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To Improve the Overal Equipment Effectiveness of Wheel Surface Machining Plant of Railway Using Total Productive Maintenance

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ABSTRACT

The core of this report is doing a study on the wheel workshop at Railway and coming up with suggestions to implement total productive maintenance in the workshop. Small losses in time or small deviations from designed capability are taken as normal machine behaviour. Total Productive Maintenance (TPM) is a plan which concentrates on total involvement of everyone from top management to all employees to implement a comprehensive maintenance program for all equipment throughout its life. This plan results in maximum effectiveness of equipment, tidier, neat and clean work place and morally boosted employees.
Keywords-5S, Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE), six big losses, focused improvement.

I. INTRODUCTION

Maintenance has been considered as a support function which is non productive since it does not generate cash directly. However for the Industry to produce goods of the right quality and quantity for the customers and be able to deliver them at the right time its plant or equipment must operate efficiently and accurately. For every manufacturing company the objective is to produce goods at a profit and this is only achieved by using an effective maintenance system that helps maximize availability by minimizing machine downtime due to unwarranted stoppages. Without an effective and economically viable maintenance system, equipment reliability suffers, and the plant pays the price with poor availability and increased downtime. Frequent machine breakdowns, low plant availability and increased overtime are a great threat to a manufacturing plant as they increase operating costs of an industry. All these mentioned poor key performance indicators (KPI) can be a result of poor machine condition and sometimes low employee morale. Low plant availability and overtime costs will negatively affect an industry's operational efficiency. Plant Engineers must therefore design an effective maintenance system for the plant and its equipment.

II. COMPANY BACKGROUND

Pratapnagar railway workshop is the first state owned railway by ruler of Vadodara and pioneer to lay the first NG railway line between Dabhoi to Miyagaon in 1963. It was then materialized in 1973 when the complete track formation was upgraded to withstand steam locus which were imported to overhaul the trains. The foundation stone of Pratap Nagar workshop was laid by his highness Lord Chelmsford, Viceroy and Governor General of India on 25th March 1919.the workshop started in 1922.

The workshop is currently being used for repairing and overhaul of coaches and wagons. The workshop consists of 8 workshops (smithy workshop, CASNUB bogie and Wheel CTRB repair shop, lifting workshop, ICF boogies shop, Narrow gate workshop, body repair workshop, painting workshop and machine workshop). All the workshops have their own different distinctive responsibility in the repair of wagons and coaches. Pratap Nagar railway workshop consists of a total 101 machines which consist of (air compressors, EOT cranes, traversal, wheel lathes, Power hammer, lathe machines, slotter machine, drill machine, shearing machine, grinder, boring machine, power hacksaw, welding transformer, Automobile, Electric hoist, pillar job crane) all these machines are in their different numbers.

The most valued machines at Pratap Nagar Railway workshop are Air compressors, EOT cranes, hyt wheel lathe machine and CNC boring machine in which currently the workshop is using preventive maintenance to take care of these machines on monthly bases. For the rest of the machines the workshop uses breakdown maintenance on the machines.

Due to these poor maintenance practices at Pratap Nagar workshop the consequence is not getting 100% from the machines and equipment they have. They are time loses due to breakdowns and deviations from designed capabilities are taken as normal behavior. Total Productive Maintenance (TPM) is a plan which concentrates on involvement of everyone from management to all employees to implement a comprehensive maintenance program for all equipment throughout its life. TPM results in maximum effectiveness of equipment, tidier, neat and clean work place and morally boosted employees.

The task at hand is to implement TPM in the Wheel workshop, activities done in this workshop are wheel inspection and wheel repair. The re-turning of wheels which is mainly a re-profiling operation maximizes railway life. The wheels are scheduled for re-profiling after every three years in operation. The wheel workshop mainly consists of HYT CNC wheel lathe machine. The CNC surface wheel lathe machine is currently being maintained by an external company on monthly based as a practice of preventive maintenance which is part of a warranty upon purchasing the equipment. In cases of minor breakdowns the maintenance technicians at the workshop repair the machine but when it comes to majors breakdowns the external company repairs the machine. The following are some of the activities done by the maintenance technicians at the workshop lubrication, V-belt tensioning, inspection, attending to minor breakdowns etc.

In thesis TPM is going to be implemented in CTRB wheel workshop. This workshop is used for re-profiling train wheels both wide gate wheels and narrow gate wheels. The workshop mainly consists of two machines which are namely the hyt CNC lathe machine and the narrow gate wheel lathe machine. These two machines have an OEE of 69% and 75% respectively based on the time study the author conducted. The resultant OEE of the two machines is 72%.

Problem statement

There is poor equipment overall equipment effectiveness (OEE) at Pratap Nagar Railway workshop is due to the absence of a proper maintenance management policy and strategy.

Aim

The aim of this project is to improve Overall Equipment Effectiveness of the wheel workshop at Pratap Nagar Railway workshop through the implementation of Total Productive Maintenance.

Objectives

- Point out losses during production and categories them into six big losses of OEE
- Improve availability and performance of the wheel workshop

- Maintain the improved availability and Performance of the wheel workshop.

III. METHODOLOGY

In the first step a literature survey was done by the author and the most common barrier to the implementation was identified. Also from the literature survey the author gained intensive knowledge with regards to how to successfully implement TPM. Literature survey was done throughout the project in parallel to the implementation of TPM.

The method used to implement and follow up with TPM will follow the PDCA kaizen method. The implementation of TPM is going to follow the following Hartmann implementation model.

Phase 1 – Improve equipment to its highest required level of performance and availability. [Focused Improvement]

- ✓ Determine existing equipment performance and availability – current OEE.
- ✓ Determine equipment condition.
- ✓ Determine current maintenance performed on equipment.
- ✓ Analyze equipment losses.
- ✓ Develop and rank equipment improvement needs and opportunities.
- ✓ Develop setup and changeover improvement needs and opportunities.
- ✓ Approach management
- ✓ Implement 5s
- ✓ Execute improvement opportunities as planned and scheduled activity.
- ✓ Check results and continue with improvement as required.
- ✓ **Phase 2**-Maintain equipment at its highest required level of performance and availability. [Autonomous Maintenance, Preventive Maintenance, Kaizen]
- ✓ Develop planned maintenance, cleaning, and lubrication requirements for each machine.
- ✓ Develop planned maintenance, cleaning, and lubrication procedures.
- ✓ Develop inspection procedures for each machine.
- ✓ Develop planned maintenance, lubrication, cleaning and inspection systems, including all forms and controls.
- ✓ Develop planned maintenance manuals.
- ✓ Execute planned maintenance, cleaning and lubrication as planned and scheduled activities.
- ✓ Check results and apply corrections to system as required.

The general idea of the method used is that focused improvement will be continuously updating the Autonomous maintenance Pillar due to its improvements. The new autonomous rules cause by focused improvement has to abide to preventive maintenance pillar constraints and also to avoid things sliding back to what they used to be. The Kaizen pillar will be continuously analyse the three pillars and ensure continuous improvement with the main aim of eliminating the six big losses of OEE which are equipment failure, setup and adjustments, idling and minor stops, reduced speed, process defects and reduced yield. The method and the relationship between the pillars during the implementation of TPM is shown in figure() .

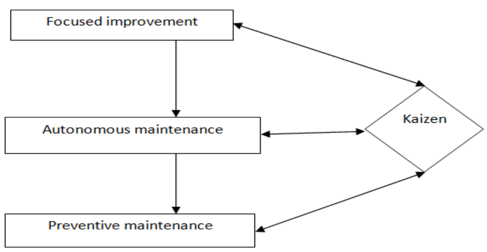


Figure 1. Methodology

Focused improvement will be used to the six big losses as in figure which is given below. The diagram also shows the solutions suggested to some of the six big losses of OEE. In this project we only managed to implement DOE (design of experiments) and SMED (single minute exchange of dies).

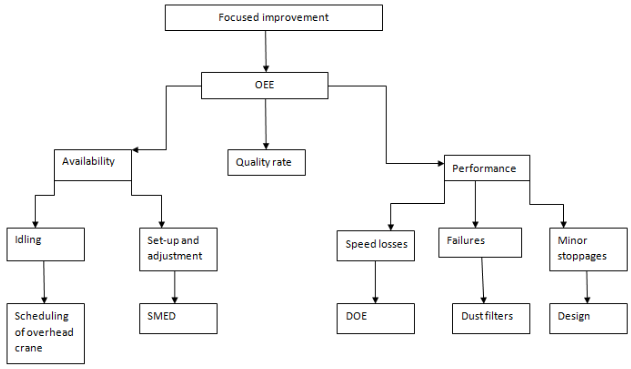


Figure 2. focused improvement

After the conducting DOE and SMED OEE will be measured again.

IV. DATA ANALYSIS

date	cusnub (Bt	RSI diame	LSI diamet	RSF diame	LSF diame	RSMD	LSMD	adjustmen	machining	minor stop	removal	real cycle time
	2655	980	979	977	977	3	2	884.38	2082.4	209.2	199.49	3375.47
	2669	992	994	990	990	2	4	79.61	2140.17	237.47	185.5	2642.75
	2667	991	990	987	987	4	3	87.91	2145.5	187.36	168.36	2589.13
	2658	988	987	985	985	3	2	97.17	1971.48	179.55	196.17	2444.37
	2653	997	994	990	990	7	4	69.17	2271.17	279.27	88.57	2708.18
	2668	990	990	987	987	3	3	57.17	2151.75	188.18	180.28	2577.38
	2663	980	981	977	977	3	4	90.02	2145.43	237.27	82.57	2555.29
	2664	977	976	974	974	3	2	92.48	2060.06	231.46	187.24	2571.24
	2657	985	985	982	982	3	3	91.23	2060.77	193.24	175.24	2520.48
	2661	998	997	995	995	3	2	81.27	1954.43	181.04	159.76	2376.5
	2670	991	984	988	981	3	3	80.24	2051.88	183.13	173.24	2488.49
totals								1710.65	23035.04	2307.17	1796.42	28849.28

date	cusnub (Bt	RSI diame	LSI diamet	RSF diame	LSF diame	RSMD	LSMD	adjustmen	machining	minor stop	removal	real cycle time
	2550	994	988	986	986	8	2	106.89	2006.27	196.89	150.96	2461.01
	2547	942	942	938	938	4	4	121.23	2072.95	221.89	206.85	2622.92
	1416	840	841	837	837	3	4	118.09	2241.02	288.09	218.47	2865.67
	1417	849	848	844	844	5	4	90.96	2153.37	142.89	221.89	2609.11
	1418	850	850	846	846	4	4	97.79	1930.49	201.19	191.79	2421.26
	1412	836	836	834	834	2	2	126.87	2005.95	231.47	228.9	2593.19
	1414	845	845	842	842	3	3	131.82	2206.02	225.23	156.79	2719.86
	1419	837	838	834	834	3	4	116.43	2324.95	281.87	164.46	2887.71
	1415	842	843	835	835	7	8	108.89	2167.27	149.44	179.46	2605.06
	2604	933	934	930	930	3	4	117.96	1965.91	199.46	179.46	2462.79
	2559	983	984	978	978	5	6	121.97	2026.14	206.29	196.92	2551.32
totals								1258.9	23100.34	2344.71	2095.95	28799.9

date	cusnub (Bt	RSI diame	LSI diamet	RSF diame	LSF diame	RSMD	LSMD	adjustmen	machining	minor stop	removal	real cycle time
	2581	962	961	959	959	3	2	99.52	1952.95	179.91	195.68	2428.06
	1410	875	876	872	872	3	4	95.95	2132.49	220.54	135.07	2584.05
	1412	871	870	866	866	5	4	81.55	2246.86	195.34	189.48	2713.23
	1409	874	875	870	870	4	5	87.11	2063.48	208.85	206.58	2566.02
	1411	875	873	870	870	5	3	106.54	2276.56	223.47	186.19	2792.76
	2558	983	983	980	980	3	3	118.41	2215.52	191.64	291.78	2817.35
	2589	936	939	930	930	6	9	124.08	2107.32	214.87	181.94	2628.21
	2561	983	984	970	970	13	14	117.54	2032.95	236.54	242.95	2629.98
	2560	984	983	980	980	4	3	106.08	2132.25	308.87	172.95	2720.15
	2565	972	973	968	968	4	5	109.59	1979.45	137.08	152.95	2379.07
	2606	936	937	932	932	4	5	121.08	2069.25	175.84	174.86	2541.03
totals								1167.45	23209.08	2292.95	2130.43	28799.91

date	cusnub (Bt	RSI diame	LSI diamet	RSF diame	LSF diame	RSMD	LSMD	adjustmen	machining	minor stop	removal	real cycle time
	1395	882	880	870	870	12	10	121.14	2162.45	167.04	207.67	2658.3
	1400	912	913	906	906	6	7	110.21	2105.99	173.66	214.57	2604.43
	1398	914	914	908	908	6	6	105.57	1987.76	185.57	202.88	2481.78
	1399	912	913	902	902	10	11	113.31	2035.74	221.7	165.14	2535.89
	1396	885	884	877	877	8	7	86.57	2119.1	214.98	176.15	2596.8
	1397	886	886	873	873	13	13	96.61	2218.4	207.08	214.05	2736.14
	1394	983	984	976	976	7	8	50.1	2262.62	172.97	214.98	2700.67
	2599	947	948	941	941	6	7	107.64	2099.1	207.08	222.88	2636.7
	2573	985	984	981	981	4	3	124.98	2229.09	170.97	205.54	2730.58
	2598	955	954	950	950	5	4	120.1	2048.39	213.67	194.09	2576.25
	2564	967	971	962	962	5	9	109.89	2022.62	221.97	187.94	2542.42
total								1146.12	23291.26	2156.69	2205.89	28799.96

item	data
shift leng	9hrs
breaks	1.5hrs
ideal cycl	30 mins
totalcoun	11
rejected c	0

Figure 3. CNC lathe data

5.1 Narrow gate wheel lathe machine

date	wheel set number	idling	RTS machi	rotating	LTS machi	idling	removal and measuring	minor stoppag	real cycle time
	1241	16.72	4066.03	328.15	3966.03	18.45	889.77	353.59	9638.74
	1821	18.52	4273.65	431.52	4053.63	25.06	722.83	96.39	9621.6
	2345	20.85	4126.85	299.88	3954.24	19.66	867.7	250.49	9539.67
	sumation	56.09	12466.53	1059.55	11973.9	63.17	2480.3	700.47	28800.01

date	wheel set number	idling	RTS machi	rotating	LTS machi	idling	removal and measuring	minor stoppag	real cycle time
	2482	15.25	3944.59	441.32	4026.56	16.25	857.15	369.12	9670.24
	2496	16.27	4034.1	242.25	3941.46	17.89	912.17	314.25	9478.39
	2321	19.81	4141.15	391.62	3966.36	19.59	823.43	289.37	9651.33
		51.33	12119.84	1075.19	11934.38	53.73	2592.75	972.74	28799.96

date	wheel set number	idling	RTS machi	rotating	LTS machi	idling	removal and measuring	minor stoppag	real cycle time
	1812	16.08	3927.81	366.79	4018.79	18.25	960.32	174.43	9482.47
	1424	16.96	4132.62	398.44	4012.83	21.25	774.83	414.72	9771.65
	1283	18.21	3990.62	299.86	3925.93	24.32	974.72	312.19	9545.85
		51.25	12051.05	1065.09	11957.55	63.82	2709.87	901.34	28799.97

date	wheel set number	idling	RTS machi	rotating	LTS machi	idling	removal and measuring	minor stoppag	real cycle time
	1456	17.81	3901.11	458.21	3609.05	19.25	1076.82	186.82	9269.07
	1811	19.28	3996.51	355.91	4011.48	20.65	1059.72	280.04	9743.59
	1204	21.22	3898.24	399.81	4118.51	23.55	946.1	379.89	9787.32
		58.31	11795.86	1213.93	11739.04	63.45	3082.64	846.75	28799.98

item	data
shift length	9hr
breaks	1hr
downtime	
ideal cycle time	2hr
totalcount	3
rejected count	0

Figure 4. conventional central lathe data

OEE calculation

				traditional wheel lathe machine								
date	machine	rejects	total production	total available time	scheduled downtime	unsheduled downtime	operating time	ideal run rat	availability rate	performa	quality rat	OEE
	wheel lathe machine	0	3	540	60	72.66000667	407.3399933	0.00833333	0.848624986	0.883783	1	0.75
		0	3	540	60	79.09599967	400.9040003	0.00833333	0.835216667	0.897971	1	0.75
		0	3	540	60	79.85649997	400.1435	0.00833333	0.833632292	0.899677	1	0.75
		0	3	540	60	87.75166648	392.2483335	0.00833333	0.817184028	0.917786	1	0.75
									0.833664493	0.899804	1	0.750135
				hyt wheel lathe machine								
date	machine	rejects	total production	total available time	scheduled downtime	unsheduled downtime	operating time	ideal run rat	availability rate	performa	quality rat	OEE
1	hyt wheel lathe	0	11	540	60	96.904	383.096	0.03333333	0.798116667	0.861403	1	0.6875
2		0	11	540	60	94.99266667	385.0073333	0.03333333	0.802098611	0.857127	1	0.6875
3		0	11	540	60	98.4563333	381.5436667	0.03333333	0.794882639	0.864908	1	0.6875
4		0	11	540	60	93.1805	386.8195	0.03333333	0.805873958	0.853111	1	0.6875
5		0	11	540	60	91.8122	388.1878	0.03333333	0.808724583	0.850104	1	0.6875
									0.801939292	0.85733	1	0.687527
									oee for both machines			0.718831

Figure 5. OEE calculation

The overall equipment effectiveness was found to be 75%, 69% and 71% for narrow gate lathe machine, wide wheel gate lathe machine and for both of the machines combined respectively.

Hyt lathe availability and performance

Below is the behavior in performance and availability obesevered for five days on theb hyt lathe machine.

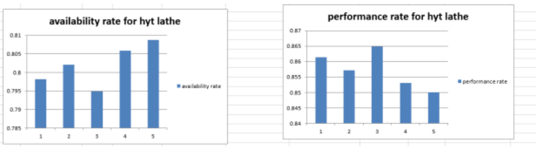
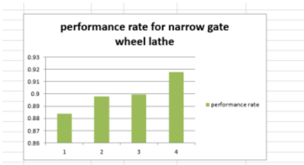
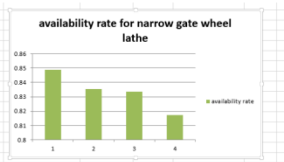


Figure 6. variations in availability and performance

Narrow gate wheel lathe

Below is the behavior in performance and availability obesevered for five days on the narrow gate wheel lathe machine.





The above calculations and analysis was done based on the following equations.

OEE = Availability × Quality × Performance

Availability = run time / planned production time

Quality = good count / total count

Performance = (ideal cycle time × total count) × run time

All the these equations were embedded in the excel sheets

V. FOCUSED IMPROVEMENT

Focused improvement is going to be used to elevate performance and availability of the wheel re-profiling workshop by aligning the correct method to the correct scenario. From analysis done by the author it was found that losses in performance and availability are the causes of low OEE of the hyt CNC lathe machine and Narrow gate lathe machine. The losses in performance are going to be solved by addressing losses in minor stoppages, reduced speed and idling. Similarly losses in availability are to be solved by addressing losses in equipment failure, set-up and adjustment.

Performance

Performance losses are factors that cause the lathe machines to operate at less than the maximum possible speed when running. Performance takes into account three losses which are idling, minor stoppages and reduced speed. Hence the approach will be to use focused improvement to address the causes of these losses. Below is a list of causes of these losses at Pratap Nagar wheel workshop.

Causes of minor stoppages in workshop

- Removal of chips on the narrow gate lathe machine
- No assistance to help change the wheel
- Changing tool
- V-belt tension problems

Causes of speed losses

- Not operating at optimum speed

Causes of idling

- Low availability of overhead crane

Availability

Availability losses take into account any events that stop planned production for an appreciable length of time. Availability takes into account equipment failure and setup and adjustment. Likewise the focused improvement is going to be used to address the causes of these losses at the wheel re-profiling workshop. Below is a list of solutions to these losses at Pratap Nagar wheel workshop.

Causes of failure

- ✓ Design of an equipment failure recording sheet
- ✓ overheating and decreased efficiency

Setup and adjustment

- ✓ SMED implementation

Minor stoppages

The causes of the minor stoppages where analysed for two weeks and the frequency of occurrence was recorded. The data recorded was used to construct the pareto chat below to help us understand the losses leading to minor stoppages.

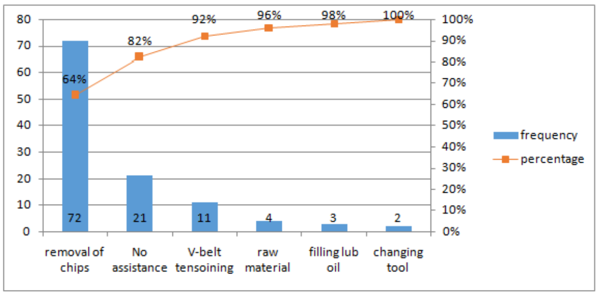


Figure 7. Causes of minor stoppages (pareto chart)

It was found from the data that from the data above that the removal of chips and unavailability of an assistant to change the wheel are the causes of 82% of the minor stoppages that occur.

Understanding losses due to the removal of chips

This is chronic event which happens over and over again as the operator manually removes the chips in the pit on the Narrow gate wheel lathe machine when it is filed. This on average takes 15-20 minutes to remove all the chips and occurs 2 or 3 times per days. Below is a picture of the pit on the narrow gate wheel lathe.

Figure 8. Pit of conventional lathe machine

Below is a graph which shows the variations in the rate of chip removal for 12 days.

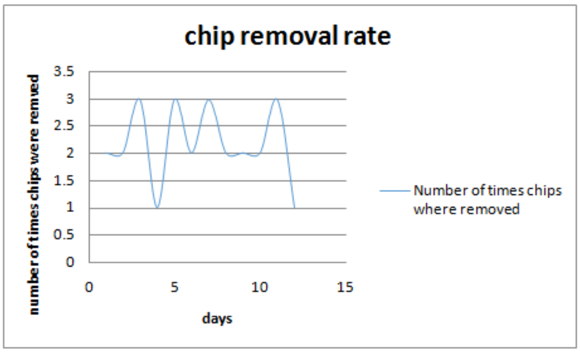


Figure 9. Chip removal rate

Theme and Target

The target is to reduce the time taken to remove the chips from the range which is 15 to 20 minutes to below 5 minutes.

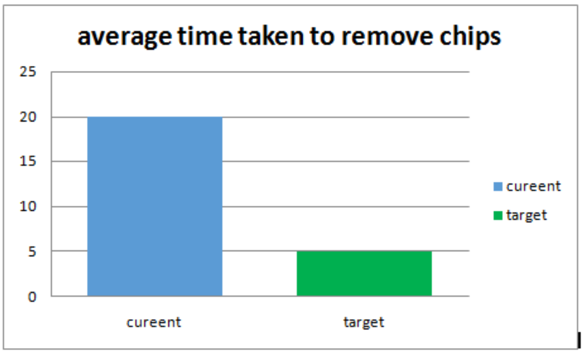


Figure 10. Chip removal time target

Draft of improvement plan

The plan is to design a component to collect the chips during machining which can easily be removed from the pit and then empty the chips into a bin nearby.

Causes of speed losses

The identified cause of speed loses which are not operating at optimum speed. The narrow gate wheel lathe machine is currently operating at 65rev/min and the depth of cut is 3mm. rolling stock wheels are made of steel and the tool used for machining is HSS. The solution will be to make use of the maximum production rate criteria in order to identify the optimum operating speed

Causes of idling

Idling is a situation in which a machine is not utilised when all the resources needed to use the machine in a productive manner are available and have been invested in. The main cause of idling on the two wheel lathe machines in this study is poor availability of the overhead crane which is shared with the CASNUB Boogie repair section. On average poor availability at the workshop results on average on downtime of (8-10 minutes). The over head crane is currently being used to spontaneously lift the wheels from one point to another. Without the crane the wheels cannot be carried to the lathe machine to be machined hence production will stop.

Understanding the losses due to poor crane availability

Below shows the frequency of stoppage due to the poor availability of the overhead crane in the wheel repair workshop.

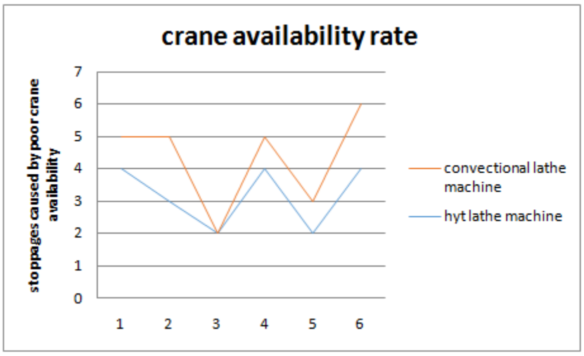


Figure 11. Crane availability rate

Select theme and target

The main aim is to improve the availability of the crane with respect to the hyt lathe machine and the convectional lathe machine by scheduling the movement of the crane throughout the day. To insure availability in each of the three sections including the CASNUB boogie section and minimise movement of the crane.

Causes of failure

Currently at the workshop they are not recording breakdowns of the machines. Hence the first step would be to design a recording sheet for the breakdowns so as to take account for the downtime caused by these breakdowns. In order to get understand the causes of the failure on the two lathe machines the student had to resort to the use of questionnaires. The main cause of breakdowns on the two machines was winding damage and damaged bearing of the electric motor mainly caused by overheating. The questions that were used by the researcher are given below.

Questionnaires

- ✓ What are the most frequent failures
- ✓ What are the causes of failure
- ✓ How does it happen and what is the sequence of events
- ✓ What are the contributing factors that lead to these failures

Target population

The above questions were mainly asked to the following target population

Table 1. Target Population

Target population	participants
Senior Section Engineers	2
Junior Engineer	4
Maintenance Technician	10
Operators	4

From the questions conducted the population identified failure of the electric motor as the main cause of failure on the lathe machines. The fishbone diagram below shows some of the causes of overheating in electric motors.

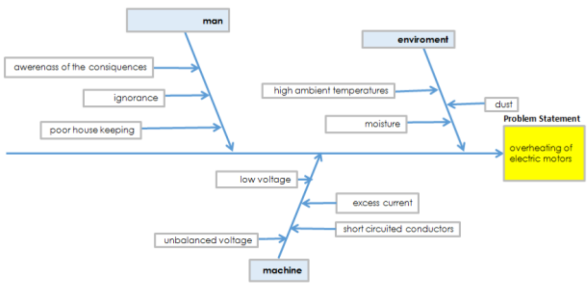


Figure 12. Ishikawa diagram for motor overheating

After an analysis by the researcher it was found that blocked ventilation and dust are more than common on all electric motors in the workshop. Hence the decision was made to use the 5 why analysis in order to come up with solutions to the problem of electric motors overheating.

Figure 13. Electric motor

Particles that block the flow of air into the motor cooling fans such as dust and other debris can lead to overheating of an electric motor. Also dust particles and other particles inside the electric motors cause some resistance to the rotation that slows down the motor. Hence the motor has to work harder to overcome this resistance causing an increase in temperature. Dust particles may also be abrasive in a way and damage the insulation. Below is a 5 why analysis of the problem of overheating of the electric motors.

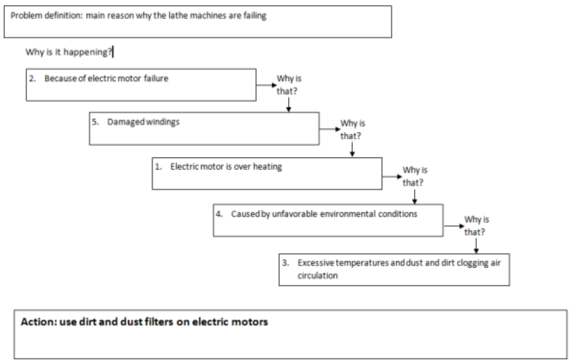


Figure 14. Why s analysis of overheating of motor

Setup and adjustment

To improve the changeover time on convectional lathe machine SMED (Single Minute Exchange of Dies) is going to be used.

VI. SMED

Single Minute Exchange of Dies is a lean tool which is used to reduce setup time and provide quick equipment changeover (Desai and Workhedkar, 2011; Shingo, 1985). The main aim of SMED is to reduce the time wasted in many changeover steps by performing many activities while the machine is running as much as possible, and to integrate and reduce the time required to perform internal tasks.

The SMED places the tasks into two categories which are internal and external activities. External activities being those activities perfumed while the machine is running. The internal activities on the other hand are activities which are done while the machine is not running. SMED goes on further to time required to perform both external and internal activities as well as eliminate unnecessary activities. The SMED method is going to be implemented to reduce the setup and adjustment time of the conventional lathe machine. The SMED is going to follow the steps below.

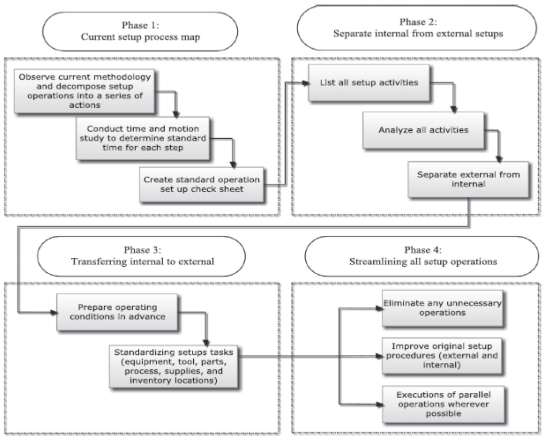


Figure 15. SMED approach framework (M.A. Almomani et al. / Computers & Industrial Engineering 66 (2013))

Phase 1 current setup

The work piece changeover process on the narrow gate lathe machine is decomposed into a series of actions. The stopwatch and motion study is used to determine the time for each step. The steps and current method for changing the work piece on the conventional wheel lathe machine are shown in table (8.1)

Phase 2 separate internal from external activities

In this phase the current activities are then analysed and classified into two groups which are internal activities and external activities as shown in table (8.1)

Table 2. Activities Before Smed

Number	Details of task	Number of employees	Time(seconds)	Task type
1	Operator movement to get the crane	1	493	internal
2	Securing the wheel set onto the crane hoist	1	95	internal
3	Carrying the wheel set to the lathe machine	1	100	internal
4	Finding an assistant	1	180	internal
5	Mounting the wheel set to the chuck	2	210	internal
6	Removing the hoist from the wheel set	2	160	internal
7	Moving of operator to get measuring tool	1	90	internal
8	Measuring the diameter of the wheel set	1	78	internal
9	Set-up depth of cut	1	20	internal
10	Start machining the wheel	1	5	external
11	Returning the tool used to measure diameter	1	90	External
12	Movement of the operator to get measuring tool	1	90	External
13	Measure the diameter of the wheel set	1	78	Internal
14	Measure the conformity of the profile	1	35	Internal
15	Finding an assistant	1	180	Internal
16	Operator's movement to get the crane	1	493	Internal
17	Secure the hoist on to the wheel set	1	95	internal
18	Remove the wheel set from the chuck	2	160	internal
19	Rotate the wheel set	2	120	internal
20	Secure the wheel set to the chuck	2	210	internal
21	Remove the hoist from the wheel set	1	160	internal
22	Movement of the operator to get measuring tool	1	90	internal
23	Measure the diameter of the wheel set	1	78	internal
24	Set-up depth of cut	1	20	internal
25	Start machining the wheel	1	5	external
26	Returning the tool used to measure diameter	1	90	external
27	Movement of the operator to get measuring tool	1	90	external
28	Measure the diameter of the wheel set	1	78	internal
29	Check conformity of the profile	1	35	internal
30	Returning the tool used to measure diameter	1	90	external
31	Movement to get the overhead crane	1	493	internal
32	Finding an assistant	1	180	internal
33	Secure the finished wheel set to the hoist	1	95	internal
34	Removing the wheel set from the chuck	2	160	internal
35	Moving the wheel set to the storage area	1	200	internal
36	Removing the hoist from the wheel set	1	95	internal
37	Operator movement to get a another wheel set	1	200	internal
Total of external tasks			460	
Total internal tasks			4596	
Total time			5056	

Phase 3 transferring internal to external

This next step is to convert as many tasks as possible from internal tasks into external tasks. The main internal tasks that are to be converted into external tasks are as follows.

- ✓ Movement to go and collect measuring tool.
- ✓ Finding assistant.

Phase 4 streamlining all setup operations

This phase involves eliminating any unnecessary operation; improve original setup operations both external and internal. The main tasks that are to be changed with respect to this phase are as follows.

- ✓ Using the overhead crane to transport three work pieces at a time and place them within the periphery of the gantry
- ✓ Providing a temporary storage area for the measuring tool throughout the operations of the day

Table 3. Activities After Smed

Activities table after SMED

Number	Details of task	Number of employees	Time(seconds)	Task type
1	Operator movement to get the crane	1	493	Internal
2	Finding an assistant	1	180	Internal
3	Securing three wheel sets onto the crane hoist	2	95	Internal
4	Carrying the wheel sets to the lathe machine	1	100	Internal
5	Secure one wheel set on the hoist of the gantry	1	10	Internal
6	Lift the wheel set up	1	15	Internal
5	Mounting the wheel set to the chuck	2	210	Internal
7	Removing the hoist from the wheel set	2	160	Internal
8	Moving of operator to get measuring tool	1	90	Internal
9	Measuring the diameter of the wheel set	1	78	Internal
10	Set-up depth of cut	1	20	Internal
11	Start machining the wheel	1	5	External
12	Hang the	1	5	External

	diameter of the wheel set			
14	Measure the conformity of the profile	1	35	Internal
15	Finding an assistant	1	180	Internal
16	Secure the hoist on to the wheel set	1	95	Internal
17	Remove the wheel set from the chuck	2	160	Internal
18	Rotate the wheel set	2	120	internal
19	Secure the wheel set to the chuck	2	210	Internal
20	Remove the hoist from the wheel set	1	160	Internal
21	Measure the diameter of the wheel set	1	78	Internal
22	Set-up depth of cut	1	20	Internal
23	Start machining the wheel	1	5	External
24	Measure the diameter of the wheel set	1	78	Internal
25	Check conformity of the profile	1	35	Internal
26	Finding an assistant	1	180	Internal
27	Secure the finished wheel set to the hoist	1	95	Internal
28	Removing the wheel set from the chuck	2	160	Internal
29	Removing the hoist from the wheel set	1	95	Internal
Total external			15	
Total internal			3315	
Total time			3330	

Table 4. Eliminated Activities

Details of task eliminated	How task was eliminated	Time(seconds) saved	Number of times(seconds) each task was repeated in one cycle time	Total Time (seconds) saved
Returning tool used to measure tool	Providing a temporary storage place for the tool near the lathe machine	90	6	540
Operator movement to get overhead crane	by transporting all the three work pieces all at once since the overhead crane has the capacity	493	2	986
Total time saved				1526

Table 5. Trimmed Activities

Details of task reduced	How the time was reduced	Time(seconds) saved from - to	Number of times(seconds) each task was repeated in one cycle time	Total Time (seconds) saved
Operator movement to get a another wheel set	By providing a temporary storage area for the wheel sets near the lathe machine	310-110	1	200
Total time saved				200

Table 6. Summary

	Before SMED	After SMED	Time save
Cycle time	5056	3330	1726

The implementation of SMED saved an average of 1726 seconds per cycle. This improved both the performance and availability of the conventional central lathe machine thereby improving the OEE of the machine.

VII. DOE (TAGUCHI METHOD)

Design of experiments using taguchi method was used to determine the optimum operating parameters for maximum material removal rate (MRR). Currently during machining the operator is changing the operating parameters during machining depending on what the operator desires. Hence because of this they are speed losses since the operator is not using the optimum operating parameters to maximise MRR.

Taguchi method was selected to be used because it minimizes the number of tests required. Taguchi method uses the design of orthogonal array system to study the entire parameter space with a small number of experiments. Taguchi focuses on mean response analysis for each run in the inner array, and also suggests analysing variation using an appropriate chosen signal-to-noise ratio.

The following are the steps to be followed to conduct the DOE using taguchi method

- ✓ Determine important input process parameters and their levels, response parameters and its characteristics
- ✓ Select the appropriate orthogonal array(OA) and assign the parameters to its various columns
- ✓ Conduct experiments for the levels given in each row randomly and not down the values of the response parameters. Repeat each experiment three times.
- ✓ Study factor effects and find out the optimum combination of the input parameters. Calculate the best value of the response characteristics
- ✓ Calculate the range within which the experimental value should lie and conduct confirmation experiment (if required) to verify the same.

- ✓ Perform analysis of variance (ANOVA) to find out the significance of the various factors and their relative contribution
- ✓ Decide important input process parameters and their levels, response parameters and its characteristics.

The selection of input parameters and response parameters was based on intuition and literature survey. Three machining parameters were selected as control factors and each designed to have 3 levels as in table L9 array based on Taguchi method was used for the design of experiments. Minitab software was used for regression and graphical analysis of the observed data.

Table 7. Parameter Levels

Symbol	Turning Parameters	Level 1	Level 2	Level 3
A	Cutting speed (mm/min)	90	100	110
B	Feed rate (rev/min)	70	80	90
C	Depth of cut (mm)	1.5	2	2.5

Response name: material removal rate (MRR)

Response type: Higher-the-better

Units: mm/second

Results of the Taguchi design done using Minitab

```
Taguchi Design

Taguchi Orthogonal Array Design

L9(3^3)

Factors:  3
Runs:     9


Columns of L9(3^4) Array
```

C1	C2	C3	C4	C5
cutting speed	feed rate	depth of cut	material removal rate	SNRA1
90	70	1.5	963.29	59.6751
90	80	2.0	2220.77	66.9301
90	90	2.5	3682.59	71.3231
100	70	2.0	1601.73	64.0918
100	80	2.5	3573.65	71.0622
100	90	1.5	2305.44	67.2551
110	70	2.5	2147.26	66.6377
110	80	1.5	2313.84	67.2867
110	90	2.0	3254.74	70.2503

Figure 16. L9 Orthogonal arrays

Each and every experiment was repeated three times and the mean of the material removal rates was entered in the above table. The signal to noise ratio was calculated using mini tab

Experimental details

ICF boogie wheel sets of (diameter range of 990-1000mm) where used for the turning experiments. The experiments were also limited to the machining of profile 22 the observations were limited to one pass. The chemical and mechanical properties of the steel cast wheel sets according to Rail wheel factory in Yelahanka, Bangalore. The experiments were carried out to determine the material removal rate under various turning parameters. TN2000 high speed steel tool was used in the experimental investigation.

Cast Wheel Specification

Table 8. Chemical Composition In %

characteristics	Class A (Carriage)	Class B (Wagons)
carbon	0.47-0.57	0.57-0.67
manganese	0.60-0.80	0.60-0.80
Silicon	0.15-0.70	0.15-0.70
Phosphorous	0.03 max	0.03 max
sulphur	0.03max	0.03max
chromium	0.15max	0.15max
Nickel	0.25max	0.25max
Molybdenum	0.06 max	0.06 max
Cr+Ni+Mo	0.40 max	0.40 max
Vanadium	-	-
Hydrogen ppm (Max)	3	3
Nitrogen % (Max)	0.007	0.007

Table 9. Mechanical And Metallurgical Properties

characteristics	Rim	Plate	Rim	Plate	Rim	Plate	Rim	Plate
U.T.S N/mm^2 (Min)	900	800	930	800	100kg/mm^2	85kg/mm^2	-	-
Yield Strength (Min)	50% of UTS	50% of UTS	50% of UTS	50% of UTS	-	-	-	-
Elongation % (Min)	5	7	4.5	7	8	12	-	-
Hardness Range (BHN)	255-320		277-341		300-340		321-363	
Grain size (ASTM)	6-8		6-8		6-8		-	
Microstructure	Fine Pearlite		Fine Pearlite		Fine Pearlite		-	
Macroscopy	No harmful defect		No harmful defect		No harmful defect		No harmful defect	
Impact strength in J/Sq.m at 20^{0}C (Min)	10	-	-	-	-	-	-	-
Closure in mm (RS)	≥1		≥1		≥1		≥1	
Sampling Size	1≤500		1≤1000		1≤100		-	

Assumptions

We assumed that the thickness of the removed on the wheel is constant throughout the circumference and the profile of the wheel.

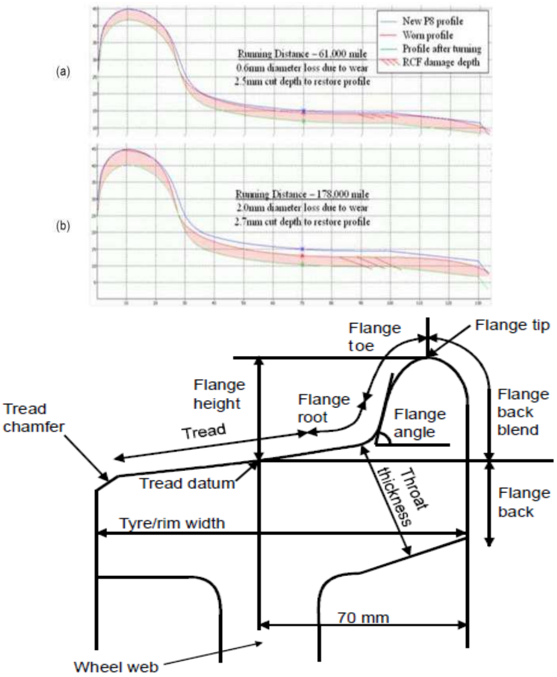


Figure 17. wheel profile (I.Y. Shevstov and V.L Morkings 2008)

The experiments were based on measuring the time taken to complete one pass across the wheel and measuring the length across the wheel using a string. The equations used to calculate wheel circumference, machined volume and material removal rate is given below.

Circumference = π × D

Machined volume = circumference × machined length × depth of cut

$$\text{Material Removal rate} = \frac{\text{machined volume}}{\text{machining time}}$$

Below are some pictures of the machine and the products in which the observation were done on.

Table 10. Experimental Results

Experiment number	column: Cutting speed	Feed rate	Depth of cut	machining time	machined lentgh (mm)	diameter (mm)	wheel circumference	machined volume	material removal rate
1	90	70	1.5	862.8	181	982	3085.444	837698	970.906
2	90	80	2	498.6	180	992	3116.864	1122071	2250.44
3	90	90	2.5	385.8	180	986	3098.012	1394105	3613.54
4	100	70	2	707.4	182	994	3123.148	1136826	1607.05
5	100	80	2.5	391.2	181	988	3104.296	1404694	3590.73
6	100	90	1.5	369.6	183	986	3098.012	850404	2300.88
7	110	70	2.5	654	180	992	3116.864	1402589	2144.63
8	110	80	1.5	385.8	183	994	3123.148	857304	2222.15
9	110	90	2	337.8	181	988	3104.296	1123755	3326.69
10	90	70	1.5	898.9	180	984	3091.728	834767	928.653
11	90	80	2	561.7	180	991	3113.722	1120940	1995.62
12	90	90	2.5	349.3	181	983	3088.586	1397585	4001.1
13	100	70	2	718.9	180	978	3072.876	1106235	1538.79
14	100	80	2.5	414.4	181	979	3076.018	1391898	3358.83
15	100	90	1.5	349.7	182	986	3098.012	845757	2418.52
16	110	70	2.5	681.9	180	985	3094.87	1392692	2042.37
17	110	80	1.5	351.6	182	991	3113.722	850046	2417.65
18	110	90	2	378.9	183	985	3094.87	1132722	2989.5
19	90	70	1.5	849.8	180	992	3116.864	841553	990.296
20	90	80	2	463.2	181	984	3091.728	1119206	2416.25
21	90	90	2.5	406.9	180	988	3104.296	1396933	3433.11
22	100	70	2	685.1	182	994	3123.148	1136826	1659.36
23	100	80	2.5	378.1	183	992	3116.864	1425965	3771.4
24	100	90	1.5	381.9	180	989	3107.438	839008	2196.93
25	110	70	2.5	638.9	186	986	3098.012	1440576	2254.77
26	110	80	1.5	366.7	182	984	3091.728	844042	2301.72
27	110	90	2	322.8	180	984	3091.728	1113022	3448.02

Figure 18. experiment setup

Analysis of MRR

The Signal to Noise ratios were calculated with Taguchi method for MRR using larger the better characteristics. The results are shown in the table below

Table 11. Analysis

C1	C2	C3	C4	C5
cutting speed	feed rate	depth of cut	material removal rate	SNRA1
90	70	1.5	963.29	59.6751
90	80	2.0	2220.77	66.9301
90	90	2.5	3682.59	71.3231
100	70	2.0	1601.73	64.0918
100	80	2.5	3573.65	71.0622
100	90	1.5	2305.44	67.2551
110	70	2.5	2147.26	66.6377
110	80	1.5	2313.84	67.2867
110	90	2.0	3254.74	70.2503

Analysis of Variance was used to analyse the experimental results and the Taguchi S/N ratio at 95% confidence interval. ANOVA analysis was done to determine the contribution of individual cutting parameters on material removal rate.

Table 12. Anovas

General Linear Model: material removal rate versus cutting speed, feed rate, depth of cut

Analysis of Variance for Transformed Response

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
cutting speed	2	0.09163	6.41%	0.091625	0.045813	9.58	0.095
feed rate	2	0.84431	59.04%	0.844308	0.422154	88.28	0.011
depth of cut	2	0.48464	33.89%	0.484644	0.242322	50.67	0.019
Error	2	0.00956	0.67%	0.009564	0.004782		
Total	8	1.43014	100.00%				

From the ANOVA for S/N feed rate has the most contribution to MRR of 59.04% followed by depth of cut which has a contribution of 33.89% and the error was found to be 0.67%.

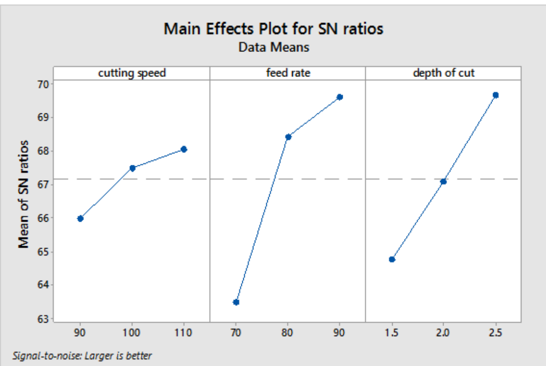


Figure 18. S/N plot

Figure (9.5) shows effect plot for S/N ratio. The optimum parameters to maximise MRR are obtained as cutting speed 110, feed rate 90 and depth of cut 2.5

Table 13. Response Table

Response Table for Signal to Noise Ratios
Larger is better

Level	cutting speed	feed rate	depth of cut
1	65.98	63.47	64.74
2	67.47	68.43	67.09
3	68.06	69.61	69.67
Delta	2.08	6.14	4.94
Rank	3	1	2

Conformation experiment for the optimum operating parameters The experiment done using the determined optimal operating parameters confirms that it is the optimal operating parameters which have the highest MRR on average of 4438.48 mm^3/s.

Table 14. Conformation Experiments

Experiment	column								
number	Cutting speed	Feed rate	Depth of cut	machining time	machined lentgh (mm)	diameter (mm)	wheel circumference	machined volume	material removal rate
1	110	90	2.5	316.8	180	992	3119.84	1403928	4431.591
2	110	90	2.5	313.4	181	990	3113.55	1408881	4495.473
3	110	90	2.5	320.4	181	988	3107.26	1406035	4388.374

VIII. CONCLUSION

Calculations of OEE after TPM implementations
Hyt CNC lathe machine

RSF diameter	LSF diameter	RSMD	LSMD	adjustment and setup	machining time	minor stoppage	removal	real cycle time
977	977	3	2	874.38	2062.4	159.2	199.49	3295.47
990	990	2	4	69.61	2120.17	207.47	185.5	2582.75
987	987	4	3	77.91	2125.5	127.36	168.36	2499.13
985	985	3	2	87.17	1951.48	119.55	196.17	2354.37
990	990	7	4	59.17	2251.17	219.27	88.57	2618.18
987	987	3	3	47.17	2131.75	108.18	180.28	2467.38
977	977	3	4	80.02	2125.43	207.27	82.57	2495.29
974	974	3	2	82.48	2040.06	201.46	187.24	2511.24
982	982	3	3	81.23	2040.77	123.24	175.24	2420.48
995	995	3	2	71.27	1934.43	141.04	159.76	2306.5
988	981	3	3	70.24	2031.88	133.13	173.24	2408.49
978	978	5	6	121.97	2026.14	206.29	196.92	2551.32
				1722.62	**24841.18**	**1953.46**	**1993.34**	**30510.6**

hyt wheel lathe machine

total available time	scheduled downtime	unsheduled downtime	operating time	ideal run rate	availability rate	performance rate	quality rate	OEE
580	60	94.5	425.5	0.033333333	0.818269231	0.846063455	1	0.692307692

Convectional central lathe machine

date	wheel set	idling	RTS machi	rotating	LTS machi	idling	removal and meas	minor sto	real cycle time
	1241	16.72	4066.03	288.15	3966.03	18.45	849.77	333.59	9538.74
	1821	18.52	4273.65	351.52	4053.63	25.06	682.83	76.39	9481.6
	2345	20.85	4126.85	209.88	3954.24	19.66	837.7	150.49	9319.67
total		**56.09**	**12466.53**	**849.55**	**11973.9**	**63.17**	**2370.3**	**560.47**	**28340.01**

traditional wheel lathe machine

date	machine	rejects	total prod	total avail	schedulec	unshedul	operating time	ideal run r	availabilit	performa	quality rat	OEE
		0	3	520	60	64.99	395.01	0.008333	0.858717	0.911369	1	0.782609

Figure 20. OEE calculation after TPM

Table 15. Results

	OEE for CNC machine	OEE for the conventional central lathe machine	OEE for both Machines
before	0.6875	0.75	0.71875
after	0.6923	0.78	**0.73615**

This project demonstrates how TPM improves OEE and uptime. The project was done on the wheel workshop at Western Indian Railways workshop. The wheel workshop consists of two machines the central convectional lathe machine used for re-profiling of narrow gate rail wheels and the HYT CNC lathe machine for re-profiling the wide gate rail wheels.

The OEE of the whole workshop was improved from 71.88% to 73.62%. The dominant pillars in this project were 5S and focused improvement. The improvements came about by using SMED to improve availability and Taguchi (DOE) to improve performance. The OEE of the conventional lathe machine improved from 75% to 78% and the OEE of the CNC lathe machine improved from 68.75% to 69.23%.

TPM is a good and easy tool that can be used to improve OEE but it's too much work for one engineer TPM requires a number of engineers from different specializations e.g. mechanical engineers, electrical and electronic engineers , design engineers etc. Also there is need to use value driven maintenance prior to the implementation of any maintenance strategy so as to determine the best maintenance strategy in a given situation.

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