of concern include:

- Action can be taken to optimize the preventive maintenance works; this will improve the overall equipment effectiveness and will reduce the breakdown maintenance cost
- Attention may be given to review the contractor recommendations for any maintenance works, the necessary spare parts, the time required for the maintenance works and frequency for better maintenance control to reduce cost.
- The selected key performance indicators should be aligned with the specific objective and linked to the overall company objectives to be more indicative, realistic and reasonable to improve the asset performance work process.

- Training and motivation of maintenance personnel using a systematic training program according to the individual training needs (on job training), this will reduce the contractor involvement, the equipment down time and the overall maintenance costs.

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