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Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement

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Abstract

This paper will review the goals and benefits of implementing Total Productive Maintenance, and it will also focusing on calculating the overall equipment effectiveness in one of Steel Company in Jordan, and it also discuss what called the big six losses in any industry (the quality, availability and speed). A case study taken from Steel Company in Jordan, the data taken along fifteen working days and teams formed in period of two months to find out the benefit of formation a multidiscipline team from different department to eliminate any boundaries between the departments and make the maintenance process more effectively, labors on the production line also included in way to adopt the autonomous maintenance operations (daily maintenance). As a result the company achieved 99% in quality factor of overall equipment effectiveness equation and 76% in availability where in performance it got 72%. Set of techniques like Single minute exchange die, computer maintenance management system, and production planning were suggested to the industry after calculating the OEE to improve their maintenance procedures and improve the productivity.

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1. Introduction

In the last few years the maintenance was traditional activities where all companies applying it without knowing its importance, but after the improving in production strategies and improve the flexibility of production line to produce a wide range of different products, the need for good maintenance strategy becomes bigger, and in the present times especially, because of automation and large-scale mechanization, higher plant availability, better product quality and long equipment life had assumed considerable significance [1]. Now many companies have shifted their focus to optimize their assets, and use equipments more effectively, and one of the main parts of the company which has a strong influence on the assets is the maintenance department or the employees responsible for maintenance [2]. The main idea behind the maintenance is to make the parts and machine ready to do what are required within the time and sizes allocated and do it with fewer amounts of resources.

Total productive maintenance (TPM) is new maintenance strategy developed to meet the new maintenance needs, TPM is an American style of productive maintenance which has been modified and improved to fit in the Japanese industrial environment. Now it is popular in Japanese industry and in other western countries [3]. It is closely tied to JIT (Just in Time) and TQM (Total Quality Management) and it is extension of PM (preventive maintenance), where the machines work at high productivity and efficiency, and where the maintenance is all employee responsibility, and focus to prevent the problem before it may occurs [4].

Bamber (1998) presents the definitions of TPM in his review about the literature of TPM he present two definitions the first one depend on the Japanese approach and the other depend on western approach. The Japanese approach to TPM is considered to be that a full definition which contains five main points:

1. To use the equipment more efficiently.
2. It establishes a total preventive maintenance system.
3. It requires a full participation from all department operator (equipment operator, designer, and departments workers)
4. It involves everyone in the company shop floor to the top management.
5. It promotes and implements preventive maintenance based on autonomous, small group activities.

Nakajima (1988) summarized these five points in briefly defining TPM as "Productive maintenance involving total participation in addition to maximizing equipment effectiveness and establishing a through system of PM" where PM is a comprehensive planned maintenance system.

In the UK TPM has been pioneered by Edward Willmott (1997), the managing director of willmott

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Consulting Group, acknowledges the five point of the which being considered definition the Japanese approach to TPM and consequently accepts this as being an accurate and true reflection of the main principles; however he provides a definition that is more suited to Western manufacturing and which is:

"TPM seeks to engender a company-wide approach towards achieving a standard of performance in manufacturing, in terms of the overall effectiveness of equipment, machines and processes, which is truly world class"

Another US advocate of TPM, Wireman (1991) suggests that TPM is maintenance that involves all employees in the organization and accordingly includes everyone from top management to the line employee and indicates:

". . . it encompasses all departments including, maintenance, operations, facilities, design engineering, project engineering, instruction engineering, inventory and stores, purchasing, accounting finances, plant /site management"

There are many different definitions for TPM and the reason behind this diversity in definition is found in the way of adoption this strategy, some industries focus on the group working more than equipment management, and other focus on equipment effectiveness, this diversity shows how important implementing TPM in company that it is covers all factors may affect the production process [5].

2. TPM Goals

TPM seeks to minimize all the potential losses in the production and to operate equipment with full design capability. TPM also take the quality in consideration by making a zero product defect rate, which means no production scrap or defect, no breakdown, no accident, no waste in the process running or changeover [6]. TPM can be defined by considering the following goals:

1. **Improving equipment effectiveness**, This mean looking into the six big losses which divided from three main losses:
   a. Down time losses: classified as Equipment breakdowns and, Setup and adjustment slowdowns.
   b. Speed losses: which can be found as Idling and short-term stoppages and Startup/restart losses.
   c. Defects or Quality losses: every thing about Scrap and rework and Startup losses.

And finding what causes these losses and starts the improvements process. The idea is to make the equipment work as it should be working always and produce as much as it supposed to produce, you cannot accept that you producing less than any one else has the same equipment and you should always seek for the best performance at all [2].

   d. Involving operators in daily maintenance, this means to achieve autonomous maintenance where the workers who operate the equipment are allowed to take responsibility for some of maintenance activities [7] such as:

- Repair level: Here the operators take the action to repair the machine according to given structure paper.
- Preventive level: the operator will take a corrective action to prevent the problems.
- Improvement level: the operator will be uncharged in any improvement strategy; moreover he will take the corrective action too on the problems when occurred.

   e. Improving maintenance efficiency and effectiveness, this mean having a systematic approach to all maintenance activities. This involves the identification of the nature and level of preventive maintenance required for each piece of equipment, the creation of standards for condition-based maintenance, and the setting of respective responsibilities for operating and maintenance staff. The respective roles of "operating" and "maintenance" staff are seen as being distinct. Maintenance staff are seen as developing preventive actions and general breakdown services, whereas operating staff take on the "ownership" of the facilities and their general care. Maintenance staffs typically move for more facilitating and supporting role where they are responsible for the training of operators, problem diagnosis, and devising and assessing maintenance practice [2].
   f. Educating and training personnel, this task is one of the most important in the TPM approach; it involves everyone in the company: Operators are taught how to work on their machines and how to maintain them properly. Because operators will be performing some of the inspections, routine machine adjustments, and other preventive tasks, training involves teaching operators how to do those inspections and how to work with maintenance in a partnership. Also involved is training supervisors on how to supervise in a TPM type team environment.
   g. Designing and managing equipment for maintenance prevention. Equipment is costly and should be viewed as a productive asset for its entire life. Designing equipment that is easier to operate and maintain than previous designs is a fundamental part of TPM. Suggestions from operators and maintenance technicians help engineers design, specify, and procure more effective equipment. By evaluating the costs of operating and maintaining the new equipment throughout its life cycle, long-term costs will be minimized. Low purchase prices do not necessarily mean low life-cycle costs [2].

3. Six Big Losses

One of the major goals of TPM and OEE is to reduce or eliminate what are called the six big losses which they are the most common causes of efficiency loss in manufacturing. The link of the losses and the effectiveness in TPM is defined in terms of both the quality of the product and the equipment availability. Any operation time may face losses and these losses can be visible like scrap, changeovers and breakdowns or invisibles such as the slow running, the frequent adjustment to maintain the production within tolerance, Nakajima summarised the loss in a six big losses as following:

- Downtime Losses:

It found if the output is zero and the system produces nothing, where the unused segments of time, during the examined period are downtime losses, and mainly it can be one of two:

2. Breakdown losses this loss is due to parts failure where they cannot work any more and they need either repair or replace. These losses are measured by how long it takes from labor or parts for fixing the problem.
3. Setup and adjustment time, These losses are due to the changes in the operating conditions, like the start of the production or the start of the different shifts, changes in products and condition of the operation. The main examples of this kind of losses are equipments changeovers, exchange of dies, jigs and tools. These losses consist of setup, start-up and adjustment down times.

- Speed Losses:

When the output is smaller than the output at references speed these are called speed losses. When considering speed losses, one dose not check if the output conforms to quality specifications. This can be found in two forms:

Minor stoppage losses these losses are due to the reason of machine halting, jamming, and idling. Many companies are considering these minor stoppages as the breakdowns in order to give importance to this problem [8].

1. Speed losses these losses are due to the reduction in speed of the equipment. In other words the machine is not working at the original or theoretical speed. If the quality defect and minor stoppages occurs regularly then the machine is run at low speed to cover the problems. It is measure by comparing the theoretical to actual working load.

- Defect or quality losses:

The produced output either dose or dose not confirm to quality specifications. If it dose not comply, this is consider a quality loss.

1. Rework and quality defects; these losses are due to the defective products during the routine production. These products are not according to the specifications. So that rework is done to remove the defects or make a scrap of these products. Labor is required to make a rework which is the cost for the company and material become a scrap is also another loss for the company. The amount of these losses is calculated by the ratio of the quality products to the total production.
2. Yield losses these losses; are due to wasted raw materials .The yield losses are split into two groups. The first one is the raw materials losses which are due to the product design, manufacturing method etc. The other group is the adjustment losses due to the quality defects of the products which are produced at the start of the production process, changeovers etc.

4. Overall Equipment Effectiveness

OEE is a result can be expressed as the ration of the actual output of the equipment divided by the maximum output of the equipment under the best performance condition. The Overall Equipment Effectiveness was originated from the Total Productive Maintenance practices, developed by S.Nakajima at the Japan Institute of Plant Maintenance, the aims of TPM is to achieve the ideal performance and achieve the Zero loss [8] which means no production scrap or defect, no breakdown, no accident, no waste in the process running or changeover. The quantification of these accumulations of waste in time and its comparison to the total available time can give the production and the maintenance management a general view of the actual performance of the plant. And it can help them to focus the improvement on the bigger loss.

4.1. OEE Calculation

OEE is equal to the multiplication of the three main bases for the main six big losses:

1. Availability indicates the problem which caused by downtime losses.
2. Performance indicates the losses caused by speed losses and
3. Quality indicates the scrap and rework losses.

$$OEE = Availability \times Performance\ rate \times Quality\ rate \tag{1}$$

4.1.1. Availability

The availability is calculated as the required availability minus the downtime and then divided by the required availability. This can be written in the form of formula as

$$Availability = ((Required\ availability - Downtime)/ Required\ availability) * 100 \tag{2}$$

The required availability can be defined as the time of production to operate the equipment minus the other planned downtime like breaks, meetings etc. The down time can be defined as the actual time for which the equipment is down for repairs or changeovers. This time is also some times known as the breakdown time. The output of this formula gives the true availability of the equipment. This value is used also in the overall equipment effectiveness formula to measure the effectiveness of the equipment.

4.1.2. Performance

The performance rate can be defined as the ideal or design cycle time to produce the item multiplied by the output of the equipment and then divided by the operating time. This will give the performance rate of the equipment. The formula to calculate the performance rate can be expressed as

$$Performance\ rate = ((design\ cycle\ time * output)/ Operating\ time) * 100 \tag{3}$$

The design cycle time or the production output will be in the unit of production, like parts per hour and the output will be the total output in the given time period interval.

The operating time will be the availability value of the availability formula. The result of this formula will be in the percentage of the performance of the equipment.

4.1.3. Quality

The quality rate can be expressed as the production input into the process or equipment minus the volume or number of quality defects then divided by the production input. The quality rate can be expressed in a formula as

Quality rate = ((production input – quality defects)/ Production input) 100* (4)

The production input mean that the unit of product being feed into the production process. The quality defects mean the amount of products which are below the quality standards i.e. the rejected items after the production process. This formula is very helpful to calculate the quality problems in the production process [9].

5. Case Study

Steel company has been taken as case study this company is applying restricted quality inspection system in addition it has ISO 9001:2000 in 2005. The study conducted along 15 days, the company produces different type of steel and used different types of plate. In the industry the production is continues there is only three main workstation the oven and the failure in this workstation is very low and the maintenance is applied regularly, the second workstation is the dies and cutting station this is form one single workstation, and the third workstation is the cooling bed. In second workstation most failure probably occurred. The company has an old record for the previous maintenance work on the production line, and the time loses that are observed in the production process in the first 15 working days in September 2007 will be recorded. There are some standard from the industry:

- ✓ Establishing time (starting of production until stabilization), this time vary between 15 – 40 minute for the chosen operation.
- ✓ Setup time (alteration of product in the production line and enhancement until smooth flow of operation), the setup time is depend on how many dies or machine will installed on the line, and this time is mostly calculated in the second shift (Shift B), in general it is between 1 – 2 hour.
- ✓ The product time process, the production line can operate at speed of 60 plates per hour, this speed is theoretical speed.

- The downtime caused by failure, all downtime for 15 operating days have been recorded, the industry work two shifts each shift ten hours (shift A from 7:00 to 17:00, Shift B 20:00 to 6:00).
- The production line speed (real) that will be matched up to that given by the producer (nominal), the nominal speed for the production is 60 tons per hour, and the real speed will calculated for each day.
- The number of products that need revising and the worthless products (scrap), the rework product is almost negligible because there is no rejected product happened during the study period, and according to record there is very low amount of rework operation happened. The scrap is happened in big number each operation there is 0.7 m of the extracted plate goes to scrap and any malfunction machine or breakdown there is scrap recorded.
- Time lost from the small blockages of machines (i.e. blocking pans) that are simply fixed. The previous points are documented with the cooperation of the operator's equipment.
- The operators are Knowledgeable and skilled for the expressions that is used and the significance of accuracy of measurements.

In table 1 and 2 the data taken direct from the production line for shift A and shift B, the batch size is the amount of tons the company starts the production with, the amount of scrap is the amount of defective steel caused by breakdown or malfunction failure. The speed is taken for the period of operating. For example lets take shift A in day number 10 the batch size is 51 tons and the maximum speed of production is 1 ton per min, so the expected time to produce the batch is 51 min, but there is some amount of time waste for several reason and that time was 104 min, so the real time required to produce the 51 tons of steel in that day was 155 min and the speed was (51 tons/ 155 min = 0.3 tons/min). The shift time is 10 hour (600 min) in day number 10, the operation was only for 2.58 hours and the rest was off, this time (the rested time) is not considered in the study because they are not operating time and there is nothing about the maintenance.

Table 1. the downtime and amount of scrap for the First 15 operating days in September 2007 for shift A.

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Downtime (min)	62	226	80	92	66	28	121	257	202	104	184	278	280	91	111
Scrap (ton)	0	2	1	0.5	1.25	0	1	3.75	1	2	0	4.3	4.5	3	3.5
Batch size (ton)	402	393	281	402	464	335	447	475	505	51	452	285	425	486	254

Table 2. the downtime and amount of scrap for the First 15 operating days in September 2007 for shift

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Downtime (min)	36	85	172	39	160	33	28	58	44	108	102	219	68	100	163
Scrap (ton)	0	0	2.3	1	0	0	0	0	1	3	0.5	0	0.3	1.25	3.5
Batch size (ton)	393	281	402	464	335	447	475	505	51	452	285	425	486	254	391

Table 3. the total downtime and amount of scrap for the First 15 operating days in September 2007

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	total
Downtime (min)	98	311	252	131	226	61	149	315	246	212	286	497	348	191	274	3597
Scrap (ton)	0	2	3.3	1.5	1.3	0	1	3.8	2	5	0.5	4.3	4.8	4.3	7	40.8
Batch size (ton)	795	683	799	922	556	737	911	645	646	662	552	135	438	555	450	9486
Production (ton)	795	681	795.7	920.5	554.7	737	910	641.2	644	657	551.5	131	433.2	550.7	443	9445.2

5.1. Calculating OEE

The next step after collecting the data is to measure the OEE which will gives an indication of where we may find the error or the weakness point, the calculation of OEE will depend on 4 main equation the first one used to calculate the availability and from the table 2 and 3 we can find out how much time the line was down and how much is the operating time and then we can use the equation (2) to find out the availability of the production line. The study was taking during 15 days in September 2007, all the days was normal working days and the holidays and weekends are not considered in the study; but if we want to calculate them there were 4 weekend only which extend the study period to 19 days, so the theoretical operating time will be 19 days * 24 hours/days = 456 hours, and the available operating time will be 19 days – 4 days = 15 days. And there are two shifts only with 10 working hours per shift which make the available operating time is equal to 15 days * 2 shift/day * 10 hours/shift = 300 hours. And there is stoppage/pause one hour per day for 1 hour, which gives in total 15 hours 300 – 15 = 285 hours available operating time.

5.1.1. The Availability Factor

Total downtime is equal to 59.95 hours as shown in table 4, for the 1st 15 operating days, the valuable operating time for the 15 days will calculated by adding the amount of theoretical time needed to produce the batch size to the amount of down time. We know that the time needed to produce one ton is one minute, so the total time needed to produce the whole batch for 15 days is equal to 158 hours (9486 tons * 1 hour/ 60 tons = 158.1 hours), and with addition

To the amount of downtime equal 59.95 hours that gives 158.1 hours + 59.95 hours = 218.05 hours valuable operating time.

Availability = valuable operating time / available operating time Availability = 218 hours / 285 hours = 0.76 = 76%

5.1.2. The Performance Factor

To calculate the performance we need two main factors, the first one is the designed cycle time and we know that design cycle time is 60 ton/hour, and the total output is 9445.2 ton by applying the performance equation we will get the following results

Performance rate = ((design cycle time * output)/ Operating time) = (1min/ton * 9445.2 ton)/ (218*60) = 0.72 = 72%

5.1.3. The Quality Factor

To calculate the quality factor we need the total amount of defect and scrap plate for the 15 operating days and we find it from the table 4, total scrap or defect amount is 40.8 tons and the total batch size is 9486 tons, and the quality factor is

Quality rate = ((production input – quality defects)/ Production input)* 10 = (9486 tons – 40.8 tons)/ 9486 tons = 0.996 = 99.6%

5.1.4. The Overall Equipment Effectiveness

After we got the three main factors we can now calculate the overall equipment by using the following equation

OEE = Availability * performance * Quality = 0.76 * 0.72 * 0.996 = 0.55 = 55%

The world class manufacturing OEE is 85%, and the best OEE score in the company was calculated by the machines designer and it was 72%, the equipment effectiveness is reduced by 17%.

5.2. Implementation TPM Strategy

The company was motivated to implement TPM to cope with the new market need and to increase their production performance to the international level, and the willing to eliminate the waste which don't add value to the production like waste of time and waste of material. The first initiative was towards to increase the quality, by implementing good quality inspection system and monitoring, and that was through the creation of the quality improvement team also train employees to identify the problems related to the quality and causes , and use the data for a continuous improvement. As the result the steel company reach ISO 9001:2000 by 2005.

Launch autonomous maintenance tasks in the aim to setup and adjust the equipments, inspecting the equipments while cleaning it and checking the machine bolt tightness. The creation of multidisciplinary teams involving all the departments, even the supplier is invited to the meeting to discuss the quality of the raw material supplied. There was

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a creation of three teams, the first team called SBU solve problem unit its job is to identify and resolve a problem if it occurs in the plant, and record in the 'Gap list' if it is not solved means the gap not closed. The second team which is the focus team take the problem in charge; this team solve it at a systematic level. This team is responsible as well for the evaluation of the equipments and the processes and set up an optimum practice to eliminate any losses and ensure the continuous improvement. The third team involve all the managers and the heads of department in the objective is to plan a safe and profitable strategy for the entire productivity journey.

6. Discussion

In Jordan Steel Company they never thought to have system which calculates their performance while they have a standard OEE since the installation of the line. But without calculated it we can not improve it, we saw the performance of the company as overall equipment effectiveness is 55%, where the availability of the line was 76% of the production time and the performance was 72% while the quality factor is 99.6%. Table 5 shows the comparison between world class measurement and the company measurement.

Table 4. the comparison between WCM and company

	OEE company	OEE world class
Availability	76%	90%
Performance	72%	95%
Quality	99%	99%

As we see from the table 4 the company achieved the world class quality factor, and as presented above the company had ISO 9001:2000 certificate in 2005, and they are applied a strong quality measurement and inspection system start from the raw materials inventory to the work in process finished with finish goods inventory. But the company needs to work hard to improve their system machines and reduce the waste time.

7. Conclusion

By implementing the TPM strategy they can eliminate most of the waste happened like the time waste while changeover or the downtime losses, with this maintenance strategy the responsibility of maintain the equipment is all operator and engineering responsibility, there will be no more "his or my" fault the break down will be solved as fast as possible. The operator in the shop floor should involve in each maintenance operation because he is the one close to the machine and he know what are the abnormality of the machine.

There are three main techniques will have a very good impact to improve the production line and make the maintenance process more effectively, CMMS, production planned, and SMED, those techniques will help the company to operate at high rate of performance without losses.

The project gives new huge step to the company in calculation the performance and how they can focus on the problems, when we formed a group from each department the company got a chance to see how the team work is important in solving the problem. Another benefit of the project is to give them the chance to know what the best techniques that they can apply which will improve their performance. Calculating the OEE also give the company where they are and where is the weakness point and how to improve.

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With equipment effectiveness at its core, total productive maintenance empowers equipment operators with skills training, proactive maintenance programs, and productivity benchmark assessments, so that they can fully take charge of the maintenance of assets assigned to them. Higher levels of workforce autonomy decrease over-dependence on breakdown/reactive maintenance. What Are the Benefits of Total Productive Maintenance (TPM)?Â OEE (Overall Equipment Effectiveness) is a metric that scores the overall effectiveness or health of equipment, as a percentage, based on its output quality, availability, and performance. OEE represents the Key Performance Indicator (KPI) of a total productive maintenance program. study of total productive maintenance and evaluating overall. equipment effectiveness. The calculation of the overall equipment. effectiveness in S alt Company (Emisal) in Egypt is carried out. The big six losses in any industry (quality, availability and speed). are also presented. The data were collected through reviewing. the technical documents available in Emisal Company. As a result, the Company achieved about 93% in average quality.Â class availability, performance efficiency, quality rate and overall equipment effectiveness. Based on these results, global maintenance management, and. production planning were suggested to improve their. OEE (Overall Equipment Effectiveness) is a metric that identifies the percentage of planned production time that is truly productive. It was developed to support TPM initiatives by accurately tracking progress towards achieving â€œperfect productionâ€. An OEE score of 100% is perfect production. An OEE score of 85% is world class for discrete manufacturers. An OEE score of 60% is fairly typical for discrete manufacturers. An OEE score of 40% is not uncommon for manufacturers without TPM and/or lean programs. OEE consists of three underlying components, each of which maps to one of the TPM goals set out at the beginning of this topic, and each of which takes into account a different type of productivity loss. Total Productive Maintenance (TPM) started as a method of physical asset management focused on maintaining and improving manufacturing machinery, in order to reduce the operating cost to an organization. After the PM award was created and awarded to Nippon Denso in 1971, the JIPM (Japanese Institute of Plant Maintenance), expanded it to include 8 pillars of TPM that required involvement from all areas of manufacturing in the concepts of lean Manufacturing. TPM is designed to disseminate the...