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A COMPREHENSIVE FRAMEWORK AND KEY PERFORMANCE INDICATORS FOR MAINTENANCE PERFORMANCE MEASUREMENT

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ABSTRACT

Effective maintenance prolongs machine lifetime, enhances equipment availability and retains the equipment in functional condition. Whereas, unreliable maintenance may result in more equipment replacement because of a shorter life. It is important to realize that maintenance function adds value, although not as obvious as other departments and that it is an equally important link as other departments. With those consequences, a good strategy of maintenance is very much needed, which helps to improve and maintain the productivity, quality and most importantly the operational cost. But unfortunately, management faces the challenges of higher maintenance cost, reworks, and unplanned shutdowns due to ineffective performance measurement and owing to the inappropriate decision of management. To make sure the plant attains the targeted performance, maintenance manager requires a better way of maintaining the performance of maintenance functions. This could only be possible through the development and implementation of a well-defined maintenance performance measurement framework and indicators that are capable of measuring the significant elements like maintenance cost, product quality, manufacturing performance, etc. The aim of this paper is to develop a maintenance performance measurement framework which is based on reliability, availability, maintainability and safety (RAMS) parameters and to show that how to calculate the KPIs related to RAMS an excel based template which comes together with list of formulas for every KPI to measure the maintenance performance. This framework will assist managers to measure the maintenance performance measurement which helps them to improve the performance of different maintenance activities and in different areas.

Keywords: maintenance, performance measurement, RAMS, KPI.

INTRODUCTION

Measurement is an effective tool which helps to understand how things work and how to work with it. Maintenance measurement is very valuable in today's challenging environment because it provides the useful information to managers to control the maintenance process. Useful maintenance measures are of two types-those that improve Maintenance effect on business performance and those that drive good reliability-building behaviours [1]. Research shows that in Sweden during 1991, the maintenance cost was about US$23 $x10^9$ billion. These total losses are due to lack of maintenance or ineffectiveness which exceed the purchase price of the equipment. The study led by the Department of Trade and Industry in the UK exposed that deprived and dangerous maintenance costs the UK industry US$1.95 $x10^9$ billion a year [2].

Actually Maintenance plays a major role in the profitability of any company; therefore, maintenance has got more importance in today's environment because several changes in the internal environment of the industries are taking place. Nowadays the majority of companies such as refineries, chemical industries and steel industries are using highly automated and expensive integrated systems. As for them one or more days stoppage could affect the accounts of the industry; improper maintenance of any single machine can produce faulty products which result in loss of materials, customers etc. To reduce the major losses in any company the important thing is to select the best maintenance strategy because it describes the failure, condition of unit and triggers of which kind of maintenance action (inspection, repair, and replacement) is needed [3]. But before selecting any strategy of maintenance management should be clear about the objectives of maintenance which helps to measure the performance of maintenance in future. Maintenance strategies should be concerned with creating the appropriate plan for the plant and formulate the best maintenance schedule for the plant. The maintenance strategy can be categorized under corrective, preventive, and predictive maintenance, depending on the function of the equipment [4]. Now the question highlights how to monitor or measure the performance of maintenance? Is the maintenance work is optimized? Is it cost effective? In general is that maintenance work providing required output? The answer to all of these questions lies in Maintenance Performance measurement (MPM). Previously, [5] divided all performance measurement system into three categories

Holistic approach

Holistic refers to an overall maintenance performance measurement based on multi-factors.

Results: It requires a large amount of data; it requires multiple inputs and outputs which create complexity in quantifying the level of importance of each factor in maintenance. As such does not portray the real maintenance function due to miscalculation and needs more time for improvement.

Methods based on machine factor

Machine is another factor for maintenance performance measurement; a machine is the main function in maintenance activities. High availability and utilization percentages of the machine to ensure the maximum production output and increase the company's profit.

Results: Based on the machine factor, the methods focused on the direct impact of maintenance towards machine performance, but the OEE emphasized merely on short-term performance, whereas reliability is a long-term performance measurement. The methods have shown an unbalanced measurement process which will give an inaccurate level of maintenance effectiveness.

Methods based on maintenance value

The value-based methods emphasize on the maintenance value rather than the cost of maintenance. It provides analytical viewpoint in measuring maintenance performance. The results from these methods can help companies to justify their investments in the operation.

Results: The drawback in maintenance value method is that it requires many data for measurement and extensive solutions, making it a rather complex measurement method. It mainly focuses on customers and ignores other parts of the company.

From these methods, it has been clear now that there is a little deficiency in every method. So to cover that gap there is a need for performance measurement framework that covers this gap. As in order to measure the efficiency of any maintenance system, it should find the zones where progress can be made [6]. It is very much clear that MPM is very strong tool which clarifies the objectives of company from the higher level to the middle level and all over the company. MPM desires to equalize from both financial and non-financial measures. Good framework and KPIs are utilized for the estimation of the performance of any procedure. A KPI relates real circumstances with a precise set of reference conditions (requirements) by measuring the difference between present results and expected results (targets). All KPIs should focus on chances for enhancement within companies, when properly utilized [7]. Thus, in this paper an absolute framework and some key performance indicators has been presented in excel format which actually shows how to measure the performance of some critical equipment among various types of equipment by using RAMS parameters, which results in firsthand knowledge about those critical equipment and aware the managers from upcoming losses due to these critical equipment.

RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY (RAMS)

Maintenance performance measurement indicators are stood on three pillars i.e. RAMS parameters, a cost model and the human factor [8], there are some basic reasons for equipment reliability, availability, maintainability and safety for plant operation [9] Such as;

- Production: High equipment reliability, maintainability and availability increase operational availability, reduce downtime, improve operating performance, and increase production capacity.
- Cost: Although initial RAMS improvement could be costly, from an equipment life cycle cost consideration, early investment in achieving reliability growth is valuable and reduces the entire life-cycle cost.
- Competitive advantage: A continued effort towards improving plant RAMS is a key strategy for business success. RAMS improvement involves using new technologies, new materials and new processes, to reduce costs, improve product quality, and ensures competitiveness.
- Environment and Safety: High equipment reliability and maintainability would improve operational safety and reduce equipment-related safety and environmental hazards.

Reliability: A measurement of whether a system can run continuously without failure

- The system continues to function for a long period of time

Availability: A measurement of whether a system is ready to be used immediately

- The system is up and running at any given moment

Maintainability: A measurement of how easy it is to repair a system

- A highly maintainable system may also show a high degree of availability.
- Can failures be detected and repaired automatically? Self-healing systems?

Safety: A measurement of how safe failures are

- The system fails, nothing serious happens.

For instance, high degree of safety is required for systems controlling nuclear power plants.

MAINTENANCE PERFORMANCE MEASUREMENT FRAMEWORK

To develop a performance measurement framework, it is necessary to have well-formulated, maintenance strategy, which supports the corporate strategy. The maintenance performance will identify key elements and processes that drive the maintenance function towards delivery of performance demanded by manufacturing objectives. This framework would support the system for stakeholders at various levels of the manufacturing and corporate objectives which direct the maintenance efforts to the reliability of equipment, availability of the system, maintainability of the system and provide enough safety parameters towards attaining the required performance and continuous improvement of the production equipment. Figure-1 is the absolute framework for maintenance performance measurement of critical equipment with several types of equipments in any industry. It starts with the corporate strategy, as every industry sets some objectives in favor of that industry such as time frame, manufacturing, maintenance or supply chain. After setting some corporate strategies some other objective will be set at departmental level, that's what kind

of machines are required to achieve the production on time and what kind of maintenance to be done, how many personnel required for maintenance and how to measure the maintenance performance. After setting the manufacturing strategy maintenance manager must also set some objectives regarding maintenance. For suppose how to reduce maintenance cost, how to achieve higher reliability of machines and how to increase the availability of machines. After selecting maintenance objectives, maintenance in-charge should now focus on the criticality, redundancy of machines and select the machines which are most critical by any criticality analysis technique because those selected machines will be used to measure the maintenance performance in terms of reliability, availability, maintainability and safety parameters. After selection of critical equipment now its turn for selecting the KPIs of the four parameters at different levels of management, i.e. reliability, availability, maintainability and safety and calculate the all KPIs related to above mentioned parameters at different level of management. After calculating all KPIs of all four parameters at different levels of management, maintenance manager should recheck all KPIs once more to verify that all calculations are correct. If everything goes in the right direction and maintenance department get results in positive and all calculations give the right directions toward improvement and provide firsthand knowledge about reliability, availability, maintainability and safety of machines, then the company should go for another mission, if calculations are wrong or not getting any positive result then the maintenance manager should start by assessing the criticality of machines again.

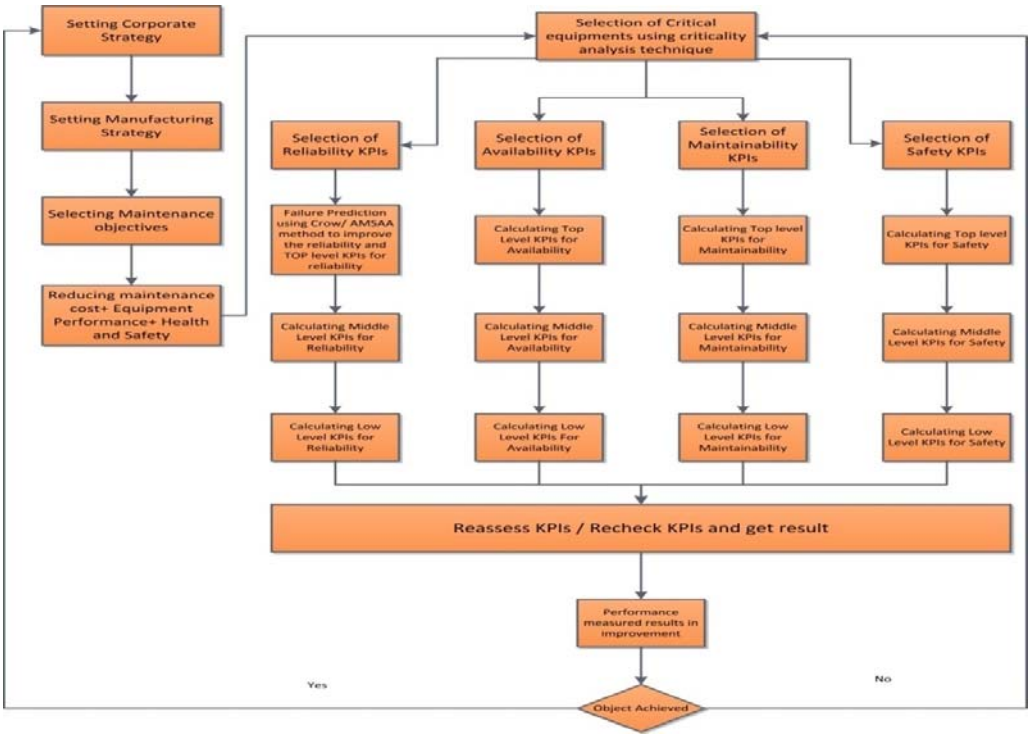

Figure-1. Maintenance performance measurement framework.

THREE LEVELS OF MANAGEMENT

Top Level of Management: Top level management is responsible for framing the policies of the business; all main decisions are prepared at this level. Tot level managers are only concerned with the different directorial functions. Board of directors, managing directors, General Manager and senior most managers are in the category of Top level management.

Middle Level of Management: This level of management is the link between other two levels of management i.e. Top level and low level. The head of various departments in any industry receives orders and directions from top level management and pass it to their sub- ordinates. These managers supervise reports of actual performance from their low level manager and then study reports and convey essential instructions. The managers are held responsible for integrating communicating the policies of top level management. Middle level management is mainly a bridge between low level and top level because these managers pass the performance reports from low level to top level managers.

Low Level of Management: Lower level of management performs various activities, they are mainly supervisors and these supervisors create a link between workers and middle level management. These managers also keep higher management aware of the performance, difficulties and several other issues related to the workers. These managers spend more time in directing and controlling and these managers mainly develop daily, weekly and monthly plans.

KEY PERFORMANCE INDICATORS

A Key Performance Indicator (KPI) is the measure of performance that is critical to the success of an organization. Reason to measure the KPIs is it manages and gathers relevant information to enable heads to make more informed decisions and drive continuous improvement in support of corporate goals. This result as change in our knowledge, changes in expectations and changes in behaviour. KPI takes us in the right direction of corporate objectives. Maintenance is an important part of an organization's long-term profitability. Maintenance can add value through equipment reliability and availability, therefore, organizations should keep an eye on maintenance performance measurement because in measuring maintenance performance organizations not only concerned with doing appropriate maintenance work but also concerned that the maintenance work successfully removes risk of failure of plant and equipment and provides desired results. In Figure 2, 3, 4, 5 different KPIs are calculated which are related to four selected parameters, i.e. RAMS and divided into three categories such as Top management, middle management and lower management. These figures shows the method to calculate the RAMS key performance indicators in excel. In this excel template, data should be inserted in yellow shaded boxes. So every manager needs to record that data and that data is very easy to record. This then helps to calculate further KPIs of middle level and top level. Table-1 contains the formulas which used in this template to calculate these KPIs.

Reliability KPI		
Low level	schedule time	480
	Scheduled downtime	20
	Unscheduled downtime	20
	no of breakdowns	4
Mid level	total uptime	440
	total downtime	40
top level	MTBF	110
Low level	schedule time	480
	Unscheduled downtime	30
	Scheduled downtime	30
	Scheduled and unscheduled maintenance events	2
Mid level	total up time	420
	Total downtime	60
top level	MTBM	210
Lower Level	No: of Breakdowns	5
	Scheduled Downtime	120
	Unscheduled Downtime	60
Mid Level	Total Dowtime	180
Top Level	MTTR	36
Lower Level	Actual output	800
	Maximum Capacity	1000
mid Level		
Top Level	Asset Utilization	80.00%
Lower Level	Planned Production Quantity	400
	Actual output	800
Mid Level		
Top Level	Manufacturing cycle Time	0.5
Lower Level	Maximum Capacity	1000
	Actual output	800
Mid Level		
Top Level	Opportunity Gap	200

Figure-2. Calculation of reliability KPIs.

Availability KPI		
Low level	Plant operating time	8
	Potential Production time	8
	Repair Time	1
	Scheduled Operating Time	7
	Delay Time	1
Mid level	Production Time	7
top level	Equipment Utilization in terms of time	0.875
Low level	Operating time	420
	Planned production time	480
	Downtime	60
	Total Production	1500
	Ideal Production Rate per min	10
	Good Quality Production	1000
	Bad Quality Production	500
Mid level	Availability	0.88
	Performance Efficiency	0.36
	Quality Rate	2
top level	OEE	62.50%
Lower Level	Uptime	6
	Operating Cycle	8
	Scheduled Operating time	7
	Downtime	1
Mid Level		
Top Level	Operational Availability	0.75

Figure-3. Calculation of availability KPIs.

Maintainability KPI		
Low level		
Mid level	Planned Maintenance Cost	25000
	Breakdown Maintenance Cost	5000
	Indirect Maintenance Cost	3000
Top level	Total Maintainenance cost	33000
Low level	Maintenace time for equipmet 1	8
	Maintenace time for equipmet 2	4
	Maintenace time for equipmet 3	2
	Maintenace time for equipmet 4	1
Mid level		
Top level	Mean time to maintain	3.75
Low level	Mean supply delay time	20
	Mean outside assistance delay time	20
	Mean administrative delay time	20
	Total time in prevnetive maintenance	60
	No: of preventive maintenance carried	2
	Total time in corrective maintenance	80
	No: of corrective maintenance carried	2
Mid level	Mean Logisitics delay time	60
	Mean preventive maintenance downtime	30
	Mean corrective maintenance downtime	40
Top level	Mean Maintenance Downtime	130
Low level		
Mid level	Work order completed for one equipment	20
Top level	Maintenance Workorder Completed	4
Low level	planned maintenance hours available	480
	Spent maintenance hours	480
Mid level		
Top level	Planned maintenance percentage	100.00%

Figure-4. Calculation of maintainability KPIs.

Safety KPI		
Low level	incinerated waste	10
	treated waste	5
	Recycled waste	2
	Waste to send landfill	3
	Total Waste	100
Mid level	Total incinerated waste	0.1
	Total treated waste	0.05
	Total Recycled waste	0.02
	Total Waste to send landfill	0.03
Top level	% Hazardous operational Waste	0.1703
Low level	Absent hours per day	10
	NO: of employees	3
	Contracted work hours per day	5
Mid level	Total Contracted time of employees	15
Top level	Absent Rate	66.67%
Low level	No: of lost time injuries in accounting peri	5
	Total Hours worked in accounting period	28400
Mid level		
Top level	Lost time injury frequency rates	176.056338

Figure-5. Calculation of safety KPIs.

CONCLUSIONS

Measuring performance of maintenance is complex as it involves various indicators with multiple criteria at various levels. In these paper different methods to measure performance of maintenance from different approaches and the proposed contribution in that area has been discussed. Based on the gap in that area, a framework is developed which measure the performance of maintenance from four different parameters which are significant to this study, i.e. RAMS at different level of organization. In the end, an excel based template is also presented to show how actually managers calculate KPIs at different levels very easily and a table of formulas is also given that are used in template. By applying this any industry will be able to find out that what are the lacking in current performance measures, either they are calculated in the right manner or not and this also helps the different managers at a different level to get the first-hand knowledge about their maintenance performance from different perspectives.

Table-1. Formulas to calculate RAMS KPIs.

MTBF	**Total Uptime(M)/No. of Breakdowns(L)**
Total downtime	Scheduled downtime(L)+ Unscheduled downtime (L)
Total uptime	Scheduled Time(L) - Total Downtime (M)
MTBM	Total Uptime(M) / No: of scheduled and unscheduled Maintenance Events (L)
MTTR	Total Downtime (M) / No: Of Breakdowns (L)
Asset Utilization	Actual output (L) / Maximum Capacity(L) *100
Manufacturing cycle Time	Planned production quantity(L) / Actual ouput (L)
Opportunity Gap	Max Capacity(L) - Actual Output(L)
Equipment Utilization in terms of time	Production Time(M)/ Plant operating time(L)
Production Time	Potential Production time (L) - Repair Time (L)

Potential Production time	Scheduled Operating Time(L) - Delay Time(L)
OEE	% Availability (M) * Performance efficiency (M) * Quality Rate (M)
Quality Rate	Good Quality production (L) /bad quality production (L)
Performance Efficiency	[Total Production (L)]/ Operating time (L) /Ideal Production rate per min (L)
Availability	Operating time (L) / Planned Production time(L)
Good Quality Production	Total Production (L) - Bad quality production(L)
Operational Availability	Uptime (L) / Operating Cycle (L)
Uptime	Scheduled Operating time (L) - Downtime (L)
Total Maintenance cost	Planned Maintenance cost (M) + Breakdown Maintenance Cost (M) + Indirect Maintenance Cost (M)
Mean time to maintain	Sum of Maintenance time for equipments/ No: of equipments
Mean Maintenance Downtime	Mean logistics delay time (M) + Mean preventive maintenance downtime (M) + Mean corrective maintenance downtime (M)
Mean corrective maintenance downtime	Total Time in corrective maintenance (L) / No: of corrective maintenance carried (L)
Mean preventive maintenance downtime	Total Time in preventive maintenance (L) / No: of preventive maintenance carried(L)
Mean Logistics delay time	Mean supply delay time(L) + Mean outside assistance delay time(L) + Mean administrative delay time(L)
Maintenance Workorder Completed	Workorders completed for one equipment(M)/ Scheduled maintenance work orders
Planned maintenance percentage	Planned maintenance hours available (L) / Spent maintenance hours (L)* 100
% Hazardous operational Waste	Total Waste incinerated waste (M) + Total waste treated (M)+Total waste recycled(M) + Total waste send to landfill (M) /Total waste (L) * 100
Total Waste to send landfill	Waste to send landfill(L)/ Total waste(L)
Total Recycled waste	Recycled waste(L)/ Total Waste(L)
Total treated waste	treated waste(L)/ Total Waste(L)
Total incinerated waste	incinerated waste(L)/ Total Waste(L)
Absent Rate	% of Absent hours per day (L) / Total Contracted time of employees (M)
Total Contracted time of employees	No: of employees (L) x Contracted work hours per day (L)
Lost time injury frequency rates	(No: of lost time injuries in accounting period (L)/ Total hours worked in accounting period(L)) * 1000000

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