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## Process Based Conditional Maintenance (PBCM) for Multistage Production Systems

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### ABSTRACT

**Background:** In this paper a concept of PROCESS BASED CONDITIONAL MAINTANENCE (PBCM) is introduced which minimizes this time gap between preventive scheduled maintenance and machine utilization. When this system is integrated with ERP then a smooth flow of preventive maintenance can be achieved. Analytical Hierarchy Process (AHP) is linked with this method to have a decision-aid on PBCM. The idea of the proposed model is to have control over preventive maintenance through process and to minimize the cost incurred in the machines which are not in use. **Objective:** Process Based Conditional Maintenance (PBCM) methodology calculates this delay time and requirements to find an optimum approach to sequence the preventive maintenance for machines. These problems shall be often found in the areas of fabrication and especially in boiler component manufacturing companies. **Results:** While considering a boiler component process as a study, it has been noted that the frequency deviation between conventional Preventive maintenance and PBCM is not more but PBCM confirms that all the machines are more conditionally maintained for adjacent processes which in turn reduces hidden process cost. **Conclusion:** In this paper, only single component of Waterwall is taken into consideration. That is why this process seems to be somewhat simpler. But when PBCM is implemented for all components then it predicted to be more complicated. At that stage there always comes a situation of same machine allotted for several processes. At this critical decision making situation, we utilize AHP as decision making tool and decide which machine to allocate for which process. This shall be next stage of this research work where many brain storming with experts and hurdle regarding the process control.

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## INTRODUCTION

Maintenance system is a set of activities performed on a system to sustain it in operable conditions, Samuel H.Huang (2007). Maintenance strategies can be classified as reactive, time based or condition based, J.C. Aurich (2011). However previously, the method of maintenance is "fix it when breaks", Samuel H.Huang (2007). Since this requires no planning, break down maintenance has increased. Research detailed by Mobley (1990) says that Corrective action is about three times higher than the same repair made in a preventive mode F.T.S. Chan (2005). And further preventive maintenance was introduced which considerably reduced the unpredictable break down time. In this type of maintenance, appropriate maintenance task is done only when warranted by equipment condition, S.K.Sethiya. In the present technological world, the maintenance technology has changed from time based to condition based. Even though preventive maintenance reduced the down time, at some scenario severe break down occurred due to several factors like wear of components and aging. This is due to the reason that preventive maintenance is conducted mainly for the running condition of the machine but not the aging and wearing of parts in that particular machine. Another practical difficulty faced in this method is that due to scheduling of maintenance, it is not guaranteed that machine will work properly at the time requirement. This is due to the time delay of scheduled maintenance and machine requirement time. For example, if a machine is required today and the maintenance schedule date is previously before one week of after the same day, then there may be chance of facing break down maintenance.

This problem cannot be neglected since a small hand grinding machine can make a delay of half shifts or two hours which accounts cost in it and affects smooth flow of forthcoming activities. This can be particularly seen in multistage production systems. This process is overcome by an idea of condition based maintenance

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(CBM) which is to monitor the equipment using various sensors to enable real-time diagnosis, Samuel H.Huang (2007). This system reduces time delay but this is being costlier when applying for handy machines. In this paper, a systematic approach is tried to reduce the delay time which analysis the process and manipulates the priority thus instructing which machine to act for maintenance. By just following the instructions of this methodology, it is being believed to have right machines at right time with proper maintenance. This process is said as PROCESS BASED CONDITIONAL MAINTENANCE (PBCM).

In this process, there may be a situation arrive where a decision has to be made for which machine to undertake maintenance. This situation occurs when there is scarcity of machines or man power. For example, if there are 'n' no of machines for 'n+1' products and decision should be taken as which machine to be allocated for which products. And in other side if there is 'm' worker and if there is 'm + 1' machines, a decision should be takes as which machine to left. This is done by giving priority of machine for preventive maintenance according to the process cycle time and other factors that influence the importance of this product. This PBCM is said to be highly useful in fabrication industry.

#### ***Problem Definition:***

In fabrication industries there are no particular products with particular cycle time. The cycle time varies for each and every component according to the sizes. And many machines like welding machine, grinding machine, lathes, Hand lathes, cranes, bend machine, rolling machine, drilling, hydro test machines are to be used in each product. There should not be scarcity for any machine for any job which in turn will delay many other products. All these machines should be properly maintained and be ready for all the times. Preventive and periodical maintenance is followed to meet these requirements.

In some cases, a hand machine may cause a trouble which in turn will make a drilling machine to wait for this component. This may happen due to difference between last maintenance time and process time. So it is necessary that a machine should always be ready with proper maintenance. In order to make it happen it might be better if preventive maintenance is done just before the process for which that machine is going to be utilized. Process Based Conditional Maintenance (PBCM) methodology calculates this delay time and requirements to find an optimum approach to sequence the preventive maintenance for machines. These problems shall be often found in the areas of fabrication and especially in boiler component manufacturing companies. We have taken a boiler component Water wall into account and tried to implement this methodology. We have assumed the number of machines for water wall by considering total available machines and allocating separately for Waterwall.

#### ***Condition Based Maintenance (CBM):***

CBM is a decision making strategy where the decision to perform maintenance is reached by observing the "condition" of the system and or its components, Samuel H.Huang (2007). Conditional based Maintenance (CBM) or Predictive maintenance differs from Preventive maintenance by basing maintenance need on actual condition of the machine rather than on some preset rules S.K.Sethiya (2005). Preventive maintenance is a time based control which prevents the problem as like changing the oil, grease and checking level of pressure factors with certain time interval. But CBM identifies the faults before they become critical which enables more accurate planning of preventive maintenance. CBM is a real time assessment which includes sensors, online test equipment. Since this CBM requires some real time monitoring components, they are costlier to some extent. CBM offers many advantages over a traditional time-based strategy, D.H. Stamatis (1995). In industry, usually production is accompanied by several vibrations which cause machine to fail. These vibrations are monitored by test equipments as a real time and indicate the prediction of failure of that particular machine. CBM is being proactive process, requires the development of predictive model that can trigger the alarm for maintenance, Samuel H.Huang (2007). This model should be precisely and accurately since this plays a major role in conditional based Maintenance (CBM). There were many models created in mix with fuzzy logic. And more over this CBM cannot be applied for small handy machines since the cost of the machine may increase highly. Some of the advantages of CBM are prior warning of impending failure and increased prediction in failure prediction, Samuel H.Huang (2007).

#### ***Analytic Hierarchy Process (AHP):***

AHP is developed first by T.L. Satty (1990) which is a tool for decision making in scenario which includes multi criteria, Ling Wang (2007). It is similar to human thinking which facilitates in complex decision making. For example, if a job has to be allocated to a sub- contractor from many decisions has to be made as to which sub-contractor this job has to be allocated. For simple jobs usually human brain thinks first criteria as cost. But delivery time shall also be major criteria. In some cases, these should be in an optimized way. If the situation occurs for many criteria, then it shall be of tedious jobs. At this case AHP helps us to take scientific decision in an optimized way.

AHP starts creating a pair wise comparison matrix. For example, when matrix  $\mathbf{A}$  is a  $m \times m$  real matrix, where  $m$  is the number of evaluation criteria considered. Each entry  $a_{jk}$  of the matrix  $\mathbf{A}$  represents the importance of the  $j^{\text{th}}$  criterion relative to the  $k^{\text{th}}$  criterion. The  $a_{jk}$  and  $a_{kj}$  satisfies the constraint  $a_{jk} \cdot a_{kj} = 1$ . Then relative importance is measured according to numerical scale from 1 to 9 hierarchies from equal importance to more importance. Then the matrix  $\mathbf{A}$  is normalized by computing each entry as

$$A_{jk} = \frac{a_{jk}}{\sum_{n=1}^m a_{jk}}$$

Finally Criterion vector  $w$  is built by averaging the entries of each row of  $A_{\text{norm}}$

$$A_{jk} = \frac{\sum_{n=1}^m A_{jk}}{m}$$

By T.L. Satty, the final decision matrix equation model is given as, T.L. Satty (1990)

$$\left\{ \begin{array}{cccc} & A_1 & A_2 & \dots & A_n \\ A_1 & (w_1/w_1) & (w_1/w_2) & \dots & (w_1/w_n) \\ A_2 & (w_2/w_1) & (w_2/w_2) & \dots & (w_2/w_n) \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \cdot & \dots & \cdot \\ A_n & (w_n/w_1) & (w_n/w_2) & \dots & (w_n/w_n) \end{array} \right\} \left\{ \begin{array}{c} w_1 \\ w_2 \\ \cdot \\ w_n \end{array} \right\} = n * \left\{ \begin{array}{c} w_1 \\ w_2 \\ \cdot \\ w_n \end{array} \right\}$$

### Methodology and Discussion:

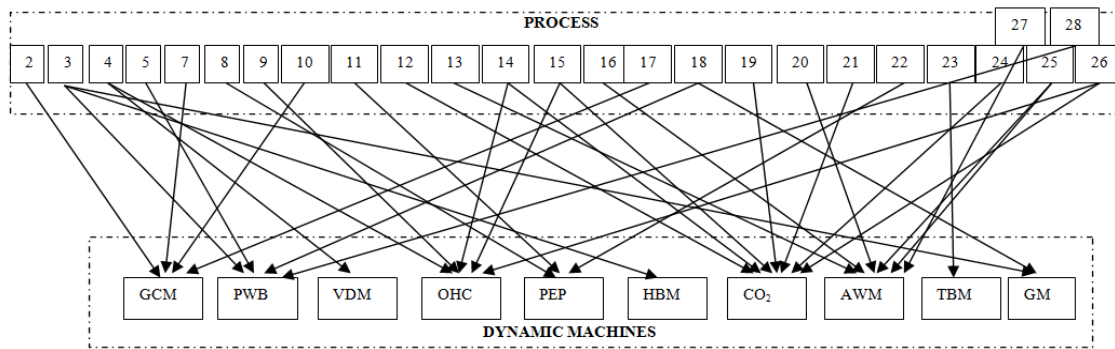
In this PBCM, preventive maintenance of the dynamic machines was done according to their requirements through process monitoring. In this study, multi stage production system of Waterwall (boiler component) is taken as a case study. This study was taken in a firm containing many departments like Design, Central Planning, Material Planning, Stores, Quality, R & D, and unit Planning, unit Production and unit Maintenance. These departments were integrated through ERP for controlled process. Our mode of study is in unit production, planning and maintenance. The main objective of unit production is to convert the raw material to components for allocated boiler components and objective of planning is to support production in all dimensions including monitoring of utilization and efficiency. The process was monitored by planning department and status of the job was continuously updated in ERP. By doing this status of the component, delivery time of the component is monitored. The prime objective of the maintenance was to supply the machines for production without interruption. In the firm preventive maintenance is followed as to have control over the machine maintenance. So usually the date of maintenance was given by ERP with respect to their maintenance frequency which was formulated initially. For example, a grinding machine is usually has preventive maintenance for every week. In this methodology, the grinding machine was given to process at the fifth day without maintenance. In some occasions, the machine gets failed due some unexpected scenario which affects process in turn. This hand machine makes the job to wait for hours and shifts which in turn affects some major machines like tube bending and drilling machine to wait. This affects the machine utilization and increase hidden cost. Our methodology is a simple process through ERP to redefine the preventive maintenance and rectify the problem. The major process of Waterwall component is given in the below Table. 1 with its required maintenance machines.

The total cycle time for completing single water wall is around 45 Days. In this quality check and rework is not considered. Flange fit-up and welding is not shown in this tabulation since it is made from sub-contractors. From the above tabulation cycle time column represents the number of shifts required to complete particular process and the day count represents the number of day to complete the process for starting of water wall. The requirement of dynamic machines is also given and it is clear that many handy machines play a major role in many processes (in some cases major machines like overhead crane). Likewise a tube bending machine is used only one in the process. So it is clear that requirement of preventive maintenance is least required than handy machines. The requirement of machines chart for process is given in Fig. 1.

From Fig. 1, we can clearly see the criticality of dynamic machine failure against the process. The first and foremost machine to be checked for preventive maintenance is CO<sub>2</sub> welding and Arc welding machine. And further hierarchy follows as Overhead crane, Grinding cutting Machine, Portable wire brush, Portable Edge preparation, Grinding Machine. So we can conclude that both CO<sub>2</sub> welding and Arc welding machine has to be done with preventive maintenance with top priority. General Preventive maintenance frequency is given in below Table. 2.

**Table 1:** Process steps of Waterwall & its day wise dynamic machines requirement.

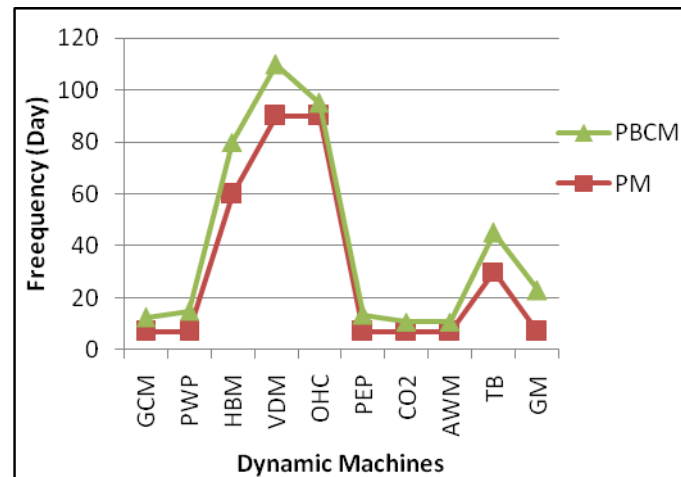
Process No	Process	Required Dynamic Machines for process	Cycle Time (No of Shift)	Day Count	Remarks
1	Header Marking (8 Nos)	Not Applicable	2	1	
2	Header Edge cutting	Gas cutting Machine	1	2	
3	Header Edge preparation	Grinding Machine, Wire brush, Boring	0.5	2	
4	Header Drilling (Ø273)	Vertical Drilling Machine & overhead cranes	4	5	(2 + 3) Days
5	Panel Cleaning	wire brush	1	6	
6	Panel Marking	Not Applicable	1	6	
7	Panel edge cutting	Gas cutting Machine	1	7	
8	Panel Edge preparation	Portable EP Machine	2	8	(0.5 + 1) Days
9	Header location	overhead crane	0.5	8	
10	Stub marking and cutting (Ø51.0)	Gas cutting Machine	2	9	
11	Stub Edge preparation	Portable EP Machine	2	10	
12	Stub fit-up	Co2 welding Machine	3	11	(10 + 1.5) Days
13	Stub Welding	Arc welding Machine	2	12	80 Stubs / Shift
14	Panel Matching with header	overhead crane and CO2 welding Machine	2	14	For Single Match
15	Panel fit-up with Header	overhead crane and CO2 welding Machine	1	15	For Single Match
16	Panel Welding with Header	Arc welding Machine	4	17	(15 + 2) Days
17	Branch Header Marking and cutting (Ø273)	Gas cutting Machine	1	18	
18	Branch Header Grinding and Edge preparation	Grinding Machine, Wire brush	1	18	
19	Branch Header fit-up	Co2 welding Machine	1	19	
20	Branch Header welding	Arc welding Machine	2	20	( 19 + 1.5) Days
21	Bend tube Marking and cutting	Gas cutting Machine	1	20	
22	Bend tube Edge preparation	Portable EP Machine	2	21	( 20 + 1) Days
23	Tube bend (Bend tube)	Tube bending Machine	0.5	21	
24	Bend tube fit-up	Co2 welding Machine	1	22	
25	Bend tube welding with header	Arc welding Machine	1	23	
26	Header to Header Matching	overhead crane and CO2 welding Machine	2	24	( 23 + 1) Days
27	Header to Header welding	Arc welding Machine	1	25	
28	Water wall cleaning	wire brush	2	26	



**Fig. 1:** Schematic representation Distribution of Dynamic machines for water wall processing.

**Table 2:** Frequency of preventive Maintenance.

SI No	Dynamic machines	Frequency (Day)
1	Gas cutting Machine	7
2	Portable Wire brush	7
3	Boring Machine	60
4	Vertical Drilling machine	90
5	Overhead cranes	90
6	Portable EP Machine	7
7	CO2 Machine	7
8	Arc Welding Machine	7
9	Tube bending Machine	30



**Fig. 2:** Graph Showing the PBCM & PM. 1.

Cycle time of this particular Waterwall is 35 Days. Only the process involving dynamic machines are taken into consideration. We consider the first to have preventive maintenance for all portable machines. Then the next PM comes at the stage of 7<sup>th</sup> day. Between the seventh day there may be two processes involving one machine. For example the Gas cutting machine has to undergo two processes namely on 2<sup>nd</sup> day and 7<sup>th</sup> day. But the Preventive maintenance has to be done only on the eighth day. There is a chance of getting some interruption by this machine due to previously operated conditions. In the same way over head cranes is used in this process at 5<sup>th</sup>, 8<sup>th</sup>, 14<sup>th</sup>, 15<sup>th</sup> and 24<sup>th</sup> day. But the PM is usually done for every 90 days. This again may cause a problem. So by this PBCM, maintenance should be done in intervals based on these intervals. Here by expert system study, it has been found that machines are highly believed on some intervals to have smooth runs. With these intervals this manipulation is done to have a smooth operation for every process.

After formulating the PBCM for this water wall, the average frequency of maintenance was determined which shown the deviation from the original PM. This shows more or less similar conditions except for some of the load carrying machines like Boring machine, Vertical drilling machine, Overhead cranes and Tube bending machines. These were also taken into consideration and formulated through expert system as stated above. The graph showing this deviation is represented in Fig. 2.

### Conclusion:

From Fig. 2, it is clear that there is not much deviation between frequency of existing Preventive maintenance and PBCM. But more precisely we can say that PBCM can eliminate some unpredicted maintenance that would incur hidden cost. In this paper, only single component of Waterwall is taken into consideration. That is why this process seems to be somewhat simpler. But when PBCM is implemented for all components then it predicted to be more complicated. At that stage there always comes a situation of same machine allotted for several processes. At this critical decision making situation, we utilize AHP as decision making tool and decide which machine to allocate for which process. This shall be next stage of this research work where many brain storming with experts and hurdle regarding the process control. The main disadvantage of PBCM is that this system is useful only linked with ERP. This is because manual manipulation may lead to several errors when taking many criteria to consideration. Future research of this PBCM would be formulating a several models to incorporate this as a general method especially multistage production system.

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