Analysis of Breakdowns and Implementing Optimal Maintenance of Engine Cylinder Block Machines for Improving Operational Availability

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Abstract

The aim of any maintenance plan is to improve machine availability. Modern manufacturing involves complicated machines and high levels of automation. The goal of automated equipment is to increase production rates while improving quality. As a result, machines must be kept in working order to deliver the desired outcome or goal. Machine failures or breakdowns cause production to be disrupted, resulting in the present system's availability being lost. This influences the production, expense of maintenance and commitment to customer. The present work aims at increasing operational availability of the Machines. One engine block manufacturing system consisting of three lines, each line having no of machines, a few critical machines were identified on the criteria of capacity and breakdowns and these breakdowns were analysed with FMEA, RCA, Why-Why analysis, etc. Implementation is in the form of a customised maintenance plan that reduces the breakdown and shifts the maintenance from reactive to proactive. The following parameters like MTTR, MTBF and Machine Uptime % and the production quantity were compared with previous year data in CMMS. The implemented maintenance plan helps to improve production rate and the machine operational availability.

Keywords
Operational availability, MTTR, MTBF, FMEA, Pareto analysis, and Maintenance.

1. Introduction
The ultimate purpose of maintenance is to offer optimal dependability that satisfies the firm's business requirements, with reliability defined as the percentage of failure-free performance for a specified period of time under specified conditions. Downtime has been a result of asset/machinery failure (Kolte and Dabhade; 2017). Equipment maintenance is becoming more important in industry as a result of the requirement to improve dependability and reduce the risk of productivity loss due to machine failure. The equipment availability/uptime is also known as the time for which it is completely functioning. The initial two thoughts that if a plant is running for 24 hours and 3 shifts for all seven days, It should have maximum output and for doing that, the training of the employees is a must, so that they can work with the best way of that particular plant, depending upon their training, depending upon their skills, they might operate the equipment, will use machines machinery, so that it can perform the best outputs . To avoid breakdown, we need to have a very proper robust planning of preventive maintenance that could fore see that what Is the maintenance requirement of this particular equipment. It is a very difficult task as one must keep balance in between the two factors those are frequency, duration of maintenance and the cost of maintenance. These factors are also very important when planning preventive maintenance (jishu hozen implementation. manual no.1 2000). The relationship between preventive maintenance and breakdown maintenance is if more efforts are put in preventive, then cost of breakdown maintenance decreases. Maintenance

operations are not limited to repairs and spare part replacement, they also have a significant impact on maintenance work performance. In this paper we have prepared maintenance plans for individual machines which has helped in reducing unplanned breakdowns, All the machines used for engine block manufacturing are divided into three sections lines each line having respective number of machines used for operations.

1.1 Problem definition

Analysis of machine breakdowns of cylinder block manufacturing line in order to improve the operational availability, the tools (5 why analysis, FMEA, Fishbone/ cause and effect) to be used to find the causes for any failure.

2. Literature review

There are several types of maintenance concepts available that can be applied in varied environments like Reliability Cantered Maintenance, Preventive maintenance, Condition based maintenance, Total Productive maintenance (Eti et al. 2004). An experiment on a 1000 tonne hydraulic forging press, and all recurring breakdowns were investigated, as well as essential parts that were in a state of breakdown. The cause of the breakdown has also been investigated, and root cause analysis tools such as the 5-why analysis and the fishbone diagram have been used to pinpoint the root of the problem. The root causes of the failures were found using this study and approaches. As a result, a new proactive maintenance checklist for such equipment was developed and improved. This strategy is used to prevent equipment failure before it actually happens. After root cause investigation, the average uptime of the essential machine 1000 Ton hydraulic forging press has raised to 4.16 percent. After root cause analysis, the average MTBF of essential machines has increased to 13.66 percent and the MTTR has fallen to 46.42 percent. The optimization of planned production has improved following root cause analysis. This is due to a proper evaluation of the available system and the implementation of a preventative maintenance programme. As a result, whenever a failure happens, the root cause of the failure must be determined. Then, utilising root cause analysis and countermeasures, some steps should be taken to modify this system so that such breakdowns can be avoided (Rudramurthy 2013). All have their pros and cons. TPM not only concentrates on equipment availability like in CBM and PM, but also considers other factors like operator performance, quality of product safety related issues and working environment. Success of TPM lies in the interest of top leadership. TPM technique approach creates many years to finish and consists of eight pillars. Its first pillar, Autonomous maintenance (AM), is implemented first, and it serves as the foundation for all subsequent pillars. AM trains operators how to repair their own machinery on a regular basis. (Day et al. 2004). As AM is implemented, improvements in machine availability and performance can be observed. Furthermore, better morale and work satisfaction result from enhanced operator motivation, which improves the industrial culture. Emphasis is given on autonomous maintenance being basic pillar of TPM, and if AM activities are not sufficient, expected results will not materialize even if other pillars are upheld (Tewari and Anurag 2017). A systematic procedure to successfully implementing autonomous maintenance is given in JH implementation manual, published by JIPM in association with confederation of Indian Industries and TPM Club India the details of documentation required while implementing AM are given in Seminar report Published by CII. Overall Equipment Efficiency is an important parameter for evaluation of effectiveness of implementation process, which gives a clear picture of the areas need to be concentrated. The calculation of OEE requires three factors, Availability Performance efficiency and rate of Quality. These can be calculated by analysing downtime and rejection data for a period. OEE considers six major losses, which can be again categorized as sixteen minor losses (jishu hozen implementation. manual no.1 2000).

A broader strategy must consider the factory's overall performance. So, in the future an extremely important objective is, to improve the performance of the whole factory instead of concentrating only on single tools. A factory-wide approach for controlling and improving Overall Factory Effectiveness (OFE) is required (Oechsner et al., 2003). The true performance of the equipment productivity in cellular manufacturing can be measured by total effective equipment productivity (TEEP) in and is a measure of resources to enable (including scheduled downtime) and OEE combined. The OEE is not an exact measure of equipment effectiveness as set-up, changeovers and adjustments are included. Therefore, to provide a more accurate analysis, the net equipment effectiveness (NEE) can be measured that When the equipment is running, it displays its genuine quality and efficacy (Chand and Shirvani 2000). Autonomous Maintenance is implemented in seven steps as given in JH Manual (JIPM, CII). Results of AM can be observed from the very first step after implementation. There are many other tools that are used simultaneously like Kaizen, Root Cause Analysis, and preventive maintenance. Machine can be selected for AM subjectively, considering various criterions like history of downtime, rejections, breakdowns, importance of machine in manufacturing line and possibility of horizontal deployment. (jishu hozen implementation. manual no.1 2000). Machine condition monitoring can be done using analytical methods like AHP, Diagraph for decision-making in multi-criteria decision approach and provides an effective way to properly quantify the pertinent data, using a pair wise comparison between parameters. The comparisons are used to obtain weightage of importance as basis of decision criteria. Comparison must fall in an admissible range of consistency. A systematic procedure by applying AHP for assessment of parameters is given (Rajiv and Kamble 2022). Ahti A. Salo and Raimo P. Hamalainen has modified AHP to produce similar results to those of multi-attribute value measurements. A new balanced scale is proposed to improve sensitivity of the AHP ratio scales. AHP can also be applied for decision making in maintenance (Salo and Hamalainen 1997). Problems in maintenance arise from not having clear criteria and not having robust decisions with which to maintain failing equipment. Labib has developed a dynamic and adaptable maintenance system that utilizes existing data and supports decision accordingly. He proposes a three-stage system that can handle multiple criteria decision analysis, conflicting objectives, and subjective judgments (Labib et al 1998). Failure analysis of machine can be performed by failure mode effect analysis (FMEA), Fault Tree Analysis along with Root Cause Analysis (RCA), Cause and Effect (Fishbone) Diagram etc, have analysed the basic failure events and failure modes, effects, and criticality assessment (FMECA) and risk priority number were used to determine the criticality of parts or sub-systems (RPN) (Kolte and Dabhade 2017).

From the literature review there is clear that researchers were focused on final remedy for the breakdown with reference to short term actions. But very less researchers aimed for long term actions in the maintenance. Therefore, in the present paper we have focused on long term actions with reference to short term actions that are necessary for machine to be kept in working condition.

3. Methodology

The following methodology is used in the present work:

- Previous year's machine breakdown data collection.
- Identification of Critical Machines with the help of process team and maintenance team.
- Critical machines breakdown analysis.
- Study of critical machine's preventive maintenance and frequency of the maintenance activity
- Recommendations for reducing the downtime and repetitive breakdowns.

Problem identified by 5W2H, check sheets, lessons learned database. Containment is done with the help of the action plan, MSA. Potential failure modes were identified by FMEA and corrected in planned maintenance. RCA is performed when there is a breakdown, 5 why analysis, pareto analysis. Corrective Action which is short term and Preventive Action which is a long term.

4. Data related to failure of cylinder block manufacturing line.

Data collection is an important part of any analysis in this we have collected the voices of the customers in this case they were the individual operators of the machines from all the three shifts as well as from the daily production report and maintenance activity report. Along with the traditional means we have gone through the computerized maintenance management system (CMMS) in this case MAXIMO as shown in Figure 1. It was found that all the machines are having major breakdowns in the areas of Air, Axis, Chillers, Coolant, Hydraulic Oil Leakages, Electric, Lubrication, ATC, and Spindle.

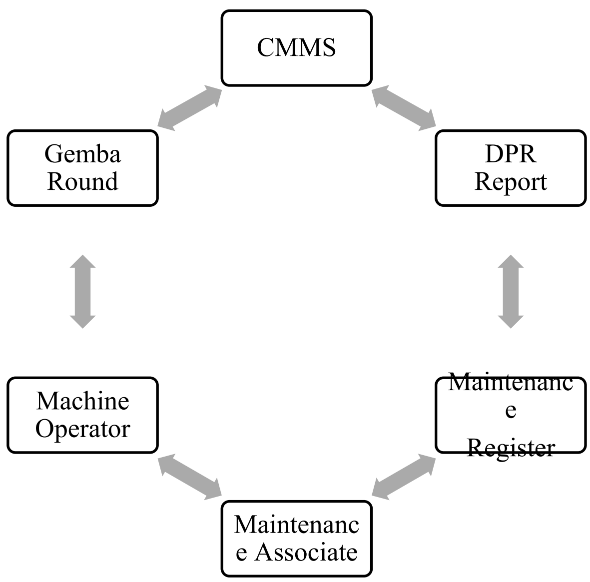

Figure 1. Data collection process.

4.1 Identification Of critical machines

The machines with bottleneck and the machines which were critical were identified, the total of 11 machines were identified.

- **Bottleneck Machines**: These are the machines which are bottleneck as per cycle time. The list of these machines is given by Process Engineering.
- **Critical Machines**: These are the machines decided by maintenance department (Plant Engineering). The criteria for these are criticality from maintenance point of view, made to order control system.
- Since the internship was of seven months, the base line data of the process in order to compare with the present project was taken of seven months before the internship.

Table 1 lists the monthly breakdown hours of a section line and the critical machines breakdown hours of that section line which in this case are the three Haas machines (Haas -1, Haas-2 Haas-3) machine which were defined by the process engineering and plant engineering team . Figure 2 gives the illustrated view of the breakdown hours of these critical machines which were more than 50 % of the overall breakdown hours of that section line machines.

Table 1. Monthly breakdown hours of cylinder block machines and critical machines.

Month	Section line total working hours	Section line Breakdown hours	Haas machine Breakdown hours	Percentage%
Jan-21	4400	591.75	311.5	53%
Feb-21	5280	393.5	194.75	49%
Mar-21	5940	384	244.25	64%
Apr-21	5500	555	399.5	72%
May-21	4180	381.25	307.5	81%
Jun-21	5500	442.25	228	52%
Jul-21	5940	427.25	258.5	61%
Aug-21	5720	446.75	266.25	60%
Sep-21	5720	517.73	337.15	65%

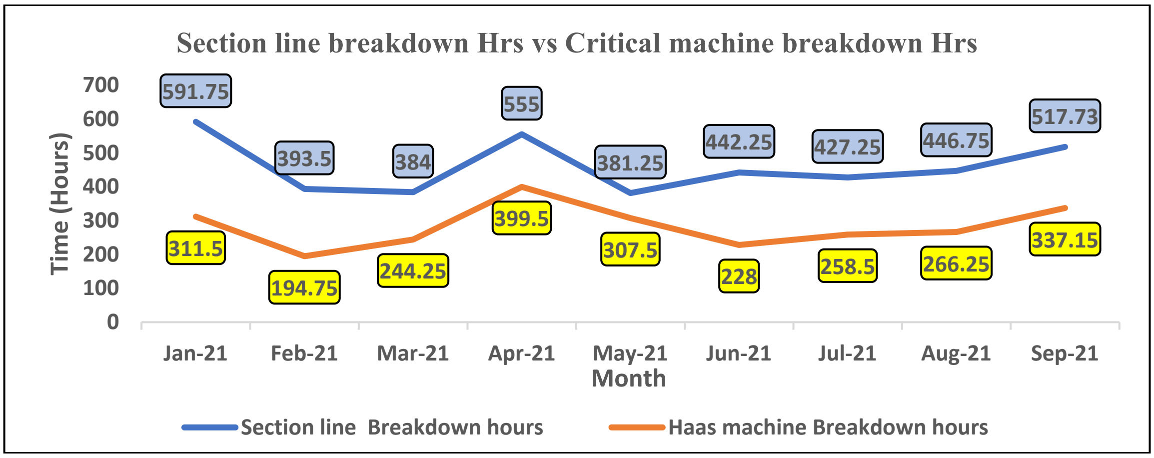

Figure 2. Section line breakdown Hrs vs Critical machine breakdown Hrs

The most critical machine among the critical machines as per the maintenance department is concerned was identified. From the pie chart shown in Figure 3 of Haas machine breakdown hours Haas-2 machine has the highest contribution at 49% to the critical machine breakdown hours followed by the Haas-1 machine at 37% and Haas-3 machine at 14%.

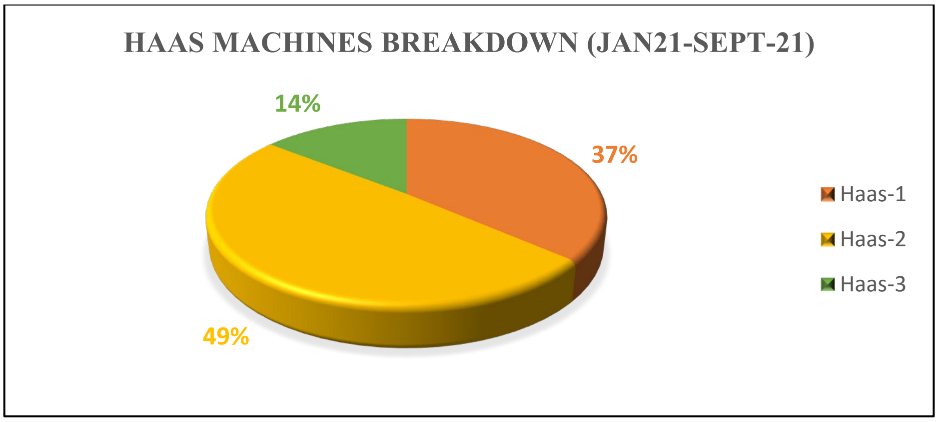

Figure 3. Contribution of Haas machines in breakdown hours

The average operational availability of these machines was at 84% for the period of the year 2021. The Table 2 gives the detail machine wise operational availability Haas-1, Haas-2, Haas-3 machines which were at 85%,77% & 93% respectively.

Table 2. Base-line data of critical machines YTD-21

Machine	Total working Hrs	Breakdown hrs	Available hrs	Up-time
Haas-1	5875.5	1070.85	4804.65	82%
Haas-2	5875.5	1328.95	4546.55	77%
Haas-3	5875.5	433.65	5441.85	93%

4.2 FMEA Analysis.

FMEA: Failure mode effect analysis is run on the C & E matrix's extra outputs, which have significant weight ratings on the inputs of all these key devices.

- S- Severity larger the effect High rating valve for the severity.
- O- Occurrence Higher the occurrence of the breakdown higher rating for that.
- D- Detection Lower the detection of the cause of breakdown higher rating will be given.

Table 3 and table 4 give the scale for severity occurrence and detection in terms for doing risk assessment of the breakdown is determined (Alwiyansyah and Ariyanti 2021).

Table 3. Scale of severity, occurrence and detection.

Rating	**Severity**	**Occurrence**	**Detection**
1	Effect is significant	Failure is very unlikely	Current safeguard will always prevent failure mode
4	Minor disruption, possible loss of production	Occasional failure possible	High probability that currents safeguard will detect or prevent
7	Major disruption, possible damage to local equipment	Infrequent failure is likely	Low probability that currents safeguard will detect or prevent
10	Severe disruption, major damage to plant, possible injury to personnel	Failure is very likely or frequent	No current method of detection

Table 4. Risk priority number calculations

MACHINE	Description	S	O	D	RPN
Haas	B Axis excess error	6	7	7	294
Haas	w axis excess error	6	9	8	432
Haas	X Axis excess error	6	7	8	336
Haas	Coolant level Problem	4	6	5	120
Haas	ATC Door Problem	8	7	8	448
Haas	B Axis shift	8	6	7	336
Haas	W Axis shift	7	7	7	343
Haas	X axis shift	7	7	7	343
Haas	Y Axis shift	8	5	7	280
Haas	ATC Problem	8	8	7	448
Haas	W-Axis reference not possible	6	5	6	180
Haas	Z Axis over travel	7	3	3	63
Haas	B Axis reference problem	7	5	4	140
Haas	Heavy oil leakage	7	8	9	504
Haas	Spindle overheats alarm	8	3	3	72
Haas	w axis pulse coder disconnects	5	7	3	105
Haas	Y axis pulse coder disconnect	6	3	3	54
Haas	Z axis pulse coder disconnect	6	3	3	54
Haas	Spindle through coolant problem	5	4	7	140
Haas	Tool change issue (From spindle side)	8	5	7	280
Haas	W Axis excess current in servo	6	6	4	144
Haas	X Axis excess current in servo	6	6	4	144
Haas Shuttle	Pulse coder problem	7	4	6	168
Haas Shuttle	SV Overload alarm	6	7	3	126
Haas Shuttle	Excess current in servo	6	5	3	90
Haas-1	Attachment change problem	7	8	8	448
Haas -1&2	Faulty fixou command	7	9	4	252
Haas -1&2	Peggy reference problem	6	5	8	240
Haas -1&2	Tool Falling issue/ Tool drop issue	9	8	8	576
Haas -2	Peggy position loops	5	4	6	120
Haas -3	ATC arm not in Position	7	6	8	336
Haas -3	Abnormal noise from spindle	9	5	9	405
Haas -3	Y axis over travel	6	3	3	54
Haas -3	W axis hard OT	8	2	6	96

4.3 Concluding Remarks of FMEA

FMEA is used for identifying the potential failure mode, identifying the risk of the failure through severity, occurrence and detection, there are four different type of breakdowns that are responsible for major equipment downtime, all these machines are having major breakdowns in the areas of Air, Axis, Chillers, Coolant, Hydraulic Oil Leakages, Electric, Lubrication, ATC, and Spindle (Table 5, Table 6).

Table 5. FMEA with causes and controls

Machine name	Problem	Cause	Temporary actions	Long term actions
Haas	Heavy oil leakage	All rubber parts worn out due to aging.	Identified the source & replaced seals/hose pipe	Replacement of all rubber parts & hoses
Haas	ATC issue	ATC issues are due to the misalignments that occur repetitively because of the worn out and sticky parts (valves and cables)	Peggy alignment done, Weekly PM.	Replacement of all cables in Drag chain Peggy replacement

Haas	Various alarm related to Servo drives	may be due to the improper feed back to the electrical component due to their failure.	Repairing the electrical component and drive	replacement of the drive and electrical components according to the requirement.
Haas-1	Attachment Change issue	Solenoid valve sticky due to aging.	Cleaning of the solenoid valve weekly.	Making sure that the valve is in proper condition.
Haas Shuttle	Various alarms related to control system	Electronic component failure	Repaired card/drive	Replace the drive.

5. Results and Discussion

The tracking of the major breakdowns was done after identifying the major breakdowns on the machine or if any major activity of maintenance work (like scale replacement in CNC machine etc.,) is done on the machine. After closing that work order we have even tracked that breakdown through condition-based monitoring and prepared one point lessons for the operator and maintenance activities with this we have improved in the following areas.

- Improved equipment uptime
- Reduction in unexpected equipment failures.
- Increase in production rate because of increased machine availability.
- MTTR, MTBF and Machine availability conclusions would be compared after implementation of revised maintenance schedule.
- Improved customer satisfaction.
- Less health and safety related complications
- Prediction of maintenance requirements.

5.1 Numerical Results

Operational availability (up time):

(Number of working days in a month) x Available hours in a month (Total No. of Working hours in a day)

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF+MTTR}}$$

Mean time between failures (MTBF):

$$\text{MTBF} = \frac{(\text{Total Available hours})}{\text{Total no. of breakdowns (Count)}}$$

*Available hours (Working Time – Breakdown time)

Mean time to repair (MTTR):

$$\text{MTTR} = \frac{(\text{Total breakdown hours})}{\text{Total no. of breakdowns (Count)}}$$

Table 6. MTTR, MTBF and uptime calculations

Machine	Available Working Hrs	Breakdown Hrs	No of Breakdowns	MTTR	MTBF	Uptime Hrs	Uptime(%)
Haas-1	3825	393.4	91	4.32	42.03	3431.60	91%
Haas-2	3825	426.6	127	3.36	30.12	3398.40	90%
Haas-3	3825	274.35	82	3.35	46.65	3550.65	93%

5.2 Graphical Results

The average time taken for the maintenance activity is calculated of all the machines and the average before the equipment failure i.e average working time of that equipment is also represented graphically.

MTTR, MTBF results of Haas-1

MTTR and MTBF of Haas-1 machine are given in Figure 4 and Figure 5 respectively. The average mean time to repair is at 4.15 hours, the average mean time between failure is at 45.2 hours.

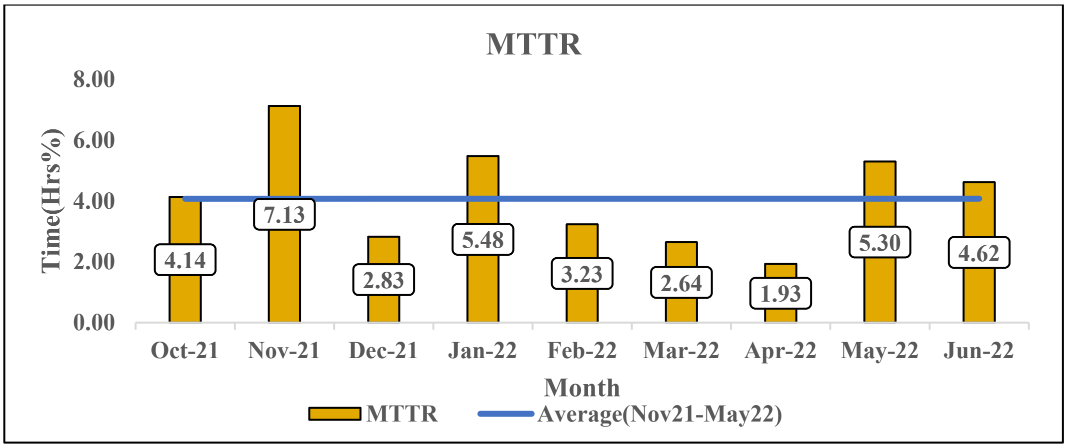

Figure 4. MTTR for Haas-1 Machine

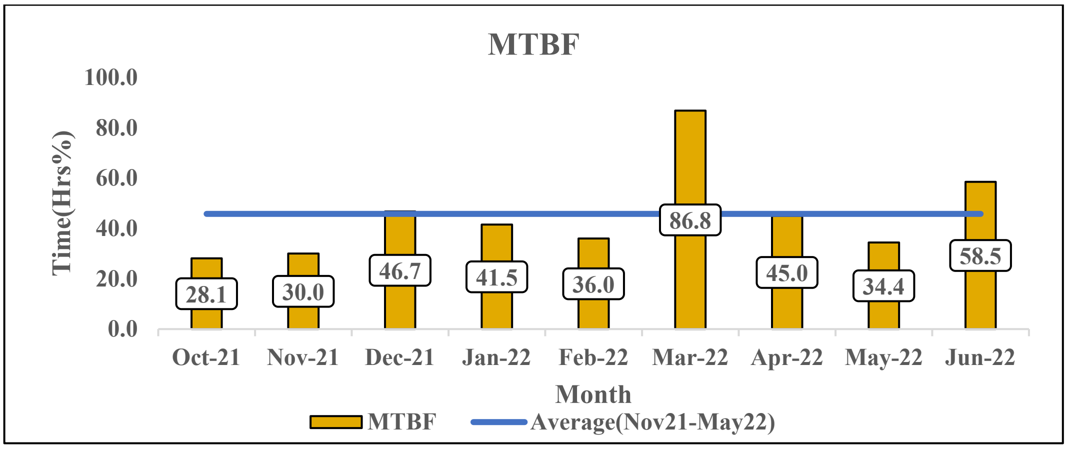

Figure 5. MTBF for Haas-1 Machine

MTTR, MTBF results of Haas-2

MTTR and MTBF of Haas-2 machine are given in Figure 6 and Figure 7 respectively. The average mean time to repair is at 3.57 hours, the average mean time between failure is at 34.1 hours.

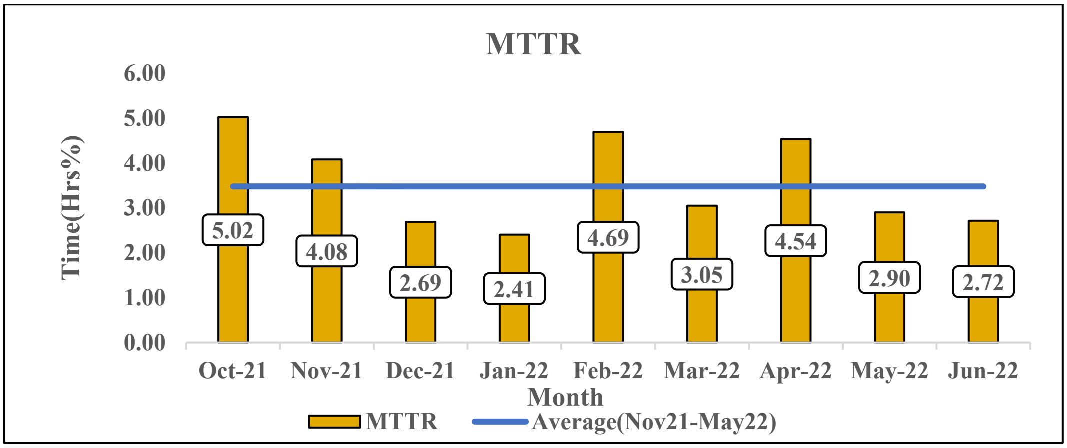

Figure 6. MTTR for Haas-2 Machine

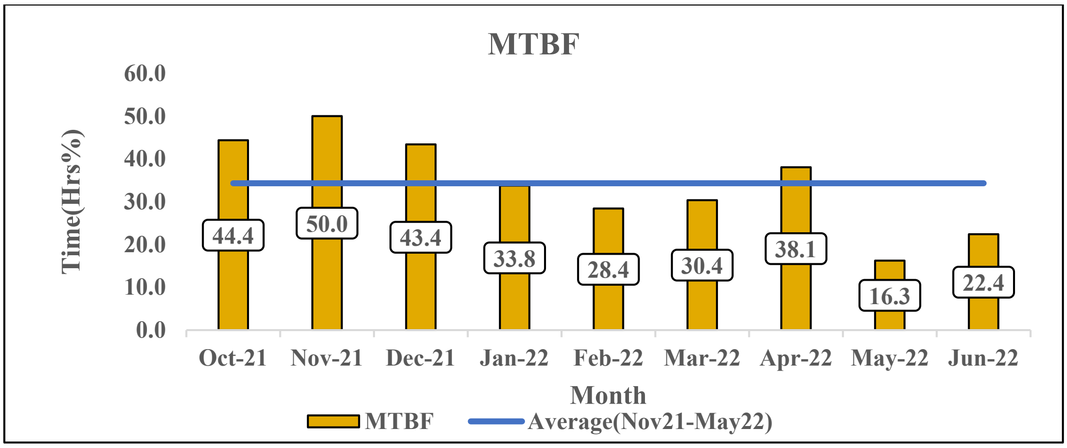

Figure 7. MTBF for Haas-2 Machine

MTTR, MTBF results of Haas-3
MTTR and MTBF of Haas-3 machine are given in Figure 8 and Figure 9 respectively. The average mean time to repair is at 3.48 hours, the average mean time between failure is at 52.57 hours.

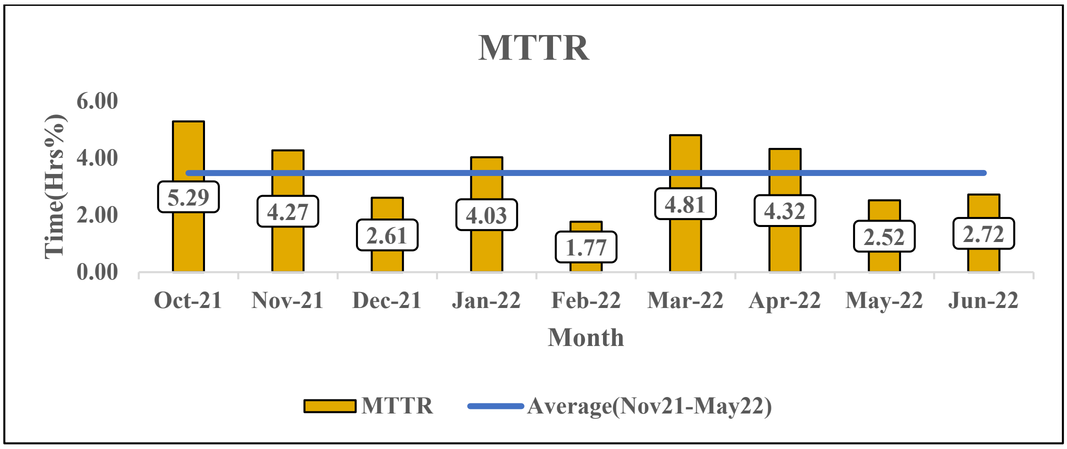

Figure 8. MTTR for Haas-3 Machine

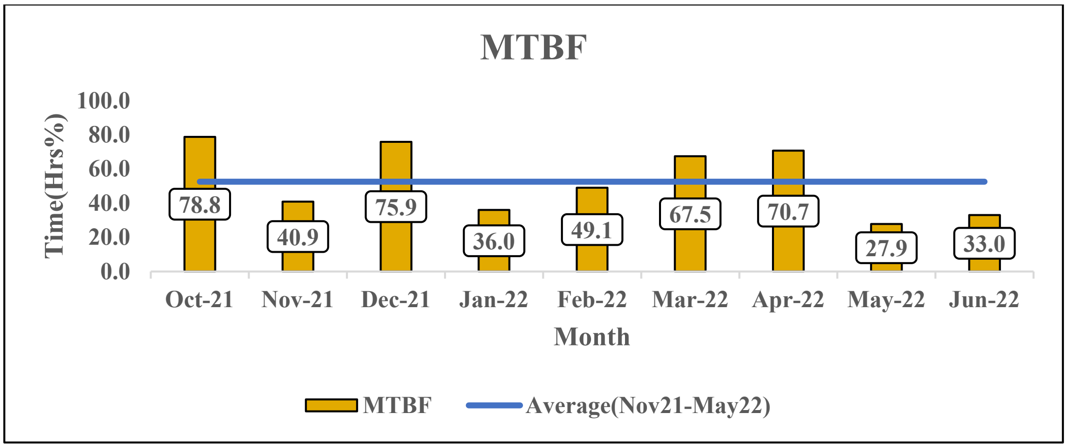

Figure 9. MTBF for Haas-3 Machine

Uptime of Haas machines.
The monthly average operational availability of Haas machines from October 2021 to June 2022 are shown in Figure10,
Haas-1 at 91 percent per month.
Haas-2 at 90 percent per month.
Haas-3 at 93 percent per month.

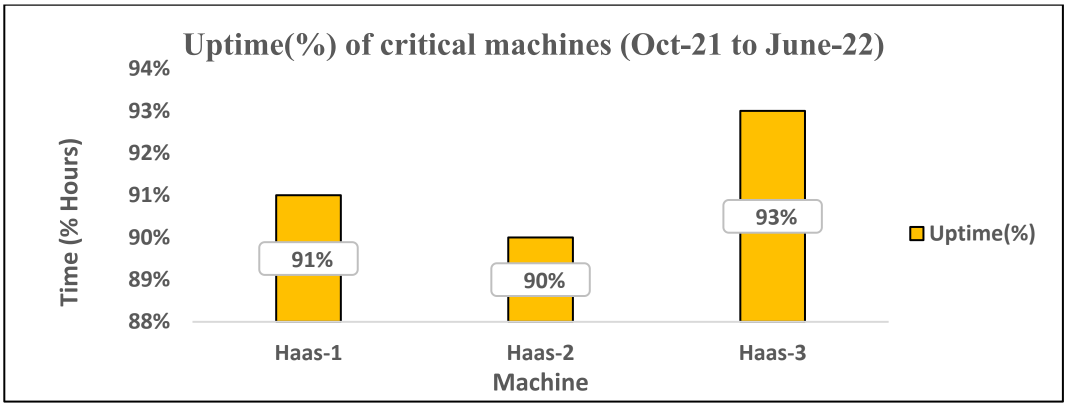

Figure 10. Uptime of Haas machines (Oct-21 to June-22)

5.3 Proposed Improvements

Improvements are necessary to grow and achieve the targets set by the organisation, here in this internship there are a few points which came under observation by closing those open points we may even improve the uptime and could use that time for planned maintenance activities.

- Increasing Manpower.
- Following the preventive Check sheets (Weekly, Monthly & Quarterly).
- Performing Autonomous maintenance.
- Identifying the failure components through machine condition monitoring.
- Predicting the life of parts and following the guidelines of OEM.
- Making sure to always have the enough quantity of critical spare parts.
- SOP's to be followed and training all employees to attend critical machines which would help in reducing the MTTR and Improving The MTBF.

5.4 Validation

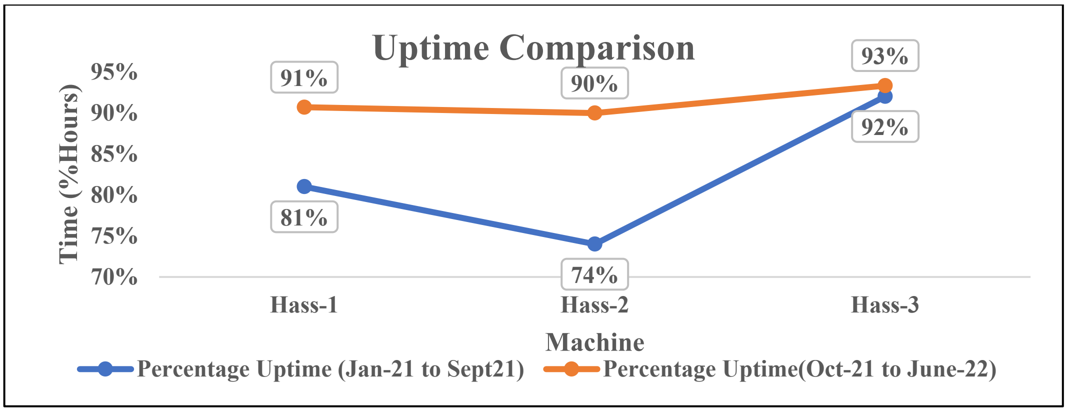

Figure 11. Operational availability comparison

Validation is an important part of any project, here as we have considered the base line data having the same time period which is of seven months before the internship for the comparison, Figure 11 gives the comparison that we have improved the uptime of almost all of the 03 critical machines. Hence the average uptime was improved by nine percent and as a result we could produce three engine blocks more on daily basis.

The overall average operational availability of Haas-1 machine was improved by 10 percent, Haas-2 machine was improved by 16 percent and Haas-3 machine by 01 percent.

6. Conclusion

As a result of this study, we conclude that the percent Uptime or Availability of the machine for production is critical in meeting production goals, and that we must reduce machine breakdowns in order to raise the percent Uptime. To reduce breakdowns, we must first analyse the current condition of any machine we are studying, as well as previous breakdown data, to determine the major breakdown areas and what solutions (maintenance work) were given/taken at the time, and then conduct analysis (FMEA, etc.) to determine the cause and effect of the breakdown, followed by developing an action plan to address those breakdowns by repairing, replacing, or updating the required, and tracking the data of these machines.

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