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Implementation of Total Productive Maintenance to Improve Productivity of Rolling Mill

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The main objective of this study is to improve productivity of the rolling mill of the steel plant by implementing Total Productive Maintenance (TPM). Due to the increasing demand of steel products, it is necessary to improve productivity of the rolling mill as various types of structural items are produced by rolling mills. Machine maintenance plays an important role in achieving maximum production in steel industry. The TPM was implemented in an integrated steel plant and its effect on production was observed. First, six months of data were collected, and then the breakdowns were analyzed using TPM. Then, TPM was implemented for the next six months and the productivity of the rolling mill was analyzed. The productivity of the rolling mill was enhanced by~10% by implementing TPM, and equipment availability was also improved by ~14%. However, after the implementation of TPM, the overall equipment efficiency (OEE) reached about 80.19%, which is close to the world steel OEE of 85%.

Keywords: Rolling mill, Equipment availability, OEE, TPM, Productivity

1 Introduction

During the last decade, steel industry has been under pressure due to the increasing global demand for steel, so the manufacturing steel industry needs to improve its production performance. Accelerated production meets the requirements of customers and also improves economic development of the company[1]. However, in a competitive environment, steel processing industry faces challenges due to high demand and low productivity. Various factors such as equipment failures, breakdowns a lack of adoption of new technologies, low performance of workers, and high cost of raw materials affect steel production. There are several ways to improve productivity of the rolling mill in steel plant, such as the lean manufacturing (LM) methodologies. LM methodologies are widely used to improve the performance of manufacturing industries.

In the literature, many researchers have reported that LM improves manufacturing productivity[2-8]. LM improves productivity by reducing or eliminating downtime in the production process. LM, also known as Lean Production System, originated from the Japanese company Toyota, which for decades set itself apart from global competition. Lean is an approach to identifying and eliminating various forms of waste from the production process, and improving business performance[9]. It is not a new technology, but it is still widely used in manufacturing industries worldwide. The most commonly used lean techniques in the steel industry to improve productivity are Total Productive Maintenance (TPM)[10], Value Stream Mapping (VSM) [11], 5S (Seiri, Seiton, Seiso, Seiketsu Shitsuke) [12], Single Minute Exchange of Die (SMED) [13], and Kaizen[14] etc. TPM is one of the Lean Manufacturing tools widely used in the manufacturing industry. The applications of TPM improve productivity by reducing machine breakdowns. This technique aims to maximize overall equipment effectiveness (OEE) by improving productivity and reducing maintenance costs. It was developed by the Japan Institute of Plant Maintenance (Fig. 1). It is a unique Japanese maintenance system for increasing machine availability. TPM is a technique that brings together both production and maintenance with a combination of practice, teamwork, and continuous improvement[15-16].

Optimized production can be achieved by the TPM methodologyas its application identifies and minimizes breakdowns and production losses throughout the production system. It is implemented by eight pillars: (1) Autonomous Maintenance, (2) Focused Improvement, (3) Planned Maintenance, (4)

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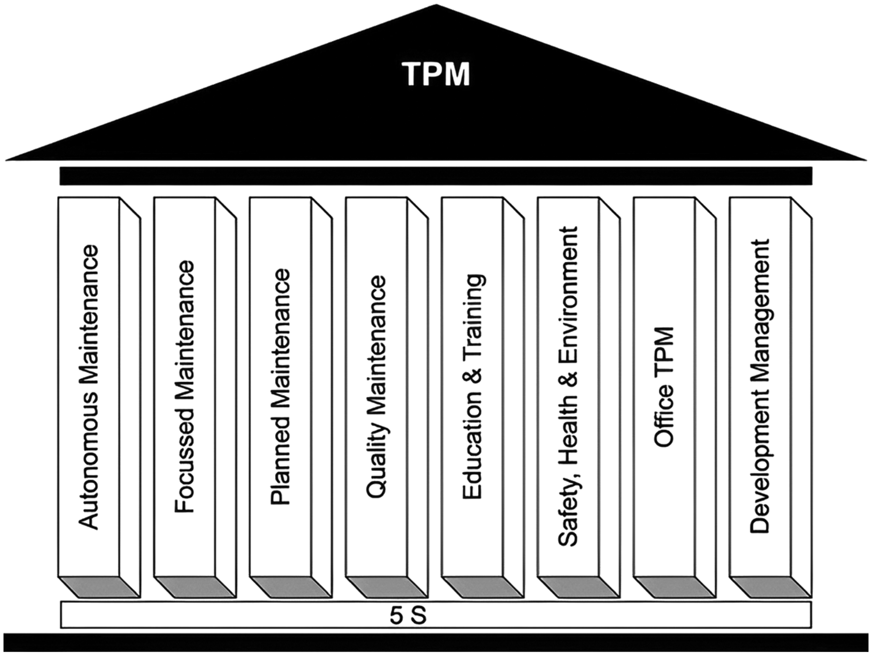

Fig. 1 — Eight-pillar approach for TPM implementation suggested by the Japan Institute of Plant Maintenance[16].

Quality Maintenance, (5) Education and Training, (6) Safety, Health, and Environment, (7) Office TPM and (8) Development Management which provide excellent planning, monitoring, and control of breakdowns[16]. In the manufacturing industry, amazing productivity is achieved by adopting TPM applications[17-20].

Many researchers/technicians have implemented the TPM applications in various manufacturing sectors such as automotive, textile, and steel industries and reported that production has improved after implementing TPM[18-20]. Arun et al.[19]implemented TPM in textile industry to improve productivity and reported that OEE increased from 61.14% to 65.68%. Dogra et al.[20] implemented TPM in a cold rolling mill and reported that the overall equipment effectiveness was 80%, which is close to the world-class OEE of 85-90%, and that the number of accidents on the shop floor was reduced. Sethia et al.[21]used TPM in a rolling mill to improve OEE and productivity. After the implementation of TPM, the company's OEE improved by 60.33%, and the availability, performance, and quality factors were also achieved at 70.90%, 91.03%, and 93.48%, respectively. The OEE value was low compared to the world-class OEE, but productivity was improved by TPM. Ovedje et al.[22] improved the OEE of plant machinery by TPM in Premium Steel and Mines Limited in Nigeria. After the implementation of TPM, the OEE value of the plant increased from 39.76% to 51.22%. However, it was far from the world-class OEE value of 85%.Singh et al.[23]implemented TPM in an Indian steel mill and reported that there is a need to develop an indigenous action plan to promote TPM implementation practices and procedures in the steel industry. The authors point out that TPM also monitors plant performance and automates daily activities related to the entire workforce.In the literature, there are not many studies on the application of TPM in rolling mills of steel plants. The aim of this study is to improve the productivity of the rolling mill in an integrated steel plant by using the TPM methodologies. Based on the literature review, the applications of TPM in rolling mill were implemented.

2 Materials and Methods

This study was conducted in the rolling mill department of an integrated steel plant in central India to improve productivity by implementing the TPM methodology, which is a proven lean manufacturing tool. The view of a rolling mill is shown in Fig. 2. A double line rolling mill was set up in the integrated steel plant for mass production. The double line rolling process is shown in Fig. 3. Throughout the rolling process, billets are rolled under 1-22 and 1-18 strands of line 1 and line 2, respectively. In rolling, two billets are passed

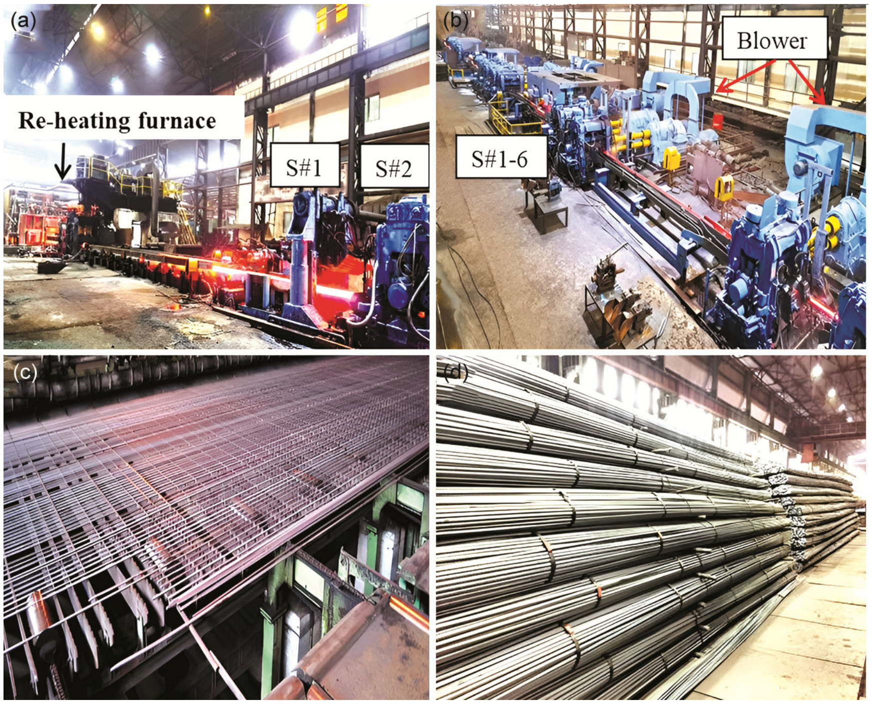

Fig. 2 — View of rolling mill (a) Reheating furnace, (b) shear in between stands 6 and 7, (c) cooling bed (d) stockyard. S# showing rolling stand.

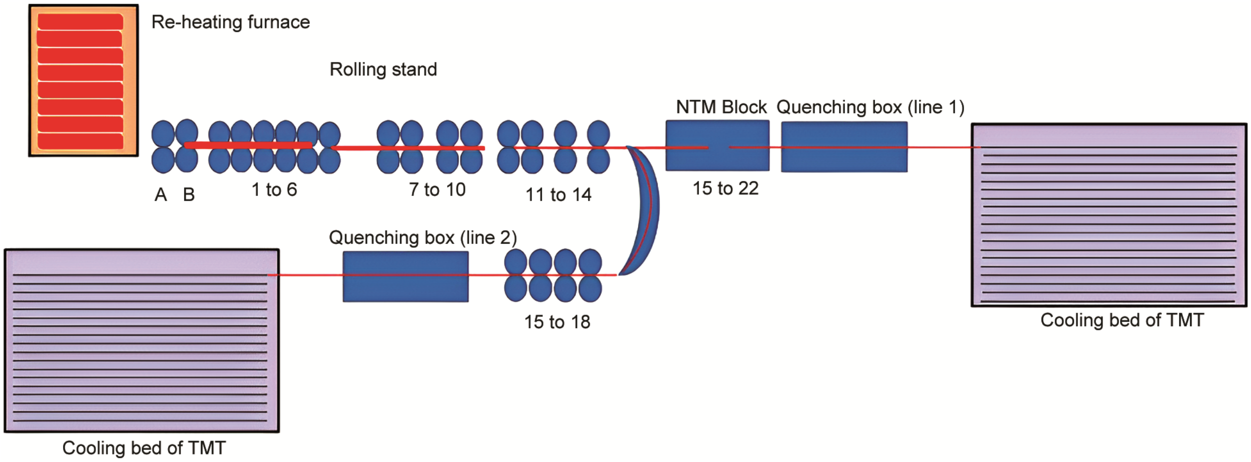

Fig. 3 —Flow diagram of the rolling mill process.

simultaneously through up to 14 strands, after which they are rolled in two separate lines and placed on separate cooling beds to produce TMT bars with two different diameters. This is done by experienced operating engineers who are familiar with the specific requirements of the production process.

The present experimental work is divided into three phases. In the first phase, a literature review was conducted to determine the application of TPM in various manufacturing industries. The literature review was based on textbooks, articles, journal articles and case studies from different industries covering the current state of research. In the second phase, the required data on production delays in the rolling mill department for the six months of April toSeptember 2022 were collected and analyzed as shown in Table 1. Then, a Pareto chart was developed to improve the 80/20 performance of the rolling mill. The Pareto chart was analyzed using Table 2. The Pareto chart shows that planned, mechanical, and operational delays contributed 80% of total delays, as shown in Fig. 4. However, 20% of the delays are due to the rolling guide (R&G) shop and electrical reasons.

Table 1 — List of delay times per day before the implementation of TPM

Month	Planned delay (h/day)	Mechanical (h/day)	Operation (h/day)	Electrical (h/day)	R & G shop (h/day)
April-22	1.99	2.29	1.8	0.58	0.6
May-22	2.29	2.17	1.73	0.61	0.59
Jun-22	2.01	1.28	1.76	0.59	0.56
July-22	2.67	2.11	1.12	0.57	0.57
Aug-22	1.91	2.10	1.79	0.48	0.45
Sep-22	2.07	1.97	1.69	0.50	0.57
Average	2.15	1.98	1.65	0.56	0.55

Table 2 — Average delay time in April to September 2022 before implementation of TPM

Cause of delay	Average production delay (h/day)	Cumulative	Cumulative (%)
Planned delay	2.15	2.15	31
Mechanical	1.98	4.13	60
Operation delay	1.65	5.78	84
Electrical breakdown	0.56	6.34	92
R & G shop breakdown	0.55	6.89	100

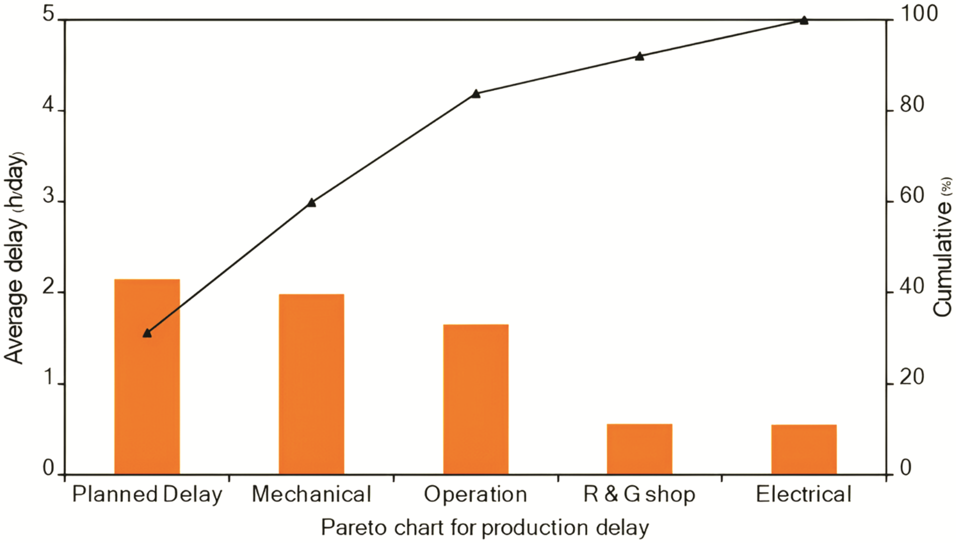

Fig. 4 — Pareto chart for production delays in a rolling mill

In the third phase, the TPM applications were implemented to reduce various breakdowns. For the implementation of TPM, a roadmap was developed to identify the various outages of the rolling mill. Then, from October 2022 to February 2023, the four pillars of TPM - autonomous maintenance, targeted improvement, planned maintenance, and education and training program were implemented. Responsibility for the implementation and follow-up of TPM activities at each stage of the plant was assigned to operators, supervisors and engineers belonging to the respective production area. Following the implementation of TPM, data were again collected and the impact on mean time to repair (MTTR) and mean time between failure (MTBF), plant availability, productivity, and overall equipment effectiveness (OEE) was examined. The values for MTTR, MTBF and OEE were calculated using the following formula:

$$\text{MTTR} = \text{Total repair time} / \text{Number of failures}$$

$$\text{MTBF} = \text{Total operating time} / \text{Number of failures}$$

$$\text{OEE} = \text{Rate of quality} \times \text{Equipment availability} \times \text{Productivity}$$

The average value of the results of the first three months is compared with the average value of the last two months and recorded. The OEE value was also compared with the OEE value of world-class steel.

3 Results and Discussion

The application of TPM was implemented for planned delay and operation breakdown to improve availability. A total of four TPM pillars were implemented: (1) autonomous maintenance, (2) focused maintenance, (3) planned maintenance, and (4) education and training to improve productivity. Production improved after the implementation of

TPM, and machines operated safer and more efficiently/cost-effectively.

(i) Autonomous maintenance: Autonomous maintenance is one of the main pillars of TPM and a key point to improve production. The main daily routine activities are listed in Table 3.After the implementation of TPM, these activities were maintained during the production of the mill.

(ii) Focused maintenance: A Fish-Bone diagram was used to identify the causes and their effects on production delays. The Fish-Bone diagram is shown in Fig. 5.

In addition, following the Pareto analysis, we considered a benchmark time for planned, mechanical, and operation delays (Fig. 6). After considering the benchmarks, the number of breakdowns was reduced and the mill uptime was improved. The reduction in the production delay after the implementation of TPM is shown in Table 4. The main focus was on mass production with good quality and zero rejection. Through the operation and maintenance skills, benchmark values were achieved and mill uptime was improved, as shown in Table 4.

Table 3 — Checklist of the main daily routine activities of a rolling mill.

S. No.	Activity	Checkpoints
1.	Check the blower motor	Housekeeping, bearing temperature, vibration, abnormal sound
2.	Check the Billet ejector motor	Temperature, vibration, abnormal sound
3.	Check to pull out the roll motor	Temperature, vibration, abnormal sound
4.	Check temperature transmitters & display	Temperature monitor
5.	Check the gearbox of all stand	Housekeeping, oil level, bearing, temperature, vibration, abnormal sound
6.	Check Roller alignment	Alignment check
7.	Check the pinch rolls	The load current, oil pressure, vibration, abnormal sound, temperature
8.	Check the high and slow speed shear	Oil pressure, motor current, temperature
9.	Check the pump house motor	Temperature, vibration, abnormal sound
10.	Check the status of the furnace	Oil tank heater, temperature
11.	Check the looper scanner	Cleaning
12.	Roll pass temperature	Temperature monitoring and recording every 4 hrs.
13.	Stand A and B power pack	Oil pressure, temperature, vibration, abnormal sound
14.	Stand 11-16 power pack	Oil pressure, temperature, vibration, abnormal sound

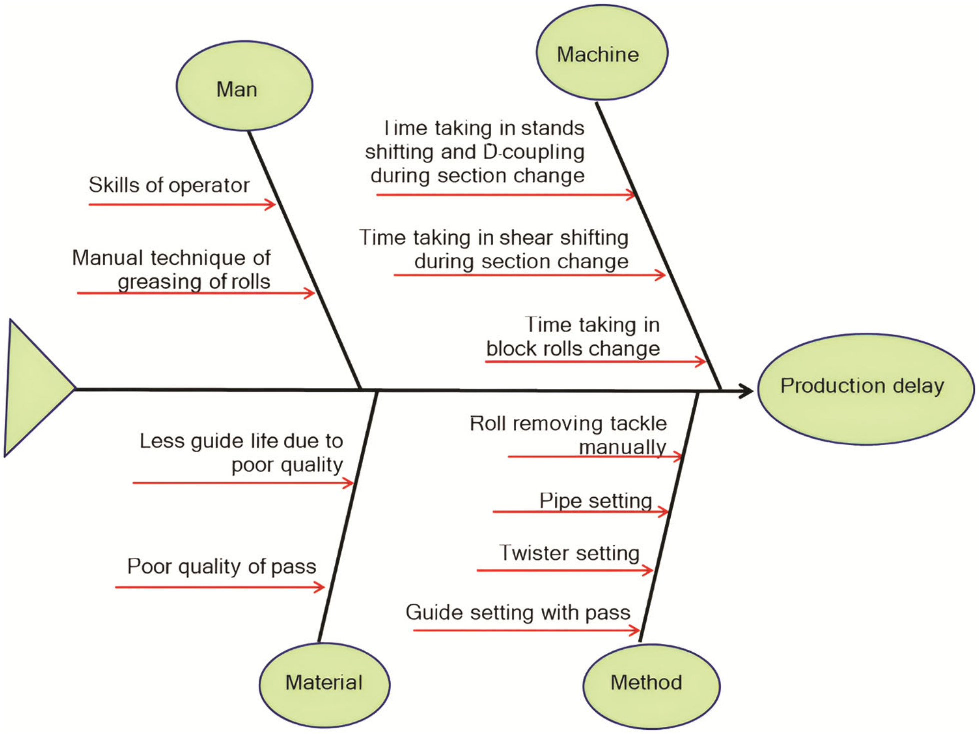

Fig. 5 — Fish bones diagram to determine the reason for the production delay.

(iii) Planned maintenance: We have documented several activities that cause downtime during production, such as guide changes, stitch and roll changes, and section changes that delay production and are related to the planned delay activities (see Table 5).These activities took a lot of time and also caused downtime. We made several changes to these activities. After the change, we saved time in these activities as shown in Table 6. Every day, guide, pass change, and role change after two shifts are required, although the section changes after two days. These activities have a greater impact on production. It can be seen that after the change, about 90 minutes were saved for the section change.

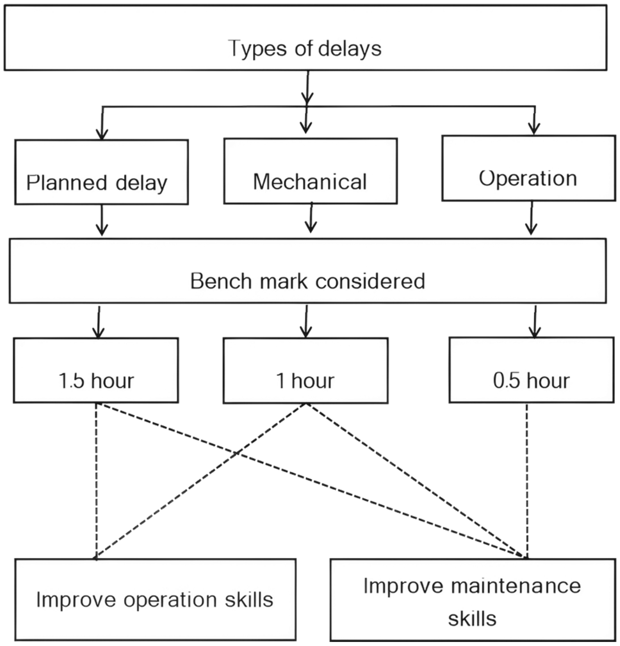

Fig. 6 — A chart for counting the number of breakdowns with TPM.

(iv) Education and training program: The objective of this pillar was to develop multi-competence in employees who have high self-confidence and work with enthusiasm, and perform all required tasks effectively and independently. Cross-training on technical skills was provided for operators and engineers. The performance of the rolling mill is also improved by the training program and the availability of the mill is increased.

The main causes of breakdowns in operation were due to cobble, stock size of billets, alignment of rough dies, twisters, guides, and delivery pipes, water hammering, etc. However, the main causes of breakdowns in mechanical were due to the spindle which is attached to the roll, and cold shear. Therefore, we replaced the spindle with a cardan shaft. The spindles were often worn and damaged, so the mill was often shut down. We replaced the

Table 4 — List of delay times per day after implementation of TPM.

Month	Planned delay (h/day)	Operation (h/day)	Mechanical (h/day)	Electrical (h/day)	R & G shop (h/day)
Oct-22	1.80	1.57	0.91	0.35	0.35
Nov-22	1.79	1.58	0.96	0.35	0.35
Dec-22	1.79	1.55	0.95	0.40	0.32
Jan-23	1.41	1.32	0.75	0.35	0.28
Feb-23	1.29	1.45	0.75	0.39	0.32

Table 5 — List of changes made to planned activities.

Activity	Modification
Guide changing	1. The service life of the guides was improved by changing the model of the guides in stands 14, 10 and 6; it was changed from the simple guide (0845) to the guides DR -3, DR -4 and DR -6, respectively.
Pass change	1. Technical skills improved the frequency of work of the operators. 2. The material of the roller (ductile iron) was replaced by cast-in carbide. Due to this the life of the roller was improved by 5 times.
Roll change	1. The roll removal technique was changed.
Section change	1. The displacement technique of shears 6.1 and 6.2 is changed from manual to hydraulic, which saves time. 2. The displacement technique of the block roller is changed from manual to motorized (electric), which saves time. 3. The shifting technique of the shear 10 is also changed from manual to hydraulic, which saves time.

Table 6 — Influence of TPM on planned delay activities.

S. No.	Activity	Before TPM (minute)	After TPM (minute)	Save time (minute)	Team	Team size
1	Guide changing	25	15	10	Operation	4
2	Pass change	90	60	30	Operation	4
3	Roll change	180	120	60	Operation	8
4	Section change	210	120	90	Operation /Electrical/ Mechanical	12

rotating device, guide, and delivery pipe which were the cause of the breakdown. Carbide cast iron rollers were used instead spheroidal cast iron because they have a longer life than spheroidal cast iron. These changes reduced the frequency of failures and improved the mill's performance. For electrical retardation, we used a blower in the mill strand to avoid motor breakdown, as shown in Fig. 2b. After implementing TPM, we reduced many breakdowns and improved the runtime of the mill by about two hours. It was observed that MTTR decreased by ~23% and MTBF increased by ~41% because breakdowns were reduced after implementation of TPM (Table 7). Equipment availability, productivity and overall equipment efficiency (OEE) were also analyzed after the implementation of TPM (Fig. 7). The average productivity of the rolling mill was improved by ~10% (MT/h) after the implementation of TPM. Equipment availability and OEE were also improved by ~14% and ~42.52%, respectively, after the implementation of TPM.

3.1 Discussion

TPM was successfully implemented from October 2022 to February 2023, followed by six months of data collection from April to September 2022. A brainstorming technique was used to identify possible causes of breakdown. A Pareto chart was also used to determine which activity contributed to 80% of the delays, and planned, mechanical and operational delays were found to have a greater impact on the number of breakdowns. A Fish-Bone diagram was also used to identify the cause of delays. The data collected also revealed that other causes of material production delays were cooling bed jams, poor roll lubrication and maintenance, pinch roll change, cold shear cutting, scale removal, lack of operator training, etc. Another main reason was also the manual techniques used before TPM. Therefore time taken to solve the problem was also longer. After six months, the TPM methodology was implemented and we were able to save the time required to perform these activities as shown in Table 6. These activities play a dynamic role in improving the productivity of the rolling mill. The implementation of TPM was decided according to the

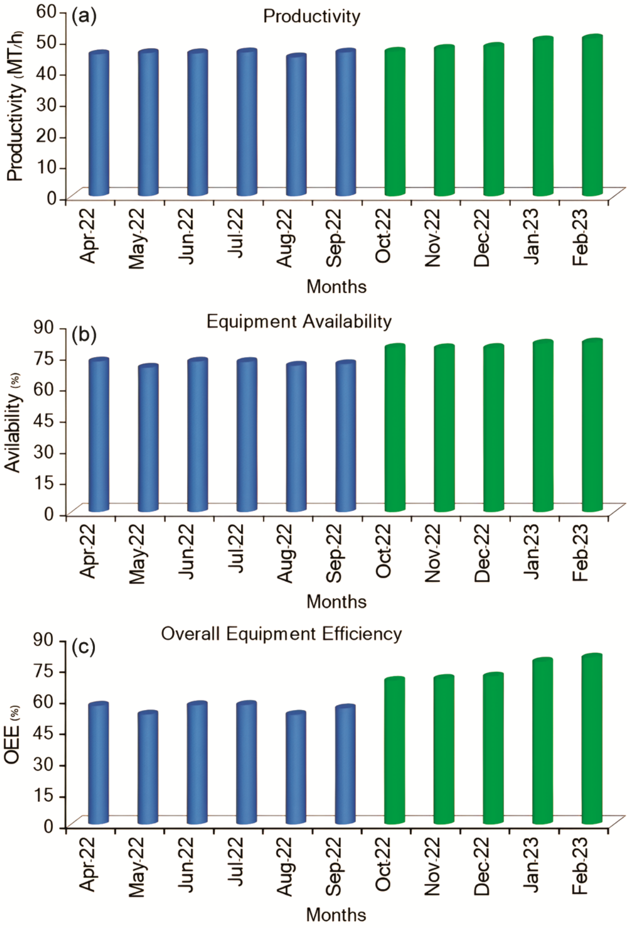

Fig. 7 — (a) Productivity, (b) Equipment availability, and (c) OEE of the rolling mill per month before and after implementation of the TPM methodology.

Table 7 — Rolling mill performance indicator

Month	Production delay (h/day)	MTTR (minutes)	MTBF (minutes)	Mill running (h/month)
April-22	6.15	52.97	139.23	485.0
May-22	6.81	60.32	137.14	480.0
Jun-22	6.21	53.0	138.7	487.7
July-22	7.04	56.1	145.6	274.3
Aug-22	6.73	59.9	142.5	496.3
Sep-22	6.80	59.7	147.5	504.0
Oct-22	4.98	47.5	178.3	579.6
Nov-22	5.03	46.2	171.2	559.1
Dec-22	5.01	45.2	168.6	578.7
Jan-23	4.11	48.6	206.0	614.6
Feb-23	4.20	44.2	194.1	527.4

requirements of marketing. The applications of TPM were implemented with work scheduling, photography and videography. Many changes and technical skills are used to reduce downtime. Implementation of TPM methodology increases productivity of the manufacturing industry[23]. After the implementation of the TPM, it was found that the average productivity of the rolling mill increased from 45.5 to 50 MT per hour, as shown in Fig. 7(a). This improvement is due to the elimination of breakdowns. It is confirmed that production can be improved by planning the work and reducing the waste of setup time in the industry[24]. Equipment availability improved by ~14% (Fig. 7b). It can also be seen that OEE improved from 55.57% to 80.19% in the February month using the TPM methodology (Fig. 7c). The improvement in OEE in the existing integrated steel mill is not far from 85% of the global steel OEE. The value of OEE was calculated based on the nominal capacity of the mill. The nominal capacity of the mill was 1000 MT/day. OEE depends on quality, equipment availability and productivity parameters. As mentioned earlier, TPM improve productivity and plant availability by reducing downtime. When productivity and plant availability improve, OEE will also improve. Almeanazel[25] has reported an improvement in OEE through the application of TPM in the manufacturing industry. OEE is an important process indicator that is expected to improve industry performance by reducing equipment downtime[26]. The adoption of lean manufacturing techniques reduces manufacturing machine setup time and tool change time, which ultimately leads to higher productivity[27, 28].

The step-by-step implementation of the work process can improve productivity in the industry[20]. The equipment availability of the rolling mill also improved after the implementation of the TPM method, as the operating time of the rolling mill was increased by ~3 h/day. The total operating time before and after TPM is shown in Fig. 8. It was divided into two parts, planned operating time and the total delay time (before TPM). Also, the total delay time was split between unplanned and planned shutdown. This split was very helpful in improving the productivity of the mill. TPM not only solved the equipment problem, but also reduced the maintenance cost of the mill. Along with the reduction in downtime, our maintenance expenses also decreased.

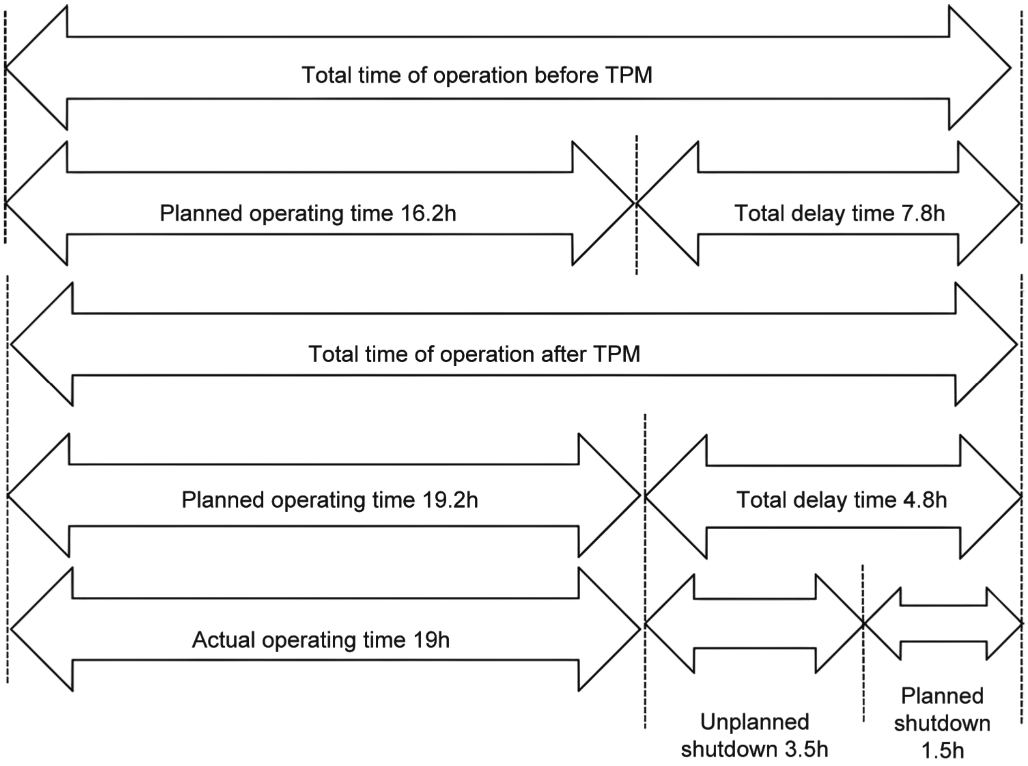

Fig. 8 — Time distribution for operation.

4 Conclusion

In this study, the TPM methodology was implemented in a rolling mill in an integrated steel plant in central India. Production time was increased by 3h/day after the implementation of TPM. Productivity, equipment availability, and OEE improved by ~10% (MT/h), ~14%, and 42.52%, respectively, after the implementation of the TPM methodology. Productivity of the rolling mill increased from 45.5 MT/h to 50 MT/h after the successful implementation of TPM. OEE increased from 55.57 to 80.19%, which is close to World Steel's performance of 85%.

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