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Machine Operational Availability Improvement by Implementing Effective Preventive Maintenance Strategies - A Review and Case Study

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Abstract
Modern manufacturing industries uses high level of automation with complex machines. The function of automated machines is to achieve higher production rate with better quality. Therefore machines must remain in operating condition in order to achieve the desired result or goal. The failures or breakdown of machineries cause disruptions in production resulting in a loss of availability of the existing system. This further increases the cost of maintenance. Because of this, to face a greater competition in the market, industrial engineers always try to improve productivity continuously. One way to increase the productivity is to increase the operational availability of existing machines. This paper highlights recent research work carried out and a case study conducted in leading automobile industry with results obtained to increase machines operational availability or up time by implementing effective preventive maintenance schedule. Finding suggest that after implementing proper preventive maintenance significant improvement in machine availability can be achieve.
Keywords: Breakdown, machine downtime, up time, operational availability, preventive maintenance, etc.

Introduction
Equipment breakdown has always contributed towards machine downtime. Industrial Engineers have always tried to reduce downtime and increase the availability of machineries. Production up time or machines availability is basically, part of active time during which an equipment, machine or system is either fully operational or actual production is going. Total production time is the sum of up time and down time or breakdown time. Machine downtime is the time during which people or machines are idle and products are not being made, which certainly affects the business's bottom line. Machine down time is again divided into two categories i.e. planned and unplanned down time. Planned downtime is operating time lost due to planned events. These are events where you have no intention of keeping the plant operational, such as breaks, scheduled maintenance and holidays. After subtracting planned downtime from plant operating time, the remaining time is called planned production time. This planned production time is the benchmark that unplanned downtime events are measured against. Unplanned Downtime is measures the loss of planned production times due to unplanned events that cause downtime. These events can occur for a variety of reasons such as emergency maintenance, operator error, mechanical problems, machines spare part unavailability during maintenance and lacks of oversight, etc.

The performance of maintenance operations becomes the crucial issue in company or operation plant. Maintenance operation does not only focus on repairs and spare part replacement activities, is also plays a big role as it influenced the performance of maintenance work. Thus, the scope of maintenance management should cover every stage in the life cycle of technical system including plant, machinery, equipment and facilities. Schedule preventive maintenance reduces the regular breakdowns and increases the availability of machine. Detection of machine faults like imbalance, shaft misalignment, gear failure, bearing defects, etc. is possible. Maintenance is an activity to ensure that equipment is in a satisfactory condition and reliable. The goal of maintenance is to ensure that the performance of the equipment is satisfactory [1, 2].

Problem definition
In this paper a case study conducted in one of the leading automobile engine manufacturing industry. The main problem faced in automobile engine cylinder block manufacturing line is that the downtime still occurs even though after maintenance activities are carried out. Therefore, the available activities of preventive maintenance (PM) needs to be improve and simplified. The main objective for this study was to reduce the machines downtime on engine cylinder block production line by analyzing and improving the available PM schedule and thus improve operational availability of machines.

Literature review
Machine Breakdown Analysis and Preventive Maintenance Practices:
Kumar and Rudramurthy[1], carried out project on hydraulic press were all repeated breakdowns analyzed along with the critical parts, which were under breakdown condition is also

identified and analyzed. Also the reasons for the breakdown analyzed and inspected by the method of fish bone diagram and why-why analysis. This analysis and methods helped to develop and improve a new preventive maintenance checklist for the machine. The average availability of critical machine 1000 Ton hydraulic forging press after root cause analysis is increased to 4.16%. Also the average MTBF of critical machine after root cause analysis is increased to 13.66% and MTTR is decreased to 46.42% respectively.

Deka and Nath [2], TPM has been proved as a successful tool for increasing the OEE of machineries by using simple effective techniques. Initially in this study Pareto analysis was used to figure out the major contributors towards downtime losses. Root cause analysis using the Why-Why technique was done so as to explain the reasons behind equipment breakdown. This helped in developing a PM schedule for the machines. Reliability is an important parameter for any piece of equipment. In this study Weibull statistics was used to measure the reliability of the system and also explain the CDF governing the rate of failure.

Mathew et al. [3], studied major breakdowns causing production losses to the company and to suggest counter measures by which these problems can be reduced. In the study a Root cause analysis is conducted to find the root cause of breakdowns and some parallel improvement opportunities were also identified for implementation so as to reduce the downtime.

Shagluf et al. [4], presented a review of maintenance management methodologies and their application to positional error calibration decision-making. The purpose of this review was to evaluate the contribution of maintenance strategies, in particular TPM, towards improving manufacturing performance, and how they could be applied to reduce downtime due to inaccuracy of the machine. This work redefined the role of maintenance management techniques and develops a framework to support the process of implementing a predictive calibration program as a prime method to supporting the change of philosophy for machine tool calibration decision making.

Ab-Samat et al. [5], studied aspects of effective preventive maintenance (PM) and to analyze the causes of inefficient PM activity in a case study and its implications. Another important approach taken is to investigate the causes of machine downtime by performing a root cause analysis. The findings of this provides prove that separating the machines into critical and non-critical categories, each having a different priority level is a crucial step towards solving the issue at hand and ensuring the reduction in downtime occurrence in addition to reducing the workload of the technicians.

Kiranet al. [6], a model for improving plant availability has been proposed. By applying this model, an optimum maintenance schedule for the process plant can be formed. Improvement in availability of plant after employing the optimum schedule was calculated. A case study of a cement plant has been used to demonstrate the methodology. Results indicate that the methodology is successful in identifying the critical equipment's and improving the availability of the system.

Mostafa et al. [7], the exhaustive literature review has been conducted to collect the up-to-date maintenance strategies and activities, lean principles and practices in the lean maintenance process. The scope of this paper includes eight types of waste (non-value added maintenance activities), maintenance value stream mapping and a scheme of lean maintenance practices. Theoutput of this paper is a proposed roadmap to apply lean thinking in a maintenance process.

Eti et al. [8], a methodology for the development of PM using the modern approaches of FMEA, root-cause analysis, and fault-tree analysis is presented. Applying PM leads to a cost reduction in maintenance and less overall energy expenditure. Implementation of PM is preferable to the present reactive maintenance procedures.

Bon and Ping [9], this paper intends to find out the difference between before and after the TPM implementation to OEE result. Elements that constitute the OEE equation will be analyzed in order to identify which one that affects OEE result. After identifying, improvement will be made on that element so that OEE result will be improved ultimately. The approach used in this paper is experimental and the resources used to collect data are observation and interview. Hence, TPM is a useful tool in helping firm to achieve optimal manufacturing process

McKone et al. [10], investigated the relationship between Total Productive Maintenance (TPM) and manufacturing performance (MP) through Structural Equation Modeling (SEM). They found that TPM has a positive and significant relationship with low cost, high levels of quality, and strong delivery performance. They also found that the relationship between TPM and MP can be explained by both direct and indirect relationships. In particular, there is a significant and positive indirect relationship between TPM and MP through Just-In-Time (JIT) practices.

Continuous Improvement:

Jevgeni et al. [15], introduced a new framework that allows continuous improvement for the reliability of production process and product throughput. The new framework helps to define and measure failures of production processes, also enable to analyze these failures. It can be done by identifying the most critical operations in the process that influence on Key Performance Indicator (KPI) such as throughput of that process. This new framework also integrates various tools and methods like Six Sigma DMAIC, FMEA, TOC, FC, swim-line diagram.

Sokovic et al. [16], presented a review of possibilities of the systematic use of seven basic quality tools (7QC tools) is presented. It is shown that 7QC tools can be used in all process phases, from the beginning of a product development up to management of a production process and delivery. It is further shown how to involve 7QC tools in some phases of continuous improvement process (PDCA-cycle), Six Sigma (DMAIC) and Design for Six Sigma (DMADV) methodologies, and Lean Six Sigma.
Gibbons [17], TPM measure OEE is introduced as an indicator of plant effectiveness to be used in conjunction with the Six Sigma DMAIC improvement methodology. Facilitating theory development through practical application, an Action Research methodology is adopted for the project. Completory is the introduction of a triangulated project approach utilizing both objective, quantitative methods for data analysis and problem solving as well as subjective, qualitative methods for dealing with the personnel elements of Six Sigma projects. Findings suggest the approach adopted was successful, achieving a near 50% improvement in the OEE over a 12-week period.

Proposed methodology

This literature analysis gives collected view and opinion of authors for the continuous improvement, machine breakdown analysis and effective preventive maintenance strategies to reduce machine downtime in manufacturing industry. Methodology proposed to improve machines up time by studying literature is shown in fig. 1.

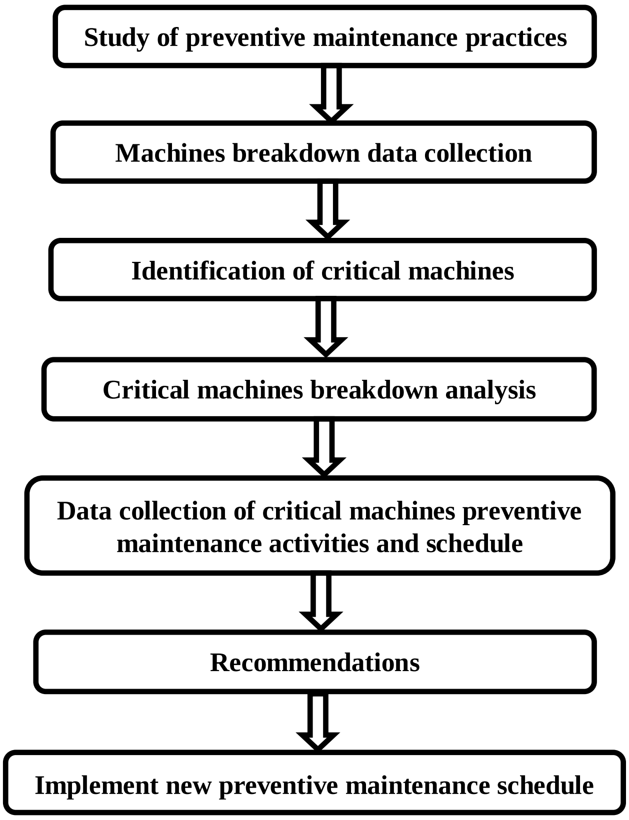

Figure 1: Flow diagram of proposed methodology

Expected outcomes

- There will be decrease in machine downtime and increase in machine or equipment operational availability.
- There will be increase in Production rate due to increase in availability of machines.
- On applying new PM schedule, Mean Time to Repair (MTTR), Mean Time between Failure (MTBF) and Operational Availability (Up Time) conclusions will be drawn. By analyzing these factors, an organization can maintain economic growth by maintaining machine properly.

Case study

This project work conducted on engine cylinder block manufacturing line in automobile engine manufacturing company. On manufacturing line only machining is carried out. Raw casted part is supplied as input material on which different machining processes are done to produce finish part. There are total 35 different machines which perform different machining operations and 24 different non machining equipment's which include conveyors, cranes and hoists for part travel and CMM and different gauges which are used to inspect the manufactured parts. In the company on cylinder block line up time target set by engineers is 95%. But in actual practice they hardly achieving on an average up to 84% as shown in fig. 2. Main objective is to improve line uptime up to 95%. Case study is done during July 2016 to January 2017.

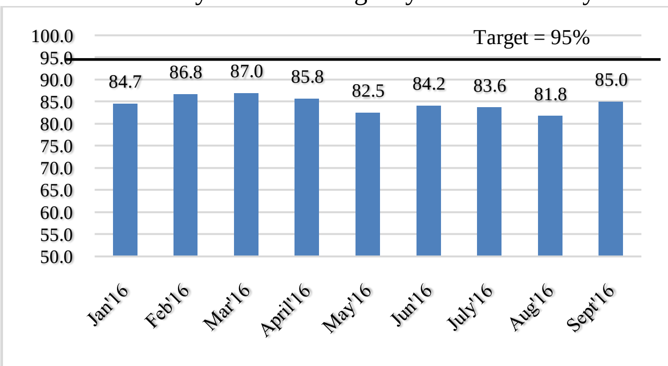

Figure 2: Up time details

Data collection

Data Collection is an important aspect of any type of research study. Data is essential for investigating the Root Cause of the problem. In order to improve line up time it is essential to find critical machines on that line. Critical machines are those machines on which frequent breakdown occurs. MTBF is key tool to identify critical machine on production line. Data is collected for three months i.e. July 2016 to September 2016.

Mean time between failures (MTBF)

It is time between two failures of machine. When failure rate constant, the mean time between failures is the reciprocal of constant failure rate or the ratio of the test time to failure. It is given by,

$$\text{MTBF} = \frac{(\text{Total available hrs.} - \text{Breakdown hrs.})}{\text{No. of breakdowns}}$$

For any particular machine MTBF should be maximum. If is low then it is considered to be critical machines [2]. MTBF (in minutes) data is collected for three months Jul. 16 to Sept. 16,

then pareto analysis is done by compiling these three month data as shown in fig. 3 to identify critical machines which mainly leads production line downtime.
From the three month MTBF data paretoanalysis, the machines which have cumulative MTBF % more than 80% mainly causes block production line major downtime are shown in table 1.

Table 1: Critical machines

Sr. No.	Critical Machines	Operation no.
1	MAG HMC (Horizontal Machining Centre)	OP 40B
2	Valiant Washer	OP 270
3	Nagel Honing Machine	OP 250 A,B and C
4	PARI (Assembly station)	OP 280
5	Inventory (Conveyor)	2

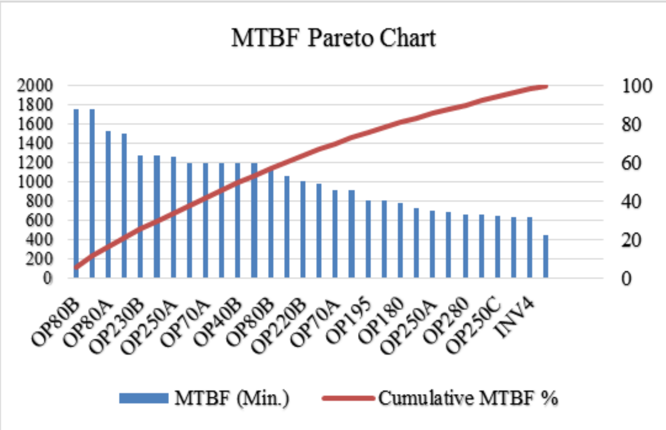

Figure 3: MTBF Pareto Chart

MAG HMC:
MAG is the German manufactured horizontal machining center as shown in fig. 4. It is 5 axis horizontal machining center used for machining of casted cylinder block line. There are total 23 MAG machines on cylinder block machining line out of which 40B is one of the critical machine. These all machines are performed different machining operations such as drilling, boring, milling, tapping, etc. Construction point of view all MAG machines are almost same only different mechanisms in spindle assembly.

Figure 4: MAG HMC 40B

MAG machine 3 months from July 2016 to September 2016 breakdown data is collected and pareto analysis is done to identify top problems which cause major machine breakdown based on both frequency of occurrence problems and time lost. Top problem identified that causes major breakdown for MAG HMC are as shown in table 2.

Table 2: Top breakdowns of MAG 40B

Sr. No.	Problem Description	Frequency	Time Lost (min.)
1	Spindle rotation sensor fault	12	1160
2	Return pumping fault	44	520
3	KF filter flood alarm	46	492
4	Fixture clamping signal problem	18	182
5	Filter paper change	10	165
6	Spindle collet tool drop	26	128
7	Part clamp and de clamp problem	3	118
8	Tool magazine retract not reached	7	90
9	Axis over travel	20	78
10	Safety brake test fail	5	76
11	Coolant pressure low fault	6	62
12	Part stuck on loader	5	60
13	Front door scanner fault	3	51
14	HMI hang	5	50
15	Coolant cabinet temperature not ok	4	50
16	Tool break sensor fault	3	50
17	Coolant flow problem	15	45

Analysis and counter measure
Root cause analysis (RCA)
Root Cause Analysis is a method used to address a problem or non-conformance, in order to get to the root cause of the problem. It is used to correct or eliminate the cause, and prevent the problem from recurring. In otherwords for a particular product problem, Root Cause is the factor that, when you fix it, the problem goes away and doesn‘t come back.

A) *Cause and effect diagram*
Cause and effect or fishbone analysis is an example of root cause analysis specifically, it‘s a type of cause and effect diagram which helps you to think through causes of a problem thoroughly. Their major benefit is that they push you to consider all possible causes of the problem, rather than just the ones that are most obvious. Possible causes for breakdown problems are found by fishbone diagram shown in fig. 5.

B) *Why- why analysis*
The Why-Why method helps to determine the cause-effect relationships in a problem or a failure event. It can be used whenever the real cause of a problem or situation is not clear. Using the 5-Whys is a simple way to try

solving a stated problem without a large detailed investigation requiring many resources. When problems involve human factors this method is the least stressful on participants. It is one of the simplest investigation tools easily completed without statistical analysis. Also known as a Why Tree, it is supposedly a simple form of root cause analysis.

Root cause analysis of MAG HMC 40B

Problem statement: Spindle rotation sensor fault
Problem location: Machine spindle
Supplier: MAG
Product: 10TG-C055

Cause analysis:

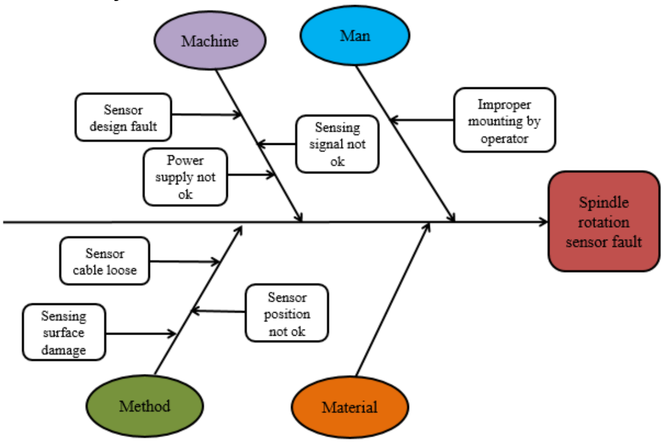

Figure 5: Fish bone diagram for spindle rotation fault

Why-why analysis:

Table 3: Why-why analysis of spindle rotation sensor fault

Problem Description:	**Spindle rotation sensor fault**
Why?	Sensor signals not ok
Why?	Sensor sensing surface not ok
Why?	Sensor sensing surface damage
Why?	Metal burr deposited over sensing surface
Why?	Sensor sensing surface protecting cap damage

Corrective counter measure

- Periodic checking of spindle rotation sensor.
- Monitoring and periodic cleaning of sensor surface and sensing surface protecting cap.

Similarly other type of problem of all identified critical machines can be solved by using these method and identifying the root causes to obtain the preventive action. Other problems root cause and its required preventive action is as shown in table 3.

Table 3: RCA and preventive action of remaining problems

Sr. No.	**Problem Description**	**Root Cause**	**Preventive Action**
1	Spindle rotation sensor fault	Sensing surface protecting cap damage	Check spindle rotation sensor
2	Return pumping fault	Float switch dirty	Clean float switch
3	KF filter flood alarm	Float switch dirty	Clean float switch
4	Fixture clamping signal problem	Air gap sensor faulty	Check for air gap sensor
5	Filter paper change	Filter paper choke up	Check mounting and length of filter paper
6	Spindle Collet tool drop	Spindle collet clamp not reached	Clean spindle collet and tool
7	Part clamp and de clamp problem	Drive connections loose	Check all drive connections
8	Tool magazine retract not reached	Spindle tool not clamp	Check input of magazine retract
9	Axis over travel	Model change	Check parameter values
10	Safety brake test fail	Drive connectors stuck up	Check drive connectors
11	Coolant pressure low fault	Pressure drain valve drop	Check for pressure drain
12	Part stuck on loader	Roller bearing jammed	Check loader bearing lubrication
13	Front door scanner fault	Sick Sensor fault	Clean sensing surface
14	HMI hang	Loose connection	Check all HMI connections
15	Coolant cabinet temperature not ok	Solenoid valve faulty	Check all sensors
16	Machine under maintenance for tool break sensor	Sensor protection cap loose	Check sensor protection accessories
17	Coolant flow problem	Pneumatic pipe broken	Check pneumatic pipe

Preventive maintenance program

The most important reason for a PM program is reduced costs as seen in the following ways:

- Reduced production downtime, resulting in fewer machine breakdowns.
- Better conservation of assets and increased life expectancy of assets, thereby eliminating premature replacement of machinery and equipment.
- Reduced overtime costs and more economical use of maintenance workers due to working on a scheduled basis instead of a crash basis to repair breakdowns.
- Timely, routine repairs circumvent fewer large-scale repairs.
- Reduced cost of repairs by reducing secondary failures. When parts fail in service, they usually damage the other parts.
- Reduced product rejects, rework and scrap due to better overall equipment condition.
- Identification of equipment with excessive maintenance costs, indicating the need for corrective maintenance, operator training, or replacement of obsolete equipment.
- Improved safety and quality conditions.

Benefits of preventive maintenance:

- Keeps equipment in good condition to prevent large problems.
- Extends the useful life of equipment.
- Improves system availability and reliability.
- Decreases system downtime.
- Parts stocking levels can be optimized.
- Reduces number of emergency breakdowns.
- Greatly reduces unplanned downtime.
- Finds small problems before they become big ones.
- Improves customer service.
- Reduces inventory cost by ensuring availability of spare parts.
- Decreases maintenance costs and replacement costs.
- Increases overall productivity.

Based on the critical machine breakdown analysis, new PM points are added in regular PM check sheets. Table 4 shows new PMcheck pointsare added in addition to previous PM points from machine breakdown analysis. Similar procedure is followed for all remaining critical machines and equipment. Similarly new PM additional check points developed from root cause analysis (RCA) of major breakdown problems of remaining critical machines and followed the PM check sheets as per schedule employed.

Table 4: After RCA new PM check points suggested

Machine name: MAG HMC		**Operation no. 40B**
Sr. No.	**PM Activity Description**	**PM Frequency**
1	Check tool change shutter open & closed cylinder flow check, check door for crack	Two monthly
2	Candel filter clean	Two monthly
5	Chilled water strainer cleaning	Two monthly
6	Coolant tank and level sensor box.	Two monthly
9	Check spindle cooling unit temperature & level sensor setting values	Two monthly
10	Tool magazine forward retract damper check , marking	Two monthly
11	Check air gap sensor & cable for any damage/hard	Two monthly
13	Exhaust filter clean, drain line clean	Two monthly
14	Loader turn table stopper mounting tightness check	Two monthly
15	Z1 and Z2 side burr cleaning, coolant path	Two monthly
16	Cleaning the tool holder in the main spindle	Two monthly
17	Check spindle rotation sensor	Two monthly
18	Check all pressure gauges in working condition.	Quarterly
19	Check front loading door LM bearing mounting bolts check if loose tighten it	Quarterly
20	Check float switch	Quarterly
21	Check tool breakage timing belt condition checking.	Half yearly
22	Chip conveyor inside filter cleaning.	Half yearly
23	Check x, y, axis telescopic guard wiper seal -------	Half yearly
24	X, y, z axis linear scale connector check if loose tighten.	Half yearly
25	Check all HMI connections	Half yearly
26	Check drive battery voltage	Half yearly
27	Check spindle axial play	Yearly
28	Drive fan clean.	Yearly
29	Replace drive battery	Yearly
30	Tool magazine to spindle alignment check w.r.t y and x axis	Yearly
31	Check spindle run out and face out	Yearly
34	Check spindle taper blue match	Yearly
35	Check accumulator gas pressure	Yearly
36	Spindle vibration analysis	Yearly
37	Z-axis vibration analysis	Yearly

Results and discussions

Operational availability (up time): Availability is the total time of utilization of a machine. Availability is the ratio of the difference between the total available hours and total breakdown hours to the total available hours. In the company considered in case study up time target is 95% on an average of all machines for each month.

$$Availabilty = \frac{(\text{Total Available Hrs.} - \text{Breakdown Hrs.})}{\text{Total Available Hrs.}} \times 100$$

Mean time between failures (MTBF): MTBF is the time between two failures. When failure rate is constant, the mean time between failures is the reciprocal of the constant failure rate or the ratio of the test time to the number of failures. In the company considered in case study MTBF target is 120 min. on an average of all machines for each month.

$$\text{MTBF} = \frac{(\text{Total available hrs.} - \text{Breakdown hrs.})}{\text{No. of breakdowns}} \text{ (in hrs.)}$$

Mean time to repair (MTTR): "Mean Time to Repair" is the average time that it takes to repair something after a failure. In the company considered in case study MTTR target is 120 min. on an average of all machines for each month.

$$\text{MTTR} = \frac{\text{Total breakdown hrs.}}{\text{No. of breakdowns}} \text{ (in hrs.)}$$

MAG HMC

Following details shows average downtime details of three months July 2016 to September 2016 of MAG HMC 40B

Available Time (min.)	Breakdown time (min.)	No. of breakdown
23000	4630	206

$$Availabilty = \frac{(23000 - 4630)}{23000} \times 100 = 79.87\%$$

$$MTBF = \frac{(23000 - 4630)}{206} = 89.17\ min.$$

$$MTTR = \frac{4630}{206} = 22.48\ min.$$

In similar way results are calculated for other critical machines. Table 5 shows three month (Jul. 16 to Sept 16) average downtime details of each critical machine. Table 6 shows results before implementing changes.

New changes in PM schedule for all critical machines are implemented from January 2017. After implementing changes in PM, critical machines downtime data is collected from 1st February 2017 to 15th February 2017. Table 7 shows 15 days average downtime details of each critical machine and table 8 shows results after implementing changes.

Table 5: Before downtime details of critical machines

Machine name	Operation No.	Available Time (min.)	Breakdown time (min.)	No. of breakdown
MAG HMC	OP 40B	23000	4630	206
Valiant	OP 270	23000	3975	189
PARI	OP 280	23000	4145	195
Nagel Honing	OP250	23000	4289	201
Inventory	4	23000	3379	164

Table 6: Results before implementing changes

Machine name	Availability %	MTBF (min.)	MTBF Target	MTTR (min.)	MTTR Target
MAG HMC	79.87	89.17	120	22.48	20
Valiant	82.72	100.66	120	21.03	20
PARI	81.98	96.69	120	21.26	20
Nagel Honing	81.35	93.09	120	21.34	20
Inventory	85.31	119.64	120	20.6	20
Average	82.25	73.6	120	22.6	20

Table 7: After downtime details of critical machines

Machine name	Operation No.	Available Time (min.)	Breakdown time (min.)	No. of breakdown
MAG HMC	OP 40B	11960	1950	95
Valiant	OP 270	11960	1498	78
PARI	OP 280	11960	1667	81
Nagel Honing	OP250	11960	1710	87
Inventory	4	11960	1461	76

Table 8: Results after implementing changes

Machine name	Availability %	MTBF (min.)	MTBF Target	MTTR (min.)	MTTR Target
MAG HMC	87.47	137.66	120	19.71	20
Valiant	86.06	131.96	120	21.37	20
PARI	85.7	117.82	120	19.66	20
Nagel Honing	83.7	105.37	120	20.53	20
Inventory	87.78	129.62	120	18.04	20
Average	85.09	114.2	120	19.1	20

It is seen from data collected and analysis there is significant improvement in critical machines availability from table 6 and 8. Before and after implementing changes availability or up time percentage of whole engine cylinder block machining line is as shown in fig. 6. Target to achieve up time was 95% but it is achieved up to 87.54% on an average of all machines till mid Feb 2017 as shown in fig. 6.

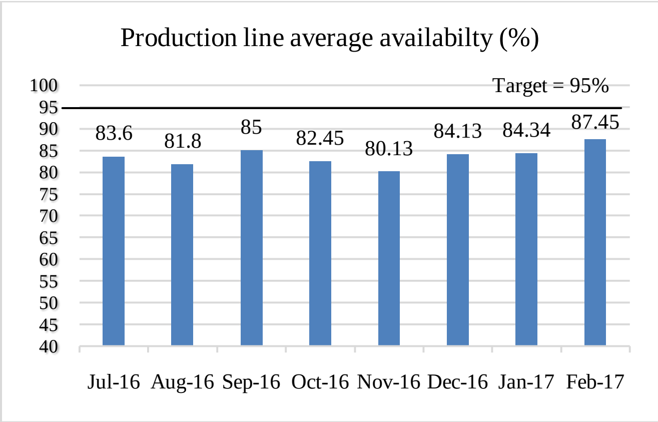

Figure 6: Block machining line monthly availability (%)

Critical machines 15 days average MTBF (min.) is as shown in fig. 7. Target was that MTBF should be greater than or equal to 120 min.

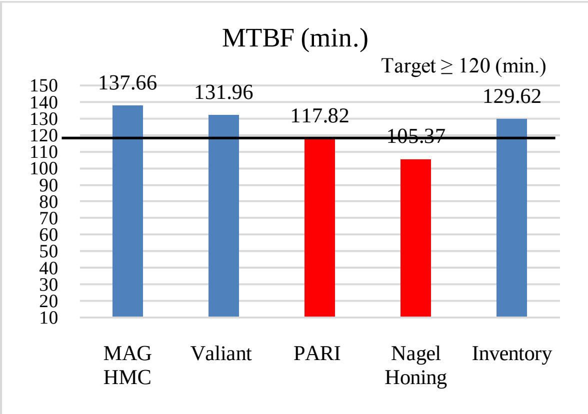

Figure 7: Critical machines average MTBF

Critical machines 15 days average MTTR (min.) as shown in fig. 8. Target was that MTTR should less than or equal to 20 min. MTBF of Nagel honing machine and PARI cup plug assembly station is not achieved as per target as well as MTTR of Valiant and Nagel honing machines are not achieved as per target. Results obtained for whole production line availability percentage are improved but not achieving target. This is because, this results obtained from initial fifteen days i.e. from 1st February 2017 to 15th February 2017. Some more duration required to get desired results. Further data collections are going on.

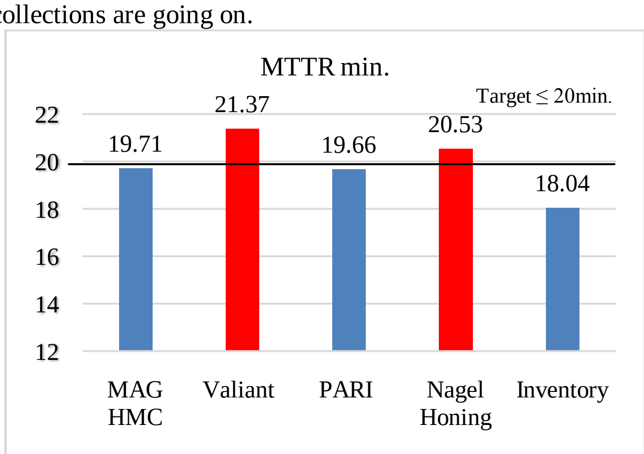

Figure 8: Critical machines average MTBF

Conclusions

The present work is an overview of previously done researches and also for new research, it gives a direction for machines up time or operational availability improvement explained with one case study. This project has been carried out on automobile engine cylinder block manufacturing line in automobile engine manufacturing company. Critical machines and stations on production line were identified. All repeated and major breakdowns of critical machines and stations were analyzed along with the critical parts, which has been under breakdown condition is also identified and analyzed. Also the reason for the breakdown has been analyzed and some of the tools of root cause analysis like 5-why analysis, fish bone diagram are implemented to identify the actual cause of the breakdown. By this analysis and methods the root causes of the breakdowns were identified. This in turn helped to develop and improve a new preventive maintenance checklist for the critical machines. This method is used to prevent the failure of equipment before it actually occurs.

In a case study considered only initial observations and result are found. Some more duration require to obtain desired results. The conclusions drawn are discussed below,

i. After implementing changes in PM of critical machines, within just fifteen days it is found that there is an increment of 4 to 9 % on machines availability or up time.

ii. Also the average MTBF of critical machines after root cause analysis is increased from 73.6 min. to 114.2 min. Target was that MTBF should be greater than or equal to120 min.

iii. Three months average MTTR of critical machines is reduced from 22.6 min. to 19.1 min.

iv. After root cause analysis there is an improvement in the maximization of planned productivity. This is because of proper diagnosis of the existing system and by employing proper preventive maintenance schedule.

v. The implementation of proper preventive maintenance (PM) can greatly reduce machine failure rates and improves up time; ensuring uninterrupted production.

vi. It is found that, on production line whole line up time improvement is depends on performance of critical machines. If we make improvement in critical machines availability there will improvement in production line up time or availability.

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